Food and Agriculture Organization of the United Nations

VERSION 1

Environmental performance of large ruminant 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 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 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 large ruminant sector is of worldwide importance. It comprises a wide diversity of systems that provide a variety of products and functions. Large ruminants, which include both cattle and buffalo, play a crucial role in sustaining livelihoods in traditional, small-scale, rural and family-based production systems. Across the large ruminant sector, there is strong interest in measuring and improving environmental performance.

In the development of these draft guidelines, which focus on cattle and buffalo, the following objectives were regarded as key:

- to develop a harmonized, science-based approach founded on a consensus among the sector's stakeholders;
- to recommend a scientific, but at the same time practical, approach that builds on existing or developing methodologies;
- to promote an approach to assessment suitable for a wide range of large ruminant supply chains; and
- to identify the principal areas where ambiguity or differing views exist as to the right approach.

Over the coming months these guidelines will be submitted to public review. The purpose of the review will be 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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The TAG on large ruminants conducted the background research and developed the core technical content of the guidelines. The large ruminants TAG was composed of 30 experts: Alexandre Berndt (EMBRAPA, Brazil - Co-Chair of the Large Ruminant TAG), Ying Wang (Innovation Center for US Dairy, USA - Co-Chair of the Large Ruminant TAG), Greg Thoma (University of Arkansas, USA - Vice-Chair of the Large Ruminant TAG), Gonzalo Becoña (Plan Agropecuario, Uruguay), Sophie Bertrand (CNIEL/IDF, France), Jacques de Groot, (VanDrie Group, The Netherlands), Jean Baptiste Dollé, Institut de l'Elevage (French Livestock Institute, France), Hongmin Dong (Chinese Agriculture Academy of Sciences, China), Philippe Faverdin (INRA, France), Anna Flysjö (Arla Foods, Denmark), Armelle Gac (Institut de l'Elevage - French Livestock Institute, France), Manget Ram Garg (National Dairy Development Board, India), Sebastian Gollnow (PE International, New Zealand), Juan José Grigera Naón (International Meat Secretariat, Argentina), Saiakbai Kulov (NGO Center for Development of Kyrgyz Nomadic Pastoralism, Kyrgyzstan), Stewart Ledgard (AgResearch, New Zealand), Mark Lieffering (AgResearch, New Zealand), Ben Lukuyu (International Livestock Research Institute – ILRI, Kenya), Sarah Meale (Agriculture and Agri-Food Canada, Canada), Tim McAllister (Agriculture and Agri-Food Canada, Canada), Julio Mosquera Losada (Wageningen UR Livestock Research, The Netherlands), Barbara Nebel (PE International, New Zealand), Donal O'Brien (Teagasc - The Agriculture and Food Development Authority, Government of Ireland), Alan Rotz (USDA/Agricultural Research Service, USA), Laurence Shalloo (Teagasc - The Agriculture and Food Development Authority, Government of Ireland), Didier Stilmant (Walloon agricultural Research Centre, Belgium), Aimable Uwizeye (Food and Agriculture Organization of the United Nations), Mary Vickers (EBLEX, United Kingdom), Metha Wanapat (Tropical Feed Research and Development Center – TROFREC, Thailand), and Stephen Wiedemann (FSA Consulting, supported by Meat and Livestock Australia, Australia). The TAG team would like to acknowledge the contribution of Andrew Henderson (University of Texas, USA), and of Julio Cesar Pascale Palhares, Patricia Perondi Anchao Oliveira, Amanda Prudencio Lemes, Daniella Flavia Vilas Boas and Leandro Sannomiya Sakamoto, (EMBRAPA, Southeast Livestock, Brazil).

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 until Jan 2015), Camillo De Camillis (LEAP manager), Carolyn Opio (Technical officer and Coordinator since Feb 2015), 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:

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MULTI-STEP REVIEW PROCESS

The initial draft guidelines developed by the TAG over 2014 went through an external peer review before being revised and submitted for public review.

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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 launched at the 2nd Annual Meeting of the LEAP Partnership on 23 April 2015 and lasted until 15 September 2015. 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 announcements and reminders circulated via the mailing list on LCA held by PRé Consultants. The public review period was also advertised in two sessions of the Society for Environmental Toxicology and Chemistry (SETAC) Europe 25th Annual Meeting. The following initiatives were also contacted and solicited to submit their inputs: Global Research Alliance, Livestock Research Group, the Global Alliance for Sustainable Livestock, Global Alliance for Climate-Smart Agriculture, the MICCA Programme, Standing Committee on Agricultural Research, Joint Programming Initiative on Agriculture, Food Security and Climate Change, European Food Sustainable Consumption Production and Consumption Roundtable, European Commission's Cattle Model Working Group members. Relevant FAO technical officers were reached and solicited to submit their inputs.

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Abbreviations and acronyms

BSI British Standards Institution
CFP Carbon footprint of a product
CHP Combined heat and power
CO2e Carbon dioxide equivalent
CW Carcass weight
dLUC Direct Land-Use Change
DM Dry Matter
DMI Dry Matter Intake
FAO Food and Agriculture Organization of the United Nations
FPCM Fat- and Protein-Corrected Milk
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
LCA Life Cycle Assessment
LCI Life Cycle Inventory
LCIA Life Cycle Impact Assessment
LEAP Livestock Environmental Assessment and Performance Partnership
LUC Land-Use Change
LW Live Weight
MCF Methane Conversion Factor
ME Metabolizable Energy
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
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.
Retail packaging	Containers and packaging that reach consumers.

Feed (feedingstuff)	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.
Repackaging facility	A facility where products are repackaged into smaller units without additional processing in preparation for retail sale.
Raw material	Primary or secondary material used to produce a product.
Secondary packaging materials	Additional packaging, not in contact with 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 kg-1) 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 is measured as the fraction of sludge combusted at 550 degrees Celsius after 2 hours.
Wealth Management	A service provided by some livestock systems, particularly in regions where banking systems are poorly developed or lacking. This is characterized by animals being kept beyond their normally productive life specifically for the purpose of saving wealth for some future expense, such as a wedding or education. This service may be considered roughly equivalent to a savings account or certificate of deposit. This service is distinct from the value of the productive herd which is used for generating cash-flow for the operation.

Terms relating to large ruminant supply chains

Beef	Beef is the culinary name for meat from bovines, especially domestic cattle, although beef also refers to the meat from the other bovines: antelope, African buffalo, bison, water buffalo and yak.
Bobby calves	Calves taken away from the mother within a few hours of birth.
Boner	An animal yielding low-quality meat.
Bovine	Ruminants belonging to the family Bovidae. It covers cattle and buffalo.
Browse	A general term applied to shrubs or trees that are fed on by cattle by picking mouthfuls as they move.
Buffalo	Popularly known as water buffalo or domestic Asian water buffalo (Bubalus bubalis) is a large Bovidae that originated from India and found on the Indian subcontinent to Viet Nam and Peninsular Malaysia, in Sri Lanka, in the Philippines, and in Borneo, used as draught animals and also suitable for milk production. Also known as carabao. In addition, buffalo are also found in North America are known as American bison (Bison bison).
Buffalo, Riverine	A type of buffalo (Chromosome number 2n=50) characterized by its high genetic capacity for milk production and is therefore considered under the dairy category (e.g. Murrah, Jaffarabadi buffalo from India, Italy and Bulgaria, as well as the Nili Ravi from Pakistan).
Buffalo, Swamp	A type of buffalo (Chromosome number 2n=48) that has natural preference for swamps and marshlands. It is primarily utilized as draught animal and also for meat (e.g. The Philippine carabaos and the Cambodian and Thai buffaloes.
Bull	An intact (not castrated) adult male of the species Bos taurus (cattle).
Calf	Bovine offspring of either sex below the age of one year.
Calving	Act of giving birth/parturition in cattle and buffalo.
Calving interval	Period between two successive calving, measured in calendar days or months.
Canned meat	Fresh or prepared meat packed in sealed containers with or without subsequent heating for the purpose of sterilization.
Canning	Preservation of meat in hermetically sealed containers.

Carabeef	Meat of buffalo.
Caracalf	Male or female buffalo under one year of age.
Caracalving	The act of giving birth in buffalo.
Caracow	Sexually mature female buffalo that has given birth.
Caraheifer	Sexually mature female buffalo that has not yet given birth.
Carcass	The fresh meat of any slaughtered animal after the bleeding and dressing with the removal of offal in the body.
Conception	Successful union of male and female gametes and implantation of zygote.
Cow	The mature female of a bovine animal.
Cull	To reduce or replace a proportion of the herd by selling or killing that portion of its members.
Cull cow	Cows removed from a dairy or beef herd based on specific criteria.
Culling rate	The number of culls over the total number in the herd or flock multiplied by 100.
Culling/ Culled	Undesirable animals eliminated from the herd or flock, usually unproductive breeders.
Dairy animals	Animals producing milk, such as cattle and buffalo, for human consumption which may also include dual purpose animals.
Dairy beef	Beef steers; includes all cows, heifers, culls and calves including veal calves.
Dairy farm	Where dairy animals raised mainly for milk production.
Direct energy	Energy used on farms for livestock production activities (e.g. lighting, heating).
Draught animals	Animals raised for work purposes, such as ploughing, harrowing and hauling.
Dressed weight	Total weight of carcass excluding hide or skin, blood, edible and inedible offal and slaughter fat other than kidney fat.
Dressing percentage	A ratio of dressed carcass weight of animals to its live weight.
Dressing	Progressive separation on the dressing floor of food animal into a carcass (sides of a carcass), offal and inedible by products. It may include the removal of the head, hide or skin, genital organs, urinary bladder, feet and, in lactating animals the removal of the udder.

Edible offal	In relation to slaughtered food animals, offal that has been passed as fit for human consumption.
Fattening	Raising of animals to gain the desired weight in marketable age at specific period of time.
Feedlot	Parcel of land or pen where livestock are confined and fattened for slaughter.
Finishing operations	Production system specialized for the finishing of beef cattle prior to slaughter. The finishing degree depends on specific criteria from the industry.
Grasslands	Forage that is established (imposed grazing-land ecosystem) with domesticated introduced or indigenous species that may or may not receive periodic cultural treatment such as renovation, fertilization or weed control. The vegetation of grassland in this context is broadly interpreted to include grasses, legumes and other forbs, and at times woody species may be present.
Graze	To feed directly on growing grass, pasture or forage crops.
Hay	Harvested forage preserved by drying generally to a moisture content of less than 200 g kg^{-1}.
Herd	A group of bovines.
Heifer	A young cow, normally over one year old, that has not produced a calf.
Hide	Outer covering of cattle/buffalo removed during the slaughtering process.
Kraals or bomas	An enclosure for cattle and other domestic animals, mainly in South Africa.
Lactating animal	An animal that is in physiological stage of milk production.
Mature milking	Mature milking refers to the stage where adult post-partum cows are milked. Note that this stage will also include the period of the year when the cows are dried off.
Mature maintenance	Mature maintenance refers to where animals are at least at their minimum mature body weight.
Mature finishing	Mature finishing refers to the stage where the body weight is deliberately increased above that of the 'Mature (maintenance)' stage for slaughter.
Meat	Fresh, chilled or frozen edible carcass including offal derived from food animals.

Meat product(s)	Any product capable of being used as human food, which is made wholly or in part from any meat or other portion of the carcass of any food animals, except products which contain meat or other portions of such carcasses only in a relatively small proportion or historically have not been considered by consumers as products of the meat industry, and which are exempted from definition as a meat product.
Mixed crop-livestock system	A combination of crop and livestock activities in a production system.
Mortality rate	Number of animals that died over the total number of animals during the reference period.
Offal	The internal organs of the body removed from the butchered animal (not included in a carcass).
Paddock	A grazing area that is a sub-division of a grazing management unit and is enclosed and separated from other areas by a fence or barrier.
Parturition	Act of giving birth.
Replacement rate	The percentage of adult animals in the herd replaced by younger adult animals each year.
Ruminant	Any of various even-toed, hoofed mammals of the suborder Ruminantia. Ruminants usually have a stomach divided into four compartments (one of which is called a rumen), and chew a cud consisting of regurgitated, partially digested food. Ruminants include cattle, buffalo, sheep, goats, deer, antelopes and camels.
(Procreation) service	The process in which mature male covers the female, i.e. in heat with the object to deposit spermatozoa in the female genital tract.
Sire	A bull parent of the calf.
Steer	A male bovine that is castrated before sexual maturity and normally raised for beef.
Tallow	Rendered fat.
Weaning	Removal of calves from their mothers, usually at about 6 to 7 months of age.
Weaned calves	Calves recently removed from their mothers.

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 mineralized. 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	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	Processes on which no or, at best, indirect influence may be exercised by the decision maker for which an LCA is carried out. - *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_2e)	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 GHG emissions and removals in a product system, expressed as carbon dioxide equivalents (CO_2e) 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_2e as the reference unit. - Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Characterization factor	Factor derived from a characterization model that 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 (LCI) 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 multi-functional 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 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 multi-functional 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 LCA and the principles and requirements of the international standards on LCA. - 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)
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. 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 favors 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	Processes that 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 ionizing 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 material acquisition 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 LCA 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 percent 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 (IOS, 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, hydrochlorofluorocarbons, 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 (NO_x, SO_x, NH_3).
- *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 man-made 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 fulfill 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* (WRI and WBCSD, 2011ba)
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 timeframe 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	Phenomenon that occurs when a product "reduces the GHGs in the atmosphere" or creates "negative emissions", by removing and storing carbon for a limited amount of time. - *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 that 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, and 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	Products include meat products and other possible co-products of processing such as tallow, hides, and renderable material; Milk products, such as cheese, yoghurt and milk powder, with possible co-products such as whey; Draught power and in some circumstances manure is a valuable (revenue generating) co-products; Wealth management	7.1
Life cycle stages: modularity.	The guideline support modularity to allow flexibility in modeling systems. The 3 main stages are feed production, animal production, and primary animal processing.	7.2
GOAL AND SCOPE DEFINITION		8
Goal of the LCA study	The goal shall define: the subject, the 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
Functional unit and Reference flows	Both functional units and reference flows shall be clearly defined and measurable, including specification of live weight, or product weight for meat products, with specified carcass or edible yield, respectively. Energy corrected milk is the recommended reference flow for farm gate studies, while milk-product weight is used for produced milk products.	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
Criteria for system boundary	The recommended system boundaries include all breeding and production/finishing animals on farms, and end with dressed carcass or milk products ready for transport to customers or storage.	8.4.2
Material boundaries	A material flow diagram should be produced and used to account for all of the material flows for the main transformation steps within the system boundary.	8.4.2
Spatial boundaries	Feed production and live animal rearing are explicitly included; details on feed production are provided in the LEAP feed guidelines.	8.4.2
Material contribution and threshold	Flows contributing less than 1% to impacts may be cut off, provided that 95% of each impact category is accounting, based on a scoping analysis.	8.4.3
Time boundary for data	A minimum period of 12 months should be used, to cover all life stages of the animal. The study should use an 'equilibrium population' which shall include all animal classes and ages present over the 12-month period required to produce the product. In case of significant inter-annual variability, the one-year time boundary should be determined using multiple-year average data to meet representativeness criteria.	8.4.4
Capital goods	May be excluded if the lifetime is greater than one year.	8.4.5
Ancillary activities	Veterinary medicines, accounting or legal services, etc. should be included if relevant, as determined by scoping analysis.	8.4.6
Delayed emissions	All emissions are assumed to occur within the time boundary for data. The feed guidelines address land-use and land use change related emissions.	8.4. 7
Carbon offsets	Shall not be included in the impact characterization, but may be reported separately.	8.4. 8
Impact categories and characterization methods	Climate change (IPCC) and fossil energy demand, eutrophication, acidification and land occupation are covered by these guidelines.	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 farm impacts of a dairy without separately assigning impacts to milk and meat as co-products.	9.1
Methodological choices	Guidance for separation of complicated multifunctional systems and application of bio-physical or economic 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
Cradle to farm gate	Multi-functional systems in large ruminant production is common: when several species share the same inputs (feed sources, or pasture) and when ruminants produce milk and meat (and inedible co-products, in the case of backyard). In some systems, draught power and wealth management also introduce multi-functionality.	9.3.1
Allocation of manure	First the determination of whether the manure is classified as a co-product, residual or waste is made on the basis of revenue generation for the operation. Co-product: use biophysical reasoning (an example provided). Residual: the system is cut-off at the boundary and no burden is carried to downstream use of the litter. Waste: emissions from subsequent activities are assigned to the main co-products.	9.3.1
Primary processing	These guidelines do not support differentiation of edible products.	9.3.2
Milk processing	Allocation of incoming raw milk shall be based on the distribution of milk solids among the products.	9.3.2
Meat processing	Revenue based allocation is recommended for products which serve different markets (e.g., edible products vs. rendering products vs. hides).	9.3.2
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
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.	10.2.3
Data quality assessment	LCI data quality address representativeness, consistency, completeness, precision/uncertainty, and methodological appropriateness.	10.3
Uncertainty analysis	Uncertainty information should be collected along with primary data. If possible, the standard deviation should be estimated, if not a reasonable range should be estimated.	10.4

(Cont.)

Topic	Summary recommendation	Section
LIFE CYCLE INVENTORY		11
Overview	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 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
Cradle-to-farm gate	Data shall be collected for feed production (FEED guidelines), breeding and milk, meat, and manure production and emissions.	11.2
Feed assessment	The type, quantity and characteristics of feed produced and consumed shall be documented, including lost or wasted feed. Because feed characteristics and environmental conditions can affect feed conversion ratio, primary data on feed consumption is critical.	11.2.1
Animal population and productivity	A full accounting of breeding animals is required, including spent and replacement animals, and shall be connected to the reference flows of relevant products. Procedures for calculating enteric methane emissions are provided.	11.2.2
Manure production and management	Estimates of volatile solids and nitrogen excretion based on daily feed intake and properties of the feed are recommended. Procedures for calculating grazing and housing emissions of methane and direct and indirect nitrous oxide are provided.	11.2.3
Emissions from other farm-related inputs	The total use of fuel (diesel, petrol) and lubricants (oil) associated with all on-farm operations, including provision of water, shall be estimated.	11.2.4
By-products and waste	Mortality management as well as disposal of packaging or other solid waste shall be included in the inventory.	11.3.5
Transportation	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.	11.3
Water use	Generally, the principles of the ISO 14046 standard are adopted. The inventory for the water footprint of large ruminants consists primarily of the indirect water footprint of the feed, in addition to the direct water footprint associated with drinking water and the consumption of service water.	11.5
Soil carbon sequestration	This relates only to the feed production stage, the specific methods are covered in the LEAP Animal Feed Guidelines.	11.6
Primary processing stage		11.7
Milk processing	Milk may be used to produce one or more of the following products: fresh milk, yoghurt, cheese, cream/butter, whey and milk powder. A material flow diagram of milk input and output products should be produced to account for a minimum of 99 percent of the fat and protein.	11.7.1
Meat processing	Primary processing of large ruminants for meat production can occur in facilities ranging from backyards to large-scale commercial processing abattoirs. The main processes that need to be accounted for are: animal deconstruction, production and use of packaging, refrigeration, water use and wastewater processing, and within-plant transportation. Data for resource consumption including energy, water, refrigerants and consumables (e.g. cleaning chemicals, packaging and disposable apparel) should be collected.	11.7.2
On-site energy generation	When surplus energy is sold, the guidelines recommend system expansion to include the additional functionality of the sold energy. When this does not match the goal and scope of the study, then the system shall be separated and the waste feedstock to the energy production facility shall be considered a residual from the processing operation.	11.7.3

(Cont.)

Topic	Summary recommendation	Section
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
Characterizing uncertainty	Data uncertainty should be estimated and reported through formal quantitative analysis or by qualitative discussion, depending upon the goal and scope.	12.2
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-gate 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 summarizing 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 large ruminant 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 calculation methods and data requirements to enable consistent application of LCA across differing large ruminant 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 a recognized, robust and transparent methodology developed to take account of the nature of large ruminant 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 and water use. Examples of impact assessment methods are also provided for acidification, eutrophication, biodiversity change and land occupation. This document does not provide support for the assessment of comprehensive environmental performance, nor the social or economic aspects of large ruminant 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 LEAP Animal Feed Guidelines, GHG emissions from direct land-use change are analysed and recorded separately from GHG emissions from 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 direct land-use change.

Regarding land occupation, the LEAP Animal Feed Guidelines divided land areas into two categories: arable land and non-arable grassland. Appropriate indicators were included in the guidelines as they provide important information about the use of a finite resource (land) but also about follow-on impacts on soil degradation, biodiversity, carbon sequestration or loss, and water depletion. Nevertheless, users wishing to specifically relate land occupation 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 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 14025:2006 (ISO, 2006a) 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 wider environmental implications, either positive or negative. It should be noted that comparisons between final products should only be based on a full LCA. Users of these guidelines shall not employ results to claim overall environmental superiority of some large ruminant production systems and products.

The methodology and guidance developed in the LEAP Partnership are not intended to create barriers to trade or contradict any World Trade Organization requirements.

These guidelines have been developed with a focus on cattle and buffalo production. Their application to other large ruminant species is possible. However, for other species, there may be specific circumstances not covered in this document. For example, the co-production of velvet (antlers) and meat by elk or deer would require additional consideration regarding allocation methodology.

3. Structure and conventions

3.1 STRUCTURE

This document adopts the main structure of ISO 14040:2006 (ISO, 2006b) and the four main phases of LCA: 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 large ruminants guidelines are not intended to stand alone, but are meant to be used in conjunction with the LEAP Animal Feed 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 is contained in the LEAP Animal Feed Guidelines.

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.

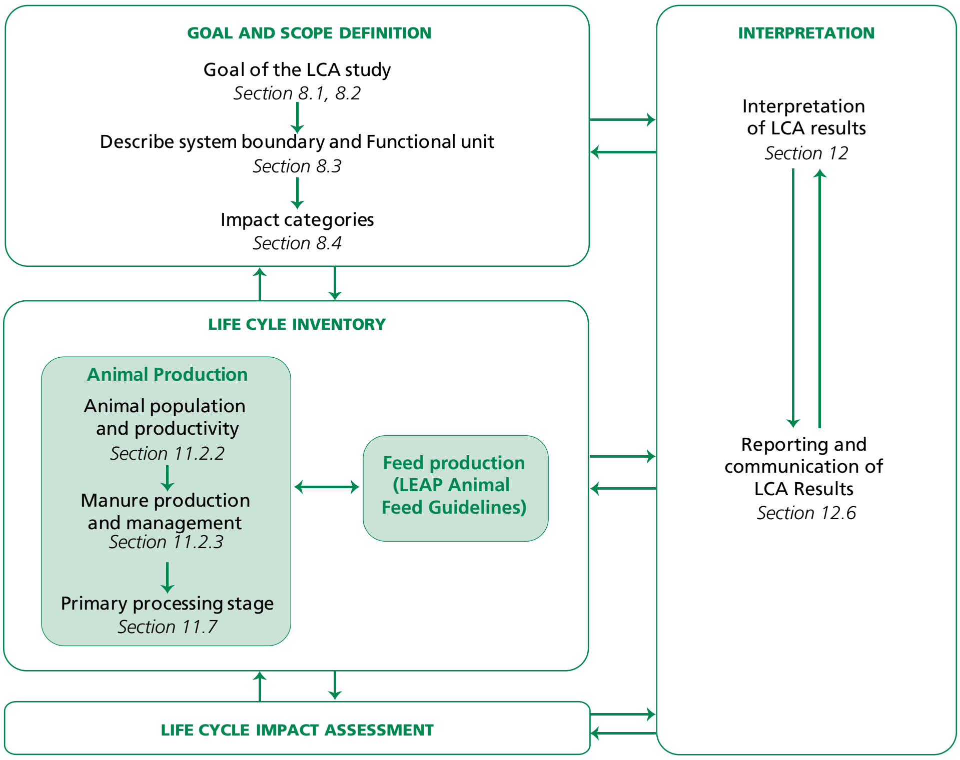
The term “should” is used to indicate a recommendation, but not a requirement.

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 large ruminant 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 developed for assessing the environmental impact of products and processes. LCA can be used as a decision support tool within environmental management. ISO14040:2006 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, LCA consist of four phases:

- goal and scope definition, including appropriate metrics (e.g. GHG emissions, water use, 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 in carbon dioxide equivalents (CO_2 e); and
- analysis and interpretation of results.

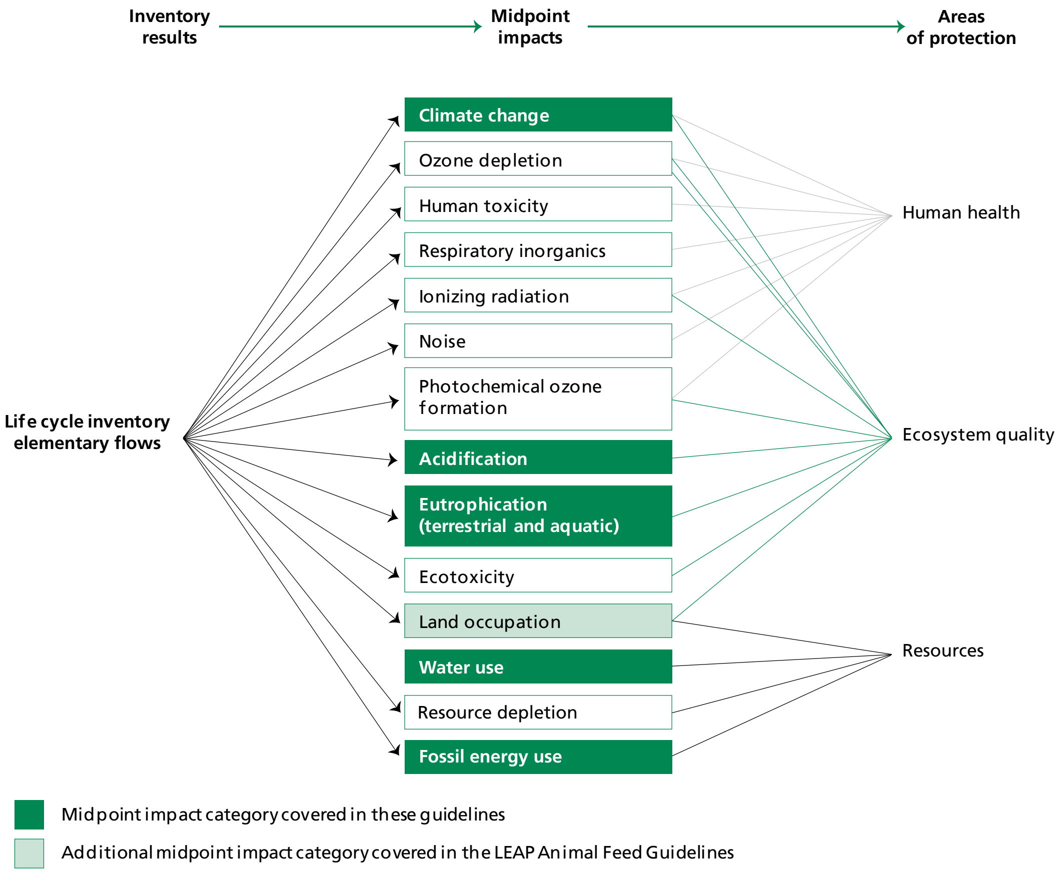
4.2 ENVIRONMENTAL IMPACT CATEGORIES

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 (kg of CO_2e per functional unit).

Figure 2
Environmental cause-effect chain and categories of impact



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

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 define 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 14046:2014 Environmental Management – Water Footprint -- Principles, Requirements and Guidelines* (ISO, 2014)
  ISO 14046:2014 establishes the principles and specifies the procedures for developing water footprints for products, processes and organizations. It provides guidance on water footprint assessment as a stand-alone assessment or as part of a larger assessment. Only air and soil emissions affecting water quality are included, but not all air and soil emissions are covered.
- 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 PAS 2050:2011 (see below), this standard excludes impacts from the production of infrastructure, but whereas PAS 2050:2011 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 to support 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) 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 14040:2006 and ISO 14044:2006. It consists of a set of documents, including a general guide for LCA and 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 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 Government of France 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 and 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 environmental impacts from large ruminant 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 year until 2050, driven by global population growth and increasing wealth and urbanization (Alexandratos and Bruinsma, 2012). 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. There is also 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 for 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 large ruminants, animal feeds and poultry supply chains. The large ruminants TAG was formed in March 2014.

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 calculation 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, PCRs or product environmental footprint (PEF) category rules, although each programme will prescribe specific rules to ensure conformity and avoid conflict with any existing parent standard.

5.2 LARGE RUMINANTS TAG AND THE PREPARATION PROCESS

The large ruminant TAG of the LEAP Partnership was formed in March 2014. The team included 30 experts in large ruminant supply chains, as well as leading LCA researchers and experienced industry practitioners. Their backgrounds, complementary between products, systems and regions, allowed them to understand and address different interest groups and ensure credible representation. The TAG was led by Ying Wang (Innovation Center for U.S. Dairy), Alexandre Berndt (EMBRAPA, Brazil), and Greg Thoma (University of Arkansas, USA).

The role of the TAG was to:

- review existing methodologies and guidelines for the assessment of environmental impacts from large ruminant supply chains and identify gaps and priorities for further work;
- develop methodologies and sector specific guidelines for the LCA of environmental impacts from large ruminant supply chains; and
- provide guidance on future work needed to improve the guidelines and encourage greater uptake of LCA of GHG, water availability, water scarcity, biodiversity change, acidification and eutrophication impacts from large ruminant supply chains.

The TAG met for its first workshop on 12–14 March 2014 in Rome, Italy. The TAG continued to work via emails and teleconferences before meeting for a second workshop on 2-3 July 2014 in Madrid, Spain. The third meeting took place on 15-16 October 2014 in Tivoli, Italy. The thirty experts were drawn from 19 countries: Argentina, Australia, Belgium, Brazil, Canada, China, Denmark, France, India, Ireland, Kenya, Kyrgyzstan, The Netherlands, New Zealand, Rwanda, Thailand, United Kingdom, Uruguay and USA.

As a first step, existing studies and associated methods (see Appendix 1 and 2) were reviewed by the TAG to assess whether they offered a suitable framework and orientation for a sector-specific approach. This avoids confusion and unnecessary duplication of work through 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.

The intention of this document is to provide an overview assessment of existing studies and associated methods that have used LCA for the evaluation of large ruminant supply chains. Seventy studies have been identified addressing the dairy supply chain; 28 studies on beef production; 10 studies that addressed both dairy and beef, and one study for buffalo (Pirlo *et al.*, 2014)as purchased feeds, chemical fertilizers and fossil fuels. Average cultivated area was 53.2ha; the forage system was based mainly on maize silage, immediately followed by Italian ryegrass and/or whole cereal silage. Average herd size was 360 and the average FPCM per lactating buffalo was 3563kg/year with an average milk fat and protein percentage of 8.24 and 4.57 respectively. The CF assessment was from cradle to farm gate. The greenhouse gases (GHG. In the remainder of this document, the common approaches, as well as differences, in methodological and modelling choices are identified.

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. Large ruminants production systems

6.1 BACKGROUND

In 2012, the world population of cattle and buffalo was about 1.5 billion and 200 million head respectively. For cattle, North and South America account for about 35 percent of the global total, with the North America contributing nearly 20 percent and South America 70 percent. In South America, Brazil dominates the cattle numbers with just over 200 million head, while the USA dominates North America with about 90 million head. Asian countries have about 35 percent of the world's cattle; Africa 15 percent; Europe 12 percent; and Oceania 3 percent. For Asia, most of the cattle are found in India (42 percent) and China (18 percent). For buffalo, the vast majority (98 percent) are found in Asia, in particular the tropical and subtropical areas of South East Asia (FAO, 2014).

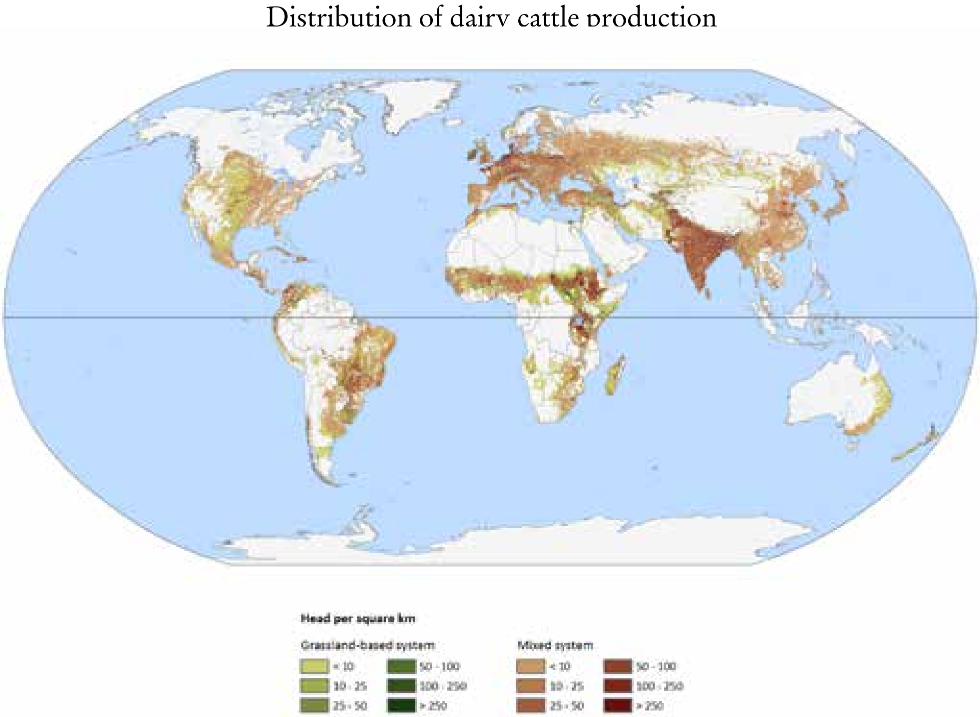
Cattle and buffalo produce two main tangible products: meat and milk (see Section 7 and Appendices 3, 4 and 5). For meat, the nearly 67 billion kg of carcass weight were produced globally in 2012; North and South America contributed about 46 percent of the total; Asia 26 percent. It is interesting to note that nearly 22 percent of Asia's bovine meat production is from buffalo, and that in 2013 it was estimated that 25 percent of the world's traded 'beef' is in fact buffalo meat from India (FAO, 2014). For milk, the global production of 625 billion kg of fresh, whole, cattle milk was almost equally divided between North and South America, Asia and Europe, with each contributing about 30 percent of the total. Africa and Oceania contributed about 5 percent each (FAO, 2014). For buffalo milk, almost all (98 percent) of the global production of nearly 100 billion kg of whole milk was done in Asia (FAO, 2014), which reflects the large number of buffalo on this continent.

The global production of meat and milk from cattle has increased by almost 40 percent and 50 percent, respectively in the last three decades. All regions except Europe have contributed to this increased production. In Europe, meat production has declined 40 percent since 1980, while milk production has declined 20 percent. However, this trend is not evident in all countries. Buffalo meat production has more than doubled in the last 30 years, while buffalo fresh milk production has increased nearly four-fold (FAO, 2014).

6.2 DIVERSITY OF LARGE RUMINANT PRODUCTION SYSTEMS

Cattle and buffalo for meat and milk production are raised under a wide variety of agro-ecological zones with different climate, soil and terrain conditions and resources that ultimately determine the quantity, quality and composition of the animals' diet and hence, productivity (Figure 3, 4 and 5). Because of the diversity of agro-ecological zones, the opportunities afforded by these different zones and the diverse production objectives and interests of the producers (e.g. family producers, medium- and large-scale enterprises) occupying and/or living in them, there is a wide variety of large ruminant production systems globally. This diversity means that there is a great variety of production systems with different production intensities and purposes within and among countries (Steinfeld, Wassenaar, and Jutzi, 2006).

Figure 3
Distribution of dairy cattle production



Source: Gerber *et al.*, 2013.

Due to the wide variety of large ruminant production systems, it is useful to have a classification system that defines the various systems, and integrates the concepts of forages and crops, and livestock interactions both among and within agro-ecological zones (Seré and Seinfeld, 1996; Thornton *et al.*, 2007). Livestock production systems and their contribution to meat and milk production are constantly changing because of shifts in driving forces, such as market demand, land occupation (especially by resource-poor households), the relationship between the production of crops and livestock, and the intensification of production. This section presents a broad classification system of the different types of large ruminant production system found globally using forage terminology based on Allen *et al.* (2011).

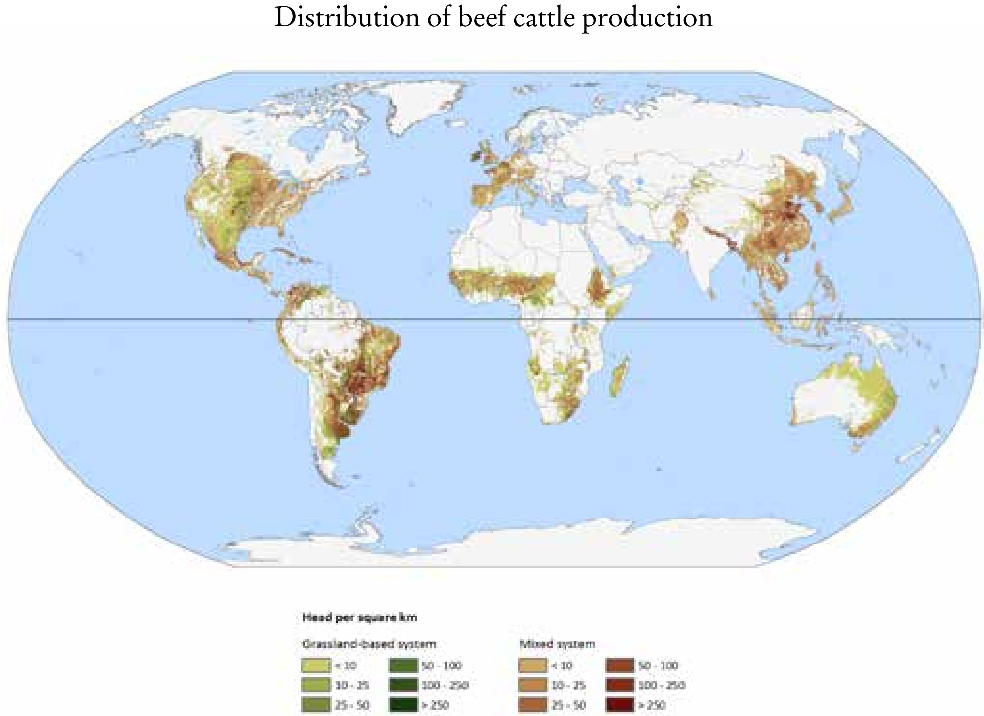
Globally, five major livestock systems can be defined and are summarized in Table 1:

1. **Intensive mixed crop–livestock systems where animals are housed permanently or through most of the year.** Feed supply can be generated from arable crops, including residues, or from cut-and-carry pasture and/or cultivated improved forages. Enterprises, including farming households, produce crops and livestock, with the ratio between the two depending on the region. There is usually intensive use of purchased inputs, especially when finishing cattle for slaughter. In some cases income and/or livelihoods depend more on crops than livestock, but some enterprises, particularly with small land holdings, may intensify their livestock production sub-system and increase its importance for income generation. In many cases, manure from the housed animals is collected and used as fertilizer in crop and/or forage production.

The occurrence of this system is usually an indicator of the pressure on land for crop cultivation and results in a high animal stocking rate. It also frequently occurs in areas with high human population densities with good linkages to markets. In some situations, irrigation is used to boost crop and/or forage productivity. Some examples of these systems includes dairy or beef production enterprises in Southern Africa, North America, South America and Europe, and 'zero grazing' systems for small-scale milk production in Eastern Africa. This system is also used in South East Asia where buffalo are raised for milk production and/or for draught power. Crop residues and planted forages are produced on the farm or imported for feeding to livestock. Concentrate feeds, i.e. feeds with a high density of nutrients and energy, but low in crude fibre, are sometimes purchased to supplement livestock feed.

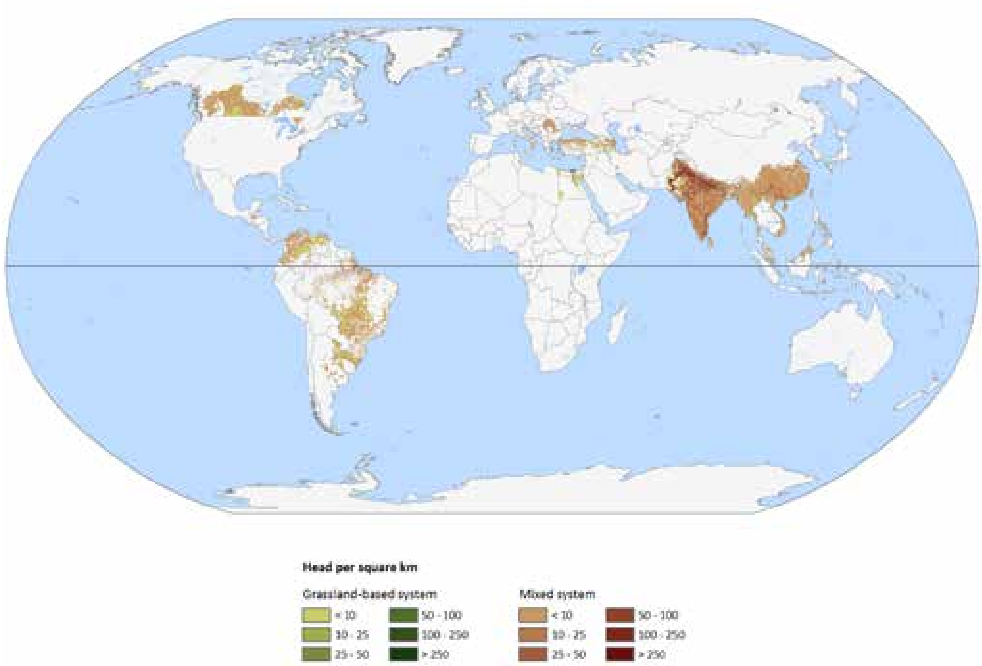
2. **Intensive systems with animals reared predominantly on pastures in confined farms.** In these systems, located in agro-ecological zones characterized by rainfall distributed throughout the year, animals derive most of their feed (60 to 90 percent) from pastures. Where climatic conditions dictate, i.e. pasture production ceases seasonally due to cold or drought, forage supplements (e.g. hay, silage) and additional feed from crop production may be supplied. Pastures may be permanent with introduced or indigenous perennial species, or may be established yearly with annual plants and sometimes in conjunction with cropping. The establishment of pastures generally involves removal of existing vegetation, soil disturbance and other cultivation practices. Both annual and perennial pastures may receive periodic treatments, such as fertilization or weed control. In many cases, there is a high utilization of the grown pastures with intensive grazing (high stocking rate). Management practices may include rotational paddock grazing using electric fences. In some situations, a high proportion of the feed in these intensive systems may be purchased off the farm. In addition, where there is the potential for livestock losses by predators, particularly in East and Southern Africa, these systems may include animals being confined overnight in *bomas* or *kraals*. Usually in these cases, supplements are fed during the confinement period. Globally, the main products from this system, which is common in many regions of the world including North America, South America, Southern Africa, Europe and Oceania, include beef and/or milk from both cattle and buffalo.
3. **Extensive systems with animals managed communally for grazing and fed on indigenous forages and residues from crops or trees.** The principal feed resources in this system are natural pastures and crop residues. This may include grazing *in situ* of post-harvest crop residues. In some regions, animals are grazed on communal land and are brought back to the human settlement and housed overnight in enclosures such as *bomas*, *kraals* or paddocks. The pastures in these systems are commonly rangelands on which the indigenous vegetation is predominantly drought-tolerant grasslands, consisting of grasses, grass-like plants, forbs or shrubs. In many cases, the grasslands are a natural ecosystem where the production of grazing livestock co-exists with wildlife. In these systems, livestock production is integrated to varying degrees with crop production, and cattle are primarily fed on pastures and crop residues. These systems are usually based on rain-fed pastures and occur in areas with low to medium human population densities. In many areas, producers

Figure 4
Distribution of beef cattle production



Source: Gerber *et al.*, 2013.

Figure 5
Distribution of buffalo production



Source: Gerber *et al.*, 2013.

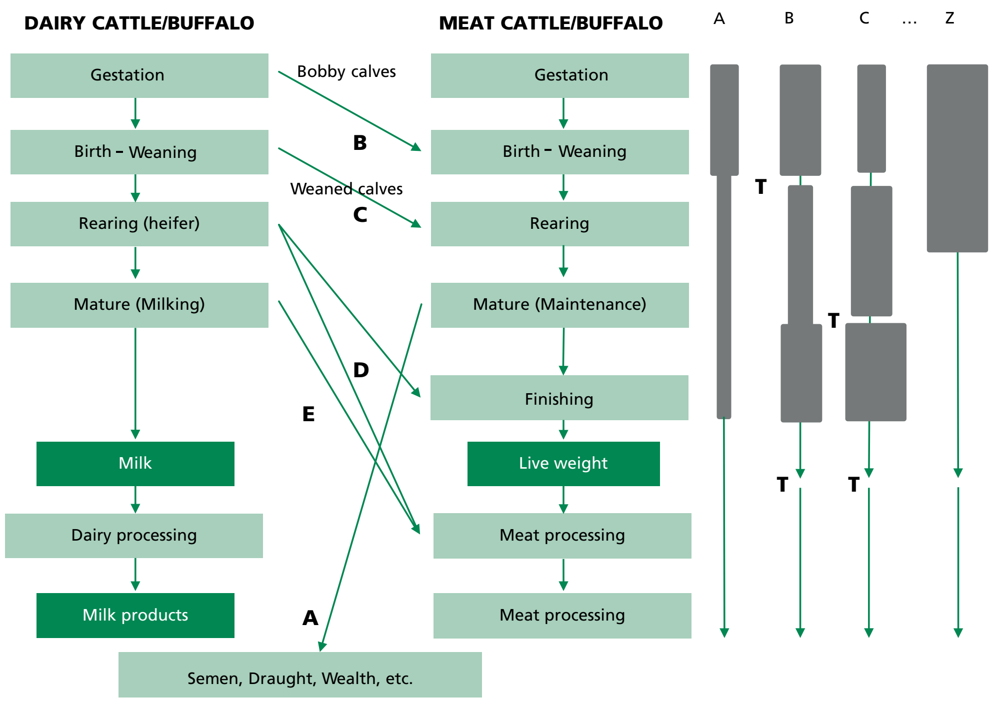
Table 1: Correlation between the five major livestock systems and those described by robinson *et al.* (2011)

Five major livestock systems	Robinson *et al.* (2011)
Intensive mixed crop–livestock systems where animals are housed permanently or through most of the year.	MRA – Rainfed mixed crop/livestock systems (arid and sub-arid) MRH – Rainfed mixed crop/livestock systems (humid and sub-humid) MRT – Rainfed mixed crop/livestock systems (highland/temperate)
Intensive systems with animals reared predominantly on pastures in confined farms.	LGA – Livestock only systems (arid and sub-arid) LGH - Livestock only systems (humid and sub-humid) LGT - Livestock only systems (highland/temperate)
Extensive systems with animals managed communally for grazing and fed on indigenous forages and residues from crops or trees.	LGA – Livestock only systems (arid and sub-arid) LGH - Livestock only systems (humid and sub-humid) LGT - Livestock only systems (highland/temperate)
Systems where large ruminant production is integrated with plantation forestry or cropping.	TREEC – Tree crop systems (including livestock) FORST – Forest-based systems (including livestock)
Large-scale Intensive livestock systems.	MIA – Irrigated mixed crop/livestock systems (arid and sub-arid) MIH - Irrigated mixed crop/livestock systems (humid and sub-humid) MIT - Irrigated mixed crop/livestock systems (highland/temperate)

depend more on livestock than crop production. In these systems, livestock serve multiple purposes, and the numbers, species and type of animals vary according to what is seen as optimal for the overall production of the farm or enterprise. In smallholder areas, households may own a mixture of small and large ruminants for meat, milk and draught power. Compared to the other systems, the levels of livestock production are low, with lower rates of reproduction, daily growth and milk production. These systems are common in many regions of South America, North America, sub-Saharan Africa, Asia, South East Asia and Oceania (Australia). In some regions, these systems may include nomadic and transhumance systems that involve regular movements of the entire herd or part of it, during seasonal climatic constraints. Grazing and water availability are the main drivers of these movements. Examples of these systems can be found in some communities in South and East Africa.

4. **Systems where large ruminant production is integrated with plantation forestry or cropping.** These systems adopt a land-use sequence where the forestry plantations share the same unit of land with cattle or annual crops. These systems create significant and positive ecological and economical interactions between forestry and beef or grain production (e.g. soybean). These integrated systems, in line with agro-ecological and sustainable intensification principles, are a good example of production diversification, which is mainly driven by seasonality and risk. They are found in South America and North America.
5. **Large-scale intensive livestock systems.** These systems are characterized by large vertically integrated production units, such as feedlots used for dairy, veal or beef production. Feed and genetics and health inputs are combined in controlled environments. There is considerable variability in the structure of these systems. For beef production in North America and Australia, breeding is typically carried out in extensive or intensive rangeland areas, and only the

Figure 6
Conceptual model of large ruminant dairy and beef production systems showing the different life stages, relationships between the systems and outputs



young animals are managed intensively. Some dairy systems may house cows continuously throughout their lifespan. The large-scale intensive production units and their sources of feed (mainly grains) are generally spatially separated by moderate to large distances, with the feed originating from specialized feed-producing farms. In these systems, usually less than 10 percent of the dry matter fed to livestock is produced on the farm. These systems are common in Europe and North America.

6.3 DIVERSITY OF LARGE RUMINANT VALUE CHAINS

Because of the wide variety of large ruminant production systems it is impossible to succinctly describe them all here. Figure 6 presents a conceptual model showing the important points that need to be considered when determining the different components and characteristics of dairy and beef production systems. The solid boxes show the different stages within the production system, while the dashed boxes denote the raw and processed products. The main dairy products (milk and milk products) and beef (live weight, meat and hide products) are presented. Other possible outputs from mature animals are shown by arrow a (e.g. semen sales, draught power, wealth management). These outputs are discussed fully in the section on product description.

In the four systems (A, B, C and Z) illustrated in Figure 6, the arrows on the right show the changes in the enterprises involved during the production cycle. The arrows reflect the buying and selling of animals, with the widths of the lines reflecting the average quality of the feed at the different stages.

The representative movement of animals between the dairy and beef systems are shown by arrows on the left: bobby and weaned calves entering the beef supply chain by arrow b; dry dairy heifers going to beef finishing operations by arrow c, or directly to slaughter by arrow d; and cull dairy cows going to slaughter by arrow e or veal to processing arrow f. Other movements are possible. For example, in systems using dual-purpose breeds, where movements occur between the dairy and beef systems, appropriate allocation decisions shall be made (see Section 9).

The solid boxes denote the various life stages of the cattle and buffalo during the production chain. For both the dairy and beef systems 'Gestation' refers to the pregnancy period after mating, when the calf foetus develops prior to birth. For both systems, 'Birth – Weaning' is the period after birth up until the calf is weaned from either its mother's milk or a milk replacement substitute, a point at which other feedstuffs, such as calf meal may also be fed in varying proportions. This stage may have different durations depending on the production system.

For the dairy system, 'Rearing (heifer)" refers to the stage where the female animal (heifer) gains weight post-weaning, reaching approximately 65 to 80 percent of the adult weight. The heifer may or may not be mated, and if she is mated she may or may not become pregnant. If she is not mated or does not become pregnant, she may be transferred to the beef system for fattening (arrow c) or immediate slaughter (arrow d). Note that the age of first mating will vary widely for the different farming systems.

For the beef system, 'Rearing' refers to the stage where the post-weaning steer/bull and heifer calves gain weight to reach adult weight. Similar to the dairy system, the heifer may or may not be mated; if mated, this usually occurs when they reach 60 to 80 percent of adult weight. The heifer may or may not become pregnant. The age of first mating will vary widely for the different farming systems. Both the male and female animals may be slaughtered at this stage or enter the mature stage.

For the dairy system 'Mature (milking)' refers to the stage where adult post-partum cows are milked. Note that this stage will also include the period when the cows are dried off. For the beef system, two distinct adult stages are recognized: 'Mature (maintenance)' and 'Finishing'. The former refers to the stage where animals are at their minimum mature body weight. The stage when the body weight is deliberately increased for slaughter is the 'Finishing' stage. This frequently involves the feeding of higher quality feedstuffs and/or reducing energy requirements (e.g. feedlots). During the 'Mature (maintenance)' stage, the animals may be used for other purposes, including the provision of draught power, which requires maintenance energy and additional energy to carry out the work.

To evaluate production systems, some key points need to be considered, and data collected in the inventory stage. Some examples of production systems are shown to the right of the diagram, as a guide to point out some of the factors that need to be considered when evaluating a production system. Real examples of a variety of production systems are illustrated in Appendix 4. This information, together with the dry matter intake at the different stages, is crucial in determining GHG and other emissions from the production system. A gap between life stages indicates that the animal(s) have moved to another farm or enterprise. Where transport is needed this is shown by a 'T'. If the arrow is continuous, there is no change in the enterprise between life stages. For example, system A represents animals kept by a single enterprise (e.g. smallholder farm) from birth to slaughter with the slaughter taking place at home. After weaning, the calves are fed relatively low-quality forage until slaughter, as denoted by the narrow width of the arrow. For system B, the calves are sold to another enterprise after weaning (illustrated by the gap), finished by the new owners, who in turn sell them to an intermediary that slaughters the animals at a meat processing plant. System C shows a complex production system with the animals being bought and sold multiple times with the wide width of the arrow at the last stage showing finishing in a feedlot using a high-quality diet. System Z shows a veal system with the animals going from the post-weaning rearing stage to slaughter with no mature stage and the calves sold to a meat processor. A more detailed description of regional production system and value chain can be found in Appendix 4.

6.4 MULTI-FUNCTIONALITY OF LARGE RUMINANT SUPPLY CHAINS

For a significant proportion of humanity, large ruminants contribute meat and milk for nourishment. For many poor and vulnerable people, large ruminants play crucial role in the four dimensions of food security (availability, access, stability and utilization). Large ruminants are important sources of nutrition, providing high-quality proteins and a wide diversity of micronutrients. In communities with no access to banks and other financial services, large ruminants also allow households to store and manage wealth, and are an important buffer in times of crisis. In addition, draught animals remain the most cost-effective power source for small and medium-scale farmers. In developing countries, using cattle and buffalo for both draught purposes and meat and milk production is a common practice. Compared with tractors, animal power is a renewable energy source and can be produced on the farm.

In mixed crop-livestock systems, large ruminants often contribute to crop productivity, as manure is used to fertilize the soil. The integration of livestock and crops allows for efficient nutrient recycling. Along with directly providing plant nutrients, manure also increases soil organic matter, maintains soil structure, improves water retention in the soil and increasing drainage capacity. In some developing countries, dung from cattle is used as fuel for cooking or heating.

In many countries, on-farm biogas production from cattle manure is used as a substitute for fossil fuel in dairy systems. This source of fuel provides energy for a number of services, such as lighting and heating for dairy operations, and for operating machinery, such as water pumps. The nutrients in the effluent from biodigesters can also be re-used as fertilizer.

Large ruminants also have cultural and religious significance. For example, in Hinduism, cows are considered sacred animals and are honoured in society, and most followers of Hinduism do not eat beef. Large ruminants can contribute to the management of cultural landscapes by maintaining traditional agricultural activities and infrastructure. They can also contribute to the preservation of ecosystems by providing ecosystem services, such as encroachment control and biodiversity conservation. Importantly, large ruminants are endemic to ecosystems in many parts of the world and are therefore an integral part of the natural ecology.

6.5 OVERVIEW OF GLOBAL EMISSIONS FROM LARGE RUMINANTS

The GHG emissions from livestock supply chain are estimated at 7.1 gigatonnes (Gt) CO_2e per year, representing 14.5 percent of all anthropomorphic GHG emissions. Large ruminants (cattle and buffalo) are responsible for about 74 percent of the emissions from the livestock sector. GHG emissions from cattle represent about 65 percent of these emissions (4.6 Gt CO_2e), making cattle the largest contributor to livestock emissions. Buffalo production contributes 618 million tonnes CO_2e or 9 percent of total sector emissions (Gerber *et al.*, 2013).

For cattle, the global average GHG emission intensity has been estimated to be 2.8 kg CO_2e per kg of fat- and protein-corrected milk (FPCM) and 46.2 kg CO_2e per kg of carcass weight for beef (Gerber *et al.*, 2013). However, there is distinct difference in emission intensity between beef produced from dairy herds and from specialized beef herds. The emission intensity of beef from specialized beef herds (68 kg CO_2e per kg carcass weight) is almost four times as much as that produced from dairy herds (18 kg CO_2e per kg carcass weight). The difference is mainly due to the fact that dairy herds produce both milk and meat, which results in the allocation of the environmental burden to two main products, while specialized beef herds mostly produce only meat as the main product. For buffalo, average buffalo milk emission intensity ranges from 3.2 kg CO_2e per kg of FPCM in South Asia to 4.8 kg CO_2e per kg of FPCM in East and Southeast Asia. Average emission intensity of buffalo meat production ranges from 21 kg CO_2e per kg carcass weight in the Near East and North Africa to 70.2 kg CO_2e per kg carcass weight in East and Southeast Africa (Gerber *et al.*, 2013). For both cattle and buffalo, high-emission-intensity production systems tend to be lower in productivity.

In large ruminant production, enteric fermentation and feed production dominate the sources of GHG emissions along the supply chains. Enteric emissions from cattle represent 46 percent and 43 percent of the total emissions in dairy and beef supply chains, respectively. Feed emissions contribute about 36 percent of milk and beef emission of cattle. Over 60 percent of emissions from buffalo production come from enteric fermentation. Fertilization of feed crops contributes 17 percent and 21 percent of emissions for buffalo milk production and beef production. Gerber *et al.* (2013) also showed that emission intensities vary greatly between production units, even within similar production systems, indicating that there is considerable room for improvement. The technologies and practices that could help reduce emissions exist but are not widely used. Their adoption by the world's large ruminant producers could result in a significant reduction in emissions. A major driver of GHG emission intensity is the efficiency of feed conversion into product, which is determined by potential animal productivity, and by the availability and quality of feed throughout the year. Manure management also has an important effect on GHG emissions. Opportunities for reducing GHG emission intensity include: the use of better quality feed and diet formulation, which would lower emissions from enteric fermentation and feed; and improved animal breeding, health and reproduction, which would shrink the herd overhead and related options. Improved management of manure reduces emissions but also ensures the recovery and recycling of nutrients and energy along supply chains. However, the potential for reducing GHG emission intensity are dependent on local climatic, animal systems and feed conditions. The application of mitigation technologies or practices requires adequate policies, increased awareness and incentives for technology transfers.

PART 2

METHODOLOGY FOR QUANTIFICATION OF THE ENVIRONMENTAL FOOTPRINT OF DAIRY, BEEF AND BUFFALO SUPPLY CHAINS

7. Definition of products

This document is intended to provide guidelines for users to calculate the GHG emissions, fossil energy use, and water use for large ruminant (buffalo and cattle) products over the key stages from the cradle to primary processing gate. In addition, other impact categories, such as acidification, eutrophication, biodiversity change and land use are briefly described in these guidelines. The guidelines are based on the use of an attributional LCA approach. Appendix 15 provides a comparative description of LCA data modelling approaches, including the attributional approach. It is expected that the primary users will be individuals or organizations with a good working knowledge of LCA.

7.1 DESCRIPTION OF PRODUCTS

These guidelines cover the cradle to primary processing gate. The main products generated may comprise:

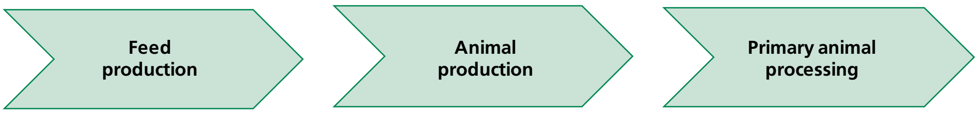
- meat products and other possible co-products of processing, such as tallow, hides and renderable material;
- milk products, such as cheese, yoghurt and milk powder, with possible co-products, such as whey;
- draught power and, in some circumstances, manure, which can be a valuable revenue-generating co-product; and
- wealth management.

These products and services are generated from a diverse range of production systems around the globe (see Appendix 5 for more details). Other co-products, such as cultural landscape management, *corrida* (bullfighting), education in agritourism and religion-related services, could be defined by the users to reflect the multi-functionality of the system under study.

7.2 LIFE CYCLE STAGES: MODULARITY

An LCA of primary products can be conducted by dividing the production system into modules that relate to different life cycle stages. The three main stages are: feed production, including feed processing, milling and storage; animal production, including animal breeding; and primary processing as outlined in Section 8.4 (Figure 7). Feed production encompasses the cradle-to-animal-mouth stage and covers a range of feeds, including processed concentrates, grains, forage crops, pastures, shrubs and trees (see LEAP Animal Feeds Guidelines). Animal production covers the cradle-to-farm-gate stage, and the main products include one or more of the following: live animals (live weight), fresh milk, draught power and wealth management services.

Figure 7
Modular scheme of large ruminant production chains



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 comparison of products or labelling of environmental performance.

It is of paramount importance that the goal and scope be given careful consideration as 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 rigour 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 will 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, particularly 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 FUNCTIONAL UNITS AND REFERENCE FLOWS

Both functional units and reference flows provide references to which input and output data are normalized in a mathematical sense. Both functional units and reference flows shall be clearly defined and measurable (ISO 14044:2006). A functional unit describes the quantified performance of the function(s) delivered by a final product. Reference flows provide a quantitative reference for intermediate products.

Livestock products are characterized by a large variety of uses (see *ENVIFOOD Protocol*, 6.2.2.2) and the functions they deliver change according to their use. In addition, many livestock products might be both intermediate products and final products. For example, farmers can distribute raw milk directly to consumers or supply it to dairy industry for further processing and bottling. For these reasons, and to ensure consistency across assessments conducted at the sectorial level, livestock products are not classified in final and intermediate products in these guidelines, and accordingly, no differentiation is made between functional units and reference flows.

Recommended functional units/reference flows for different main product types are given in Table 2. Where meat is the product, the functional unit/reference flow when the animal leaves the farm, shall be live weight, and when the product leaves the meat processing plant (or abattoir) it shall be the weight of product (meat-product weight) destined for human consumption. In many Western countries with commercial processing plants, the product weight has traditionally been identified as carcass weight at the stage of leaving the meat processing plant. Carcass weight (sometimes called dead weight) generally refers to the weight of the carcass after removal of the skin, head, feet and internal organs, including the digestive tract (and sometimes some surplus fat). However, these internal organs, for the most part, are edible. Red offal (e.g. liver, kidney, heart) and green offal (e.g. stomach and intestines) are increasingly being harvested and should be included in the edible yield where they are destined for human consumption.

Note that the 'product weight' may include a small proportion of bone and cartilage retained within the animal parts for human consumption, which are wasted at the consumption stage. The edible yield therefore needs to be specified in the functional unit/reference flow. An example of a functional unit/reference flow of meat products would be 1 000 kg of meat, with specified edible yield, moisture, fat and protein packaged for secondary processing.

The bone content of the total meat product should be defined using assumptions relevant to the country being investigated. Where specific data for product weight is not available, the cold carcass weight shall be used and can be estimated from the live weight using default values, based on a summary of international data. An example of the relative content by weight of different meat cuts and co-products is given in Appendix 8.

Table 2: Recommended functional units/reference flows for the three different main product types from large ruminants according to whether it is leaving the farm or primary product processing gate.

Main product type	Cradle to farm gate	Cradle to primary processing gate
Meat	Live weight (kg)	Meat product(s) (kg)
Draught Power	MJ	N/A
Milk	FPCM (kg)	Dairy product(s) with specific fat and protein content (kg)

Where milk is the main product type, the functional unit/reference flow shall be the weight of the milk as it leaves the farm gate corrected for fat and protein content. The latter standardizes the milk after adjustment for differences associated with breed and production. After the milk primary processing stage, a wide range of products are possible, and the appropriate functional unit/reference flow that is reported shall be the weight of the specific product (milk-product weight) with appropriate information supplied regarding fat and protein content.

There are situations in which additional functions of large ruminant systems may be of interest, especially for smallholder systems in developing countries. These include draught power and wealth management. When these functions fall within the goal and scope definition, then the multi-functional character shall be accounted following the procedures provided in Section 9.

8.4 SYSTEM BOUNDARY

8.4.1 General/Scoping analysis

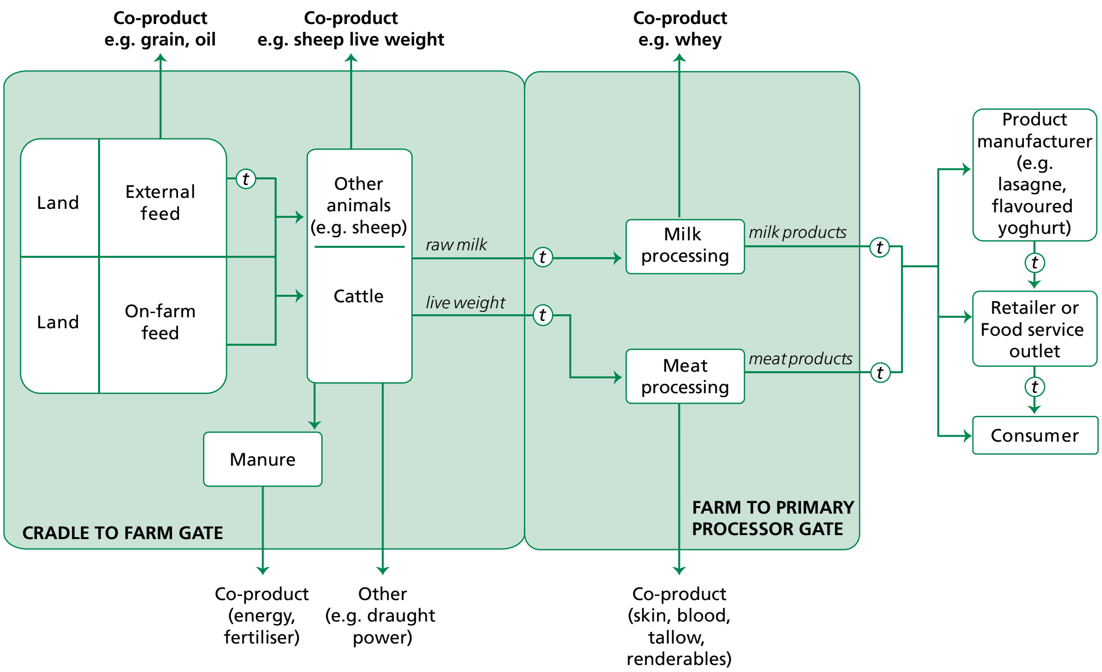
The system boundary shall be defined following general supply chain logic and include all phases from raw material extraction to the point at which the functional unit is produced. A full LCA would include processing, distribution, consumption and product end-of-life management. However, this guide does not cover post-primary processing stages in the supply chain.

The overall system boundary covered by these guidelines represents the cradle-to-primary-processing-stages of the life cycle of the main products from large ruminants (Figures 8 and 9). It covers the main stages from the cradle to farm gate, the transportation of animals to primary processor and to the primary processing gate (e.g. to the output loading dock).

The modular approach outlined in Section 7.2 illustrates the three main stages from the cradle to primary processing gate. The feed stage is addressed in detail in the LEAP Animal Feed Guidelines and encompasses the cradle-to-animal-mouth stage for all feed sources, including raw materials, inputs, production, harvesting, storage and feeding, and other feed-related inputs (e.g. milk powder for feeding calves and nutrients directly fed to animals), which are covered in detail in Section 11.2.

The animal-production stage deals with all other inputs and emissions associated with animal production and management not covered by the LEAP Animal Feed Guidelines. It is important to ensure all farm-related inputs and emissions are included in the feed and animal stages, and to avoid double counting. The animal-production stage includes accounting for breeding animals and animals used directly for meat and milk production. This may involve more than one farm if animals are traded between farms before processing.

Figure 8
System boundary diagram for the life cycle of beef and dairy cattle covering the main products of milk and meat and other co-products



Note: The large box covering the cradle to primary processing gate represents the stages covered by guidelines in this document, while the inner left box relating to land and feed is covered in the LEAP Animal Feed Guidelines. The encircled t symbol refers to the main transportation stages. The terms in italics refer to functional units of products leaving several different stages. The 'cattle' box may include up to several phases of movement of animals between different farms/areas/systems before progress to primary processor.

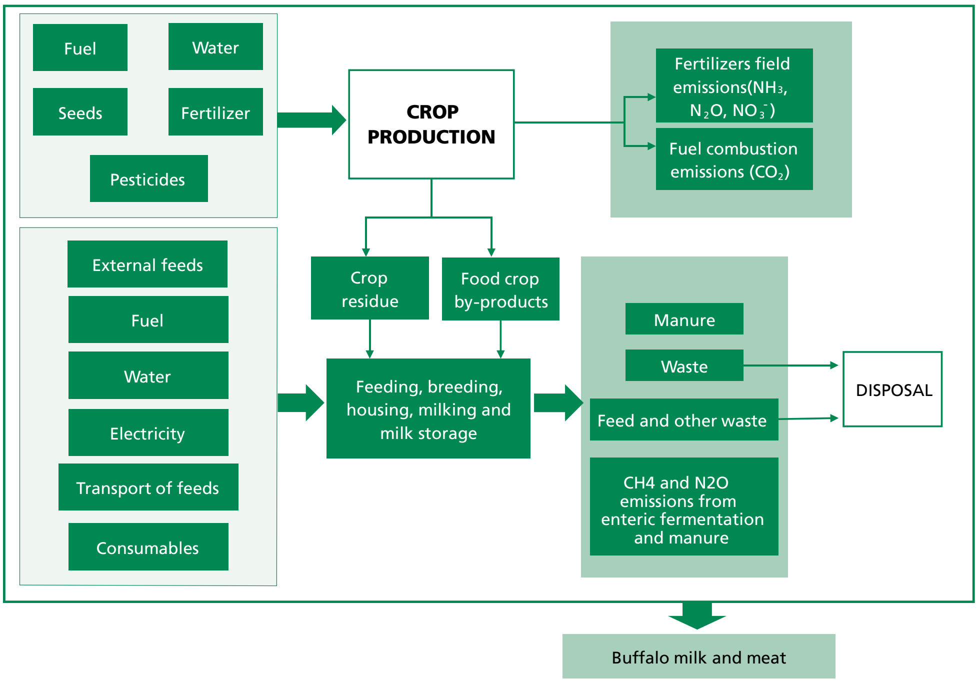
The primary processing stage shall be limited to the primary milk processing factory and animal slaughter facility (backyard, village slaughter centre and abattoir) for meat processing. All transportation steps within and between the cradle and the primary processing gate shall be included.

The choice of basic milk and meat products as typical sector outputs is intended to provide a point in the supply chain that has an analogue across the range of possible systems, geographies and goals that may be encountered in practice. The basic milk and meat products may be used directly by the consumer (particularly in developing countries) or may undergo further secondary processing with the addition of other constituents to make more complex food products (e.g. sausage).

Several PCRs extend beyond the system boundary covered in these guidelines and include the post-primary processing supply chain for meat (e.g. Boeri, 2013), dairy cow milk products (e.g. IDF, 2010; Sessa, 2013a, 2013b) and veal (e.g. Blonk Consultants, 2013).

Figure 8 and 9 illustrates a range of co-products produced from the farm to primary processing gate, which are outside the system boundary covered by these Guidelines. There are no PCRs relating specifically to these co-products. However, there are some relevant LCA publications for leather (Joseph and Nithya 2009; Milà

Figure 9
Cradle to farm gate system boundary for the buffalo supply chain



Note: The dotted line represents the system boundary of the LCA study. Blue lines represent system inputs and red lines represent system outputs.

i Canals *et al.*, 1998, 2002), biofuel from tallow (Thamsiriroj and Murphy, 2011), thermoplastic from blood meal (Bier, Verbeek and Lay, 2012) and products from rendering the by-products of animal processing (Ramirez *et al.*, 2011).

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. A scoping analysis can be conducted using secondary data to provide an overall estimate of the system's impact. Furthermore, based on existing literature reviews relating to the large ruminants sector, it is relatively clear that for production systems the following factors are extremely important to assess with high accuracy: the diet, the use of feed additives (e.g. methane inhibitors), the feed conversion efficiency, reproduction efficiency, livestock daily growth rates and manure production and management. Depending upon the particular operation under study, additional effects may be observed. In the post-farm supply chain, energy efficiency at the processing and manufacturing stages, as well as an accurate assessment of transportation modes and distances are important.

8.4.2 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 be produced and used to account for all of the material flows (e.g. within the milk processing stage, the mass of milk solids entering the factory is defined and shall equate to the sum of the mass of milk solids in the range of products produced).

Spatial system boundaries: The cradle-to-farm-gate stage includes feed and animal components. The LCA of feeds is covered in detail in the LEAP Animal Feed Guidelines and covers the cradle-to-animal-mouth stage for all feed sources, including raw materials, inputs, production, harvesting, storage, loss and feeding. Feeds may be grown on farm, or animals may graze or browse across a range of feed sources on land with multiple ownership, and/or a proportion of the feeds may be produced off-farm and transported to the farm for feeding to animals. The LEAP Animal Feed Guidelines covers all emissions associated with direct land occupation and land-use change.

These guidelines cover all other inputs and emissions in the large ruminant supply chain not covered by the LEAP Animal Feed Guidelines, i.e. emissions associated with large ruminant production and management. Management includes accounting for the fate of excreta, where it is important to avoid double counting, if excreta is captured as manure and is used as a direct input for feed production. The estimation of manure emissions from transport and application is included in the LEAP Animal Feed Guidelines. Animal production may involve more than one farm if animals are traded between farms prior to processing. For example, calves may be weaned or partly grown on one farm and sold on to another farm for finishing. These multiple components shall be accounted for in the calculations.

The primary processing stage is limited to animal slaughter, which may be done in the backyard, village slaughter unit or abattoir, for meat processing to produce the functional unit. For primary processing in developing countries, village slaughter centres are common. These can include direct processing, as well as sale of live animals to consumers for home processing or selling to large abattoirs near cities. All emissions directly related to inputs and activities in the cradle-to-primary-processing-chain stages are included, irrespective of their location. All transportation steps within and between the cradle to primary processing gate are included, as well as any packaging materials associated with products sold from the slaughtering facility. The system boundaries covered shall include feed production, animal production and primary processing stages.

8.4.3 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. 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 impact 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.

8.4.4 Time boundary for data

For products from large ruminants, a minimum period of 12 months should be used, if this is able to cover all life stages of the animal through to the specified endpoint of the analysis. To achieve this, the study shall use an 'equilibrium population' that shall include all animal classes and ages present over the 12-month period required to produce the given mass of product.

Documentation for temporal system boundaries shall describe how the assessment deviates from the one-year time frame. The time boundary for data shall be representative of the time period associated with the average environmental impacts for the products.

In extensive production systems, it is common for important parameters to vary between years. For example, reproductive rates or growth rates may change based on seasonal conditions. In these cases where there may be considerable inter-annual variability in inputs, production and emissions, it is necessary for the one-year time boundary to be determined using data averaged over 3 years to meet representativeness criteria. An averaging period of 3 to 5 years is commonly used to smooth the impact of seasonal and market variability on agricultural products.

It is important to state that in this section the time boundary for data is described, and not the time boundary of a specific management system. When the specific management system or additional system functions, such as wealth management or the provision of draught power, influence the life cycle of the animal this needs to be clearly stated. However, this would in general not influence the time boundary for the data being 12 months.

8.4.5 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.

8.4.6 Ancillary activities

Emissions from ancillary inputs (e.g. veterinary medicine, 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.

8.4.7 Delayed emissions

All emissions associated with products to the primary processing stage are assumed to occur within the time boundary for data, generally of one year. Delayed emissions from soil and vegetation are considered in the LEAP Animal Feed Guidelines. PAS 2050:2011 provides additional guidance regarding delayed emissions calculations for interested practitioners.

8.4.8 Carbon offsets

Offsets shall not be included in the carbon footprint. However, they may be reported separately as 'additional information'. If reported, details for the methodology and assumptions need to be clearly documented.

8.5 IMPACT CATEGORIES

For the LCA, all impact categories that are qualified as relevant and operational should be covered (Section 2). These include: climate change, acidification, eutrophication, land occupation, biodiversity change, water use and fossil energy use. For climate change (as well as 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 examples of possible methods that are often applied in the modelling of the impacts. Table 3 does not, however, cover all available methods and models. Other methods and models may be applied if: a) these have greater local relevance; b) they have scientific underpinning, proven in peer-reviewed scientific publications; and c) are publicly available for other users.

Any exclusion shall be explicitly documented and justified. The influence of such exclusion on the final results shall be discussed in the interpretation and communication stage and reported. The following sections describe in detail three impact categories: eutrophication, acidification and biodiversity.

8.5.1 Eutrophication

Nutrients in manure, mainly nitrogen (N) and phosphorus (P), or in the chemical fertilizers to produce feed may flow into surface water either directly or after field application. This process can provide limiting nutrients to algae and aquatic vegetation leading to a proliferation of aquatic biomass. Decomposition of this biomass consumes oxygen, creating conditions of oxygen deficiency, killing fish and other aquatic organisms. While many countries have strict regulations aimed at containing manure or fertilizer nutrients (e.g. catchment basins) or preventing their direct flow (e.g. soil phosphorus directives) into surface or ground water, some countries lack such regulations or climatic events can lead to the uncontrolled release of nutrients into water bodies. Eutrophication is considered to be one of several impact categories that could be considered in LCA, and its documentation would require the use of an impact assessment method and a description of the relevant emissions influenced (see Table 3). Quantifying eutrophication directly from large ruminants in grazing systems with access to streams or in close proximity to streams or water bodies remains difficult and is likely imprecise, as these areas are often shared with other wildlife. Approaches for developing an eutrophication score associated with manure arising from large ruminants or chemical fertilizers used in crop production are covered in the LEAP Animal Feed Guidelines.

Table 3: Examples of impact categories and impact assessment methods

Impact category	Impact category indicator	Characterization model	Sources and remarks
Climate change	kg CO_2e	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_2e	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 ReCiPe 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

8.5.2 Acidification

Nutrients in manure (mainly nitrogen) or in the chemical fertilizers used to produce feed can emit mono-nitrogen oxides (NO_x), ammonia (NH_3) and sulphur oxides (SO_x) leading to a release of hydrogen ions (H^+) when these gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in soil and lake acidification. Lupo *et al.* (2013) estimated potential terrestrial acidification impacts of beef cattle production systems at 328 g sulphur dioxide equivalents (SO_2eq) per kg carcass weight. The main contributors to this impact were manure emissions and handling (286 g SO_2e), followed by minor contributions from feed production (23.2 g SO_2e) and mineral and supplement production (11.5 g SO_2e). Ammonia emitted from manure can also be a major contributor to soil acidification. Quantifying ammonia emitted from large ruminant production systems shall account for factors, such as manure management, ambient temperature, wind speed, manure composition and pH. Current approaches include micro-meteorological methods, mass balance accounting and chamber methods. Hristov *et al.* (2011) indicated that data on ammonia emissions from large ruminant production systems are highly variable with dairy farms in North America emitting 59 g ammonia/cow/day (ranging from 0.82 to 250 g ammonia/cow/day) and beef feedlots emitting an average of 119 g ammonia/animal/day. While many countries have enacted strict regulations aimed at preventing soil acidification (e.g. European Union Thematic Strategy for Soil Protection) in response to the direct flow of excessive manure or fertilizer nutrients into the environment, some countries lack such regulations. Acidification is considered to be one of several impact categories that can be considered in LCA, and its documentation requires the use of an impact assessment method and a description of the relevant emissions influenced. Approaches to developing an acidification score associated with manure arising from large ruminants or chemical fertilizers used in crop production are covered in the LEAP Animal Feed Guidelines.

8.5.3 Biodiversity

Five main drivers of biodiversity loss are recognized by the Millennium Ecosystem Assessment (2005) and described in the LEAP Biodiversity Principles: habitat change, pollution, climate change, over-population and invasive species. Large ruminants can have positive or negative effects on most of these drivers of biodiversity loss. In some cases, continuous gradients between negative and positive effects exists, i.e. different management practices can lead to either degradation or restoration in the same region. It is important that pressure indicators reflect both of these attributes. A primary example of habitat change putting pressure on biodiversity is the deforestation of the Amazonian rainforest to produce pastures and arable crops for livestock feed. Such a process simplifies the landscape, restricting species composition and fragmenting ecosystems. Additionally, intensification of large ruminant production and overgrazing can lead to desertification, soil degradation and preferential selection for invasive species. In contrast, extensively managed large ruminants on permanent semi-natural grasslands are among the habitats with the highest biodiversity levels (Baldock *et al.,* 1993), and large ruminant activities can contribute to enhanced levels of biodiversity. For example, in African savannas, pastoralism is often compatible with wildlife and can enrich savanna landscapes (Reid, 2012). Without grazing large ruminants, ecological succession would result in the loss of many specialized species in several of the world's grassland regions. Extensive large ruminant grazing facilitates the restoration of abandoned grazing areas, increasing species richness of vascular plants (Pykälä, 2003) and arthropods (Pöyry *et al.,* 2004). Large ruminant producers can also help preserve biodiversity through the control of feral animals and weeds, and manage the damaging environmental impact of wildfires. In grazed grasslands, large ruminant excreta makes an essential contribution to nutrient cycling (Gibson, 2009). Nutrient loading in grasslands can benefit biodiversity and contribute to carbon sequestration. However, in intensive systems, excessive nutrient excretion can lead to acidification and eutrophication (Sections 8.5.1 and 8.5.2), causing changes in community composition and losses of plant species.

Quantifying the impact of livestock systems on biodiversity is crucial, as mitigation options to address environmental impacts may have varying impacts on biodiversity. If biodiversity and ecosystem services were considered with environmental impacts to develop a sustainability assessment, extensive large ruminant systems could result in higher levels of sustainability even though they typically have higher levels of GHG emission per kg of meat or milk. Trade-offs exist between the environmental performance and biodiversity environmental criteria. Therefore, assessing both criteria is needed to reveal what mitigation options will improve the overall sustainability of large ruminant production. Approaches to considering biodiversity in LCA are under development and discussed extensively in LEAP Biodiversity Principles.

9. Multi-functional processes and allocation

One of the challenges in LCA has always been associated with the proper assignment (allocation) of shared inputs and emissions to the multiple products from multi-functional processes. The choice of the method for handling co-production often has a significant impact on the final distribution of impacts across the co-products. Whichever procedure is adopted shall be documented, explained and including a sensitivity analysis of the choice on the results. As far as feasible, multi-functional procedures should be applied consistently within and among the data sets. For the purposes of these guidelines consistent use refers to choosing the highest method from the ISO hierarchy that can be applied for all multi-functional processes at a given stage of the supply chain. If economic allocation is used for soymeal/oil, then all meal/oil combinations should also use economic allocation. More specifically, these guidelines require adoption, in the following order and in alignment with the specific goal and scope definition of the study, of system separation (e.g. separate inventory for dairy, chickens and goats in multi-species systems) and system expansion to include multiple products as the functional unit.

For situations where system separation or expansion is not used, the sum of allocated inputs and outputs should equal unallocated inputs and outputs. Systems with two major products, such as dairy cattle, should consider the optimization of impacts from both live animal and milk sales/production concurrently. It is recommended that impacts be reported for all products and considered in research discussions to help overcome the problems associated with 'burden shifting', i.e. where apparent mitigation in one product is simply the result of 'shifting the burden' from one major product to another, such as from milk to live animals. In general, the aim of these guidelines is to aid in overall reductions in environmental impacts. Therefore, the evaluation of mitigation options should always consider reductions for the operation as a whole and not exclusively for one of several co-products.

When several LCAs are combined to obtain an aggregated view of the larger system, it is essential that the system models of the LCAs are the same. This ensures that all burdens caused by the aggregated demand are fully accounted, and no burdens are omitted or double-counted. For example, when a food crop uses the manure from an animal system, and the two systems are combined to determine the impacts of the aggregate demand, the impacts of the manure management shall be included only once, and the fertilizer use shall be the full fertilizer requirement of the food crop minus the amount of fertilizer displaced by the manure. This can only be ensured if all inputs are modelled as marginal, and system substitutions are not mixed with other allocation procedures (an additional reason for exclusion of substitution as a method for handling multi-functionality in these guidelines). This guidance strongly encourages that aggregated data not be included if it applies other methods for allocation, except when it is necessary to use proxy data for inputs with low significance.

It has been demonstrated that mitigation strategies focusing on one product (milk) without taking into account changes in the co-product system (live animals sold) can result in erroneous conclusions as negative changes in the co-product system have the potential to outweigh positive changes in the main product system (Zehetmeier *et al.*, 2012). Cederberg and Stadig (2003) found that higher milk production and fewer dairy cows in the Swedish dairy herd resulted in lower emissions intensity for milk, but no change to total emissions when the expanded system included the necessary additional production of beef from suckler cows to meet existing demand for meat. Considering these two studies and others (Puillet *et al.*, 2014), there is sufficient evidence of the limitations of attributional allocation in guiding future management decisions. The attributional allocation approach is appropriate for both benchmarking and hotspot analysis.

The function of wealth management, which is relevant in many systems, presents a challenge with regard to the allocation of the whole system environmental footprint because it is a service rather than a product directly derived from the animal's physiological functions (e.g. milk, meat or draught power). For the purposes of the guidelines, the allocation to wealth management shall be based on an importance assessment in consultation with the stakeholders involved in the study. This involves consulting stakeholders to determine their perception of the relative contribution of each function delivered (Weiler *et al.*, 2014). If stakeholders perceive that the wealth management function is 20 percent of the value of the system, then before making any other allocation among the system's other functions, 20 percent of the whole system emissions are allocated to wealth management. Draught power, particularly from swamp buffalo, can be estimated from known energy requirements for the provision of power as described below.

9.1 GENERAL PRINCIPLES

The ISO 14044:2006 standard gives the following guidelines for LCA practitioners with respect to practices for handling multi-functional production:

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 between its different products or functions in a way that reflects the underlying physical relationships between them. In other words, they should reflect the way in which the inputs and outputs are affected by quantitative changes in the products or functions delivered by the system.

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

Where allocation of inputs is required (e.g. the allocation of energy use at the abattoir between large ruminant meat and non-human edible products), the allocation procedures should follow the ISO 14044:2006 allocation hierarchy. When allocation choices significantly affect the results, a sensitivity analysis shall be performed to ensure the robustness of conclusions. Below is a list of commonly used procedures for addressing multi-functional processes in attributional studies:

- biophysical causality, arising from underlying biological or physical relationships between the co-products, such as material or energy balances;
- physical properties, such as mass, or protein or energy content; and
- economic value (revenue share) based on market prices of the products.

9.2 A DECISION TREE TO GUIDE METHODOLOGY CHOICES

A decision tree diagram to help with decisions on the appropriate methodology for dealing with co-products is given in Figure 10. It uses a three-stage approach, and the principles involved in working through it are as follows:

Stage 1: Avoid allocation by subdividing the processing system.

A production unit is defined here as a group of activities (along with the inputs, machinery and equipment) in a processing facility or a farm that are needed to produce one or more co-products. Examples include 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 for the production of milk); or the individual processing lines in a manufacturing facility.

flow 1.a. In the first stage (ISO step 1a: subdivision) all processes and activities of a farm/processing facility are subdivided based on the following characteristics:

flow 1.b. Inputs/activities that **can be directly assigned to a single co-product should be assigned to that co-product** (e.g. packaging and post-processing storage for meat products, or rendering energy requirements in the post-exsanguination phase at the processing plant).

flow 1.c. Inputs/activities that **can be assigned to single production units** and that may provide multiple co-products should be assigned to the specific production unit (e.g. input of pesticides for corn are assigned to the 'corn production unit' of a farm with multiple crops; or energy inputs for a specific barn operation or manufacturing facility; or feed for a specific animal, which may yield multiple products, in a farm operation with several species).

Inputs/activities of a **non-specific nature in a farm or processing facility** such as heating, ventilation, climate control and internal transport in a manufacturing facility or farm that cannot be directly attributed to specific production units. For example energy to pump drinking water for multiple animal species in a small-scale, multi-species operation would be categorized as non-specific. It may be possible for these inputs to 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).

Stage 2. Attribute combined production to separate production units

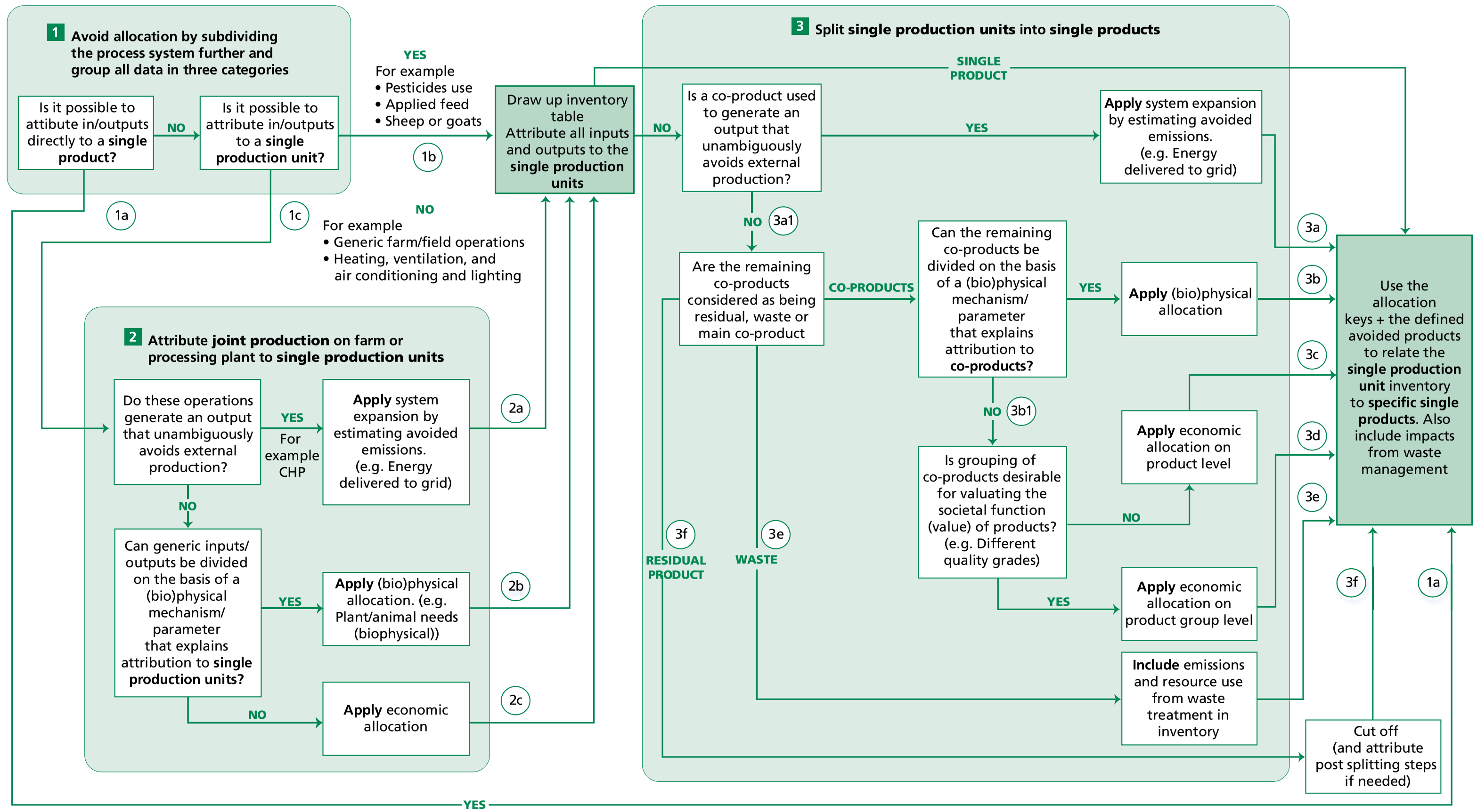
In theory, all combined production systems are separable, where sufficient detailed data exist, and should normally follow path 1a. Some joint production systems may also be separable through the use of process models, as with the IDF methodology (IDF, 2010a) and Thoma *et al.* (2013a). Nevertheless, situations exist where this is impractical, and the next stage (stage 2 in Figure 10), the non-specific processes should be attributed to production units on the basis of ISO steps 1b, 2 and 3. For example, cattle and sheep may be grazed on common fields in a single combined production unit. In this situation, farm overhead operations that cannot be explicitly assigned to an individual species should be handled using the criteria in Box 2 in Figure 10. For some production systems (particularly large commercial operations), the 1b path to Box 3 in Figure 10 will be followed, as the inputs and outputs in a single animal species system are clearly assigned to the single production unit and its activities/operations and products. An example in the dairy sector of specific inputs attributable to a single farm activity is electricity and refrigeration linked only to milking.

System expansion: ISO step 1b: As part of the harmonization effort behind these guidelines, the range of allocation options in application of LCA are restricted to large ruminant systems 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 (ISO 14044:2006). For dairy operations for example, this implies that the environmental impacts can only be attributed to the combined multiple outputs of cull cows and calves (as meat), milk and draught power, and that no individual function receives a separately identified impact. For example, the functional unit might then be 6 000 kg milk, plus 200 kg live weight, plus 48 hours of draught ploughing. For benchmarking operations, this is an entirely appropriate perspective; the overall reduction of impacts for the multi-functional system can be easily monitored and managed. 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 desired, because, for example, the study goal is to report the impact of a single product (e.g. milk), then the second question is whether a physical allocation is possible. The condition imposed by these guidelines here is that the products should have similar physical properties and serve similar goals or markets (e.g. human food as opposed to pet food markets for products of meat processing). Alternatively, known processing or biophysical relationships can be used to assign inputs and outputs of a single production unit to each product that is produced from that production unit (ISO 14044:2006, 4.3.4.2, Step 2). For example, if feed is provided to multiple animal species, the animal growth requirements may be used to apportion the shared feed between the species. The result of this stage will be a splitting of some inventory flows between the production units, and if the resultant process is multi-functional (e.g. separation of dairy operations from free-range layers, in a system with both species feeding from the same pasture still leaves a multi-functional production unit of the dairy), these inventory flows will be allocated to single co-products in the next stage of the procedure (Box 3 in Figure 10).

Allocation: ISO step 3: When physical allocation is not possible or allowed, the last option is economic allocation. As with physical allocation, the result of this step will be a splitting of some inventory flows between the production units, and if the resultant unit process is still multi-functional, these inventory flows will be allocated to single co-products in the next stage of the procedure (Box 3 in Figure 10).

Figure 10
Multi-functional output decision tree



Note: The choice of method for handling multi-functional outputs for each stage or process in the supply chain shall be based on this decision algorithm. Allocation keys used in the right-most box refer to the factors derived during application of the decision tree that are used to allocate inputs among multiple functions. For example, if economic allocation is used (e.g. to arrive at 3c), the allocation key for that stage is the ratio of the revenue of the co-product of interest to the total revenue for the activity.

Stage 3. Split single production units into individual co-products.

After stages 1 and 2, all inputs and operations will have been attributed to the single production unit, or already to a single product. An inventory table is made for the production unit. Stage 3 guides the assignment of inputs and emissions from a single production unit to each co-product produced by the unit. If there is only a single product at this stage, the process is complete. The same rule holds as the one defined above for production units, so system expansion (without substitution) should be applied in situations where supported by the goal and scope definition. Any flow arising from 2a will follow this path. When system expansion is not used, the remaining outputs shall be classified as co-products, residual products or wastes.

The output of a production process are considered as residual flows (3f) if:

they are exported in the condition in which they are created in the process and do not contribute revenue to the owner they are included in value-added steps beyond the boundary of the large ruminant system under study, but these activities do not impact the large ruminant system calculations in these guidelines.

Residual products will not receive any allocated emissions, nor will they contribute emissions to the main co-products of the production unit. However, it is useful to track residual flows for the purpose of understanding the mass balance for the production unit.

An output of a production process shall be considered as waste if the production unit incurs a cost for treatment or removal. Waste has to be treated and/or disposed of, and these emissions shall be included in the inventory and allocated among the co-products. It is, of course, necessary that all activities associated with waste treatment fully comply with any local legal or regulatory requirements. For the large ruminant sector, the most common process in this category is wastewater treatment at manufacturing facilities.

Co-products (not residual or waste) are subject to allocation where a fraction of the entire production unit's emissions is assigned to each co-product, leading to flows 3b, 3c, and 3d in Figure 10. Assignment to these flows depends upon whether biophysical or mechanistic allocation or an allocation based on physical characteristics is possible or allowed under these guidelines (3b), or whether an economic allocation at a single product (3c) or product group level (3d) is applied.

Following the ISO standard, the preferred approach is to identify a straightforward mechanistic algorithm, or biophysical, causal relationship that can be used to assign inputs and emissions to each co-product. The condition for determining whether physical characteristic-based allocation (e.g. energy or protein content) is appropriate is that the products should have similar physical properties and serve similar functions or markets. When physical allocation is not feasible (interactions are too complex to accurately define a mechanistic relationship) or is not allowed (dissimilar properties or markets), the last option is economic allocation. See also ISO/TR 14049: 2012 *Environmental management -- Life cycle assessment -- Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis* (ISO, 2012) for additional information.

In the case of economic allocation, one option (flow 3d) is grouping a number of co-products and performing the allocation with some co-products at the group level instead of the single product level. This option is relevant for the various edible meat components (e.g. carcass cuts and edible offal), which shall be grouped before allocation between them and possible other inedible co-products, such as hide and renderables.

9.3 APPLICATION OF GENERAL PRINCIPLES FOR LARGE RUMINANT SYSTEMS AND PROCESSES

In practice, dealing with multi-functional processes and the choice of allocation method is a contentious issue in LCA studies. For large ruminants, there are a number of steps where allocation decisions are required. Thus, these guidelines go into some detail on each of these steps and give recommendations on the preferred allocation methodology for each one (Section 9.2). The recommended methods, based on use of the decision tree, are summarized in Table 4.

9.3.1 Cradle to Farm gate

Within the cradle-to-farm-gate boundary there are a number of allocation decisions associated with feeds. The multi-functionality of feeds is addressed the LEAP Animal Feed Guidelines. This last point may be more of a system boundary issue, but depending on how the material is classified at the processor gate, could be considered as an allocation issue. Within the animal production stage, there are two main areas where co-products need to be accounted for. These are:

- where different animal species consume the same feed source(s) and/or share non-feed related inputs (path 1c in the decision tree); and
- where large ruminants produce multiple products of live animals (e.g. cull cows, weaner steers, replacement heifers), milk, draught power and wealth management.

In ruminant livestock systems, the major determinant of GHG emissions is enteric methane (CH_4) and excreta methane and nitrous oxide (N_2O) emissions, and the driver of these is feed intake and feed characteristics. Consequently, if the activities, inputs or emissions cannot be separated, the preferred method to account for multi-functional processes and co-products shall be a biophysical approach based on feed intake associated with the different animal species or co-products.

In practice, accounting for multiple animal species (step 1c in Figure 10, since this is not a single production unit) is based initially on the separation of activities between species and then on the determination of feed intake for each species (step 2b in Figure 10). Remaining shared inputs (e.g. energy use for water provision) are allocated according to relative feed intake between species.

At a whole farm level, the equivalent output from this approach would be to determine all feed and animal-related emissions for the farm, and use the allocation factors for the target large ruminant species based on relative feed intake to determine that species' total emissions.

Accounting for different animal species and non-feed activities within a farm

Many farms present a mixture of animal species (e.g. sheep, cattle, buffalo, poultry and swine), which are often farmed together. It is recommended to separate activities of the farm system for the different animal species where specific uses can be defined (e.g. the use of summer forage crops for dairy cattle only; use of nitrogen fertilizer specifically for pasture grown to feed beef cattle). For the remainder of the environmental impacts for the cradle-to-farm-gate stage, where there is common grazing or feeding of the same feed source, the actual amount of feed consumed by

Table 4: Recommended methods for dealing with multi-functional processes and allocation between co-products for the cradle-to-primary-processing-gate stages of the life cycle of large ruminant products

Source/stage of co-products	Recommended method*	Basis
Animal species (within farm)	System separation Biophysical causality	First, separate the activities specific to an animal species. Then determine emissions specific to feeds relating to the ruminants under study. For remaining non-feed inputs, use biophysical allocation based on the proportion of total energy requirements for each of the different animal species.
Live animals, milk, draught power, wealth management (within farm)	System separation Biophysical causality	First, separate activities specific to products (e.g. electricity for shearing or milking). Then use biophysical allocation according to energy requirements for animal physiological functions of growth, milk production, reproduction, activity and maintenance.
Milk processing to milk products	System separation Physical	First, separate activities specific to individual products where possible. Then use allocation based on dry matter content
Meat processing to edible and non-edible products	System separation Economic	First, separate the activities specific to individual products where possible. Then use economic allocation possibly based on a five years of recent average prices.

* Where choice of allocation can have a significant effect on results, it is recommended to use more than one method to illustrate the effects of choice of allocation methodology. Specifically, it is recommended that biophysical causality and economic allocation are used in sensitivity assessment, and that market price fluctuations be included as a tested parameter in all economic allocation (*ENVIFOOD Protocol*).

the cattle under study shall be calculated as outlined in Section 11.2.2, along with the intake of other animal species. Emissions associated with other non-feed shared activities (e.g. fuel used for animal transport, drain cleaning, hedge cutting, fencing maintenance) shall be allocated between animal species using a biophysical allocation approach. Preferably, this should be based on the calculation of the total feed intake for each of the different animal species, and the allocation based on the relative feed intake between species (see Box 1).

Cattle and Buffalo Meat Production

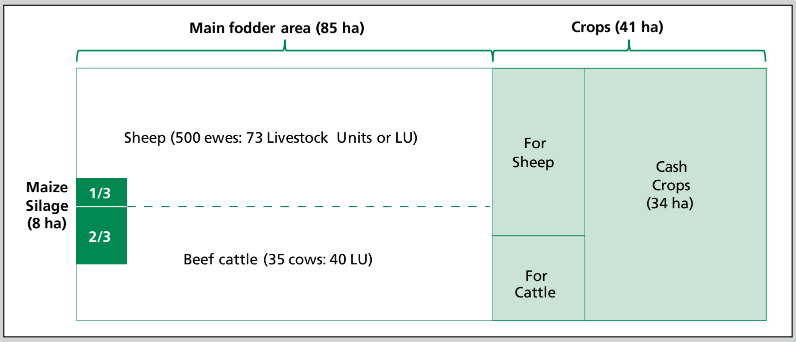
For dedicated meat production systems, there are two potential stages of separation into multiple products: the cow-calf suckler (Birth - Weaning in Figure 6) stage, and the meat processing stage. The potential co-products depend on the specific system and the boundaries chosen for the study. They include cull bulls and breeder cows, weaner steers and heifers, finished steers and heifers, and a range of meat (human edible) and non-meat (all non-human edible) products from processing.

Cow-calf stage: Here, cull suckler cows and bulls are sent to slaughter, suckling calves may be sent to veal fattening operations and weaner steers and heifers are sold to finishing operations. If a self-replacing herd is being modelled, replacement breeding animals are retained from a proportion of the annual weaned calves bred, and these may represent an internal flow with no allocation required. However, allocation is still required to the proportion of weaners that are sold.

Stocker/background stage: This is an intermediate stage between weaning and finishing where animals are normally grazed on pasture or fed high-forage diets in confinement until they are sent to a finishing operation. Some animals may be kept

Box 1: Calculation of multi-functional processes and allocation in a french mixed sheep and cattle farm

The figure above describes the farm system and is based on Benoit and Laignel (2011). The area identified as being used for cash crops is excluded in the calculation of the environmental impacts from animals on farm. The main fodder area is pasture (in white), which is commonly grazed and used for silage or hay production for both sheep and beef cattle. Table below describes a process used in France to apportion environmental impacts between cash crops and animal species for the case study farm. Table below describes the result of the allocation among sheep, cattle and cash crops.



Allocation among cattle, sheep and field crops

	Recommended method*	Basis
1st: Split between cash crops and animal production (including crops for animals and forages)		
Fuel	Total fuel use only	French empirical references (litres/ha and litres/LU) used to build specific allocation keys
Electricity	Total electricity only, except for specific usages (irrigation)	French empirical references (kilowatt-hour /LU) used to build specific allocation keys
Manure fertilizers Manure application	Amounts known for each crop and forages	Split between cash crop and feeds for animals (system separation)
2nd: Then split between the different types of animal production		
Forages (production and conservation for silage or hay [e.g. including plastics])	General data on forages only	Biophysical allocation based on relative feed intake for forages (pasture, silage, hay) used by both animal species
Cereal crops and maize silage for animals	Quantities distributed to each animal species are known	System separation
Feed inputs (concentrates, vitamins, minerals, milk powder)	Quantities (or amount in €) distributed to each animal species are known	System separation
Breeding operations (e.g. reproduction, veterinary, drenches)	Can be assessed through economic value, but are known for each animal type	System separation

Total fuel use is known, but this is used for multiple purposes, including production of cash crops, feeds for animals and general farm activities relating to animals (e.g. provision of feed, removal of feed waste, manure management, vehicles for animal movements). French researchers allocate fuel-related emissions between cash crops and each animal type using empirical functions derived from regional survey data and related to hectares of crop or livestock units (LU). In this case, a LU was estimated in terms of body weight (500 kg body weight per LU). Conversion to LU was accomplished using average estimated body weights for sheep and beef cattle.

(Cont.)

Output of allocation among sheep, cattle and cash crops

	Sheep production	Cattle production	Cash crops	Total
Allocation across livestock, fodder areas and	1 GJ LU^{-1} $year^{-1}$ + 0.9 GJ/ha of fodder area +0.4GJ/ha crop	1.8 GJ LU^{-1} $year^{-1}$ + 1.4 GJ/ha of fodder area +0.4GJ/ha crop	4.3 GJ/ha	
Theoretical consumption	1*73LU +0.9*56 = 123.4	1.8*40LU +1.4*36 = 122.4	4.3*34ha =146.2	392
Allocation %	31.5	31.2	37.3	100

An alternative approach for fuel is to use records of all specific farm operations relating to each crop (e.g. ha ploughed, rotary-tilled, sown, harvested), then use country-specific or published values for typical fuel use per hectare (e.g. Witney, 1988) and integrate these for each system using a system separation approach. In this case, biophysical allocation would then be applied for the remaining fuel used for pasture-related activities and non-feed animal activities (e.g. manure management, animal movements) to establish allocations between sheep and cattle (see below).

A similar approach is used for electricity use in France based on a database of average use for sheep, cattle or cropping [0.4 GJ/LU or 0.4 GJ/ha]. Alternatively, a biophysical allocation ratio could be applied to allocate between animal types (see below).

System separation can be used for the main crops, other feed sources and animal breeding operations (see table above). However, the sheep and cattle both graze the pasture on the farm and are both fed silage and hay. Therefore, some method is required for apportioning the related inputs and emissions between sheep and cattle. The simplest biophysical allocation method is to use the total energy requirements or dry matter (DM) intake for sheep and cattle. In this case, the allocation factor (A) for cattle was calculated using:

A (%) = 100 x Cattle total DM intake/ (Sheep total DM intake + Cattle total DM intake)

In this farm, ***A = 100x190/ (347+190) = 35%*** *(where 347 and 190 are the DM intake calculated for sheep and cattle, respectively). Thus, 35 percent of farm management-related GHG emissions (or fossil fuel use) that could not be separately estimated or derived through system separation would be attributed to cattle.*

on pasture and marketed as grass-fed.

Finishing stage: All animals leaving this stage for slaughter, under these guidelines, are considered equivalent and considered on a live weight basis. For complete systems that include the suckler and stocker stages, the cull cows and bulls, along with the finished steers and heifers, shall be considered as the aggregate production from the system, and allocation among these different animal classes is not required. If the cow-calf stage is considered as a background system, for which secondary data is used, then the first multi-functional issue will already have been accounted for in the secondary data.

Milk Production

For dairy production systems that are a single production unit and therefore follow step 1b, the allocation between live weight of animals and milk co-products shall be based on biophysical allocation according to feed requirements for their production (following steps 3a1 and 3b in Figure 10). This aligns with the IDF methodology (IDF, 2010a) for allocation between milk and live animals sold for dairy cows. Previous studies have shown that the choice of allocation method for co-products can have a significant effect on reported product-specific environmental impacts (Cederberg and Stadig, 2003; Flysjö *et al.*, 2011; Gac *et al.*, 2014; Nguyen *et al.*, 2012). As noted previously, where the choice of allocation can have a significant effect on results, more than one method shall be used to illustrate the effects of choice of allocation methodology. Alternate methodological approaches include: system expansion, economic allocation, and mass, energy or protein allocation. This is also important when the guidelines are used for analysing the implications for co-products and the potential benefits of mitigation options. For example, depending on the methodology employed, the use of mitigation to reduce emissions from a main product may have unintended effects on increasing emissions from co-products and their associated production systems, leading to no overall benefits (e.g. Flysjö *et al.*, 2012; Zehetmeier *et al.*, 2012).

Allocation between draught, meat and milk production

Large ruminants produce meat and milk and are occasionally used for draught power. However, in most ruminant production systems, the focus is on one main product, or the product that may provide the largest proportion of economic return to the producer. For instance, in the case of dairy cows, where the main product is milk and meat is a co-product, a biophysical or economic allocation approach is most widely used (e.g. Flysjö *et al.*, 2011; IDF, 2010a; Thoma *et al.*, 2013b).

Biophysical allocation is applied based on the feed energy consumption requirements for milk and meat production. This is calculated using the Intergovernmental Panel on Climate Change (IPCC) Tier-2 approach, an internationally acceptable methodology (Section 11.2.2). In large ruminants used principally for draught, power can be considered as the main product and meat can be considered as a co-product. Appendix 6 provides calculations for the estimation of energy requirements for draught power. The allocation ratio for milk, relative to milk plus meat is then calculated from the ratio of the energy requirement for milk production to the energy requirement for milk and meat production (the animal growth component):

Allocation % to milk = 100 x (energy req. for milk/(energy req. for milk + energy req. for meat + energy req. for draught))

Where milk or meat is the main product from the production system, biophysical allocation based on energy requirements shall be used.

In conformance with ISO/TS 14067:2013, where the choice of allocation can have a significant effect on results, it is recommended to conduct a sensitivity analysis making use of more than one method to illustrate the effects of choice of allocation methodology (see Box 2). For example, protein mass or economic allocation should be used for comparison, with the latter based on the relative gross economic value of the products received (e.g. using regional/national data) over a period of at least three years to reduce potential effects of price fluctuations over time.

Allocation of manure exported off-farm

This discussion follows the decision tree presented in Figure 10. The first determination that shall be made is the classification of manure as a co-product, waste

Box 2. The influence of mass, protein, energy, economic and biophysical allocation on the proportion of ghg emissions attributed to milk for an irish grass-based research dairy system

Data in Table below were based on a summary of the average outputs of a specialized grazing dairy farm in Ireland from 2002-2005. The economic value of the different components was calculated using the market average from 2008 to 2013. The energy and protein content of milk was based on measured values, but for meat from surplus calves and culled cows, default values were used (USDA, 2010). The biophysical energy requirement to produce milk and meat was first calculated according to a regression equation of the IDF (2010b) guidelines and then using energy requirement algorithms of the French ruminant nutrition guidelines (Jarrige, 1989). Table below shows that mass allocation attributed the least environmental impacts to milk, followed by allocation according to the energy and protein content of the products produced. Allocation based on energy requirements (IDF and biophysical allocation) attributed the least environmental impacts to milk, given the higher energy requirements to produce live weight as compared to milk. Economic allocation attributed more environmental impacts to milk than using a biophysical approach. Overall, Table below illustrates the effect the various allocation methods have on the carbon footprint for milk, which corresponded to approximately an eight-fold difference in the carbon footprint of meat. (Data provided by O'Brien et al.*, 2014)*

The outputs and energy requirements per cow, and allocation factors calculated for milk for a specialized grazing dairy system

Allocation method	Milk	Surplus dairy calves	Culled cows	Milk allocation factor	Carbon footprint of milk (kg CO_2e/tonne milk)	Carbon footprint of meat (kg CO_2e/tonne live weight)
Mass (kg)	6,667	47	88	98%	820	840
Energy Content (MJ)	21,165	371	689	95%	795	2,070
Protein Content (kg)	222	5	9	94%	789	2,370
Economic Value (€)	1,979	80	123	91%	759	3,850
IDF (g live weight/kg milk)	-	13	7	88%	739	4,840
Biophysical (MJ)	32,938	1,512	4,987	84%	703	6,610

The economic allocation percentage (EA) for milk relative to the total returns for the dairy cow was calculated using:

EA (%) = 100 x Σ (weight of milk component x relative value of milk component) / [Σ (weight of milk component i x relative value of milk component i) + Σ (weight of co-product i x relative value of co-product i)]

The mass allocation percentage (MA) for milk was calculated using:

MA (%) = 100 x Σ (weight of milk component i) / [Σ(weight of milk component i + Σ (weight of co-product i)]

The following equation from IDF (2010b) was used to calculate the allocation factor for milk and meat:

$$IDF = 1 - 5.7717 \times (Mmeat/Mmilk) \quad (1)$$

where IDF = IDF allocation factor for milk, Mmeat = sum of live weight of all animals including bull calves and culled mature animals and Mmilk = sum of mass of milk sold, corrected to 4 percent fat and 3.3 percent protein.

or residual. This results in a separation of the system where all post-farm emissions from use of the manure are assigned to that subsequent use, while all on-farm management is assigned to the main product(s) from the farm (live animals, milk, draught power and possibly wealth management) for which the previous allocation procedures apply.

Co-product: When manure is a valuable output of the farm, and if the system of manure production cannot be separated from the system of animal production, then the full supply chain emissions to the farm gate shall be shared by all the co-products. Following the recommendations provided in Table 10, the first method for allocation is to apply a biophysical approach based on the energy for digestion that must be expended by the animal to utilize the nutrients and create the manure. This is calculated as the heat increment for feeding of the diet. It represents the energy expended by the end associated with the process of feeding and digestion, and is distinct from maintenance energy requirements (Emmans, 1994; Kaseloo and Lovvorn, 2003). This situation may occur in any large ruminant system. There may be several co-products: cull cows, cull steers, cull calves, milk and manure, as well as draught power and wealth management. The allocation fraction assigned to each of the co-products (except wealth management) shall be calculated as the ratio of the feed consumed that was required to perform each of the respective functions to the total feed consumed for all of the functions. In situations where energy content of the diet is unknown, the next step in a decision tree results in an economic allocation, because allocation based on physical characteristics parameters is clearly not appropriate as the functions are different for the product (in the case of manure, fertilizer as opposed to energy). However, it should be noted that in this situation, an inconsistency in methodology arises if biophysical allocation is used for part of the system while economic allocation is used for another part. An example of manure as co-product is provided in Appendix 7.

The practitioner shall make note of any inconsistencies and evaluate the possible impacts on the study conclusions in the reporting of results.

Residual: Manure has essentially no value at the system boundary. This is equivalent to system separation by cut off, in that activities associated with conversion of the residual to a useful product (e.g. energy or fertilizer) occur outside of the production system boundary. In this recommended approach, as previously stated, emissions associated with manure management up to the point of field application are assigned to the animal system, and emissions from the field are assigned to the crop production system.

Waste: Manure is classified as a waste generally only in two situations: when it is disposed of by landfill, incineration without energy recovery, or sent to a treatment facility; and when it is applied in excess of crop nutrient requirements. In the first case, all on-farm emissions shall be assigned to the animal product(s). However, in the second case, the fraction of manure applied to meet crop nutrient requirements should be considered as a residual as described above. The excess manure application shall be treated as a waste, and field emissions assigned to the animal production system. Emissions associated with the final disposition of manure as a waste are within the system boundary and shall be accounted and assigned to the animal product(s).

Box 3. Example calculation **for on-farm energy generation**

Advanced options for manure management are continually being developed. One technology that holds high promise is anaerobic digestion. In this example, manure management calculations, following the attributional approach required by these guidelines, are considered. The example is from a 550 head dairy farm that uses a covered lagoon as an anaerobic digester. The biogas produced is used to produce electricity, in a 130-kilowatt generator, for on-site consumption, and excess electricity is sold to the local grid. Data for this operation indicate that approximately 59.5 litres of manure are produced per animal per day. The total solids in the manure are 6.7 kg per cow per day, and total volatile solids are 5.7 kg per cow per day. The digestibility (in the anaerobic reactor) of the total volatile solids is 30 percent. This results in the production of 2 210 litres per head per day of biogas with a composition of 59.1 percent methane, 39.2 percent carbon dioxide and 1.7 percent other gases, including ammonia and hydrogen sulfide in trace quantities. This results in the production of 1 430 kilowatt-hours per day, equivalent to 1.176 kilowatt-hour per cubic meter of biogas. The animals are housed in a tie-stall barn, which is regularly scraped to remove manure for transfer to the digester. Emissions associated with the residence time of the manure in the barn are attributed to the animal system, while the feedstock to the anaerobic digester is considered as a residual and carries no burden into the digester process. Based on unit processes from the EcoInvent database (V 2. 2: biogas, agriculture covered, in co-generation with ignition biogas engine) for electricity and heat co-generation from manure slurry, and assuming a 1 percent leak rate of methane and 1.4E-3 kg nitrous oxide per cubic metre of biogas processed from the anaerobic digester, the carbon footprint for this electricity is 115 kg CO_2e per day. This analysis accounts for energy required to operate the anaerobic digester, primarily derived from steady-state operation of the digester itself in which excess heat from the electricity generation system is used to maintain appropriate operating temperatures for the digester.

*The digester produces approximately 5 cubic metres of solid material per day, which can be composted to remove pathogens, and sold for US$17 per cubic metre. The liquid effluent, which contains the majority of the remaining nutrients from the manure, is stored on site and used as a fertilizer for crop production. This liquid is treated as a residual and emissions associated with its application are assigned to the subsequent crop. Electricity is valued at US$.08/kilowatt-hour, and an economic allocation among the co-products of the compost and electricity in the ratio of (1430*0.08 = US$114.4) / (114.4 *5*17= US$199.4) =0.574. Thus, the carbon footprint for electricity produced from the anaerobic digester system is 0.574*115/1430 and equals 0.046 kg CO_2e/kilowatt-hour. The electricity used by the dairy operation, supplied by the anaerobic digestion process, is treated as a normal input with the carbon footprint of 0.046 kg CO_2e/kilowatt-hour. From an attributional perspective, the GHG burden of the electricity sold to the grid is the same as for the dairy.*

9.3.2 Post-farm gate

Milk Processing: For the first milk processing stage, where raw milk may be converted into multiple products (considered a single production unit following steps 1b, 3a1 and 3b in Figure 10), and allocation between co-products shall be based on dry matter content. The use of this approach for dairy products aligns with that used in recent publications for milk products from dairy cows (IDF, 2010a; Thoma *et al.*, 2013b), and meets the requirements for similarity of products in grouping as shown in Figure 10.

Meat processing: The primary point of separation of multiple products in meat production systems is at the processing stage, where meat, hides, bone and blood meals, as well as tallow and rendering products are generated. As discussed above, there are several approaches for handling this multi-functionality. The recommendation of this guidance is to choose economic allocation for products that serve similar markets or functions. However, because of the potential sensitivity of the reported results to this methodological choice, if information is available, mass and physical property based allocation may also be examined to determine the robustness of the results to the choice of allocation methodology. It is acknowledged that from a consumer perspective, there is a difference in the products derived from a cull dairy cow and finished steer, and between different cuts of meat (either cow or buffalo). However, from a nutritional perspective, there is little difference, and all serve the function of providing an equivalent nutritional value. Therefore, for purposes of these guidelines, all products edible by humans from the supply chain are considered as equivalent, and other products should be classified in groups according to function or market (e.g. pet foods or livestock feed, tallow for biodiesel and hides for leather).

The assessment of meat processing will follow path 1b, as the facility is a single production unit. If a whole-facility analysis is not being performed (path 3a), then the outputs of the production unit shall be classified as co-products, residual or waste. It is likely that the primary waste stream will be wastewater, which will be treated on site or transferred to a treatment facility. For the remaining material products, the decision regarding classification as a residual or a co-product depends upon the revenue generated. For meat-processing facilities, the co-products may have different end uses and serve different markets. Therefore, economic allocation is considered the most appropriate approach using the decision tree (path 3b1 followed by 3c or 3d). In the practical application of the decision tree, the guidelines require that all edible materials should be classified together and separated from non-edible materials. This approach is seldom used for manufactured meat products, as a mass-based or protein-based approaches fail to clearly differentiate products and is not appropriate for products targeting different markets. It is recognized that some materials crossing the system boundary may have no economic value after primary processing, and in Figure 10 would be classified as a residual (step 3f). However, these materials may be collected and used for secondary processing (e.g. used for burning for energy or producing blood-and-bone meal). In this case, the product of the secondary processing is beyond the system boundary for these guidelines, and the proper accounting of the materials used as input to the secondary processing is to treat them as a residual.

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 large ruminant 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 compared to industrial systems. First, production may not be static from year to year, and second, 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 of 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. For example, for a feedlot operation, measured secondary data may include fuel use, feed utilization and cattle numbers; while modelled secondary data may include GHG emissions from enteric fermentation and manure.

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):

- **representativeness**: qualitative assessment of the degree to which the data set reflects the true population of interest. Representativeness covers the following three dimensions:
  - *a. temporal representativeness:* age of data and the length of time over which data was collected;
  - *b. geographical representativeness:* geographical area from which data for unit processes was collected to satisfy the goal of the study;
  - *c. technology representativeness:* specific technology or technology mix;
- **precision**: measure of the variability of the data values for each data expressed (e.g. standard deviation);
- **completeness**: percentage of flow that is measured or estimated;
- **consistency**: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
- **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;
- **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 and 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. Some emissions, such as those arising from enteric fermentation in the rumen of cattle or buffalo, are calculated from a model, and are therefore considered secondary data. For agricultural production, a large proportion of the data used will be secondary.

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, are depicted in Figure 11 under feed, water and animals. Raw material acquisition represents background data. In most systems, the production of feed on farm is fully integrated into the production system and is therefore a foreground process, whereas brought-in feeds from off farm can be considered a background process. Some foreground processes are impractical to measure for an LCA, for example, a farm's methane emissions from enteric and manure sources. In cases such as this, a model is used to estimate emissions, but if possible the input data used for the model should be obtained from sources where direct measurements were made. 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 large ruminant sector is planned, it is impractical to collect farm-level data from all large ruminant 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.

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 large ruminant sector is planned, it is impractical to collect farm-level data from all large ruminant 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.

Prior work (see Appendix 1) has identified the main hotspots and primary data (or modelled estimates using primary input data) that shall be used for these stages of the supply chain. Specifically, the cradle-to-farm-gate stage can dominate whole life cycle emissions (e.g. around. 72 percent in Thoma *et al.*, 2013b) and animal enteric methane can represent around 50-70 percent of cradle-to-farm-gate emissions. Thus, data on animal population and productivity, and feed quality are key primary activity data needed to calculate enteric methane emissions and subsequently total emissions. Similarly, methane and nitrous oxide from animal excreta can represent about 5-35 percent of cradle-to-farm-gate emissions and also require data on feed composition and chemical analysis to be calculated. Where manure is collected from animals, methods of storage and use can have a significant impact on emissions. Primary activity data on this area is therefore required. The contribution from emissions associated with feed production can vary greatly, from minimal in low-input extensive grassland/rangeland/nomadic/transhumance systems to about 40 percent in intensive crop-based or zero-grazing systems where large amounts of chemical fertilizer may be used. Corresponding direct on-farm energy use is also variable from minimal to about 20 percent, with a global average of about 2 percent (Gerber *et al.*, 2013). The global average emissions associated with processing represent 6 percent of life cycle emissions to the primary processing stage for milk, but only 0.5 percent for meat (Opio *et al.*, 2013). The dominant contributors to emissions from meat processing are fuel use, electricity use and wastewater processing.

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

Secondary data refers to LCI data sets that are 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 should 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 for animal assessment and 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.

10.2.3 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).

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 (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 a single data set has been suggested as an option to reduce uncertainty, as has bridging data gaps by extrapolating from another related data set (Milà I Canals *et al.*, 2011). For example, data from one species of large ruminants (e.g. cattle) could be extrapolated for production of other large ruminant species (e.g. buffalo, yak), based on expert knowledge of differences in feed requirements, feed conversion ratios, excreta characteristics and milk production. Adapting an energy emission factor for one region to another with a different generation mix is another example. While use of proxy datasets is the simplest solution, it also has the highest element of uncertainty. Extrapolation methods require expert knowledge and are more difficult to apply, but provide more accurate results.

For countries where environmentally extended economic input-output tables have been produced, a hybrid approach can also be used 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, Hauschild and Ekvall, 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 and 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 (ISO 14040:2006). 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); the 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 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.

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 primary 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	Primary data gathered shall be representative for at least the past 3 years and 5-7 years for secondary data sources. The representative time period on which data is based shall be documented.

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 variations in year-to-year 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 to capture and identify either seasonal or inter-annual variability in the efficiency of the product system.

11. Life cycle inventory

11.1 OVERVIEW

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 study (Figure 8). This typically follows an iterative process (as described in ISO 14044:2006), with the first steps involving data collection adhering to principles outlined in Section 10. The subsequent steps in this process involve recording and validation of the data; relating the data to each unit process and functional unit, including the allocation for different co-products; and aggregating the data, ensuring all significant processes, inputs and outputs are included within the system boundary. The system boundary has pre- and post-farm-gate stages.

11.2 CRADLE TO FARM GATE

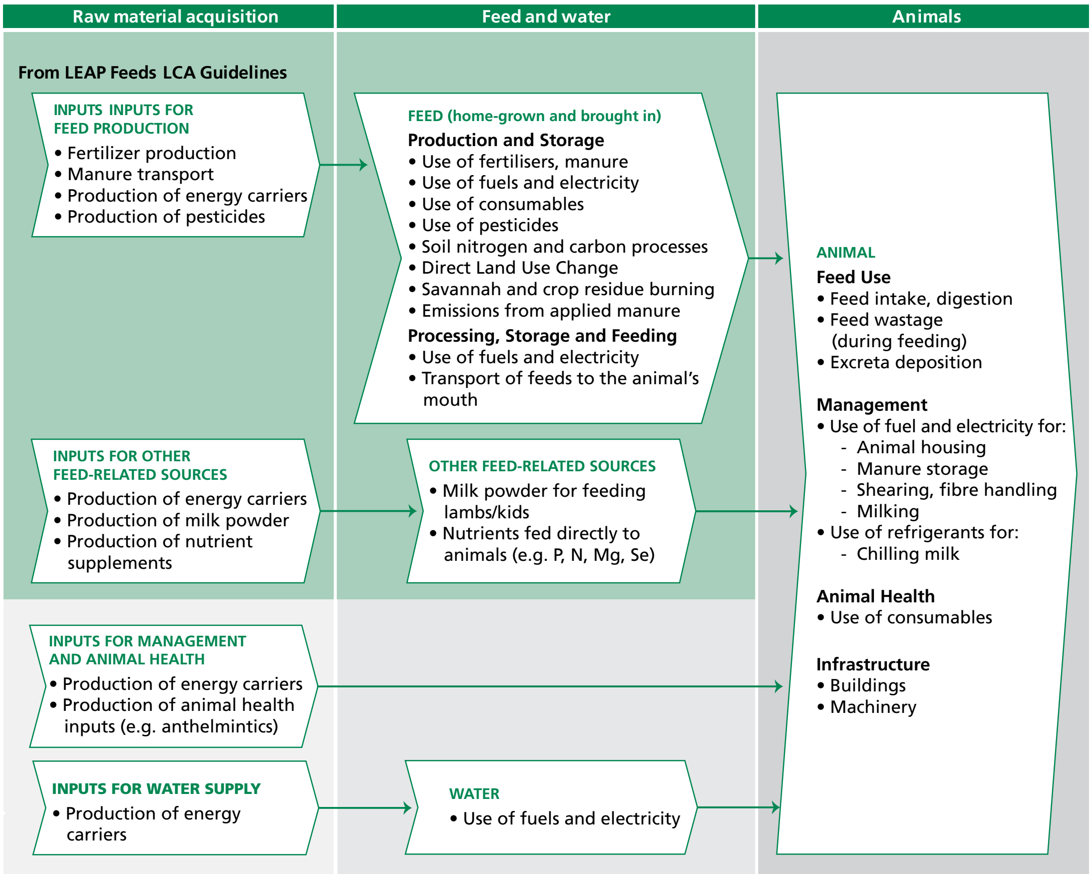
The cradle-to-farm-gate stage consists of three main processes: the acquisition of raw material; the supply of water and feed; and animal production (Figure 11). Most raw material acquisition is associated with the production of feeds. Note that these guidelines provide limited background information related to animal feeds, as these are covered in the LEAP Animal Feed Guidelines document. Information on animal feed presented in this document is largely for context and because of the strong linkages between feeds and animal production. These linkages need to be considered when completing the LCA.

Supplying water to animals is essential for their survival, and energy inputs are often required for the provision of water (e.g. for pumping and reticulation) and/or its transport. The environmental impacts associated with these activities and other uses of energy shall be included. The production and provision of animal health inputs, which may include treatments for internal and external parasites, and infectious, reproductive and metabolic diseases, also make a small contribution to resource use and GHG emissions (e.g. Besier *et al.*, 2010).

To assist the user in working through the process of calculating the carbon footprint of products for the cradle-to-farm-gate stage, a flow diagram is presented in Figure 12.

At the cradle-to-farm-gate stage, previous research has shown that the largest single source of GHG emissions is methane from the digestion of feeds in the rumen of cattle (enteric fermentation). For example, Beauchemin *et al.* (2010) estimated enteric methane at 63 percent of the total life cycle emissions for beef cattle production in Western Canada. O'Brien *et al.* (2011) estimated methane emissions associated with dairy cattle at 50 percent of total emissions from the cradle to the farm gate. Thus, it is important to obtain an accurate estimate (measured or modelled) of feed intake by large ruminants. This aspect is covered in detail in Section 11.2.2. However, an important first step is to define the feed types used and their feed quality characteristics. The greatest differences are likely to be found between confinement and grazing production systems and where there are varying ratios of forage to concentrate in the diet.

Figure 11
Processes that contribute to environmental impacts and fossil energy use covering raw materials, water use, feed production and use, and animal production within the system boundary of the cradle to farm gate



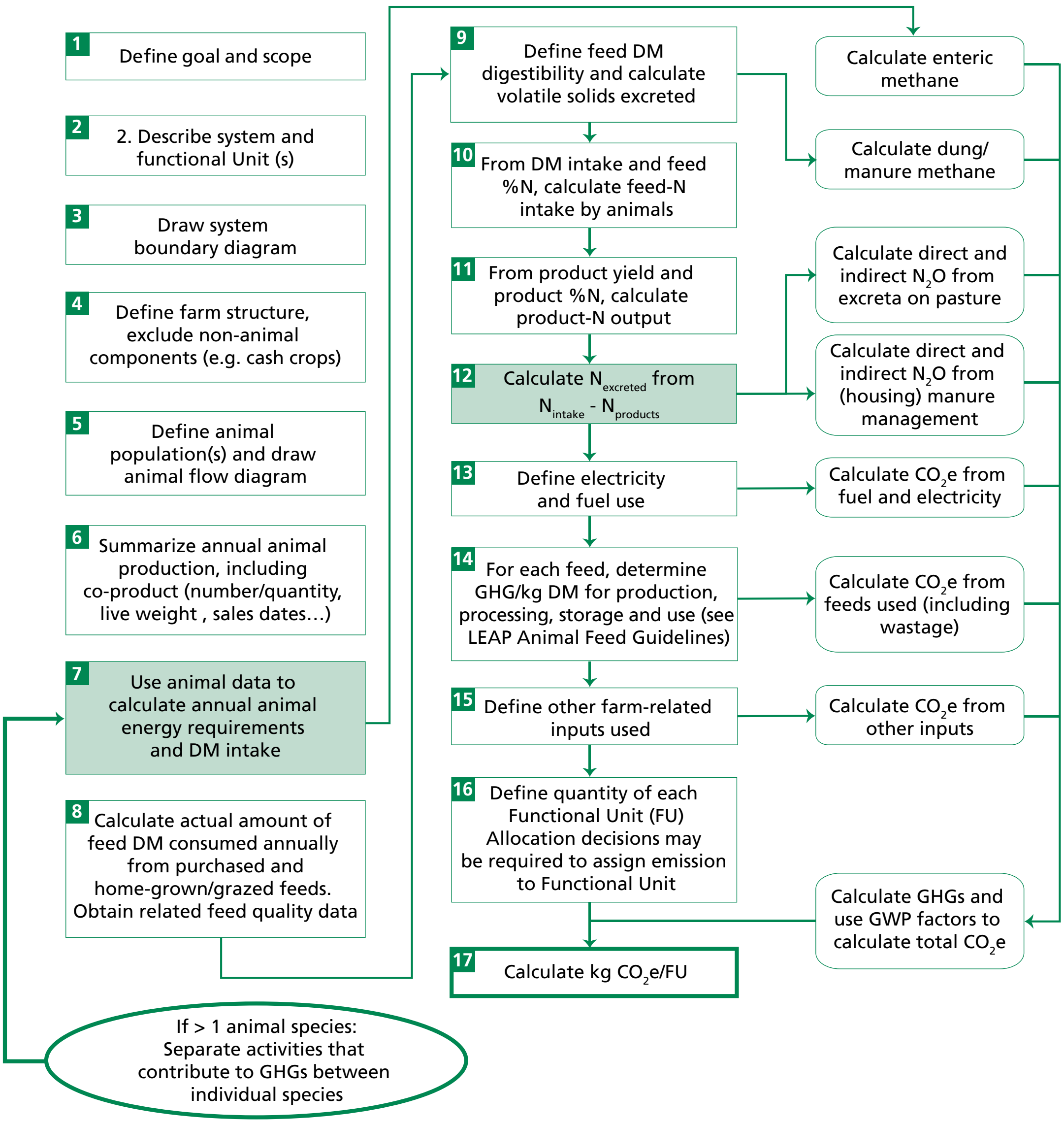
Note: The box with a green background refers to inputs, processes and emissions covered by the LEAP Animal Feed Guidelines and are not part of the current guidelines.

11.2.1 Feed assessment

The production, conservation and use of feeds can be a significant contributor to the total resource use and environmental impacts from large ruminant products. It is important to accurately identify the number and types of feeds used, as they can vary markedly in different large ruminant production systems, as discussed in Section 6.2. The determination of the amount of each feed used is described in detail in Section 11.2.

Feed types can include: annual crops where the feed source may be harvested grains; whole crop silage/hay or forage crops grazed *in situ*; and perennial plants, including pasture, range and browse forages. A summary of the typical composition (dry matter, energy, protein, fibre and phosphorus concentrations) of a very wide range of these feed types is given in United States National Research Council documents on nutrient requirements for cattle (NRC, 2000, Table 11.1; NRC, 2001, Table 15.1). Primary data on the composition of the main feed sources used shall be

Figure 12
Flow diagram as a guide to the procedure for determining the carbon footprint of large ruminant products for the cradle-to-farm-gate stage



Content within the ellipse relates to allocation decisions, while rounded boxes are the specific GHG calculation steps.

obtained for use in the LCI analysis wherever possible, but the National Research Council tables provide default values when primary data cannot be obtained.

Calculating environmental impacts of feed production

The LEAP Animal Feed Guidelines describes the methodology for the calculation of environmental impacts associated with the production, processing and storage of animal feeds. The main raw materials and processes that shall be accounted for in determining the emissions of feeds are given in Figure 8. Key contributors to environmental impacts are: inputs of fertilizers, manures and lime, including their manufacturing, transport and application; fuel used for production, processing and transport; crop residues that produce nitrous oxide emissions; and land-use change. Land-use change and carbon sequestration in soil can be important contributors to GHG emissions or removals, but these relate specifically to the feed production and, therefore, these aspects are covered in the LEAP Animal Feed Guidelines (see also PAS 2050:2011). Land-use change resulting from large ruminant production systems can also have implication for the loss or gain of biodiversity, as discussed in Section 11.5.

A wide range of processed feeds or concentrates are used globally. Various databases are being developed by a number of groups, including FAO. Vellinga *et al.* (2012) provide default values for the total GHG emissions per kg of feed. Default values are appropriate where relevant region-specific data are unavailable, and where their use is a minor component of the main feeds used.

When default published values for environmental impacts from the production of feeds are used, it is important to account for their system boundary. For example, the system boundary for the default values in the LEAP Animal Feed Guidelines ends at the 'animal's mouth'. When feed production emissions are integrated into the calculation of emissions for the cradle to farm gate, it is important to ensure that double counting is avoided and that all emissions are included. For feeds that can be fractionated, (e.g. the generation of cereal grain and cereal straw as feed) the emissions should be assigned based on the nature of the fractionation.

In practice, there is wastage of feed at various stages between harvest, storage (covered in the LEAP Animal Feed Guidelines) and during the feeding of animals, and this wastage shall be accounted for. For example, if there is 30 percent wastage between the amount fed to large ruminants and the amount consumed, the emissions from feed inputs shall be based on the amount fed. This waste feed may end up in the manure management system, and its contribution to subsequent methane and nitrous oxide emissions during storage shall be accounted for. In pasture-based systems, the waste feed may actually be available for the next grazing event.

As noted in Section 6, a large proportion of large ruminants globally are managed in extensive systems in which animals graze on perennial pastures or browse on mixed forage systems. In contrast to annual crops and concentrates, the important characteristics of these feed types include: relatively low inputs associated with their production; lack of crop residues associated with regular plant renewal; and variable feed quality throughout the year. The latter characteristic means a single average dataset will be less accurate than if a seasonal or monthly profile of plant analyses is linked with seasonal or monthly estimates of animal feed intake.

The amount of feed used shall be based on the calculated intake by the animal over a one-year period. Thus, for a feed that is harvested and brought to the animal (e.g. a concentrate), the annual amount of feed dry matter (DM) used (plus any allowance for wastage) shall be calculated and multiplied by the emissions per kg feed (kg CO_2e/kg DM). During periods of extended drought or winter seasons when crop growth ceases, large ruminants may be supplemented on pasture with other feeds. In such cases, to determine feed-related emissions, there is a need to account for any inputs used in their production, the harvesting and transport of feed to the animals and any wastage that may occur.

Cereal straw or other plant residues may be used for bedding in housed large ruminant systems or as a cover for manure storage systems. In such cases, environmental impacts associated with the harvest and transportation of such products shall be included.

11.2.2 Animal population and productivity

The calculation of animal-derived GHG emissions (e.g. methane from enteric fermentation, and nitrous oxide and methane from excreta) requires data on total feed intake and some feed quality parameters. In many large ruminant production systems, it is not possible to obtain direct data on feed intake. This applies particularly to farm systems in which large ruminants graze on forages. Thus, feed intake is commonly determined indirectly using models that calculate feed requirements according to large ruminant numbers and their productivity.

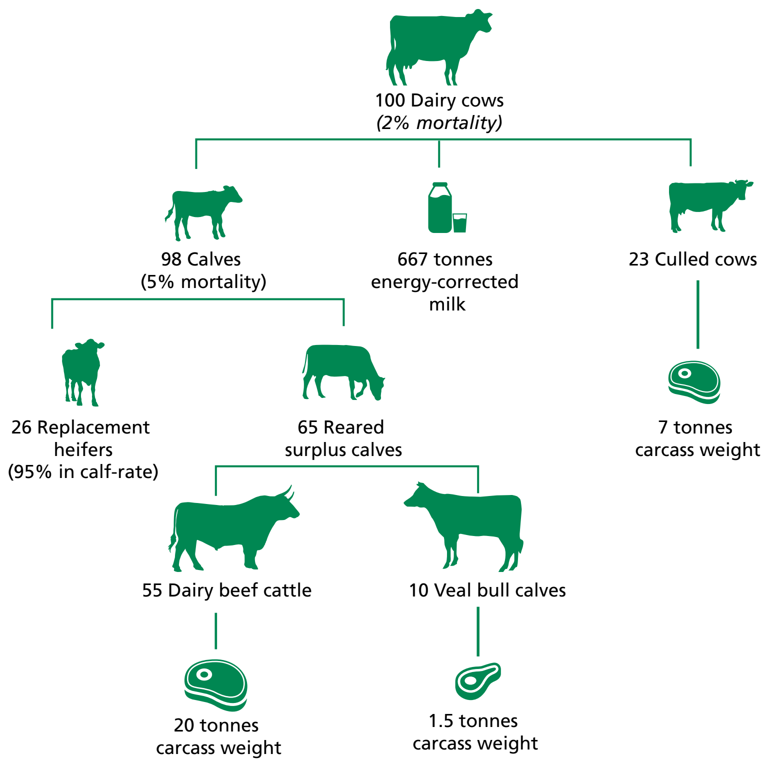
Most models used for the calculation of feed requirements derive intake from the energy requirements for the processes of growth, reproduction, milk production, activity (grazing, walking, and working) and maintenance (e.g. IPCC, 2006; NRC, 2000, 2001). This requires data on the numbers and productivity of large ruminants.

To account for the total environmental impacts from large ruminant products over a one-year time period, it is necessary to define the population associated with the production of the products (see Figure 13 for an example from a simplified dairy cow population; more examples can be found in Appendices 3, 4, 5 and 10). This requires accounting for the number of breeding female and male large ruminants, replacement female and male animals, and surplus animals (not required for maintenance of the herd) that are sold for meat. A minimum requirement for animal numbers for a stable population could be the number of adult breeding animals and the number and class (age, category and gender) of animals sold for meat. However, it is recommended that an animal population 'model' be constructed from:

- the number of adult breeding animals;
- a herd replacement rate, from which the numbers of replacement animals could be calculated, not including the additional animals required if the herd is expanding;
- fertility (calving percentage), which is the equivalent to the number of calves that are born as a percentage of the breeding fertile females that are bred; in many production systems cows that are not successfully bred are subsequently culled from the herd;
- death rate;
- average age at first calving;
- growth rate of young cattle; and
- age of replacements at first mating.

From the base animal population data, an annual stock reconciliation needs to be derived that accounts for the time of calving and time of sale of surplus animals. Ideally, a monthly stock reconciliation would be used. The benefit of having a Tier-2 methodology that uses calculated energy requirements (see Glossary) and specific seasonal or monthly data is that the effects of improvement in animal productivity on reducing the carbon footprint of products can be determined. For example, achieving the final slaughter weight of cattle earlier results in a lower feed intake, and the maintenance feed requirement is reduced relative to the feed needed to achieve a given level of animal production. If possible, monthly input data is the most desirable for calculations.

Figure 13
Simplified example of a dairy farm illustrating annual flows of animals (dairy cows, replacement heifers and reared surplus calves) and product flows of energy-corrected milk and meat



Note: Based on breeding cow herd of 100 cows, 100 percent calving, 25 percent replacement rate, 2 percent mortality rate and first calving at 2 years of age. A dressing percentage (carcass weight/body weight) of 50 percent for culled cows and 59 percent for dairy beef and veal bull calves was used. All cows were bred by artificial insemination.

The population data may need to be extended to include large ruminants transferred among farms. In some production systems, large ruminants may be exchanged among 3 or more owners during the production process. For example, growing beef cattle may be sold or moved from the primary producer to a secondary producer during the growing stage of production, before being sold to a third producer for finishing. Similarly, the rearing of replacement dairy heifers may be done on a different farm from the one where lactating cows are maintained. In these cases, all necessary components for the production of the acquired animals on the contributing farm shall be accounted for, including adult breeding stock. For national or regional level analyses, this can be accounted for using average data. However, for case studies, it will require primary data from all the source farms. Where these data are unavailable, it will be necessary to use regional data for the specific large ruminant classes on the contributing farm(s), with this being considered based on the system boundary of the study. Simplifications may be necessary for minor contributors, such as accounting for breeding bulls. These are often sourced from other farms, but can be accounted for by assuming that they are derived from within the base farm system or that artificial insemination is being used, at which point they may lie outside the system boundary. Ideally, the transport component of externally sourced bulls should be included in the calculations.

Calculation of animal productivity also requires average data on male and female adult live weight, the live weight of animal classes at slaughter, and milk production for dairy cattle. Average birth weight is also required, but a reasonable default value for cattle is 5 percent of the adult cow live weight.

Primary data on the animal population and productivity shall be used where possible. The minimum amount of primary data to develop an animal population summary was described above, but if this is unavailable, then an example of beef and dairy cattle herd parameters for different regions of the world is given in Appendix 9.

Calculating energy or protein requirements of animals

A range of models are used internationally for estimating the energy requirements, either as net or metabolizable energy (ME) of ruminants from population and productivity data. Many of these have similar driving functions (e.g. maintenance requirements based on metabolic weight = body-weight$^{0.75}$), with variations in equation parameters according to data from specific animal metabolism studies and field validations.

Where country-specific models for calculating the energy requirements for large ruminants have been published, and used in that country's National Greenhouse Gas Inventory, these shall be used. Where alternative models (e.g. region-specific published models) are used to improve the accuracy of the calculations, these should be described in detail and justified. Many groups in the GHG research area use the IPCC (2006) energy requirement model. Therefore, it is recommended that this model be used as the main default methodology. The recommended order of preference is:

1. region-specific models used in the country's National Greenhouse Gas Inventory;
2. other models that have been peer-reviewed and published that are applicable to the region or are country-specific;
3. IPCC (2006) Tier 2 method; and
4. IPCC default Tier-1 values (this should be seen as a last resort).

A similar approach can be used to estimate the nitrogen intake of large ruminants, information that is needed to estimate nitrogen excretion per animal (kg nitrogen per animal per year) in order to estimate nitrous oxide emissions from manure. Once dietary dry matter intake (DMI) has been estimated, nitrogen intake can be estimated based on the crude protein requirement of the diet (see Section 11.2.3).

Assessment of feed intake

In a limited number of situations, it will be possible to use measured data to define the amount of feed intake on farm to produce animal product(s). This is only likely to apply where large ruminants are permanently housed, and all feed is brought to them. However, in most cases, large ruminants obtain feeds from a number of sources, including by grazing, and it may not be possible to have an accurate measurement of the total amount of feed consumed. In such cases, the total feed intake is calculated from the total energy requirements of the animals.

Calculation of feed intake from the energy requirements of large ruminants that consume a number of feed types will commonly require several steps. The following describes the process using ME

The first step is to define the measured amount of feed intake from any supplied feed source brought into the farm from an outside source (e.g. where concentrates are provided). This must account for the total amount of the particular feed(s) provided and adjusted for the level of feed consumption and wastage, using a utilization percentage. Losses by wastage are 5-10 percent when feed is provided to large ruminants in specialized feeding facilities. These losses can be as high as 20-40 percent when animals are fed by spreading feed on the ground or pasture (DairyNZ, 2012). The first step in the calculation will involve subtracting the amount of ME consumed from the supplied feed(s), based on the amount of feed DM intake and its specific energy concentration in MJ ME/kg DM) from the total energy requirements to determine ME intake from other feed source(s):

$$\text{ME intake}_{other} = \text{Total ME requirement} - (\text{DM intake x MJ ME/kg DM})_{feed1} - (\text{DM intake x MJ ME/kg DM})_{feed2}$$

The difference (ME intake_{other}) will be the amount of energy consumed from other feed sources, such as from grazing pasture forages. If there is one source (e.g. pasture), then the amount of DM intake from that source can be calculated (based on its specific energy concentration in MJ ME/kg DM) from:

$$\text{DM intake}_{other} = \text{ME intake}_{other} / (\text{MJ ME/kg DM})_{other}$$

If there is more than one other feed source, it will be necessary to determine the DM intake for each source from an estimate of the proportion of each feed type consumed and their specific energy concentrations in MJ ME/kg DM.

For each feed source utilized by large ruminants, there is a need to have an accurate average estimate of the feed's chemical composition, concentrations of DM, ME, digestibility and nitrogen content of the faeces. This estimate will be based on either a weighted annual average or on a monthly basis, and account for feed quality and differences and changes in the profile of energy demand, especially in pasture-based systems throughout the year. While these will be necessarily averaged values, the most accurate data available for the specific regional system should be used. Digestibility and nitrogen content of the faeces are used in the calculation of methane and nitrous oxide emissions from excreta. These feed compositional parameters can be obtained from feed measurements at the farm system(s) studied by using average published data relevant to the agro-ecological zone of interest, or consulting published national or global data for the relevant feeds. Where available, multiple published studies of a feed within an agro-ecological zone and within a similar production system are preferred. For forage species that show marked seasonal variation in quality, seasonal data (or monthly data if available) should be used where possible. Default annual average data for a wide range of different feed sources are given in NRC (2000; 2001). Where appropriate, rapid analyses techniques, such as near infrared spectroscopy can increase confidence in the chemical composition of select feeds.

Animal enteric methane emissions

The *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) advise the use of a Tier-2/Tier-3 approach to calculate enteric methane emissions from mature dairy and non-dairy cattle, and young cattle. For buffalo, either a Tier-1 (55 kg methane/head/year for both developed and developing countries) or a Tier-2 approach is suggested.

The Tier-2 approach relies on calculating the enteric methane production from large ruminants using data on feed intake, in particular gross energy (GE) intake based on the total net energy or ME intake by each animal class as described above and methane conversion factors (MCF) i.e. the percentage of GE lost as enteric methane. The first step is the conversion of total net energy or ME intake to GE, using data on feed percentage digestibility (IPCC, 2006). When dry matter intake (DMI) is available, GE can be calculated as:

$$\text{GE (MJ / animal / day)} = \text{DMI (kg DM / animal / day)} * 18.45 \text{ MJ / kg DM}$$

Regarding MCF, according to IPCC (2006) an average of 6.5 percent (±1 percent) of GE intake is lost as enteric methane from the rumen of mature cattle and buffalo, including their young; animals that are primarily fed low-quality crop residues and by-products; and grazing cattle. Large ruminants fed more than 90 percent concentrate diets are assigned a MCF of 3.0 percent (±1 percent). Data for cattle generally indicate that this loss factor is higher for lower digestibility feeds, but there are limited data for the development of scaling factors. If reliable information on forage quality is available, emission factors can be lowered or increased based on quality information. Otherwise a single emission factor for forage diets can be used. When feed additives, such as methane inhibitors, are included in the diets, the MCF can be further reduced. Adjustments to the MCF should be based on peer-reviewed publications and clearly reported.

The annual quantity of methane emitted for each animal class is then calculated using the following equations:

$$\text{kg methane/ animal /year} = \text{GE intake (MJ/year)} \times \text{MCF} / 55.65$$

Where 55.65 is the energy content of methane in MJ/kg.

To summarize, annual enteric methane emissions per animal per year are calculated through the above equations, using data on GE intake for one year for each animal class and integrating them across the number of animals. This represents a default international emission approach based on Tier-2 methodology. Where country-specific emission factors have been peer reviewed, published and integrated into the national GHG inventory, then these shall be used instead. For instance, the Netherlands uses a Tier-3 approach for mature dairy cattle to calculate methane emissions from enteric fermentation by using dynamic modelling (Mills *et al.,* 2001; Smink *et al.*, 2005; Bannink *et al.*, 2006).

If a user of these guidelines is unable to access sufficient basic data to apply the above Tier-2 or Tier-3 approaches, then a Tier-1 emission factor could be used based on the IPCC (2006) regional default values for dairy and other cattle and 55 kg methane/animal/year for buffalo. However, the use of Tier-1 factors means that the user has no ability to account for carbon footprint reductions associated with improvements in large ruminant productivity. An example of the calculation of enteric methane emissions from animal energy requirements is described in Appendix 10.

11.2.3 Manure production and management

Methane emissions from animal excreta and manure

According to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), methane emissions from manure management can be calculated as:

kg methane/ animal / year = VS * 365 * Bo * MCF * methane density (0.67 kg m^{-3})

Where:

Volatile solids (VS): daily volatile solid excreted (kg DM/animal/day)

365: conversion factor to calculate annual VS production based on daily values (day/year)

Bo: maximum methane production potential (m^3 methane/kg VS) for the excreted manure

MCF: methane conversion factor for the manure management system (percentage of Bo)

First of all, the amount of VS produced shall be calculated. This represents the amount of feed consumed corrected for the component digested by animals and the non-volatile ash component that remains. For cattle, the equations for calculating VS in IPCC (2006; Equation 10.24) can be simplified to:

kg VS = kg DMI / animal x (1.04 – DMD) x 0.92

Where dry matter digestibility (DMD) is expressed as a fraction. For example, the percentage of DMD for perennial pastures in New Zealand varies throughout the year, from about 74 percent in summer to 84 percent in winter (Pickering, 2011). In this equation, it is assumed that a value of 4 percent of GE can normally be attributed to urinary energy excretion by most large ruminants. This value should be reduced to 2 percent of GE for ruminants fed diets that contain 85 percent or more grain. Where available, country-specific values should be used, and users should be aware that factors, such as feed processing, can influence DMD estimates. The 0.92 factor in the above equation is based on a default of 8 percent ash content of cattle manure (using 1 – (%ash/100)), which should be modified if measured or known system-specific values differ from this default.

Since Bo is not only dependent on the large ruminant category, but also on diet, IPCC (2006) recommends using country-specific values for Bo. MCF gives an indication of the conversion of degradable compounds in the manure into methane. It depends both on the way manure is being managed in terms of handling and storage, and on the climatic conditions. Similar to the other factors affecting methane production from manure management, country-specific MCF values are strongly encouraged. However, if country-specific MCF values are not available, default values may be applied (IPCC, 2006; Table 10A4 for dairy cattle; Table 10A5 for non-dairy cattle; Table 10A6 for buffalo).

To summarize, methane emission factor calculations vary according to the manure management system and climate (IPCC, 2006). The Tier-2 approach is recommended. If this approach cannot be used, generic Tier-1 emission factors are given by IPCC (2006) for large ruminants in different regions of the world. Where country-specific emission factors have been peer reviewed, published and integrated into the national GHG Inventory, then these shall be used instead.

Nitrous oxide emissions from animal excreta and manure

Nitrous oxide emissions result from direct emissions from excreta, indirectly from ammonia released from excreta into the atmosphere and deposited back onto soil, and from nitrate leached to ground and surface waterways. The total nitrous oxide emissions from excreta and manure are calculated by adding the direct and indirect nitrous oxide emissions, after adjustment for the N_2O/ N_2O-N ratio of 44/28. Implications of nitrogen emissions for eutrophication of water ways and acidification of soils are discussed in Sections 8.5.1 and 8.5.2, respectively.

Preferably, a Tier-2 approach shall be used, whereby the amount of nitrogen excreted by large ruminants is calculated using the production and feed intake model outlined in Sections 11.2.2a–11.2.2.b. The amount of DM intake is multiplied by the average nitrogen concentration (percentage nitrogen) of the diet (weighted according to the relative proportions of different feed types ‘t’ in the diet) to get the amount of nitrogen consumed (crude protein/6.25):

$$\text{kg N consumed} = \Sigma\,(\text{kg DM intake}_t \text{ x } \%\text{N in feed}_t\,/100)$$

Nitrogen output that is retained in product(s), (meat, hide, blood and milk) is then subtracted from the nitrogen consumed to calculate the amount of nitrogen excreted:

$$\text{kg N excreted} = \text{kg N consumed} - \text{kg N in products}$$

Data on the average nitrogen concentration of a wide range of different feed sources is given in the LEAP Animal Feed Guidelines and NRC (2000; 2001), but this shall be over-ridden by measured values (primary data) or region-specific, peer-reviewed published values, if available. The nitrogen output in products is calculated from the amount of product multiplied by the protein concentration of the product and divided by 6.25 to convert protein to nitrogen:

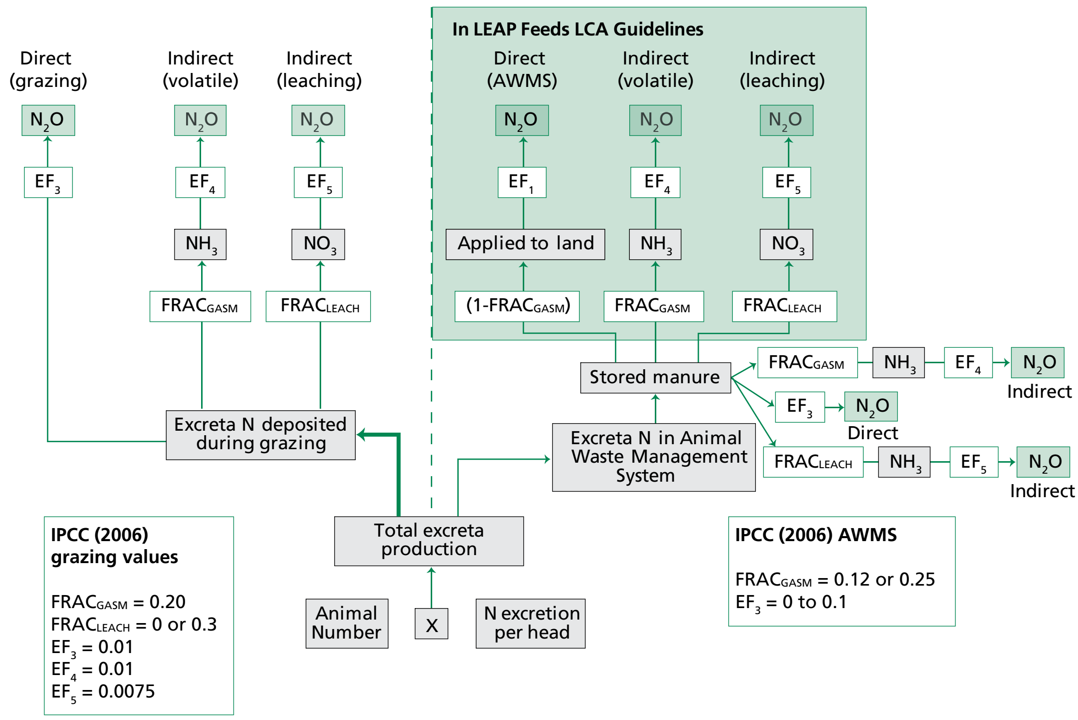
$$\text{kg N in products} = \Sigma\,(\text{kg product x } (\%\text{ protein in product } / 100) / 6.25)$$

The values for protein concentration of products should be based on measured values or region-specific peer-reviewed published values, where possible. Typical default values for the protein concentration of meat (live-weight gain basis), and milk are 20, and 3.3 percent, respectively (e.g. USDA, 2010).

It should be noted that in some cases, large ruminants may be moved from confined systems where manure is subject to management practices to grazing system where the manure is deposited on pasture within the duration of a single day. In this situation, the practitioner should estimate the total amount of time that the herd spends in each location and apportion the amount of VS, calculated as described in Section 11.3.2, on the basis of the duration that the animals spend in each location. For example, if dairy cattle were held in confinement for 12 hours per day where manure was collected and subject to management practices, and allowed to

Figure 14

Summary of approach for calculating nitrous oxide emissions from large ruminant excreta and waste management systems



Note: Summary of approach for calculating N_2O-N emissions from animal excreta and the animal waste management system (AWMS) using IPCC (2006, Volume 4, Chapter 10) activity factors (FRAC refers to fraction of N source contributing) and emission factors (EF in kg N_2O-N/kg N). GASM = gaseous loss as ammonia; FRACgasm and EF1 vary with type of AWMS. For manure, only manure storage losses are included in these guidelines. Losses from land application are covered in the LEAP Animal Feed Guidelines.

graze pasture for 12 hours per day, the total VS produced would be divided equally between manure management and pasture deposition. It is equally important to carefully consider the fraction of manure that is managed in each type of manure management system (e.g. composting, liquid storage). The best means of obtaining manure management system distribution data is to consult regularly published national statistics. If such statistics are unavailable, the preferred alternative is to conduct an independent survey of manure management system usage. If the resources are not available to conduct a survey, experts should be consulted to obtain an opinion of the system distribution.

Direct nitrous oxide emissions from excreta deposited on soil during grazing of cattle (dairy, non–dairy, buffalo) are calculated by multiplying the annual amount of nitrogen excreted by the IPCC (2006) emission factor of 0.02 kg N_2O-N/kg N excreted (see Figure 14 for a summary of calculation components). Where country-specific emission factors have been published and integrated into the national GHG inventory, then these shall be used instead.

For the calculation of nitrous oxide emissions from manure during storage, the relevant IPCC (2006) emission factors shall be used. For example, direct nitrous oxide emission factors in kg N_2O-N/kg N from storage vary from nil for uncovered anaerobic lagoons; 0.005 to 0.01 from aerobic ponds (being less with forced aeration); 0.02 from dry lot; to 0.1 for composting with regular turning and aeration (IPCC, 2006, Table 10.21).

Indirect nitrous oxide emissions from ammonia during manure storage first require an estimate of the amount of ammonia emitted. This can be calculated using model-predicted emissions, country-specific factors that have been published and integrated into the national GHG inventory. These estimates should be aligned with manure handling and storage practices. If these estimates are not available, IPCC (2006) default ammonia loss factors ($FRAC_{GASM}$) from excreta nitrogen with consideration for manure handling practices may be used. Ammonia-nitrogen loss is then multiplied by the IPCC (2006) emission factor (EF_4) of 0.01 kg N_2O-N/kg N excreted

Indirect nitrous oxide emissions from ammonia loss and nitrogen leaching from excreta deposited directly to land during grazing shall be calculated as shown in Figure 14. Calculations first require an estimate of the amounts of ammonia loss and nitrogen leaching from excreta deposited on land. The default IPCC (2006) loss factor for $FRAC_{GASM}$ is 20 percent of nitrogen excreted, and 30 percent for $FRAC_{LEACH}$ (for soils with net drainage, otherwise 0 percent) of nitrogen excreted by grazing cattle. There is evidence (Sherlock, Jewell and Clough, 2008; Velthof *et al.*, 2012) that the default IPCC $FRAC_{GASM}$ value may overestimate actual ammonia losses during grazing. However, due to the limited amount of data available, this default value is still often applied. If available, country-specific factors that have been published and integrated into the national GHG inventory shall be used. These are then multiplied by the corresponding IPCC (2006) emission factors (EF4 and EF5) of 0.01 kg N_2O-N/kg N lost as ammonia and 0.0075 kg N_2O-N/kg N lost from leaching/runoff, respectively.

Methane and Nitrous oxide emissions from manure treatment

When excreta is collected and processed through a manure management system, the storage-related emissions shall be included in this analysis. Where the stored manure is transported away and applied to land growing a crop or pasture used to produce feed, the emissions associated with transport and application (after adjustment for nitrogen lost by volatilization) shall be included. If the manure is transported to a secondary user for other purposes, such as land reclamation or tree fertilization, emissions should be allocated to the secondary user. Under most circumstances, if the application of manure exceeds the limiting nutrient for crops, then the emissions associated with the amount of manure applied above crop requirements is allocated back to livestock. Emissions associated with feed sources are found in the LEAP Animal Feed Guidelines.

Where country-specific emission factors for specific manure management technologies have been peer reviewed, published and integrated into the national GHG inventory, then these values shall be used, otherwise default values based on the type and characteristics of the manure management system may be applied.

11.2.4 Emissions from other farm-related inputs

The other main inputs on farm contributing to environmental impacts are largely associated with the use of fuels and electricity. Additional farm-related inputs that need to be accounted for include consumables used on farm. Nutrients administered directly to large ruminants and milk powder used for rearing calves is covered in the LEAP Animal Feed Guidelines.

The total use of fuel (diesel, petrol) and lubricants (oil) associated with all on-farm operations shall be estimated. Estimations shall be based on actual use and shall include fuel used by contractors involved in on-farm operations. Where actual fuel-use data are unavailable, these should be calculated from the operating time (hours) for each activity involved in fuel use and the fuel consumption per hour. This latter parameter can be derived from published data or from appropriate databases, such as EcoInvent, European Life Cycle Database, USNAL or GaBi. Note that any operations associated with the production, storage and transportation of large ruminant feeds are not included here, but are covered in the LEAP Animal Feed Guidelines. Figure 8 indicates some of the main non-feed processes associated with the use of fuels, such as water transport, use of vehicles for large ruminant transport, manure transport, the removal of wasted feed and other farm-specific activities (e.g. visits by veterinarians or artificial insemination technicians).

The total amount of a particular fuel type used is then multiplied by the relevant country-specific GHG emission factor, which accounts for production and use of fuel, to determine fuel-related GHG emissions. The process for calculating fuel-related GHG emissions also applies to electricity. Thus, all electricity use associated with farm activities, excluding feed production and storage where they are included within the emission factor for feeds, shall be estimated. This includes electricity for water reticulation, animal housing and milking (Figure 8). Country-specific emission factors for electricity production and use shall be applied according to the electricity source. This would typically be the national or regional average and would account for the electricity grid mix of renewable and non-renewable energy sources, and should be based on the demand load from the farms if national data is available.

In some extensive production systems, nutrients required to avoid deficiency by animals (e.g. energy, protein, minerals) may be delivered directly to grazing large ruminants. In such cases, transport and their contributions to total environmental impacts shall be accounted for, as described in the LEAP Animal Feed Guidelines. Any implications that this practice may have on biodiversity, water eutrophication or soil acidification shall be considered.

Where there is a significant use of consumables in farm operations, the environmental impacts associated with their production and use should be accounted for. An example of this would be the emissions associated with the production of farm machinery or building infrastructure. This would generally be estimated from published data or from appropriate databases (e.g. EcoInvent). However, in practice, these will often constitute a minor contribution, and relevant data may be difficult to access. See Section 8.4.3 on cut-off criteria for exclusion of minor contributors.

11.3 TRANSPORTATION

This section refers to transportation stages and covers: transport of large ruminants or milk from the site of production to the site of primary processing; manure transport off farm; and any internal transport within the primary processing site(s) to the output loading dock. It also includes transportation of inputs, such as water, within the farm and the movement of animals between different farms that contribute to production before going for processing.

Fuel consumption from transport can be estimated using: (i) the fuel cost method; (ii) the fuel consumption method; or (iii) the tonne-kilometre method. When using the fuel cost method (fuel use estimated from cost accounts and price) or the fuel consumption method (reported fuel purchased), the 'utilization ratio' of materials transported shall be taken into account. Transport distances may be estimated from routes and mapping tools or obtained from navigation software.

The allocation of empty transport distance (backhaul) is often done already in the background models used for deriving the secondary LCI data for transportation. However, if primary data for transport should be derived, the LCA user should make an estimate of the empty transport distance.

It is good practice to provide a best estimate with a corresponding uncertainty, per the requirement in Section 10.4.

Allocations of empty transport kilometres shall be carried out on the basis of the average load factor of the transport that is representative for the transport under study. If no supporting information is collected, 100 percent empty return should be assumed. However, the maximum weight can only be achieved if the density of the loaded goods allows.

Allocations of transport emissions to transported products shall be performed on the basis of mass share, unless the density of the transported product is significantly lower than average, to the extent that the volume restricts the maximum load. In the latter case, it shall be done on a volume basis. When cold chain is used, life cycle emissions from cold and frozen storage shall be collected, including refrigerant loss.

Where live exports of large ruminants occur, it is necessary to account for all related transport emissions and loss of animals during transportation. The use of fuels and GHG emission factors associated with the type of transportation shall be calculated according to the size of transportation vehicle and the typical fuel consumption rate. The type of fuel utilized should also be considered. Where refrigerated transportation is used, the typical rate of loss of refrigerant, fuel use associated with refrigeration and associated GHG emission factor shall be included.

11.4 INCLUSION AND TREATMENT OF LAND-USE-CHANGE

Land-use-change relates to the feed production stage and is covered in the LEAP Animal Feed Guidelines. These guidelines describe two calculation methods, including a global averaging method if specific land-use-change details are unknown and where land-use-change effects are spread across all land-use change. Calculations using the latter method shall exclude long-term perennial forages, such as perennial pastures and rangeland systems (i.e. global average land-use-change GHG is zero). Long-term perennial forage systems can be significant feed source in some large ruminant systems. GHG emissions associated with land-use-change should be accounted separately and reported. PAS 2050:2011 provides additional guidance.

11.5 WATER USE

Water is a finite and vulnerable natural resource. Livestock and agriculture are water-intensive activities. Their use of water and their impact on water resources can vary widely depending on the region, climate, watershed and competing activities for water.

The water footprint of large ruminants consists primarily of the indirect water footprint of the feed, in addition to the direct water footprint associated with drinking water and the consumption of service water (Chapagain and Hoekstra, 2003). A milk LCA from the United States showed that around 93.5 percent of water scarcity is caused by the irrigation of crops used as dairy feed. Water used on dairy farms and in dairy processing account for a small proportion of the contribution to total water scarcity (Henderson *et. al.*, 2013). The production system determines the size, composition and geographic spread of the large ruminant water footprint, as this impacts feed conversion efficiency, feed composition and origin of feed.

There are two major parallel developments on the water footprint. One is the supply chain perspective of the Water Footprint Network, the other is the LCA-based water availability and scarcity assessment. The LCA methodology was used for the assessment of the potential environmental impact of blue water (withdrawal from water bodies) and green water (uptake of soil moisture) consumption. The latter has so far been disregarded in LCA. This section builds on recent water footprint activities of the water use LCA of the UNEP/SETAC Life Cycle Initiative and aligns with the ISO 14046:2104 water footprint principles, requirements and guidelines.

Water footprint is based on LCA methodology, and as such it is important to conduct the assessment at a scale and resolution that is relevant to the goal and scope of the study and takes into account the local context (ISO 14046:2014). A water footprint assessment according to this standard shall include the four phases of life cycle assessment:

- goal and scope definition;
- collection of data and water footprint inventory analysis;
- water footprint impact assessment; and
- interpretation

A water footprint is the result of a comprehensive LCA, which results in a profile of impact category indicator results. The scope, system boundary and allocation and other actions shall be conducted and reported in accordance with ISO14044:2006, as described in these guidelines. A water footprint assessment may be performed as a stand-alone assessment or as part of a comprehensive LCA. The results of a water footprint inventory analysis may be reported, but shall not be reported as a water footprint. Appendix 11 describes the challenges related to water footprint in agriculture.

11.5.1 Methods addressing freshwater use inventory

There are several methods of assessing water use within a LCA. This guide adopts the terminology proposed by the UNEP/SETAC Life Cycle Initiative (Bayart *et al.,* 2010). The terms related to LCA and water footprint assessment can be found in Appendix 10 and the Glossary of this document.

It is important to define the scope of 'water use', which is the total input of freshwater into a product system. As parts of the water input is released from the product system as wastewater, the remaining portion which has become unavailable due to evaporation or product integration is referred to as 'water consumption' (Berger and Finkbeiner, 2010). Konini *et al.* (2013) reviewed relevant methods of addressing freshwater use in LCI and LCIA and identified the key elements that could be used to build a scientific consensus for comprehensive water assessment.

11.5.2 Inventory: collection of data

The water inventory analysis phase involves data collection and modelling of the product (e.g. milk, cheese, beef) systems, and a description and verification of data.

According to ISO 14046:2104, the following data related to water shall be considered for data collection for assessing the environmental impacts of water consumption:

- quantities of water used, including water withdrawal and release;
- types of water resources used, including for water withdrawal and water receiving body;
- forms of water use;
- changes in drainage, stream flow, groundwater flow or water evaporation that arise from land-use change, land management activities and other forms of water interception;
- locations of water use, including for water withdrawal and release, that are required to determine any related environmental condition indicator of the area where the water use takes place;
- seasonal changes in water flows, water withdrawal and release; and
- temporal aspects of water use, including, if relevant, timing of water use and length of water storage.

Following the ISO 14046:2014, total flows of evapotranspiration from a land-based production system are not considered to be relevant at the inventory level, as at present there is a gap in available methods. While reference values can be calculated, and the difference in evapotranspiration assessed as water consumption (Nunez *et al.,* 2013), the uncertainties linked to the methodology remain too high.

A description of data needed for the calculation of water footprint is provided in Appendix 12, and an example of a United States dairy water footprint is described in Appendix 13.

Water is a local issue. Water availability, water scarcity and water quality should be discussed in a local context. There is no universal model to effectively estimate water use inventory and water quality impact in all geographical areas. Where possible, region-specific hydrological information should be obtained for the development of a water footprint.

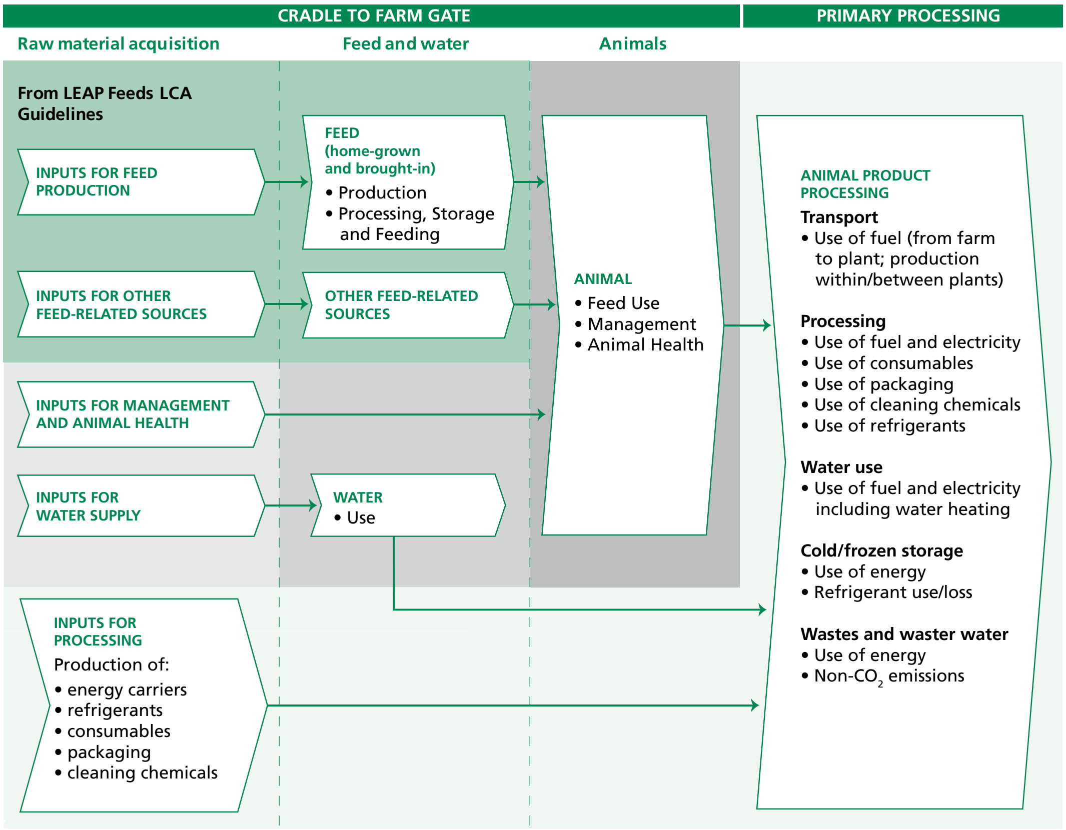
11.6 SOIL CARBON SEQUESTRATION

Soil carbon sequestration can be important for some large ruminant systems. However, since this relates only to the feed production stage, the specific methods are covered in the LEAP Animal Feed Guidelines. Where no data relating to soil carbon sequestration are available, the LEAP Animal Feed guidelines provide default values (only for temperate climates). If data are available, it is important to consider that sequestration is likely to diminish over time, eventually reaching a plateau with zero change in soil carbon, if the system remains in stasis. Management practices that disrupt this stasis, such as cultivation on grassland or overgrazing, can result in a loss of soil carbon until sequestration returns to equilibrium. Additional descriptions on assessment of carbon soil sequestration are provided in Appendix 14.

11.7 PRIMARY PROCESSING STAGE

The primary products of milk and meat are covered in these guidelines. For all products, there are a number of generic processes that contribute to environmental impacts. These are summarized in Figure 15 and include: transportation of products

Figure 15
Processes that contribute to environmental impacts and fossil energy use within the system boundary of the cradle to primary processing gate



Note: Related cradle-to-farm-gate processes are also given and a further breakdown of these is given in Figure 8. The box with a green background refers to inputs, processes and emissions covered by the LEAP Animal Feed Guidelines and are not part of the current guidelines.

within or between primary processing plants, processing, water use, cold/frozen storage, and wastes and wastewater treatment. Each component requires raw materials associated with production of energy carriers, refrigerants, consumables, cleaning chemicals and packaging. The following sections discuss the specific products and the assessment of environmental impacts with their primary processing.

11.7.1 Milk processing

The milk collected from large ruminants may be used to produce one or more of the following products: fresh milk, yoghurt, cheese, cream, butter, whey and milk powder. A very diverse range of products are produced during processing, and a wide range of technologies are used for their production, from cottage industries to large multi-process facilities.

The main processes that need to be accounted for are milk collection, milk processing, the production and use of packaging, refrigeration, water use and wastewater processing and within-plant transportation (Figure 15). The milk-processing stage covers the use of resources, including energy, water and consumables (e.g. detergents, cleaning chemicals). The energy related to the production of specific products should be included in the outputs, including the co-allocation of products. General milk assembly should be handled across the milk pool, while specific products should be related to their direct energy and water use.

Data collection and handling of co-products

Representative data needs to be collected from the milk-processing plant(s) for the defined one-year period on the amount of milk, along with its fat and protein content, that enters the plant and the fat and protein content of the different products produced. A material flow diagram of milk input and output products should be produced to account for a minimum of 99 percent of the fat and protein.

Representative data shall also be collected on the resources used for processing. Ideally, this should be collected for each unit process so that it can be allocated according to the products produced. However, these data are rarely available. In some cases, data may be available that can be attributed to the production of one specific product. In such cases, these process data should first be separately assigned to the specific product before applying an allocation methodology to the remaining data. In most cases, it is only possible to obtain data for a whole processing plant, and in these cases, a method for the allocation of resource use and emissions between the products is required.

Packaging is generally a relatively small contributor to total environmental impacts (less than 1 percent) and, where this is the case, secondary data are often used where no specific on-site production data are available. When packaging is manufactured off site, the calculated environmental impacts should include the production of the packaging and the raw materials. Where glass bottles are used for liquid milk, the rate of re-use should be accounted for in the calculations. Similarly, many other consumables and cleaning chemicals are used in the processing of dairy products, and secondary data sources from databases, such as EcoInvent, may generally be used for their production and use. This also applies to refrigerants, although the use of primary activity data on the type and amount of refrigerants used is desirable.

Calculating environmental impacts from milk processing

Activity data are required on the amounts of the various resources used. Energy use shall account for the type of energy. Similarly, the type of packaging materials and refrigerant(s) used should be identified. The activity data are then combined with relevant emission factors to calculate total emissions. For refrigerants, Myhre *et al.* (2013) provide a list of global warming potential factors (100-year period) for a wide range of refrigerants, which should be updated to coincide with future revisions by IPCC. It is also important that the specific refrigerant type being used be identified, as emissions differ substantially among refrigerants. The distribution of milk solids among the different products shall also be known to follow the allocation procedure for incoming raw milk burdens.

Data are required on the quantities of wastewater produced, its composition and the method of processing (e.g. anaerobic ponds, aerobic ponds, land application). The method of processing will determine the GHG emissions produced (e.g. methane from anaerobic digestion). Emission factors for methane and nitrous oxide for the different wastewater processing systems are given in IPCC (2006).

Total GHG emissions are calculated from the sum of all contributing sources and converted to CO_2e according to the latest global warming potential factors from the IPCC (Myhre *et al.*, 2013). The calculation of total environmental impacts shall include adjustment for allocation between the various co-products, as outlined in Section 9.3.

11.7.2 Meat processing

Primary processing of cattle and buffalo for meat production can occur in facilities ranging from backyards to large-scale commercial processing abattoirs (see Appendix 8). Processing results in a wide range of co-products, including hides (e.g. for leather), tallow (e.g. for soap, biofuel), pet food, blood (e.g. for pharmaceutical products), gelatine and renderable material (e.g. for fertilizer). Meat, hides and tallow can be considered to be the major products arising from meat processing.

All stages of meat processing, which include chilling, boning and rendering of co-products, yields different products depending on the species. Yields may be determined from primary output data, but in the absence of these data, the mass of products may be determined from a series of factors. The mass of unprocessed rendering material and products from rendering are included as co-products in the evaluation of meat processing. Yield factors including the edible fraction for the retail portions, which vary between different breeds of livestock and differ depending on the amount of bone included in the product sold at retail, should be evaluated based on data reflective of the supply chain being investigated. This will vary depending on the degree of processing (boning) and the degree of trimming for excess fat. Here the edible portion is specified, meaning the mass of product exclusive of bone and cartilage mass, which is not easily digested. Offal sold for human consumption is considered here as part of the functional unit, because this product is functionally equivalent to meat from the animal carcass with respect to nutritional characteristics. Indicative yield factors for beef cattle have been supplied in (Wiedemann and Yan, 2014). Importantly, the mass of meat actually consumed may be lower depending on consumer preferences, and this would need to be accounted for during the consumption phase, which is beyond the scope of these guidelines.

Product category rules

Boeri *et al.,* (2012) have produced a PCR for generic meat processing, where the core functional unit is 1 kg of meat (fresh, chilled or frozen), and includes details on accounting for cold and frozen storage. It also covers upstream and downstream processes, including the use phase (meat cooking). Although the PCR requires economic value allocation, it also states that all products which are "*…destined to other chains (such as animal food) must be considered waste…*", which is inconsistent with these LEAP guidelines, where an economic allocation among all of the revenue generating co-products is required in Section 9.3.2.

The present guidelines refer to primary processing for fresh, chilled or frozen meat, and do not account for secondary processing (e.g. further processing of meat into ready-to-cook dishes) or subsequent retail, use and waste stages, which would be included in a full 'cradle to grave' LCA. The main processes that need to be accounted for are: animal deconstruction into many component parts; production and use of packaging; refrigeration; water use and wastewater processing; and within-plant transportation (Figure 12). The meat processing stage involves the use of resources including energy, water, refrigerants and consumables (e.g. cleaning chemicals, packaging and disposable apparel). Secondary processing of products, such as plasma, gelatine and pharmaceuticals, are beyond the scope of these guidelines.

Data collection and handling of co-products

Representative data need to be collected from the meat-processing plant(s) for a recent representative one-year period on the amount of large ruminant live weight entering the plant and the amount of different products produced. A material flow diagram of input and output products should be produced to account for a minimum of 99 percent of the mass. While primary data shall be used for meat, they may not be available for the numerous co-products (e.g. blood, gut contents), and therefore secondary data would be required, or information could be aggregated across several minor co-products. As with dairy, data for some of these co-products arising from meat processing is also likely to be limited, making the value of going into greater detail beyond that available for meat, hides and tallow, questionable.

Data are required on the use of the various resources. Energy use is a major contributor to total environmental impacts for the processing stage. Therefore, it is important to obtain primary data on the various sources of energy use. Similarly, water use can be relatively large and wastewater processing can represent a sizeable component of the environmental impacts of processing. Thus, data shall be collected on the volume and composition (e.g. chemical oxygen demand and nitrogen load) of the wastewater and the method of wastewater processing. Some resources, such as consumables and refrigerant use, are relatively small and typically constitute a minimal proportion of the total environmental impacts (e.g. less than 1 percent). Secondary data on use of these resources are acceptable.

Some abattoirs process multiple animal species (e.g. cattle, buffalo and sheep). In such cases, there is a need to allocate emissions according to species. This shall be based on the relative number and carcass weights of the animal species processed. In addition, this approach will need to account for relative differences in requirements (e.g. for energy use) between species. For example, the energy use per kg live weight processed for sheep can be about 1.3 to 2 times that for cattle. Similarly, some abattoirs may have an associated rendering plant, and if separate energy use data are not available for meat processing and rendering, an adjustment should be considered to account for the greater energy requirements for rendering (e.g. requirements associated with steam production). One available method is to apply specific energy-adjusted values based on survey data, where specific energy uses between rendering and non-rendering facilities have been obtained from the facility operators. For example, Lovatt and Kemp (1995) obtained specific fuel use per tonne of meat processed at eight-fold and two-fold higher for fuel and electricity use, respectively.

Following the product category rules proposed by Boeri *et al.* (2012), the present guidelines recommend the use of economic allocation. However, some co-products may be identified as having limited economic value, but may be collected and used for secondary processing (e.g. used for burning for energy or for producing blood-and-bone meal). If there is no revenue generated from sales of these materials, they are classified as residual and are not subject to allocation (Section 9.3.2).

Calculating environmental impacts from meat processing

Calculation of environmental impacts shall account for resource use, wastewater processing, animal wastes and the associated GHG emission factors. Electricity and other sources of energy use shall account for total embodied emissions relevant to the country where the primary processing occurs. Data on wastewater quantity and composition are used with the emission factors to calculate environmental impacts from wastewater processing (IPCC, 2006). In meat-processing plants, wastewater will generally include excreta from animals held prior to processing; the contents of the stomachs and intestines of slaughtered animals; and various wastes (e.g. blood, if not collected for further processing). However, where these sources are not specifically captured in wastewater systems, they shall be estimated and their environmental impacts accounted. Total environmental impacts shall be allocated between the various co-products, as outlined in Section 9.3.

To assist in understanding the relative importance of the various contributors to meat processing in abattoirs, Opio *et al.* (2013) calculated, from an assessment of beef cattle supply chains, that the average energy use is 1.4 MJ/kg of carcass weight, where the energy used during slaughter accounted for 20 percent of GHG emissions, evisceration was 3 percent, cooling 41 percent and other energy use (compressed air, lighting and machinery) 30 percent.

11.7.3 On-site energy generation

In some processing plants, waste material may be used for on-site energy generation. This may simply be used to displace energy requirements within the plant, in which case emissions from the energy generation system are assigned to the main products, and net energy consumption from external sources used as input to the process for the analysis. Where there is a surplus of energy generated within the primary processing system, and some fraction sold outside the system under study, the present guidelines recommend the use of system expansion to include the additional functionality of the sold energy. This is in line with ISO 14044:2006. When this does not match the goal and scope of the study, then the system shall be separated, and the waste feedstock to the energy production facility shall be considered a residual from the processing operation. All emissions associated with the generation of energy shall be accounted, and the fraction used on site treated as a normal input of energy (with the calculated environmental burdens). The fraction sold carries the burden associated with its production.

11.7.4 Disposal of Specified Risk Materials

In some countries, specified risk materials, including the skull, brain, trigeminal ganglia, eyes, palatine tonsils, spinal cord and dorsal root ganglia of cattle 30 months or older, as well as the distal ileum from cattle of all ages must be disposed of and are not allowed to enter the food chain. Disposal methods include incineration and/or rendering and burial of the material. Although this process may represent a relatively small contribution to the overall LCA, energy use associated with the disposal of this material should be considered.

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 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 key issues', 'Characterizing uncertainty' and 'Conclusions, limitations and recommendations'.

12.1 IDENTIFICATION OF KEY ISSUES

Identifying important issues encompasses the identification of the 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 processes, 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.
- **Consistency checks:** Ensure that the principles, assumptions, methods and data have been applied consistently with the goal and scope throughout the

Table 6: Guide for decision robustness from sensitivity and uncertainty

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

study. In particular, ensure that the following are addressed: (i) data quality along the life cycle of the product and across production systems; (ii) methodological choices (e.g. allocation methods) across production systems; and (iii) impact assessment steps have been applied with consideration for goal and scope of study.

12.2 CHARACTERIZING UNCERTAINTY

This section is related to 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. In addition, there is bias introduced if the LCA model is missing processes that are critical to model outputs.

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 and uncertainty associated with the proposed changes provides valuable information regarding decision robustness, as described in Table 6. 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. When 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 log normal 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 an 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 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 on the study results, then it is necessary to fully consider whether differences in method or data quality used in the model of the compared products impair the comparison. Any inconsistencies in functional units, system boundaries, data quality or impact assessment shall be evaluated and communicated.

Recommendations are based on the final conclusion of the LCA study. They shall be logical, reasonable, plausibly founded and strictly related 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). Results from the application of these guidelines cannot be used to represent the whole life cycle of large ruminant products. 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 and impact reduction strategies. In addition, the functional units recommended are intermediary points in the supply chains for virtually all large ruminant sector products and therefore will not be suitable for a full LCA. However, they can provide valuable guidance to practitioners to the point of divergence from the system into different types of products.

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

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

- possible positive or negative impacts on other (non-GHG) environmental criteria;
- possible positive or negative environmental impacts (e.g. biodiversity, acidification, eutrophication, 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. farm gate to primary processing gate);
- 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;
- feed intake and application of LEAP Animal Feed Guidelines, including description of emissions and removals (if estimated) for land-use change;
- LCI modelling and calculated 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 the 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 available life cycle assessment studies focused on large ruminant supply chain analysis

INTRODUCTION

GHG emissions from livestock systems have been identified as a significant contributor to total global emissions (e.g. Steinfeld *et al.*, 2006). This was defined as being of particular significance for ruminant animals because of their high enteric methane emissions.

There have been many published studies of GHG emissions from livestock systems globally. However, the methodologies used for estimating GHG emissions have varied widely. Various authors have highlighted the difficulties in making comparisons across published studies because of the large differences in methodologies used (e.g. Edwards-Jones *et al.*, 2009; Flysjö *et al.*, 2011b). Consequently, there has been interest in trying to agree on a common methodology for estimating GHG emissions both between and within sectors. In 2010, the International Dairy Federation (IDF, 2010) developed a common methodology for estimating the carbon footprint (i.e. total GHG emissions) for dairy products. Estimates of total GHG emissions are now often been based on the use of LCA to account for all GHG sources and to determine the extent of emissions on a product basis.

This document was prepared as part of the LEAP technical advisory group for large ruminants. The intention of this document is to provide an overview assessment of existing studies and associated methods that have used LCA for evaluation of large ruminant supply chains. Seventy studies have been identified addressing the dairy supply chain; 28 studies on beef production; 10 studies that addressed both dairy and beef; and 1 study for buffalo (Pirlo *et al.,* 2014)as purchased feeds, chemical fertilizers and fossil fuels. Average cultivated area was 53.2ha; the forage system was based mainly on maize silage, immediately followed by Italian ryegrass and/or whole cereal silage. Average herd size was 360 and the average FPCM per lactating buffalo was 3563kg/year with an average milk fat and protein percentage of 8.24 and 4.57 respectively. The CF assessment was from cradle to farm gate. The greenhouse gases (GHG. This document will identify the common approaches and point out differences in methodological and modelling choices.

GOAL AND SCOPE

The goal and scope of the studies range from hotspot identification (Arsenault *et al.*, 2009; Becoña *et al.*, 2014; Castanheira *et al.*, 2010; Cederberg and Mattsson, 2000; Chen *et al.*, 2005; DairyCo, 2012; Heller and Keoleian, 2011; Nguyen *et al.*, 2010; Thomassen *et al.*, 2008b) to commodity analysis (Basset-mens *et al.*, 2003; Battagliese *et al.*, 2013; Bianconi *et al.*, 1998; Casey and Holden, 2005; Christie *et al.*, 2011; Conestoga-Rovers & Associates, 2010; DairyCo, 2012; Dudley *et al.*, 2014; Castanheira *et. al.*, 2007; Henriksson, 2014; Jacobsen *et al.*, 2014; Nutter and

Kim, 2012; Thoma *et al.*, 2013b; Thomassen *et al.*, 2009; Vergé *et al.*, 2007; Weiss and Leip, 2012) to benchmarking for understanding and opportunities for improvement (Bartl *et al.*, 2011; Basarab *et al.*, 2012; Beauchemin *et al.*, 2011; Castanheira *et al.*, 2010; Cederberg and Flysjö, 2004; Eide, 2002; Grönroos *et al.*, 2006; Heller and Keoleian, 2011; Henriksson *et al.*, 2011; Hospido and Sonesson, 2005; Hospido *et al.*, 2003; Lizarralde *et al.*, 2014; O'Brien *et al.*, 2012; Weidema *et al.*, 2008), with several studies that targeted a comparison of production method, including other protein sources as well as organic and other alternate production methods (Arsenault *et al.*, 2009; Basarab *et al.*, 2012; Cederberg and Mattsson, 2000; de Boer, 2003; Grönroos *et al.*, 2006; Henriksson *et al.*, 2011; Kristensen *et al.*, 2011; Nguyen *et al.*, 2010; O'Brien *et al.*, 2014b; Olesen *et al.*, 2006; Pelletier *et al.*, 2010; Thomassen *et al.*, 2008b; Weidema *et al.*, 2008). In addition numerous papers evaluated the consequences of methodological choices in LCA of ruminant systems (Basset-Mens *et al.*, 2009a; Cederberg and Stadig, 2003; Cederberg *et al.*, 2011; Dalgaard *et al.*, 2014; Dudley *et al.*, 2014; Gac *et al.*, 2014a, 2014b; Nguyen *et al.*, 2012; O'Brien *et al.*, 2011; Persson *et al.*, 2014; Puillet *et al.*, 2014; Schmidt, 2008; Thoma *et al.*, 2013a; Thomassen *et al.*, 2008a; Wiedemann and Yan, 2014; Zehetmeier *et al.*, 2012). Some papers were targeted at the post-farm-gate supply chain, evaluating improvement opportunities or packaging efficiency (Aguirre-Villegas *et al.*, 2012; Berlin, 2005; COWI Consulting Engineers and Planners, 2000a; Eide, 2002; Eide *et al.*, 2003; Favilli *et al.*, 2003; Feitz *et al.*, 2005; Flysjö, 2012, 2011; Flysjö *et al.*, 2014; Keoleian and Spitzley, 1999; Kim *et al.*, 2013; Milani *et al.*, 2011; Nutter *et al.*, 2013; Ramirez *et al.*, 2006; Weidema *et al.*, 2008). In developing the draft guidance and methodology, it was considered important to allow sufficient flexibility to encompass this range of potential reasons for conducting an LCA of large ruminant systems.

GEOGRAPHIC REGION

There is a wide range of geographic coverage for the studies: Europe (Berlin, 2002; Bianconi *et al.*, 1998; Casey and Holden, 2005; Castañeda-Gutiérrez *et al.*, 2006; Castanheira *et al.*, 2010; Cederberg and Flysjö, 2004; Cederberg and Mattsson, 2000; DairyCo, 2012; del Prado *et al.*, 2010; Doublet *et al.*, 2013; Eide, 2002; Flysjö *et al.*, 2012; Foley *et al.*, 2011; Grönroos *et al.*, 2006; Guerci *et al.*, 2014; Henriksson, 2014; Henriksson *et al.*, 2014; Hospido *et al.*, 2003; Jacobsen *et al.*, 2014; Meneses *et al.*, 2012; Mosnier *et al.*, 2011; Nguyen *et al.*, 2010, 2012; O'Brien *et al.*, 2012; Pirlo and Carè, 2013; Thomassen *et al.*, 2008a; van der Werf *et al.*, 2009; Weiss and Leip, 2012); the United States (Adom *et al.*, 2012; Battagliese *et al.*, 2013; Beauchemin *et al.*, 2011, 2010; Capper and Cady, 2012; Capper, 2011, 2009; Capper *et al.*, 2009; Dudley *et al.*, 2014; Heller and Keoleian, 2011; Kim *et al.*, 2013; Nutter *et al.*, 2013; Pelletier *et al.*, 2010; Rotz *et al.*, 2010; Stackhouse-Lawson *et al.*, 2012; Thoma *et al.*, 2013b; Vergé *et al.*, 2008, 2007); South America (Bartl *et al.*, 2011; Becoña *et al.*, 2014; Cederberg *et al.*, 2011; Dick *et al.*, 2014; Lizarralde *et al.*, 2014); and Australia/New Zealand (Basset-Mens *et al.*, 2009b; Basset-mens *et al.*, 2003; Chen *et al.*, 2005; Christie *et al.*, 2011; Flysjö *et al.*, 2012, 2011b). A few studies have taken a global or regional perspective (Christie *et al.*, 2011; Gerber *et al.*, 2010; Hagemann *et al.*, 2011; Vergé *et al.*, 2007; Weiss and Leip, 2012). In reviewing these publications there do not seem to be significant differences that are driven by geographic location, aside from the need for life cycle inventory data that are relevant to that location.

MATERIALITY

The question of materiality related to the cut-off criteria chosen for the study. The ISO 14044, PAS 2050, and Product Category Rules (PCRs) all provide guidance regarding life cycle inventory or emissions impacts which should not be neglected. Only a few of the published studies that were reviewed make specific mention of cut-off criteria regarding life cycle inventory or impacts (Henriksson *et al.*, 2014; Nutter and Kim, 2012; Nutter *et al.*, 2013)that is the carbon footprint (CF. The Veal PCR states that a cut off of 2 percent of chemicals and other inputs used (mass basis as percentage of dry matter of feed processed) should be used (Blonk Consultants, 2013). The PAS 2050:2011 requires that all material contributions should be included, and that 95 percent of all GHG emissions must be accounted (BSI, 2011). The ISO 14044 standard does not specify cut-off percentages, but does require a full description of the criteria used for cut-off flows (ISO, 2006).

FUNCTIONAL UNIT

Dairy

The majority of published studies have taken as the functional unit a specified weight of fat- and protein-corrected milk (FPCM) at the farm gate (Bartl *et al.*, 2011; Basset-Mens *et al.*, 2009b; Basset-mens *et al.*, 2003; Berlin, 2002; Casey and Holden, 2005; Castanheira *et al.*, 2010; Cederberg and Flysjö, 2004; Cederberg and Mattsson, 2000; Christie *et al.*, 2011; DairyCo, 2012; Dalgaard *et al.*, 2014; de Boer, 2003; del Prado *et al.*, 2010; Flysjö *et al.*, 2011a, 2011b; Gerber *et al.*, 2010; Grönroos *et al.*, 2006; Guerci *et al.*, 2014, 2013; Hagemann *et al.*, 2012, 2011; Henriksson, 2014; Henriksson *et al.*, 2011; Kristensen *et al.*, 2011; Lizarralde *et al.*, 2014; McGeough *et al.*, 2012; Meneses *et al.*, 2012; O'Brien *et al.*, 2014a, 2014b, 2012; Pirlo and Carè, 2013; Rotz *et al.*, 2010; Sheane *et al.*, 2011; Thoma *et al.*, 2013b; Thomassen and de Boer, 2005; Thomassen *et al.*, 2009, 2008a, 2008b; van der Werf *et al.*, 2009; Vergé *et al.*, 2007). Relatively few report impacts for the animals sold as kg live weight or carcass in conjunction with milk production (Bartl *et al.*, 2011; Cederberg and Stadig, 2003; Cederberg *et al.*, 2009b; Elmquist, 2005; Flysjö *et al.*, 2012, 2011b; Gerber *et al.*, 2010; McGeough *et al.*, 2012; Weiss and Leip, 2012; Zehetmeier *et al.*, 2012). Some report a functional unit of land occupation for production of milk (Basset-Mens *et al.*, 2009b; Christie *et al.*, 2011; de Boer, 2003; del Prado *et al.*, 2010; Haas *et al.*, 2007; O'Brien *et al.*, 2014b; Thomassen and de Boer, 2005). Some studies only specified a volume of milk (without fat and protein content specified), sometimes at the farm gate (Capper, 2011; Capper *et al.*, 2008; Castanheira *et al.*, 2010; Castanheira *et. al.*, 2007; Foster *et al.*, 2007; Haas *et al.*, 2007; Vergé *et al.*, 2007), sometimes with specified packaging or otherwise ready for delivery to consumers (Eide, 2002; Heller and Keoleian, 2011; Nutter *et al.*, 2013; Thoma *et al.*, 2013b).

Beef

Most of the studies on beef were based on kg live weight (LW in Table A1.1) at the farm gate (Beauchemin *et al.*, 2010; Dudley *et al.*, 2014; Pelletier *et al.*, 2010; Stackhouse-Lawson *et al.*, 2012; Vergé *et al.*, 2008)little information exists on the net emissions from beef production systems. A partial life cycle assessment (LCA while others reported on the basis of kg carcass (Beauchemin *et al.*, 2011; Capper, 2011; Cederberg *et al.*, 2009a; Foley *et al.*, 2011; Nguyen *et al.*, 2010, 2012; Weiss and Leip, 2012) SML (silage maize starch plus linseed, rich in omega-3 FAs.

However, some studies reported on the basis of the carcass weight equivalent at the farm gate, which results in a mismatch between the system boundary definition and functional unit because live animals cross the farm-gate boundary. Three studies used one kg of live weight gain as the functional unit (Becoña *et al.*, 2014; Dick *et al.*, 2014; Modernel *et al.*, 2013).

Buffalo

The available studies for buffalo meat and milk have been performed using FPCM or carcass weight as the functional units for milk and meat, respectively (Carè *et al.*, 2012; Opio *et al.*, 2013.; Pirlo *et al.*, 2014).

Post-farm gate

Some studies have evaluated dairy products other than milk (Aguirre-Villegas *et al.*, 2012; Berlin, 2002; Capper and Cady, 2012; Castañeda-Gutiérrez *et al.*, 2006; Favilli *et al.*, 2003; Flysjö, 2011; Keoleian *et al.*, 2004; Kim *et al.*, 2013), and these studies used functional units specific to the product studied: kg butter or cheese delivered to consumers. One study also reported on a dry solids basis for cheese (Nutter and Kim, 2012). Other post-farm gate studies have focused on processing energy or manufacturing sector improvement opportunities (Berlin, 2005; Flysjö, 2011; Ramirez *et al.*, 2006; Weidema *et al.*, 2008), as well as methodological issues (Bianconi *et al.*, 1998; Feitz *et al.*, 2005; Gac *et al.*, 2014a; Wiedemann and Yan, 2014). The methodological studies do not recommend differentiation between cuts of meat at the processor gate, but current methodological approaches do differentiate dairy products on the basis of milk solids. A current proposal to the International Dairy Federation recommends a weighting of milk solids on the basis of the relative value of fat, protein and lactose (Flysjö, pers comm).

SYSTEM BOUNDARIES

Dairy

The majority of dairy studies used the cradle to farm gate as the boundary (Arsenault *et al.*, 2009; Basset-Mens *et al.*, 2009b; Basset-mens *et al.*, 2003; Beukes *et al.*, 2008; Capper and Cady, 2012; Capper *et al.*, 2008; Casey and Holden, 2005; Castanheira *et al.*, 2010; Cederberg and Flysjö, 2004; Chen *et al.*, 2005; Dalgaard *et al.*, 2014; de Boer, 2003; del Prado *et al.*, 2010; Flysjö *et al.*, 2011b; Guerci *et al.*, 2014, 2013; Hagemann *et al.*, 2012, 2011; Henriksson, 2014; Henriksson *et al.*, 2011; Hospido and Sonesson, 2005; Kristensen *et al.*, 2011; Lizarralde *et al.*, 2014; McGeough *et al.*, 2012; O'Brien *et al.*, 2014a, 2014b, 2012; Olesen *et al.*, 2006; Pirlo and Carè, 2013; Rotz *et al.*, 2010; Thoma *et al.*, 2013b; Thomassen and de Boer, 2005; Thomassen *et al.*, 2009, 2008a, 2008b; van der Werf *et al.*, 2009; Vergé *et al.*, 2007). However, several studies did include processing (Daneshi *et al.*, 2014; Castanheira *et. al.*, 2007; Gerber *et al.*, 2010; Grönroos *et al.*, 2006; Hospido *et al.*, 2003), and some were full-cradle-to-grave analyses (Berlin, 2002; Eide, 2002; Flysjö, 2011; Foster *et al.*, 2007; Gough *et al.*, 2010; Heller and Keoleian, 2011; Kim *et al.*, 2013; Meneses *et al.*, 2012; Thoma *et al.*, 2013b).

Beef

There were three boundaries defined for beef systems as well: cradle to farm gate (Basarab *et al.*, 2012; Beauchemin *et al.*, 2011; Becoña *et al.*, 2013, 2014; Capper, 2011; Dick *et al.*, 2014; Dudley *et al.*, 2014; Eady *et al.*, 2011; Foley *et al.*, 2011; Nguyen *et al.*, 2012, 2010; Pelletier *et al.*, 2010; Stackhouse-Lawson *et al.*, 2012; Vergé *et al.*, 2008; Weiss and Leip, 2012); cradle to processor gate (Cederberg *et al.*, 2009a; Jacobsen *et al.*, 2014); and cradle to grave (Battagliese *et al.*, 2013). One study conducted a gate-to-gate analyses, focusing on the finishing stage only (and excluding the cow-calf phase) (Modernel *et al.*, 2013).

Buffalo

The available studies for buffalo meat and milk have been conducted on a cradle-to-farm gate basis (Carè *et al.*, 2012; Opio *et al.*, 2013.; Pirlo *et al.*, 2014).

ANCILLARY ACTIVITIES

This could include items in the life cycle, such as: veterinary, accounting and legal services, as well as corporate overhead (potentially air travel) and worker commutes. Few studies mention ancillary activities, but some partially included these effects (Bianconi *et al.*, 1998; Foster *et al.*, 2007; Gough *et al.*, 2010; Kim *et al.*, 2013). One paper was explicit regarding inclusion of ancillary activities through a hybrid input-output modelling approach (Peters *et al.*, 2010).

BIOGENIC CARBON/METHANE

Few of the studies mentioned biogenic carbon. Only one treats biogenic methane differently than fossil methane by assigning global warming potential 24 to account for the fact that the carbon dioxide decay product in the atmosphere was biogenic in origin (Capper, 2009). The most recent IPCC global warming potentials have been updated to account for this effect (Myhre *et al.*, 2013). Only one study explicitly accounted for the animal's respiratory carbon dioxide (Rotz *et al.*, 2010).

SOIL CARBON/SEQUESTRATION

The majority of studies assumed that soil carbon stocks were constant for purposes of carbon accounting; the effect of land use change was generally discussed separately (following section). For the studies that made an accounting of soil carbon stock changes, it was generally treated as a scenario for comparison (Basarab *et al.*, 2012; Beauchemin *et al.*, 2011; Cederberg *et al.*, 2009a; DairyCo, 2012; del Prado *et al.*, 2010; Dudley *et al.*, 2014; Eady *et al.*, 2011; Gerber *et al.*, 2010; Guerci *et al.*, 2013; Hörtenhuber *et al.*, 2010; Nguyen *et al.*, 2010, 2012; O'Brien *et al.*, 2014b; Weiss and Leip, 2012).

LAND-USE CHANGE

Indirect land-use change (iLUC) was included in very few of the studies (Dalgaard *et al.*, 2014; Persson *et al.*, 2014); however direct land-use change (dLUC) for recent (less than 20 years) conversion was included on a country specific basis (in particular for palm and soy) in several studies (DairyCo, 2012; Dudley *et al.*, 2014; Gerber *et al.*, 2010; Hörtenhuber *et al.*, 2010; Nguyen *et al.*, 2010, 2012; O'Brien *et al.*, 2014a, 2012; Persson *et al.*, 2014; Weiss and Leip, 2012). Land occupation, as an inventory item, was accounted as a means of denoting an opportunity cost for use of the land in ruminant systems in a number of studies (Arsenault *et al.*, 2009; Bartl *et al.*, 2011; Basset-Mens *et al.*, 2009b; Basset-mens *et al.*, 2003; Berlin, 2002; Capper and Cady, 2012; Capper, 2011; Cederberg and Flysjö, 2004; de Boer, 2003;

del Prado *et al.*, 2010; Foster *et al.*, 2007; Grönroos *et al.*, 2006; Guerci *et al.*, 2013; Henriksson *et al.*, 2014; Kristensen *et al.*, 2011; Lizarralde *et al.*, 2014; Lovett *et al.*, 2006; O'Brien *et al.*, 2012; Thomassen *et al.*, 2009, 2008a; van der Werf *et al.*, 2009).

DELAYED EMISSIONS

None of the studies included consideration of delayed emissions, although the study by Rotz *et al.* (2010)along with all other types of animal agriculture, is a recognized source of GHG emissions, but little information exists on the net emissions from dairy farms. Component models for predicting all important sources and sinks of CH(4 would allow calculation of carbon sequestered for some period (e.g. as leather) because they provide a full accounting of the carbon in the system.

INFRASTRUCTURE

There is a range of approaches in accounting for capital infrastructure. It is either not mentioned or excluded for the majority of studies. Some studies do provide a relatively complete estimate of the full infrastructure burden (Basset-Mens *et al.*, 2009b; Foster *et al.*, 2007; Hagemann *et al.*, 2011; Meneses *et al.*, 2012; Nutter *et al.*, 2013; Stackhouse-Lawson *et al.*, 2012). For studies that count, to some extent, for infrastructure in the supply chain, the most common approach is inclusion of background infrastructure (through existing databases), but to exclude foreground infrastructure (Becoña *et al.*, 2014; Cederberg *et al.*, 2009a; Conestoga-Rovers & Associates, 2010; Nguyen *et al.*, 2012). The exceptions include partial accounting of on-farm infrastructure (machinery, but not buildings) (Flysjö *et al.*, 2011b; Henriksson *et al.*, 2011; Pirlo and Carè, 2013; Rotz *et al.*, 2010; Vergé *et al.*, 2007).

ALLOCATION

The predominant choices for allocation are economic value, biological causality and system expansion. However some additional approaches are taken, including mass allocation. Others suggested gross chemical energy content and physical/cost relationships. The stages of the large ruminant supply chain for which allocation is required include: ration production (meal/oil – refer to LEAP Animal Feed Guidance); dairy farm gate (milk and cull animals, possibly manure); cow-calf and stocker (some studies separately account for feeders, bulls, and cull breeding animals) (Eady *et al.*, 2011); and processing - multiple dairy products and meat and co-products (Feitz *et al.*, 2005; Gac *et al.*, 2014a; Wiedemann and Yan, 2014).

Dairy

Several studies assigned the entire dairy operation to milk with no allocation to culled animals (Capper *et al.*, 2008; Casey and Holden, 2005; Chen *et al.*, 2005; Christie *et al.*, 2011; Castanheira *et. al.*, 2007; Flysjö *et al.*, 2011b; Henriksson, 2014; Henriksson *et al.*, 2011; Pirlo and Carè, 2013; Vergé *et al.*, 2007; Zehetmeier *et al.*, 2012). Some of these studies also included other (economic, mass, system expansion) as alternate scenarios (Casey and Holden, 2005; O'Brien *et al.*, 2014b; Pirlo and Carè, 2013). Biological causality was commonly used as a means of allocation between culled (live weight) animals sold from the farm and milk production (Arsenault *et al.*, 2009; Basset-Mens *et al.*, 2009b; Basset-mens *et al.*, 2003; Cederberg and Mattsson, 2000; Daneshi *et al.*, 2014; de Boer, 2003; Eide, 2002; Flysjö, 2011; Flysjö *et al.*, 2011a; Guerci *et al.*, 2013, 2014; Hagemann *et al.*, 2012, 2011; Kim *et al.*, 2013; Kristensen *et al.*, 2011;

Lizarralde *et al.*, 2014; McGeough *et al.*, 2012; O'Brien *et al.*, 2014b, 2012; Pirlo and Carè, 2013; Thoma *et al.*, 2013b). Relatively few studies used system expansion for the milk/cull animal relationship (Foster *et al.*, 2007; Grönroos *et al.*, 2006; Hospido and Sonesson, 2005; Thomassen *et al.*, 2008a), although some included it as a scenario (Cederberg and Stadig, 2003; Kristensen *et al.*, 2011; O'Brien *et al.*, 2014b). Only one paper addressed non-food functionality (draught power, financial holding, dowry) of smallholder systems (Weiler *et al.*, 2014). A second paper mentions the importance of non-food functions, but did not quantify these functions (Hagemann *et al.*, 2011).

Beef

Most of the beef studies did not require allocation; all the live weight leaving the system was considered equivalent (Beauchemin *et al.*, 2010; Dick *et al.*, 2014)and to examine the proportion of whole-farm emissions attributable to enteric methane (CH 4. One study separately accounted for feeders, bulls, and cull breeding animals because of system boundary choices that necessitated transfer of animals between operations (Eady *et al.*, 2011).

Buffalo

Gerber *et al.* (2013) report on a global assessment of emissions published by FAO is based on LCA methodology and uses IPCC (2006) guidelines. FAO used a recently developed framework called Global Livestock Environmental Assessment Model for quantification of GHG emissions for geographically defined spatial units. Tier 2 approach of IPCC was followed for quantification of the GHG emissions. The functional unit was 1 kg of carcass weight for meat and 1 kg of FPCM for milk. Economic and protein content based allocation was used.

Care *et al.* (2012) report the carbon footprint of buffalo milk estimated in 6 farms in the 'Mozzarella di bufalacampana-DOP' production area (Caserta, Italy). The system boundary was limited to cradle to farm gate and the functional unit was 1 kg of FPCM. The allocation of co-products generated during milk production was on the basis of co-products economic value. IPCC Tier 2 approach was followed for estimating the GHG emissions.

Pirlo *et al.* (2014) report the carbon footprint of milk produced in 6 Mediterranean buffalo farms. The assessment was from cradle to farm gate and the functional unit was 1 kg of FPCM using economic allocation.

Mixed farming systems

The study of Eady *et al.* (2011) was for a case farm with mixed cropping and livestock. The authors used system expansion to allocate between crop and livestock and compared biophysical and economic allocation for lamb/mutton/wool. Similarly, the New Zealand system (Ledgard *et al.*, 2011) included mixed sheep and cattle farming and used biophysical allocation to allocate between each animal type (apportioning according to the amount of feed dry matter consumed), and then used economic allocation for lamb/mutton/wool. Enteric methane was a significant contributor to the carbon footprint, and therefore most studies used a Tier-2 methodology, whereby feed intake was estimated from a number of animal productivity parameters (e.g. live weight, growth rate, lambing percentage and replacement rate). However, two studies used a Tier-1 methodology where each sheep class had a constant methane emission per animal. In view of the large contribution from enteric methane, it is desirable to use a Tier-2 methodology since there can be large differences in animal productivity, feed conversion efficiency and methane emissions per kg animal production, including from sheep (e.g. Ledgard *et al.*, 2011; Benoit and Dakpo, 2012).

Processing

Relatively few studies considered post-farm gate stages of the supply chain (Aguirre-Villegas *et al.*, 2012; Berlin, 2002, 2005; COWI Consulting Engineers and Planners, 2000a; Gerber *et al.*, 2010; COWI Consulting Engineers and Planners, 2000b; Keoleian *et al.*, 2004; Milani *et al.*, 2011; Nutter *et al.*, 2013; Raggi *et al.*, 2008; Ramirez *et al.*, 2006). Several were methodological in nature (Feitz *et al.*, 2005; Gac *et al.*, 2014a; Wiedemann and Yan, 2014).

DATA QUALITY ASSESSMENT

Data quality was thoroughly discussed and evaluated in relatively few of the studies (Adom *et al.*, 2012; Capper, 2009; DairyCo, 2012; Foster *et al.*, 2007; Thoma *et al.*, 2013b). Other studies included a qualitative discussion or mentioned adoption of the EcoInvent pedigree for background datasets (Bartl *et al.*, 2011; Berlin, 2002; Dalgaard *et al.*, 2014; Hospido *et al.*, 2003; Kim *et al.*, 2013; Meneses *et al.*, 2012; Thoma *et al.*, 2013b; Thomassen and de Boer, 2005; Thomassen *et al.*, 2009).

UNCERTAINTY ANALYSIS

Monte Carlo analysis was the method used for determining the propagation of input uncertainties to the environmental impacts reported (Adom *et al.*, 2012; Basset-Mens *et al.*, 2009b; Flysjö *et al.*, 2011b; Gerber *et al.*, 2010; Henriksson, 2014; Henriksson *et al.*, 2011; Kim *et al.*, 2013; Nutter *et al.*, 2013; Thoma *et al.*, 2013b; van der Werf *et al.*, 2009)an operational method for the environmental evaluation of dairy farms based on the life cycle assessment (LCA. However, the majority of studies do not mention the role of uncertainty in LCA of large ruminant systems.

PRODUCT CATEGORY RULES

The generic GHG methodology guidelines refer to PCRs and recommend that these are used where they have been produced. A detailed search revealed that there are no specific PCRs for beef or dairy products. However, there are generic PCRs on 'Meat of mammals' (Boeri, 2013), 'Processed liquid milk' (Sessa, 2013a) and a draft PCR on 'Textile yarn and thread from natural fibres, man-made filaments or staple fibres' (Rossi, 2012), which can be used to assist in developing methodology guidelines for large ruminants.

GHG FOOT-PRINTING TOOLS COVERING LARGE RUMINANTS

There are a number of GHG foot-printing tools that are being used or available for use on farms for evaluation of the GHG footprint of large ruminants and mitigation options. Ten carbon calculators available within the United Kingdom were recently reviewed by EBLEX (2013). Many of these use an LCA approach and account for United Kingdom-specific management practices, but in most cases the specific methodology and algorithms are not published and therefore specific methodology details are unavailable. This makes it difficult to assess these models, but it gives an indication of the potential for practical use on farm. It also highlights the importance in having a commonly agreed methodology for estimating GHG emissions from large ruminants and their products for comparison of production and processing systems.

Table A1.1: Overview of large ruminant literature

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Dairy										
O'Brien *et al.*, 2014b	Model study	UK	cradle to farm gate	ton FPCM	837 - 914	none, economic, mass, protein, biological causality (M/LW); system expansion	scenario analysis	assumed neutral / not included	not mentioned	climate change
Capper and Cady, 2012	Comparison	USA	cradle to farm gate	milk required for 500,000 t of cheddar	6.4 - 8.1 (e9)	not mentioned	assumed neutral	not included	included as inventory	climate change
O'Brien *et al.*, 2012	Case study	Ireland	cradle to farm gate	ton FPCM	874 - 1027	economic (rations); biological causality (M/LW)	scenario analysis	included	included as inventory	climate change, eutrophication, acidification, land use and non-renewable energy use
Pirlo and Carè, 2013	Model study	Italy	cradle to farm gate	kg FPCM	0.97 - 1.22	None; physical; economic	not included	discussed; not included	not mentioned	climate change
Lovett *et al.*, 2006	Model study	Ireland	cradle to farm gate	kg milk	1.03 - 1.2	not mentioned	assumed neutral	not mentioned	included	climate change
Christie *et al.*, 2011	National Sector	Tasmania	cradle to farm gate	kg FPCM	1.04 ± 0.13	all to milk	not mentioned	not mentioned	not mentioned	climate change
O'Brien *et al.*, 2014a	Case study	Ireland	cradle to farm gate	kg FPCM	0.87 - 1.72	economic allocation	not included	included	not mentioned	carbon footprint
Casey and Holden, 2005	National Sector	Ireland	cradle to farm gate	kg FPCM	1.5	none; mass; economic	not mentioned	not mentioned	not mentioned	climate change
van der Werf *et al.*, 2009	Model study	France (West)	cradle to farm gate	1000 kg FPCM	1037 - 1082	economic allocation	not mentioned	not mentioned	included as inventory	eutrophication potential, Acidification potential, terrestrial ecotoxcicity, climate change, land occupation
Bianconi *et al.*, 1998	National Sector (post-farm)	Italy	farm-gate to grave	5 kg butter delivered to final consumer (250-g packets)	n/a	mass allocation (where allocation couldn't be avoided)	N/A	N/A	N/A	none; primarily LCI
Thomassen *et al.*, 2008a	Methodology	The Netherlands	cradle to farm gate	1 kg FPCM	1.61	economic and mass and allocation (ALCA) system expansion (CLCA)	not mentioned	not mentioned	included as inventory	land use, energy use, climate change, acidification and eutrophication
Hagemann *et al.*, 2011	Multi-national	38 countries	cradle to farm gate	100 kg FPCM	135 ± 49	biological causality (M/LW)	not mentioned	not included	not mentioned	climate change

(Cont.)

Table A1.1: (*Cont.*)

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Henriksson *et al.*, 2014	Animal ration	Sweden	cradle-to-feed consumed by cattle	feed consumed to produce 1 kg FPCM	0.42 - 0.53	economic (meal/oil)	not included	included (Brazilian soy)	included as inventory	climate change
Sultana *et al.*, 2014	Multi-national	Global	cradle to farm gate	1 kg FPCM	1.5 (0.9 - 4.1)	biological causality (M/LW)	not mentioned	not included	mentioned but not clear if included	climate change
Arsenault *et al.*, 2009	Comparison	Canada (Nova Scotia)	cradle to farm gate	1000 kg of unprocessed, unpackaged milk	974	mass (rations); biological causality (M/LW)	not mentioned	not mentioned	included as inventory	abiotic depletion, climate change, ozone layer depletion, human toxicity, freshwater aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidification, eutrophication, Land use
Basset-Mens *et al.*, 2009b	Comparison	New Zealand	cradle to farm gate	kg of milk (specified fat and protein)	0.86	biological causality (M/LW)	not included	not included	included as inventory	climate change, eutrophication potential, acidification potential, energy use and land occupation
Gough *et al.*, 2010	Case study	USA (CO)	cradle to grave	one gallon of packaged fluid milk	7.79	energy allocation	not mentioned	not mentioned	not mentioned	energy consumption, climate change, acidification potential, eutrophication potential, water consumption, water utilization, municipal solid waste, indirect solid waste
Kristensen *et al.*, 2011	Comparison	Denmark	cradle to farm gate	kg FPCM	1.2 - 1.27	none; economic, protein, system expansion; biological causality (M/LW)	not included	not mentioned	included as inventory	climate change,
Guerci *et al.*, 2014	Regional	Italy	cradle to farm gate	kg FPCM	1.55 ± 0.21 (no grazing) 1.72± 0.37 (grazing)	biological causality (M/LW); economic; milk and meat nitrogen content; mass allocation	not included; LUC for soy as scenario	yes. Allocation and LUC	not mentioned (only LUC for soy)	climate change
Grönroos *et al.*, 2006	Case study	Finland	cradle to processor gate	1000 L (1.5% of fat) transported to a retailer	6.4 GJ energy conv. 4.4 GJ energy organic	system expansion	N/A	N/A	included as inventory	energy use

(*Cont.*)

Table A1.1: (*Cont.*)

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Meneses *et al.*, 2012	Regional	Spain	cradle to grave	packaging to contain 1 L	0.05 - 0.18	not mentioned	not mentioned	not mentioned	not mentioned	climate change and acidification potential
de Boer, 2003	Review article	Sweden, Netherlands, Germany	cradle to farm gate	ton FPCM	888 - 1300	economic and biological causality (M/LW)	not mentioned	not mentioned	included except for Germany	climate change, acidification, eutrophication, ecotoxicity, energy use, ozone depletion
Castanheira *et. al.*, 2007	National Sector	Portugal	cradle to processor gate	1626880 ton milk (Portugese production in 2005)	~2.1e6 ton	all to milk	not mentioned	not mentioned	not mentioned	climate change, photochemical oxidation, acidification, eutrophication
Berlin, 2002	Dairy products	Sweden	cradle to grave	1 kg of Angsgarden cheese wrapped in plastic.	8.8	Economic allocation.	not mentioned	not mentioned	Discussed.	Use of resources, energy consumption, climate change, acidification, eutrophication and photochemical ozone creation potentials.
Thomassen and de Boer, 2005	Methodological	The Netherlands	cradle to farm gate	kg FPCM	1.81 ± 0.86	Economic allocation.	not mentioned	not mentioned	Land use is considered one of the impact categories.	land use, fossil energy use, climate change eutrophication and acidification potential; ecological footprint
Basset-mens *et al.*, 2003	National Sector	New Zealand Sweden, Germany	cradle to farm gate	kg FPCM milk (4% fat)	0.72 – NZ conv. 1.1 – SE conv. 1.3 – DE conv.	biological causality (M/LW)	not mentioned	not mentioned	land occupation accounted	climate change, eutrophication & acidification potential
Dalgaard *et al.*, 2014	Model study	Denmark and Sweden	cradle to farm gate	1kg FPCM at farm gate	1.05 – 1.8	Economic, system expansion, biophysical.	sequestration is not included	included	Effects of iLUC are included.	carbon footprint
Nutter *et al.*, 2013	Processing	USA	gate to gate	1 kg of packaged fluid milk delivered to the plant's customers	0.203 ± 0.0174	volumetric basis for other packaged fluids (e.g. juices)	N/A	N/A	not mentioned	climate change
Thoma *et al.*, 2013b	National Sector	USA	cradle to grave	1 kg of 'average' milk consumed in US	1.77 – 2.4	economic (rations); biological causality (M/LW); mass (cream-milk)	assumed neutral	not mentioned	not mentioned	climate change
Hörtenhuber *et al.*, 2010	Model study	Austria	not mentioned	kg milk	0.81 - 1.17	system expansion	included	included	not mentioned	assumed climate change
Henriksson, 2014	National Sector	Sweden	cradle to farm gate	1kg FPCM delivered at farm gate.	1.13 ± 0.2	economic (rations); all to milk	not included	emissions from LUC with Brazilian soy bean production	discussed; need for better accounting stressed	climate change

(*Cont.*)

Table A1.1: (*Cont.*)

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Vergé *et al.*, 2007	National Sector	Canada	cradle to farm gate	kg milk (fat/protein not reported)	1.02	all to milk	Soil carbon decomposition was not considered in this analysis	not mentioned	not mentioned	climate change
Gerber *et al.*, 2010	Multi-national	Global	cradle to farm gate and farm gate to retail	kg FPCM	2.4	economic and protein content	Sequestration accounted (IPCC -PAS 2050)	Included for soya only. Deforestation in Brazil and Argentina.	see table 4.2 for land use	climate change
Daneshi *et al.*, 2014	Case study	Tehran	cradle to processor gate	one litre of pasteurized milk packaged in a plastic pouch	1.73	economic (rations); biological causality (M/LW)	not included	not mentioned	not mentioned	carbon footprint
DairyCo, 2012	National Sector	UK	cradle to farm gate	Not stated but assumed 1 liter fat corrected milk.	1.309 ± 0.273	not specific	they did a calculation with sequestration and one without	included	not mentioned	climate change
Flysjö *et al.*, 2011a	Methodological	New Zealand and Sweden	cradle to farm gate	1 kg (FPCM)	0.6 – 1.52 (NZ) 0.8 – 1.56 (SE)	physical, economic, protein, and mass allocation	not mentioned	not mentioned	not mentioned	climate change
Eide, 2002	Case study	Norway	cradle to grave	1,000 litres of drinking milk brought to the consumers.	525 - 610	economic (rations); biological causality (M/LW); mass (post-farm-gate)	not included	not included	not mentioned	Climate change, ozone depletion, eutrophication, acidification, Eco toxicity and photo-oxidant formation.
Bartl *et al.*, 2011	Case study	Peru	cradle to farm gate	1 kg FPCM and 1 animal	Highland: 13.78 Coast: 3.18	Economic and mass allocation.	not included	not mentioned	included	climate change, acidification and eutrophication
Kim *et al.*, 2013	National Sector	USA	cradle to grave	One ton of cheddar consumed (dry weight basis); One ton of mozzarella consumed (dry weight basis)	Cheddar: 8.60, Mozzarella: 7.28,	economic (rations);biological causality (M/LW); economic, expert judgement and milk solids allocations (processor)	not included	not included	not included	climate change, marine eutrophication photochemical oxidant formation freshwater eutrophication ecosystems human toxicity ecotoxicity
Thomassen *et al.*, 2008b	Comparison	The Netherlands	cradle to farm gate	1 kg of Fat and Protein Corrected Milk leaving the farm-gate	1.4 ± 0.1 (conv) 1.5 ± 0.3 (org)	Economic allocation.	not mentioned	not mentioned	one of the impact categories	land use, energy use, climate change, acidification, and eutrophication

(*Cont.*)

Table A1.1: *(Cont.)*

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Heller and Keoleian, 2011	Case study	USA	cradle to grave	1 L of packaged fluid milk	yr 1: 2.39 yr 2: 2.22	energy allocation	not included	Soy biodiesel inventory does not include iLUC	not mentioned	climate change, energy use
Chen *et al.*, 2005	Model study	Australia	cradle to farm gate	one litre of raw milk leaving at the farm gate	Single combined score	all to milk	not mentioned	not mentioned	shown in graphical form	resources: fossil fuels, land use; ecological quality: climate change, acidification/ eutrophication, radiation, ozone depletion, eco-toxicity; human health: cancer and respiratory
Cederberg and Mattsson, 2000	Comparison	Sweden	cradle to farm gate	1000 kg FPCM	950 - 1050	economic (rations); biological causality (M/LW)	not mentioned	talk about land use between the two systems but not LUC	brief discussion	·resources: energy, material and land use; · human health: pesticide use; ·ecological effects: climate change, acidification, eutrophication, photo-oxidant formation and depletion of stratospheric ozone
Cederberg and Flysjö, 2004	Case study	Sweden (South West)	cradle to farm gate	kg FPCM	0.896 ± 0.038 (conv H), 1.037 ± 0.041 (conv M) 0.938 ± 0.048 (org)	economic for both dairy and feed production	not mentioned	not included	Included	resources, energy, land, toxicity, climate change, eutrophication, acidification
McGeough *et al.*, 2012	Model study	Canada (Eastern)	cradle to farm gate	kg FPCM kg LW	Milk: Beef 0.92 0 0.84 1.72 0.67 5.32	none; economic; biological causality (IDF)	not included	not mentioned		climate change
Guerci *et al.*, 2013	Comparison	Denmark, Germany, Italy	cradle to farm gate	kg FPCM	1.1 – 1.91	biological causality (M/LW)	included	not included	included (one of the impact categories)	climate change, eutrophication, acidification, non-renewable energy use, land occupation, biodiversity: damage score
Flysjö, 2011	Processing	Denmark	cradle to grave	kg butter consumed w/ consumer waste	14.7	Milk solids with economic weighting	not mentioned	not mentioned	not mentioned	climate change
Lizarralde *et al.*, 2014	Case study	Uruguay (Southern)	cradle to farm gate	kg FPCM	0.99 coefficient of variance 10%	biological causality (M/LW)	discussed, but not taken into account in this study	assumed neutral / not included	included	climate change
Thoma *et al.*, 2013b	Regional	USA	cradle to farm gate	kg FPCM	1.23	biological causality (M/LW)	not included	not mentioned	not mentioned	climate change

(Cont.)

Table A1.1: *(Cont.)*

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Adom *et al.*, 2012	Animal ration	USA	cradle to farm gate	1 kg of dairy feed	N/A	Economic and mass allocation	not included	not mentioned	not mentioned	climate change
Thomassen *et al.*, 2009	National Sector	The Netherlands	cradle to farm gate	kg FPCM	0.76 ± 0.1	Economic allocation.	not mentioned	not mentioned	it is one of the impact categories	land use, energy use, acidification, climate change, eutrophication
Hospido *et al.*, 2003	Case study	Spain	cradle to processor gate	1L of packaged liquid milk, ready to be delivered.	1.05	Mass (rations); biological causality (M/LW)	not mentioned	not mentioned	not included	climate change, ozone depletion, acidification, eutrophication, photo-oxidant formation and depletion of abiotic resources, energy consumption
Rotz *et al.*, 2010	Model study	USA	cradle to farm gate	kg FPCM	0.37 – 0.69	Economic allocation.	no net sequestration - though included as a scenario	not mentioned	not mentioned	climate change
Capper *et al.*, 2008	Comparison	USA	cradle to farm gate	kg milk	1.38 (w/rBST) 1.53 (w/o rBST)	all to milk	Crops under conventional tillage were not considered to sequester carbon	reported as lower LU in modern dairies	not mentioned	acidification (AP), eutrophication (EP), and climate change (GWP) potentials
Capper *et al.*, 2009	Comparison	USA	assumed farm gate	1kg of milk produced	1944: 3.66 2007: 1.35	not mentioned	not included	not mentioned	not mentioned	climate change
Foster *et al.*, 2007	Literature review	UK	cradle to grave	1000 liter of milk	1039	economic allocation (rations) ; system expansion (manure and cull cows)	Discussed. Credit desirable, but not yet justified.	not mentioned	they talk about land use (direct) but not LUC (look at tables)	Primary energy used, climate change, eutrophication & acidification potential, abiotic resource use, land use
Hospido and Sonesson, 2005	Comparison	Spain	cradle to farm gate	milk sold by typical Galacian herd	normalized	system expansion for meat – included in FU	not included	not mentioned	not mentioned	Climate change
Castanheira *et al.*, 2010	Case study	Portugal	cradle to farm gate	one tonne of raw milk	approximately 1021	Economic allocation.	not discussed	not mentioned	not mentioned	abiotic depletion, climate change, photochemical oxidation, acidification and eutrophication
Henriksson *et al.*, 2011	Case study	Sweden	cradle to farm gate	kg FPCM	1.13	all to milk	discussed but not included	not included	not mentioned	climate change

(Cont.)

Table A1.1: *(Cont.)*

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Flysjö *et al.*, 2011b	Methodological	New Zealand and Sweden	cradle to farm gate	kg FPCM at farm gate in NZ and SE, including co-products	NZ: 1.00 SE: 1.16	economic (rations); all to milk	not included	not included	not included	climate change
Beef										
Becoña *et al.*, 2013	Comparison	Uruguay and New Zealand	cradle to farm gate	kg LW	UR: 18.4 – 21 NZ: 8 - 10	calves from dairy carry no burden	assumed constant	no LUC (deforestation)	included	climate change
Stackhouse-Lawson *et al.*, 2012	Model study	California	cradle to farm gate	kg HCW	Angus: 22.6 ± 2.0 Holstein: 10.7 ±1.4	economic allocation	Accounted, but not included in reported emission	not mentioned	reported as inventory	climate change
Pelletier *et al.*, 2010	Comparison	Upper Midwest United States	cradle to farm gate	kg LW	Pasture finished: 19.2, Feed lot finished: 14.8	no cow/calf allocation. Biophysical properties (rations)	assumed constant	not mentioned	ecological footprint was used instead of land occupation	cumulative energy use, ecological footprint, climate change and eutrophication
Nguyen *et al.*, 2012	Case study	France	cradle to farm gate	kg carcass (farm gate); kg LWG (live weight gain)	27.0 – 27.9	live weight; protein; economic	included	included	included	climate change eutrophication & acidification potential, cumulative energy demand and land occupation
Nguyen *et al.*, 2010	Comparison	EU	cradle to farm gate	kg carcass delivered from farms	cow-calf: 27.3 dairy bull calf: 12mo: 16, 16mo: 17.9, 24 mo: 19.9	system expansion (soymeal/oil); biophysical causality (bull calves from dairy)	included	included	discussed	Climate change, acidification potential, eutrophication potential, land occupation and non-renewable energy use.
Conestoga-Rovers & Associates, 2010	National sector	Canada	cradle to slaughter house receiving dock	1 kg LW at slaughterhouse	14.5	No allocation to hides, intestines. All dairy to milk except replacement heifers allocated to beef	included			
Modernel *et al.*, 2013	Case study: background: range, seeded pasture, finish: feedlot	Uruguay	gate-to-gate (cow-calf excluded)	kg LW	R-R: 16.7 R – F: 10.5 S – F: 6.9	not mentioned	assumed constant	no LUC (deforestation) for the systems	reported as inventory	climate change
Basarab *et al.*, 2012	Case study	Canada	cradle to farm gate	kg LW and kg carcass	LW: 11.6 - 13.2 CW: 19.9 - 22.5	not mentioned	included	included	included	climate change

(Cont.)

Table A1.1: (*Cont.*)

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Vergé *et al.*, 2008	National sector	Canada	cradle to farm gate	kg LW	10.37	not mentioned	not included	not mentioned	not mentioned	climate change
Weiss and Leip, 2012	Regional Assessment	EU	cradle to farm gate (including slaughter)	kg carcass; kg milk (4% fat)	Beef: 21 -28 Milk: 1.3 – 1.7	physical allocation (Nitrogen/protein/ energy content); biological causality (M/LW)	included	included	included	climate change
Becoña *et al.*, 2014	Case study	Uruguay	cradle to farm gate	kg of live weight gain produced on farm	20.8	not discussed	not mentioned	not included	discussed but not included	climate change
Dick *et al.*, 2014	Case study	Brazil	cradle to farm gate	kg of live weight	22.5 (extensive) 9.2 (improved)	not needed - single product (LWG)	not included	discussed, not included	one of the impact categories	Climate change, land use, freshwater & metal & fossil depletion, terrestrial acidification and freshwater eutrophication.
Beauchemin *et al.*, 2010	Case study	Western Canada	cradle to farm gate	kg LW	13.04	not needed (system included culled breeding animals)	discussed but not included	not mentioned	not mentioned	climate change
Cederberg *et al.*, 2009a	Case study	Brazil	processor gate	kg carcass (farm gate); kg boneless shipped to Sweden	Carcass: 28 Boneless: 41	biophysical causality (M/LW); no allocation to meat by-products	included	included	reported as inventory	climate change; energy use; land occupation
Beauchemin *et al.*, 2011	Regional Assessment	Western Canada	cradle to farm gate	kg carcass	21.7	no allocation (animals); DDG production to ethanol	included	included	reported as inventory	climate change
Battagliese *et al.*, 2013	National sector	united states	cradle to grave	1 lb consumed, boneless beef	23.6 (kg/lb)			not mentioned	reported as inventory	climate change, land occupation, energy consumption, eutrophication, acidification, consumptive water, solid waste toxicity
Eady *et al.*, 2011	Case study	Australia	cradle to farm gate	kg LW	Beef heifer: 17.5 Weaner steer:20.8 Beef bull: 22.9	economic and mass between animal types (some as cull, weaners to another enterprise)	included	discussed	not mentioned	climate change

(*Cont.*)

Table A1.1: *(Cont.)*

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Peters *et al.*, 2010	Comparison	Australia	cradle to processor gate	kg HSCW	Grain finished: 9.9, Grass finished: 12.0	Mass-based and economic allocations applied at scale of individual process units	not mentioned	not mentioned	mentioned briefly	climate change
Capper, 2009	Comparison	United States	cradle to grave	kg LW	Conv: 15.2 Natural: 18 Grass finished: 26	mass and economic	not mentioned	not mentioned	included	climate change
Capper, 2011	Comparison	United States	cradle to farm gate	billion kilogram of HCW beef	17.945E9	biological causality (dairy to beef)	discussed; considered in balance so not accounted	not included	reported as inventory	climate change
Dudley *et al.*, 2014	Regional Assessment	United States	cradle to farm gate (cow-calf, background feedlot)	kg LW	8 - 8.3	mass	included	included	reported as inventory	climate change
Foley *et al.*, 2011	Case study	Ireland	cradle to farm gate	kg carcass; ha	23.1 (national survey result)	not mentioned	discussed, but not included	discussed but not included	mentioned, not included	climate change
Zervas and Tsiplakou, 2012	Comparison	Greece	cradle to farm gate	not mentioned	N/A	not mentioned	discussed	discussed, not quantified	not mentioned	not mentioned
de Vries and de Boer, 2010	Review	EU	cradle to farm gate	kg beef	14 - 31	various - from different studies	not mentioned	recommended for inclusion in future studies	reported as inventory	climate change; acidification; eutrophication; land use; energy consumption
Zehetmeier *et al.*, 2012	Comparison dairy + beef combined system	Germany	cradle to farm gate but it is a bovine system including milk and beef systems	kg milk; kg beef	Milk: 0.98 – 1.35 Beef: 14.6 – 5.6 Milk: 0.89 – 1.06 Beef: 16.2 – 10.8 (nb: paired production of milk and meat)	None (dairy to milk); economic (for M / LW)	not mentioned	scenario	not mentioned	climate change
Elmquist, 2005	Model Study	Sweden	cradle to farm gate	1000kg FPCM plus 28 kg lean meat	~1250	economic (rations); system expansion (combined FU)	not mentioned	not mentioned	reported as inventory	eutrophication, climate change, acidification (terrestrial), primary energy use, and land use

(Cont.)

Table A1.1: (*Cont.*)

	Classification	Region	System Boundaries	Functional Unit (FU)	GHG Emissions (kg CO_2e / FU)	Allocation	Soil Carbon / Sequestration	LUC / iLUC	Land use/ occupation	Impact categories
Cederberg *et al.*, 2009b	Retrospective	Sweden	cradle to farm gate	kg carcass; kg FPCM	Milk: 1.27 (1990) 1.02 (2005) Beef: 18 (1990) 19.8 (2005)	physical and economic allocation	not mentioned	not included	not mentioned	climate change
Puillet *et al.*, 2014	Methodology	France	cradle to farm gate	N/A	N/A	avoided - bovine sector as whole modeled	not mentioned	not mentioned	not mentioned	climate change
Cederberg and Stadig, 2003	Methodology	Sweden	cradle to farm gate	kg FPCM; kg of bone-free meat	Milk: 1.05 Meat: 22.3	none; economic; biological causality(M/LW); system expansion	not mentioned	not mentioned	one of the impact categories	climate change, acidification, eutrophication and the inventory results for energy use, land use and toxicity
Doublet *et al.*, 2013	National Survey	Romania	cradle to processor gate	kg of bone-free beef; kg raw milk	33 1.1	biological causality (M/LW)	not mentioned	not mentioned	inventory	climate change, human toxicity (cancer and non-cancer), acidification, eutrophication (terrestrial, freshwater, and marine), ecotoxicity (freshwater), land use, water depletion
Flysjö *et al.*, 2012	Comparison	Sweden	cradle to farm gate	kg FPCM	1.07 (no LUC) 2.07 (worst case LUC)	none system expansion	briefly discussed	included	included	climate change
Buffalo										
Pirlo *et al.*, 2014	Case study	Italy	cradle to farm gate	kg FPCM 8.24% F 4.57% P	3.75 3.60	none economic allocation	not mentioned	not included		climate change
Gerber *et al.* (2013	Case study	Global	cradle to farm-gate	1 kg CW, 1 kg FPCM	53.43 3.44	Economic, protein content	discussed	not included	discussed	climate change
Gerber *et al.* (2013	Case study	Asia	cradle to farm-gate	1 kg CW, 1 kg FPCM	51.0 3.2	Economic, protein content	discussed	not included	discussed	climate change
Carè *et al.*, 2012	Case study	Italy	cradle to farm gate	kg FPCM	3.93	none	not mentioned	not mentioned	not mentioned	climate change

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Appendix 2

Summary of available standards and specifications of LCA methodologies for large ruminant supply chain analysis

INTRODUCTION

This document was prepared as part of the LEAP TAG for large ruminants. The intention of this document is to provide an overview assessment of existing standards and specifications that have been created to guide LCA. This summary is a synopsis of a detailed evaluation performed by the European Commission Joint Research Centre, Institute for Environment and Sustainability (Chomkhamsri and Pelletier, 2011). That study considered seven product-specific and seven organization-specific methodologies. This synopsis focuses only on the following product-specific methodologies:

- ISO 14044:2006 *Environmental management - Life cycle assessment - Requirements and guidelines* (ISO, 2006);
- ISO/TS 14067:2013 *Greenhouse gases: Carbon footprint of products – Requirements and guidelines for quantification and communication* (ISO, 2013)
- *International Reference Life Cycle Data System (ILCD) Handbook: - General guide for Life Cycle Assessment - Detailed guidance* (European Commission, 2010);
- *Product Life Cycle Accounting and Reporting Standard* (WRI and WBCSD, 2011);
- *BPX-30-323-0 General principles for an environmental communication on mass market products - Part 0: General principles and methodological framework* (French Environmental Footprint) (AFNOR, 2011); and
- *PAS 2050:2011 Specification for the assessment of life cycle greenhouse gas emissions of goods and services* (BSI, 2011).

This document evaluated a wide range of methodological issues, including: applications of LCA, target audience, functional unit, system boundary, cut-off criteria (materiality), impact categories, data modelling and quality, primary and secondary data, allocation, biogenic carbon emissions, direct and indirect land-use change, carbon sequestration, renewable energy, land occupation, offsets, review and reporting, interpretation and uncertainty.

The ISO 14044:2006 standard is the basis for remaining standards, and therefore all of them are largely in agreement, certainly for all of the major points. However, there are some points of divergence, which will be summarized at the end of this document.

GOAL AND SCOPE

All the extant methodological guidelines employ the life cycle concept/approach in product evaluation. The goal and scope (applications) of LCAs range from hotspot identification, to commodity analysis to benchmarking for understanding and opportunities for improvement. All of the methodologies and standards support improvement identification and benchmarking for the purpose of performance tracking. Only the *Product Life Cycle Accounting and Reporting Standard* guidance does not support comparative assertion as defined in the ISO 14044:2006 standard. It is considered important to allow sufficient flexibility to encompass this range of potential reasons for conducting an LCA of large ruminant systems.

TARGET AUDIENCE

The target audience is that group (individuals or organizations), identified by the authors of the study, who rely on the study for decision-making. All the standards except for PAS 2050:2011, which does not specify requirements for communication, refer to both business-to-business and business-to-consumer communications (the BPX 30-323-0 standard only refers to business-to-consumer communications). In general, the target audience should be explicit in the LCA report.

FUNCTIONAL UNIT

The functional unit describes the characteristic function(s) delivered by the system related to the questions "what", "how much", "how well", and "for how long". Without identical functional units, among other requirements, different LCA's are not comparable. All of the standards are clear that the functional unit should be clearly defined, measurable and consistent with the project goal and scope.

SYSTEM BOUNDARY DEFINITION

System boundary definition involves the determination of the processes to be included in the LCA, based on the goal and scope of the study and defined iteratively to identify and focus on the most relevant processes. In general, the extant protocols defined the system as beginning with raw material acquisition and concluding with end-of-life and disposal. *Product Life Cycle Accounting and Reporting Standard*, PAS 2050:2011, and ISO/TS 14067:2013 allow for both cradle-to-grave and cradle-to-gate studies, while the other protocols imply a full cradle-to-grave analysis is necessary.

MATERIALITY

The question of materiality is related to the cut-off criteria chosen for the study, in particular, specification of material or energy flows that are insignificant enough to be excluded from the system. This is important in the context of providing appropriate balance between representativeness of the model and data collection efforts by the practitioner. The standards all provide guidance regarding life cycle inventory or emissions, which should not be neglected. The ISO 14044:2006 standard and *ILCD Handbook* do not specify cut-off percentages, but do require a full description of the criteria used for cut-off flows. Typically the cut-off criteria are reported in terms of an estimated percentage of materials or emissions that have been excluded. The PAS 2050:2011 and BPX 30-323-0 require that all material contributions be included, and that 95 percent of all GHG emissions/impacts shall be accounted. The *ILCD Handbook* does not specify cut off, but also requires justification for exclusion of attributable processes and an estimation demonstrating the process is insignificant as well as a reporting of the insignificance threshold (cut off) to justify any exclusion.

Infrastructure

There is a range of approaches in accounting for capital infrastructure. It is a requirement of BPX 30-323-0 that infrastructure associated with transportation be included. Infrastructure is considered a non-attributable process by the *Product Life Cycle Accounting and Reporting Standard*, and is not mandatory, but if included shall be disclosed. PAS 2050:2011 excludes capital goods, unless supplementary requirements have been established, in which case those requirements should be adopted. In addition, the PAS 2050:2011, allows for inclusion of capital goods when a materiality assessment has been conducted which shows a significant contribution.

Ancillary activities

The PAS 2050:2011 explicitly excludes capital goods, human energy inputs, transport by animals, transport of the consumer to and from retail, and employee commuting. BPX 30-323-0 excludes carbon offsets, research and development, employee commuting, associated services (advertising or marketing), and consumer travel to and from retail.

IMPACT CATEGORIES

Potential effects to the environment or human health or natural resource depletion that result from activities of the system under study. The PAS 2050:2011 and the *Product Life Cycle Accounting and Reporting Standard* focus only on climate change (including the effects of land-use change on GHG emissions, but reported separately). However, the remaining protocols recommend a wider range of impact categories. BPX 30-323-0 follows the *ILCD Handbook* recommendations, with impact categories fixed by the product category. The *ILCD Handbook* provides recommendations for the following impact categories (which is a superset of the ISO 14044:2006 categories): climate change, acidification, eutrophication, ozone depletion, summer smog, human toxicity (respiratory inorganics, carcinogens, non-carcinogens), land use (includes biodiversity, land productivity), and material and energy resource depletion.

BIOGENIC CARBON/METHANE

ISO 14044:2006 does not provide specific guidance on biogenic carbon emissions. However, the remaining standards are in fundamental agreement that both fossil and biogenic carbon emissions are included in the analysis and should be reported separately. Regarding climate change impact, all of the guidelines refer to the IPCC for characterization factors. In the most recent publication, biogenic methane has been given a different global warming potential than fossil methane (Myhre *et al.*, 2013).

CARBON SEQUESTRATION/DELAYED EMISSIONS

This refers to either fossil or biogenic carbon that is removed from the atmosphere not re-released (sequestered) to the atmosphere during the process itself or end-of-life disposal, but may be slowly released over longer time periods. Chomkhamsri and Pelletier (2011) suggested that ISO 14044:2006 considers carbon storage and delayed emissions to be outside the usual scope of study. This is explicitly stated by the ILCD Handbook. However, if considered part of the study goal, operational guidance is provided. It also differentiates temporary from permanent storage if guaranteed for more than 10 000 years. ISO/TS 14067:2013, PAS 2050:2011, and the Product Life Cycle Accounting and Reporting Standard all require separate reporting of temporary carbon storage. The Product Life Cycle Accounting and Reporting Standard, PAS 2050:2011 and BPX 30-323-0 allow for waiting factors in calculation of delayed emissions (reported separately).

LAND USE

This refers to emissions or sequestration of carbon associated with changes in land management practices. As such, it is primarily relevant for its impact on climate change through its effect on the GHG balance. ISO 14044:2006 does not mention land-use change. The remaining documents all rely on the IPCC guidelines, generally amortizing to products for 20 years after land-use change has occurred.

BPX 30-323-0 and ISO/TS 14067:2013 indicate that indirect land-use change induced effects shall be considered once there is an internationally accepted methodology. The *ILCD Handbook* considers indirect land-use change for consequential LCA, but, in agreement with PAS 2050:2011, excludes indirect land-use change from attributional, product-level LCA's. The *Product Life Cycle Accounting and Reporting Standard* does not require indirect land-use change, but if shown to be significant should be reported separately.

Land occupation, as an inventory item, is not specifically addressed by any of the standards.

EMISSION OFF-SETTING

In general, this refers to third-party GHG mitigation activities. These are discrete reductions used to compensate for emissions elsewhere. ISO 14044:2006 does not provide guidance on this topic. However, all of the remaining methodologies do not allow including emission offsets in the calculations.

RENEWABLE ENERGY

The principal concern associated with renewable energy in those standards that address it is associated with the potential for double counting. ISO/TS 14067:2013 requires exclusion of renewable energy sources if they have been claimed elsewhere. PAS 2050:2011 provides guidance on avoiding double counting associated with renewable electricity generation, and BPX 30-323-0 allows different energy models provided the renewable electricity is not connected to the main grid.

MULTI-FUNCTIONALITY/ALLOCATION

When a unit process in the system provides more than one function, the inputs and emissions/impacts need to be partitioned among all of the provided functions. All of the standards follow ISO 14044:2006 in recommending that allocation be avoided by system separation, if possible. The *ILCD Handbook*, *the Product Life Cycle Accounting and Reporting Standard* and ISO/TS 14067:2013 adopt the ISO 14044:2006 hierarchy. This may provide slightly more refined guidance, but the preferential order of system separation followed by system expansion and then physical relationships with economic value as the final option. The PAS 2050:2011 standard allows for supplementary requirements (e.g. PCR) to be used if appropriately specified, prior to the economic value allocation. BPX 30-323-0 switches the process of allocation based on physical relationships (e.g. mass, energy) with system expansion, and leaves economic value allocation as the lowest priority choice.

DATA QUALITY ASSESSMENT

Data quality refers to the suitability of the data with regard to achieving the goal and scope of the study. It is important to evaluate in order to ascertain the robustness of decisions that may be made on the basis of the study results. The characteristics of data quality have been identified in part one of this document as well as being detailed in the standards. The data quality requirements given by ISO 14044:2006 include:

a. time-related coverage: age of data and the minimum length of time over which data should be collected;
b. geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study;
c. technology coverage: specific technology or technology mix;
d. precision: the measure of the variability of the data values for each data expressed (e.g. variance);
e. completeness: the percentage of flow that is measured or estimated;
f. frepresentativeness: the qualitative assessment of the degree to which the data set reflects the true population of interest (geographical coverage, time period and technology coverage);
g. consistency: the qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
h. reproducibility: the 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;
i. sources of the data;
j. uncertainty of the information (e.g. data, models and assumptions).

ISO/TS 14067:2013 and PAS 2050:2011 both adopt the ISO 14044:2006 data quality assessment guidance. The *ILCD Handbook* and the *Product Life Cycle Accounting and Reporting Standard* both make slight modifications referring to temporal, technological, and geographical representativeness and combining other categories into completeness and precision. BPX 30-323-0 has a governance committee that advises on these issues, as well as clarity, recognition, transparency, format and updates.

PRIMARY/SECONDARY DATA

Primary data refers to information that is collected as part of the current study, while secondary data refers to data that may be available in existing lifecycle inventory databases or maybe collected from published literature. There is general agreement among the standards that foreground processes, those owned or operated by the study commissioner should be populated with primary data. The *ILCD Handbook* also recommends primary data for the main background processes. Secondary data is acceptable for background processes, but is subject to the same data quality assessment requirements as primary data. All of the standards acknowledge the utility of a data collection template for the project. However, none of them provide examples of templates. (Note: the LEAP guidance for the poultry sector includes a data collection template as one of the Annexes).

UNCERTAINTY ANALYSIS

In order to determine whether the apparent differences between the compared alternatives are real (statistically significant), it is necessary to perform an assessment of the uncertainties accompanying the results. Three main sources of uncertainty may be addressed (*ILCD) Handbook*): stochastic uncertainty; choice uncertainty; lack of knowledge of the studied system. However, detailed guidance is lacking in all of the guidelines. The *Product Life Cycle Accounting and Reporting Standard* and PAS 2050:2011 provide guidance in separate, supplementary documents, while BPX 30-323-0 shifts the focus to sector specific working groups and refers to ISO 14044:2006.

As a practical matter, Monte Carlo analysis is generally the method used for determining the propagation of input uncertainties to the environmental impacts reported. However, there may be alternate methods that are appropriate for a given study.

REVIEW OF PCR AND OTHER PROTOCOLS FOR LCA OF CATTLE PRODUCTS

Organization and method	**INRA, ADEME** **AGRIBALYSE®**
Date of publication	2013
Developed by	INRA, ART etc
Products	Co-products : all products generated by a process in addition to the main product Beef, culling cows, calves and milk but Agribalyse® also account for products of feed supply chains
Objectives	To contribute to environmental labelling of food products, To provide reference methodologies to the agricultural sector for LCA assessment and to guide mitigation strategies.
Review panel	Yes
Public review/ open consultation	No
Co-products	Beef meat, cow milk, calves
Functional unit	1 kg of live weight 1 kg of FPCM
System boundaries	Cradle to gate Off-farm activities excluded Co-products from crop processing excluded
Handling multi-functional processes (allocation)	Biophysical allocation based on physiological functions Beef vs heifers: Biophysical allocation Milk vs culling cows vs calves: Biophysical allocation
Impact categories	GHG emission (climate change), resource depletion, fossil fuel energy demand, eutrophication, eco-toxicity, acidification, human toxicity, land use, land use change.
Additional information	Koch and Salou, 2013

Organization and method	**AFNOR Normalisation** **Référentiel d'évaluation de l'impact environnemental des produits laitiers en France**
Date of publication	2013
Developed by	Quantis, Cniel
Products	Milk products (all)
Objectives	To simplify the methods for assessment of environmental impacts for dairy companies
Review panel	Yes
Public review/ open consultation	Yes
Co-products	Milk
Functional unit	100g/ml or portion of milk products with variable weight
System boundaries	Cradle to grave Exclusion: carbon credit, flows related to research and development, transport of farm's staff, marketing, consumers activities
Handling multi-functional processes (allocation)	Allocation factor: calculated based on dry matter weight Farm: meat and milk: biophysical based on proteins content Milk processing: milk co-products: based on dry matter content Retailer: transport and refrigeration: based on product weight Refrigeration stage (energy consumption): based on storage time and weight Storage at consumer's stage: based on storage time and weight
Impact categories	GHG emission (climate change), eutrophication, acidification, biodiversity
Additional information	

Organization and method	**Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS)**
Date of publication	2010
Developed by	European Commission, Joint Research Centre
Products	Milk products
Objectives	To provide an estimate of the net emissions of GHGs and ammonia (NH_3) from livestock sector in the EU-27 according to animal species, animal products and livestock systems following a food chain approach.
Review panel	Yes
Public review/ open consultation	No
Co-products	Milk, meat, calves
Functional unit	Meat: Carcass weight Milk: 1kg of FPCM
System boundaries	Cradle to retail Exclusion: carbon credit, flows related to research and development, transport of farm's staff, marketing, consumers activities System expansion for manure Substitution of the application of mineral fertilizer (avoided emissions)
Handling multi-functional processes (allocation)	Based on nitrogen content of products except for methane from enteric fermentation and manure allocated based on energy requirement for lactation and pregnancy.
Impact categories	GHG emission (climate change)
Additional information	

Organization and method	**Guidelines for the Carbon Footprinting of Dairy Products in the UK**
Date of publication	2010
Developed by	Carbon trust, Dairy UK, DairyCo
Products	Milk products
Objectives	The product carbon footprint is the measurement of all the greenhouse gasses emitted during the life cycle of the product. The GHGs included within the scope of the measurement are those listed in Annex A of the PAS 2050:2011. The GHG emissions are expressed as carbon emissions in terms of carbon dioxide equivalent (CO_2e) by using the latest IPCC 100-year global warming potential (GWP) coefficients as specified within the PAS 2050:2011.
Review panel	Yes
Public review/ open consultation	Yes
Co-products	Milk, cream, milk products, cheese, butter, yogurt Milk, meat Co-products: Where a single process gives rise to more than one product. These co-products cannot be created separately, but both occur inherently as outputs of a single process.
Functional unit	1 litre of milk
System boundaries	Cradle to grave Including disposal and recycling
Handling multi-functional processes (allocation)	Allocation factor: calculated based on dry matter weight Milk co-product: Biophysical allocation (dry mass percentage) Energy allocation: based on biophysical principle (mass allocation)
Impact categories	GHG emission (climate change)
Additional information	

Organization and method	**Greenhouse gas emissions from ruminant supply chains** **FAO**
Date of publication	2010
Developed by	FAO
Products	Milk, meat
Objectives	To present the first comprehensive and disaggregated global assessment of emissions which enable the understanding of emission pathways and hotspots? To quantify the main sources of GHG emissions from the world dairy sector, and to assess the relative contribution of different production systems and products to total emissions from dairy sector.
Review panel	Yes
Public review/ open consultation	No
Co-products	Milk, meat, draught power, capital
Functional unit	1 kg of meat 1 kg of FPCM
System boundaries	Cradle to retail
Handling multi-functional processes (allocation)	Biophysical allocation Economic allocation
Impact categories	GHG emission (climate change)
Additional information	

Organization and method	**A common carbon footprint approach in dairy**
Date of publication	2010
Developed by	IDF
Products	Milk
Objectives	To support the production of consistent and comparable carbon footprint figures internationally, and enable the evaluation of dairy products on a consistent basis.
Review panel	Yes
Public review/ open consultation	Yes
Co-products	Milk, meat, calves Co-products: any of two or more products from the same unit process or product system (ISO 14044:2006)
Functional unit	1 kg of FPCM
System boundaries	Cradle to processing
Handling multi-functional processes (allocation)	Feed stage: Economic allocation Milk, meat and calves: Biophysical allocation based on energy requirement Milk products: biophysical allocation (physio-chemical) Manure: system expansion Heat and power: System expansion
Impact categories	GHG emission (climate change), land use and land-use change, carbon sequestration,
Additional information	

Organization and method	**Earth sure Meat Environmental Product Declarations**
Date of publication	2006
Developed by	Earth sure Meat, IERE
Products	Meat
Objectives	To support the EPD; to learn more about environmental impacts of the product; to improve environmental performance
Review panel	Yes
Public review/ open consultation	Yes
Co-products	Meat, calves, milk
Functional unit	One pound of meat at the processing plant exit gate
System boundaries	Cradle to plate
Handling multi-functional processes (allocation)	All impact allocated to meat
Impact categories	Climate Change, Stratospheric Ozone Depletion, Acidification, Eutrophication, Photochemical Smog, Aquatic Toxicity, Fossil Fuel Depletion, Mineral Resource depletion, Water Use, Antibiotic Use, Soil losses, Hormone Used, Genetically Modified Organisms
Additional information	

Organization and method	**Development of Carbon Calculator to promote low carbon farming practices**
Date of publication	2013
Developed by	EC, JRC, SOLAGRO
Products	Beef, dairy
Objectives	The aim of the Carbon Calculator is to assess GHG emissions from farming practices and to suggest climate change mitigation and sequestration actions at farm level.
Review panel	Yes
Public review/ open consultation	No
Co-products	Milk, meat,
Functional unit	A tonne of milk A tonne of meat
System boundaries	Cradle to farm gate
Handling multi-functional processes (allocation)	Economic allocation Mass allocation Allocation according to the production cycle Protein or energy allocation (meat and milk)
Impact categories	Climate Change
Additional information	

Organization and method	EPD, PCR CPC Class 2912 Version 1.0
Date of publication	2011
Developed by	EPD
Products	Finished bovine leather
Objectives	Environmental product declaration
Review panel	No
Public review/ open consultation	No
Co-products	Finished Bovine leather, meat, milk
Functional unit	1 m2 "Finished bovine leather"
System boundaries	Cradle to grave: Including upstream emissions related to cattle raising
Handling multi-functional processes (allocation)	Mass allocation between hides, edible meat and inedible co-products
Impact categories	Climate Change, acidification, eutrophication, ozone depletion,
Additional information	

Organization and method	**EPD, PCR Meat of mammals** **CPC 2111 and 2113**
Date of publication	2011
Developed by	EPD
Products	Meat of mammal: fresh or chilled Meat of mammal, frozen
Objectives	Environmental product declaration
Review panel	No
Public review/ open consultation	No
Co-products	Meat, Milk, skin
Functional unit	1 kg of meat in packaging.
System boundaries	Cradle to grave
Handling multi-functional processes (allocation)	Economic allocation Process at slaughterhouse: Biophysical allocation
Impact categories	Climate change, acidification, ozone depletion, eutrophication
Additional information	Ecological footprint

Organization and method	**EPD, PCR, PRODUCT GROUP: UN CPC 022 RAW MILK**
Date of publication	2013
Developed by	EPD
Products	Meat of mammal: fresh or chilled Meat of mammal, frozen
Objectives	Environmental Product Declaration
Review panel	No
Public review/ open consultation	No
Co-products	Meat, milk, leather
Functional unit	1 kg of milk
System boundaries	Cradle to grave
Handling multi-functional processes (allocation)	Economic allocation: Milk, surplus calves, meat for heifer stage Milk and surplus calves for lactation stage
Impact categories	Climate Change, Acidification, Eutrophication, Land use and land-use change Eco-toxicity
Additional information	Ecological footprint, Water footprint

Organization and method	**EPD, PCR, PRODUCT GROUP: UN CPC 221 PROCESSED LIQUID MILK AND CREAM**
Date of publication	2013
Developed by	EPD
Products	Processed liquid milk and cream Processed liquid milk Cream, fresh Whey
Objectives	Environmental product declaration
Review panel	No
Public review/ open consultation	No
Co-products	Milk products
Functional unit	1 kg of dairy products
System boundaries	Cradle to grave
Handling multi-functional processes (allocation)	Allocation based on physical relationships between the mass of protein and fat of co-products
Impact categories	Climate Change, Acidification, Eutrophication, Land use and land-use change Eco-toxicity
Additional information	Ecological footprint, Water footprint

Organization and method	**EPD, PCR, PRODUCT GROUP: UN CPC 2223, 2224 & 2225 YOGHURT, BUTTER AND CHEESE**
Date of publication	2013
Developed by	EPD
Products	Yoghurt and other fermented or acidified milk and cream Butter and other fats and oils derived from milk Cheese, fresh or processed
Objectives	Environmental product declaration
Review panel	Yes
Public review/ open consultation	No
Co-products	Milk products
Functional unit	1 kg of dairy product
System boundaries	Cradle to grave
Handling multi-functional processes (allocation)	Allocation for mass of protein and fat
Impact categories	Climate Change, Acidification, Eutrophication, Land use and land-use change Eco-toxicity
Additional information	Ecological footprint, Water footprint

Organization and method	**World Food LCA Database**
Date of publication	2014
Developed by	World Food LCA Database
Products	Agricultural products
Objectives	Environmental product declaration
Review panel	Yes
Public review/ open consultation	No
Co-products	Milk, meat, calves and other non-animal products Slaughterhouse: high quality meat, low quality meat, fat, non-edible (skin), non-edible (bones).
Functional unit	1 kg animal, live weight at farm exit gate 1 kg fat and protein corrected milk (FPCM), unpackaged, at farm exit gate
System boundaries	Cradle to farm gate
Handling multi-functional processes (allocation)	Allocation based on physical causality (IDF approach) At slaughterhouse: Allocation based on dry matter basis for co-products (AGRIBALYSE®; Gac *et al.*, 2014
Impact categories	Climate Change, Acidification, Eutrophication, Land use and land-use change Eco-toxicity
Additional information	Ecological footprint, Water footprint

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Appendix 3

Large ruminants - main producing countries

Table A3.1: Relative number of buffaloes in 2013

Country	Buffaloes (heads)
Top 20 countries (for herd)	
India	115.420.000
Pakistan	33.700.000
China	23.253.900
Nepal	5.241.873
Egypt	4.200.000
Myanmar	3.250.000
Philippines	2.912.842
Viet Nam	2.559.500
Indonesia	1.484.000
Bangladesh	1.465.000
Brazil	1.279.000
Thailand	1.219.000
Lao People's Democratic Republic	1.180.000
Cambodia	676.000
Sri Lanka	413.500
Italy	402.659
Iraq	307.000
Azerbaijan	260.889
Iran (Islamic Republic of)	135.000
Malaysia	120.000
Remaining countries	303.386

Source: FAO, 2013: FAOSTAT

Table A3.2: Relative number of cattle in 2013

Country	Cattle (heads)
Top 20 countries (for herd)	
Brazil	217.399.800
India	214.350.000
China	113.636.600
United States of America	89.299.600
Ethiopia	54.000.000
Argentina	51.095.000
Sudan (former)	41.917.000
Pakistan	38.300.000
Mexico	32.000.000
Australia	29.290.769
Bangladesh	24.000.000
Colombia	23.141.388
United Republic of Tanzania	21.500.000
Nigeria	20.000.000
Russian Federation	19.930.354
Kenya	19.500.000
France	19.095.797
Indonesia	16.607.000
Myanmar	14.700.000
Venezuela (Bolivarian Republic of)	14.500.000
Remaining countries	420.085.461

Source: FAO, 2103: FAOSTAT

Appendix 4

Summary of carcass weight and live weight ratios for dairy and beef cattle and buffalo for different regions

Table A4.1: Average ratios (as percentages) of carcass weight to live weight for dairy and beef cattle and buffalo

Region	Dairy Cattle	Beef Cattle	Buffalo
North America	51	57	51
Russian Federation	51	57	51
Near East and North Africa	49	52	51
Western Europe	51	57	51
Eastern Europe	51	57	51
East and South East Asia	52	52	51
Oceania	51	52	51
South Asia	52	52	51
Latin American countries	51	52	51
Sub-Saharan Africa	47	47	51

Source: Based on a summary by Opio *et al.* (2013).

Carcass weight, sometimes called dead weight, generally refers to the weight of the carcass after removal of the skin, head, feet and internal organs including the digestive tract (and sometimes some surplus fat). The 'hot carcass weight' may be recorded after slaughter and refers to the unit by which farmers in some countries are paid. In practice, the carcass loses a small amount of moisture as it cools (e.g. about 1-2 percent) to the cold carcass weight.

The variation in these average default carcass weight values of 47-52 percent for dairy cattle and 47-57 percent for beef cattle probably reflects differences in method of calculation from the literature that it was derived from (e.g. hot versus cold carcass weight), as well as differences associated with key factors of age, breed, weight, gender and diet.

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Appendix 5
Diversity of large ruminant supply chains

As described in Section 6.3, there are wide varieties of dairy, beef and water buffalo production system around the world. To further explain and showcase the differences in production system, eight case studies are listed below.

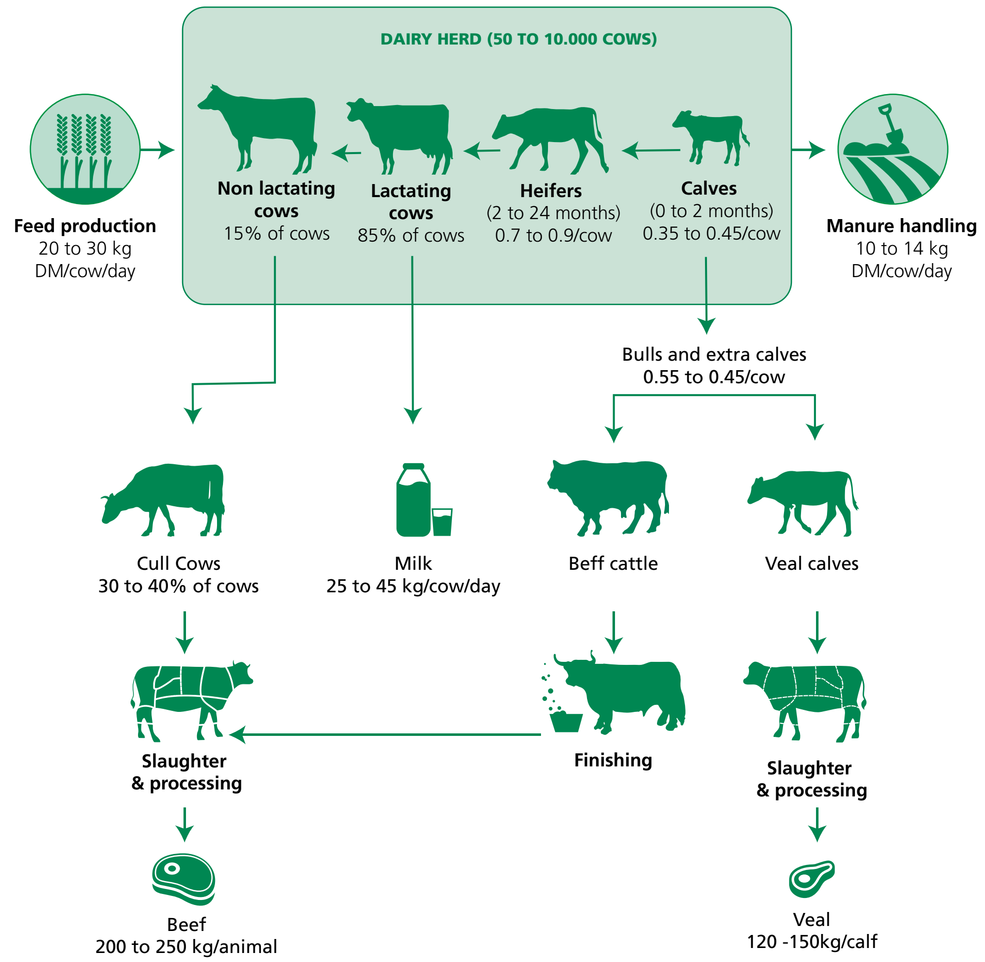
US DAIRY FARMS

American dairy farms range in herd size from about 50 to 10 000 cows, with an average size of around 120 as illustrated in Figure A5.1. Most dairy herds consist of high-producing Holstein cattle, producing 4 700 to 14 000 kg of milk per cow per year. Herds normally calve randomly throughout the year, so at any point about 85 percent of the cows are lactating, and 15 percent are non-lactating and pregnant. Young stocks are produced to replace cows that are culled for failure to be rebreed, illness or other reasons. In typical herds, 30 to 40 percent of the cows are replaced each year requiring 0.35 to 0.45 two-year old heifers per cow. Therefore, 0.7 to 0.9 replacement heifers per cow must be raised each year. Replacement heifers are often raised on the same farm as the cows, but contract raising on separate farms is also used, particularly by larger dairy farms. Artificial insemination is used, so no bulls are maintained in the dairy herd. Bull calves, extra female calves and culled heifers are sold from the dairy herd for use in either beef or veal production. Occasionally calves are directly slaughtered, so-called bob-calves, and may yield as little as 10 kg veal. It is more common in the U.S. to feed them for several months and reach yields of nearly 100 kg. All cull cows leaving the herd are harvested for beef.

Most dairy cows are housed year around in free stall barns where they have a bedded stall for resting and free access to walk to the feed bunk. Tie-stall barns are also common on smaller farms, and in the drier regions in the western U.S. animals are housed in open lots with or without access to free stall barns. Dairy herds produce 10 to 14 kg of manure solids per cow per day. Manure is typically scraped or flushed from the barn floor. Scraped manure is often handled as slurry (8 to 10 percent solids) where it is stored in a tank for 4 to 6 months before application to cropland. Flushed manure is handled as a liquid (about 5 percent solids) where a separator may be used to remove a major portion of the solids and the liquid is stored in a sealed earthen pond or lagoon for up to a year before application to cropland. With greater use of bedding in a tie-stall barn, manure is handled as a semi-solid (12 to 15 percent solids) typically with daily hauling to cropland with only short-term storage. Manure nutrients are recycled through feed production, but when available land is limited for feed production, excess manure must be exported to other farms or composted for other use.

Dairy herds consume 20 to 30 kg of feed dry matter per cow per day depending upon their size and production level. Lactating cow diets consist of 40 to 60 percent forage with the remainder being corn grain and other energy and protein feed supplements. Higher forage diets are used for growing animals and non-lactating cows. Most of the forage required is normally produced on the farm, and some or all of the corn grain may also be produced. Forage feeds are primarily corn silage

Figure A5.1
The U.S. dairy production system

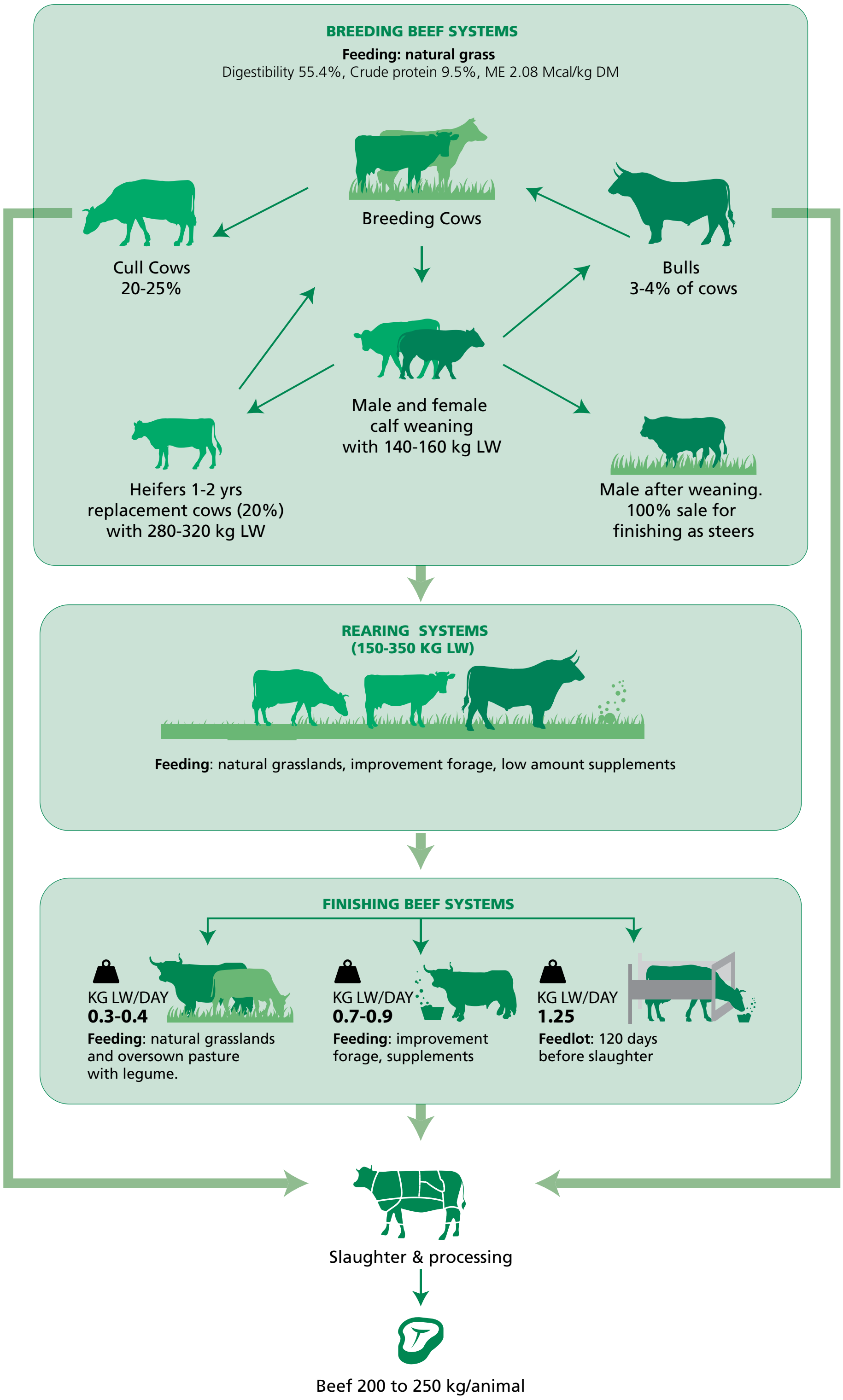


and alfalfa silage or hay but small grain silage, sorghum silage and various grass silages and hays are used in various regions of the country. Commercial fertilizers are used to meet crop nutrient needs beyond that supplied by manure.

SOUTH AMERICAN BEEF FARM

South American beef farms range widely in herd size from about 30 to 40 000 animals with an average size of around 100 per farm (Figure A5.2). Most beef herds consist of pure breeds from Indian (*Bos indicus*) and European (*Bos taurus*) origins. Herds normally calve in determined breeding seasons of 3 months, depending on the country and production system. Young female stock are produced to replace cows that are culled for failure to rebreed, illness, worn teeth or other reasons. In typical herds, 15 to 25 percent of the cows are replaced each year, and replacement heifers are raised on the same farm as the cows. Usually natural breeding with bulls is used, and they represent 3 to 4 percent of the number of cows. Artificial insemination is used in more

Figure A5.2
South american beef system



intensive systems (in some cases for the heifer's first mating), and bulls are maintained in the herd for a final option for pregnancy. Bull calves, young steers, extra female calves, culled heifers and cows are sold from the beef herd or fattened in the farm for use in either beef or veal production.

Most of the beef herds are kept in pasture year around, subject to different forage availability due to the seasonality of grass production. The most common management in farms is based on natural grasslands with vegetation characteristics determined by climate and soil conditions and by grazing animals (i.e. Campos, Cerrado, and Pampa). Feedlots are used during part of the year for finishing animals that go to slaughter (average between 100 to 120 days). Beef animals in feedlot produce 8 to 12 kg of manure solids per head per day. Manure is typically removed at the end of the fattening period and distributed in pasture or cropland. Manure nutrients are recycled through feed production and usually there is enough land available for feed production to receive the manure.

Beef calves are weaned with 5 to 7 months and 140 to 170 kg live weight. Usually calves are reared for 6 to 24 months and finished for 4 to 6 months. The rearing phase is critical for determining the slaughter age. Animals can go directly from weaning to feedlot and be slaughtered very young within 12 months, while others can be slaughtered within 36 months. In the rearing phase, beef herd can receive supplements to improve growth performance and shorten their slaughter age. Usually daily weight gain can vary from 300g per day in natural grasslands, 900g per day in cultivated pastures with supplements and 2000g per day in high grain feedlots. The average slaughter weights can vary from 450 to 650 kg. Average carcass yield for Indian breeds is 52 percent and 56 percent for European breeds.

In feedlots, beef herds consume 10 to 15 kg of feed dry matter per head per day depending upon their breed, cross breed, size and age. Diets consist of 20 to 30 percent forage with the remainder being maize grain, soybean meal and other energy and protein feed and by-products. Most of the forage required is normally produced on the farm as well as some of the maize or sorghum grain. Soybean meal, by-products, minerals and vitamins are usually bought. Forage feeds are primarily maize, alfalfa, sorghum or grass silage. High moisture maize and sorghum silage is also used. Commercial fertilizers are used to meet crop nutrient needs beyond that supplied by manure, but usually no fertilizer is used in the natural grasslands, and in some cases, in cultivated pastures or annual pastures.

DAIRY, BEEF AND WATER BUFFALO SUPPLY CHAIN IN INDIA

Total cattle and buffalo population in India is 190.9 and 108.7 million head, contributing about 37.3 and 21.2 percent, respectively, to the total livestock population in the country (Ministry of Agriculture, 2012). India is the world's largest milk producing country, producing 132.4 million tonnes during 2012-13. Over the past few years, 53 percent of the fluid milk produced comes from buffaloes and 43 percent from cows (FAO, 2013). Officially, the slaughter of cows is banned in India, and beef production is mainly buffalo meat where slaughter is restricted to buffalo males and unproductive buffaloes. In spite of this, India is the biggest beef exporter in the world: 1.89 million tonnes in 2012-13 (BAHS, 2013).

Intensive mixed crop-livestock systems mainly predominate in the northern region and in some western areas of India. Feed supply to livestock comes from arable crops (including residues) or from cut-and-carry pastures and/or cultivated improved forages. In some parts of the country, manure from housed animals is collected and used in crop and/or forage production. This system also applies for buffaloes raised for milk production and/or used for draught power. Crop residues and planted forages are produced on the farm or imported from the neighbouring states for feeding livestock. Concentrate feeds, the by-products of food crops, are mostly purchased to supplement the ration of livestock.

In all other regions of the country, semi-intensive livestock systems are used in which unproductive and low yielding animals are managed on grazing and fed on indigenous forages/natural pastures and residue from crop or trees. At the end of the day, animals are brought back to the paddocks after grazing. The types of pastures used in this system are commonly rangelands with indigenous vegetation that is usually draught-tolerant (grasses and shrubs). This system is commonly based on rain-fed pastures and occurs in areas of low to medium human population densities. In many areas, households depend more on livestock than crop production. Compared to other systems, the level of livestock production (reproduction, growth rate and milk production) is usually low, under the semi-intensive system of livestock rearing.

With regard to the modelling of emissions, the equations pertaining to the emissions of enteric methane and nitrous oxide from manure as mentioned in IPCC (IPCC, 2006) guidelines may be followed.

WATER BUFFALO PRODUCTION SYSTEMS IN ASIA

Buffalo (*Bubalus bubalis*), a triple-purpose animal, provides milk, meat and mechanical power. Buffalo are recognized as efficient convertors of poor quality forages into high-quality milk and meat. Buffalo is mainly categorized as Asian and Mediterranean with two main sub-species: water buffalo (chromosome n=50) and swamp buffalo (chromosome n=48). These animals are a major source of food (milk and meat), power, fuel and leather, especially in developing countries. Buffalo is distributed worldwide, but around 95 percent of the total world buffalo population is found in Asia, with India, Pakistan and China being the major buffalo-holding countries. In these countries, animals are fed on low-quality roughages, agricultural crop-residues and industrial by-products containing high fibrous materials. Contrary to cattle, buffalo are unique in their capability to efficiently utilize poor-quality feed resources, through better rumen fermentation (Wanapat *et al.*, 2000) and better nitrogen utilization (Devendra, 1985). This is an indication of their natural potential to survive and produce in harsh environments with limited feed resources. However, imbalanced nutrition has led to low milk production, poor growth, high mortality rates and poor reproduction performance (Sarwar *et al.*, 2009; Pasha and Khan, 2010).

Water (river) buffaloes are generally large in size, with curled horns and are found in the Indian subcontinent, the near Middle East, Eastern Europe, and are most common in India and Pakistan. They prefer clear water, and are primarily used for milk production, but also for meat production and draught purposes. The buffalo population in South Asian countries is increasing more rapidly than rest of the world due to the unique qualities of the animal and its emerging role in economic development. This region possesses most of the well-known breeds of buffaloes, which are reared in extensive, semi-intensive and intensive production systems. India is home to some of the best riverine breeds of buffaloes, with the germplasm of the Murrah, Nili-Ravi, Surti, Mehsani and Jaffarabadi breeds being highly valued.

Table A5.1: Buffalo population (in million)

Year	World	South Asia	India
2004	174.09	131.00	99.72
2005	177.02	133.78	101.56
2006	180.55	136.81	103.43
2007	183.96	139.71	105.34
2008	187.06	142.61	107.24
2009	190.09	145.92	109.44
2010	192.70	148.13	111.89
2011	195.25	151.63	112.92
2012	198.09	154.34	114.48
2013	199.78	156.38	115.42

Source: FAO, 2103.

Research over past three decades has confirmed that the buffalo digest feed more efficiently than cattle do, particularly when feeds are of poor quality and high in ligno-cellulose. The ability of buffalo to digest fiber efficiently is partly due to the presence of some typical microorganisms in the rumen that convert feed into energy more efficiently than those in cattle. Other reasons for the buffalo's being a better converter of feed might be the higher dry-matter intake; the longer retention time of feed in the digestive tract; ruminal characteristics that are more favourable to ammonia nitrogen utilization; less depression of cellulose digestion by soluble carbohydrates; their superior ability to handle the stress environment; and a wide range of grazing preferences. The preference for buffalo has continued to increase due to the higher fat content of milk (7-8 percent); their ability to thrive on harsh conditions; their genetic potential; their disease resistance mainly on low quality rations; and the ever increasing export market for buffalo meat and milk products. In the future, it is expected that buffalo will continue to be the central animal in the dairy and meat industry in the region.

Population dynamics

South Asian buffaloes dominate the world population (Table A5.1), representing about 75 percent of the world buffalo population. During the last ten years, the world buffalo population has increased at the rate of 1.24 per cent per year. In South Asian countries, the buffalo population increased at the rate of 1.49 per cent per year, largely contributed by India and Pakistan.

The distribution of the buffalo population in different Asian regions (1961-2007) is presented in Table A5.2. Important riverine buffalo breeds in Asia are presented in Table A5.3.

Buffalo milk

According to the definition of United States Department of Agriculture (USDA, 2011), buffalo milk is the normal lacteal secretion practically free of colostrum, obtained by the complete milking of one or more healthy water buffalo. Buffalo milk can be consumed like any other milk. It is one of the richest products from a compositional point of view and characterized by higher fat, total solids, proteins, caseins, lactose and ash content than cow, goat, camel and human milk. General composition, fatty acids composition, amino acids composition and physico-chemical characteristics of buffalo

Table A5.2: Buffalo population in different asian regions (% of world)

Region	1961	1971	1981	1991	2001	2007
World total	100	100	100	100	100	100
Asia Total	97.39	97.38	97.20	96.67	97.06	96.96
Southern Asia	68.19	63.67	67.27	69.96	74.50	75.25
South-Eastern Asia	18.15	17.46	14.00	11.93	8.51	8.57
Eastern Asia	9.48	14.97	14.95	14.45	13.68	12.82
Western Asia	1.58	1.28	0.97	0.32	0.35	0.31

Source: Pasha and Hayat, 2012.

Table A5.3: Important riverine buffalo breeds in asia

Breed	Distribution	Lactation (days)	Milk yield (kg)	Milk fat (%)
Azeri	Iran, Azerbaijan	200-220	1200-1300	6.6
Azi-Khel	Pakistan	NA	NA	NA
Bangladeshi	Bangladesh	NA	NA	NA
Bhadawari	India	274	780	7.2
Jafarabadi	India	350	1800-2700	8.5
Jerangi	India	NA	NA	NA
Kundi	Pakistan	320	2000	7.0
Lime	Nepal	351	875	7.0
Manda	India	NA	NA	NA
Mehsani	India	305	1800-2700	6.6-8.1
Murrah	India	305	1800	7.2
Nagpuri	India	243	825	7.0
Nili Ravi	Pakistan, India	305	2000	6.5
Parkote	Nepal	351	875	7.0
Sambalpuri	India	350	2400	NA
Surti	India	350	2090	6.6-8.1
Tarai	India	250	450	8.1
Toda	India	200	500	NA

NA = Data not available.

Source: Sethi, 2003; Moioli and Borghese, 2008.

Table A5.4: General composition of buffalo milk (g/kg)

Protein	Fat	Lactose	Ash	Total solids	References
43	77	47	8	175	Altman and Dittmer (1961)
40	70	51	8	167	Sindhu and Singhal (1988)
40	80	49	8	175	Jan (1999)
44	71	52	8	175	Ahmad *et al.* (2008)
46	73	56	-	176	Menard *et al.* (2010)
50	71	46	9	177	Han *et al.* (2012)

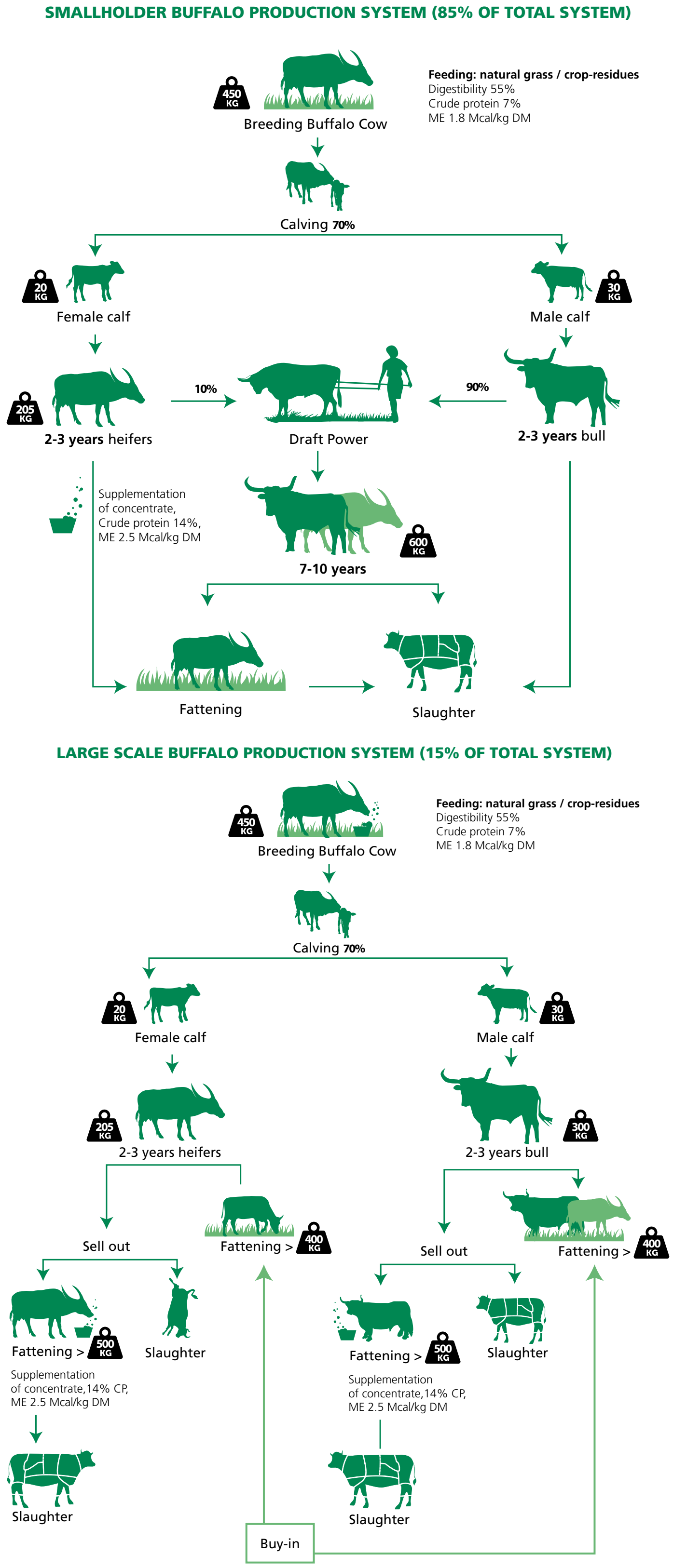
milk are given in the Table A5.4. Buffalo milk has higher levels of total protein, medium chain fatty acids, conjugated linoleic acids, and content of retinol and tocopherols than those of cow milk. Some components may only be present in buffalo milk, such as specific classes of gangliosides (Berger *et al.,* 2005).

SWAMP BUFFALO PRODUCTION SYSTEM

Buffalo (*Bubalus bubalis*) are important domesticated livestock for farmers engaged in integrated crop-livestock farming in many countries, including China, Indonesia, Lao People's Democratic Republic, Malaysia, the Philippines, Thailand and Viet Nam, as well as in some countries of Africa and America. They provide multiple products and services: draught power, transportation, manure, meat, milk, other by-products that are essential to livelihood in rural communities. Figure A5.3 describes the buffalo production systems including smallholder system (a), which represents 85% of the total buffalo population and the large-scale system (b). Research has been conducted investigating the uniqueness of their abilities in utilizing fibrous low-quality feeds, including crop-residues, to produce fermentation end-products (volatile fatty acids) and microbial protein for the synthesis of useful products, such as meat and milk. Furthermore, the use of molecular techniques to study existing rumen microbes (bacteria, protozoa and fungi) forming the rumen consortium and fermentation characteristics have been generating useful data pertaining to the buffalo digestion and the potential applications in the food-feed-system to support sustainable livestock production. Livestock production, in particular buffalo and cattle, are an integral part of food production systems, making important contributions to the quality and diversity of human food supply and providing other valuable services, such as nutrient recycling. Large increases in per capita and total demand for meat, milk and eggs are forecast for most developing countries for the next few decades. In developed countries, per capita intakes are forecast to change slightly, but increases in developing countries, with larger populations and more rapid population growth rates, will generate a very large increase in global demand. Most importantly, the transformation of human-inedible materials, such as roughages, tree fodders, crop residues and by products, into human food by ruminant animals will continue to be an important function of animal agriculture. However, since much of the projected increase for meat is expected to come from pork, poultry and aquaculture production (species consuming diets high in forage carbohydrates), meeting future demand will depend on achieving increases in cereal yields. Therefore, there are opportunities and challenges for researchers to increase animal productivity through the application of appropriate technologies, particularly in production systems, nutrition and feeding.

The feed utilization of buffalo is more effective than cattle, when cattle and buffalo were kept under similar conditions. Buffalo are particularly well-adapted to harsh environment and capable of utilizing low-quality roughages, especially agricultural crop-residues and by-products. Because of this, they have tremendous potential for meat production using locally available feed resources. However, a decrease in the number of buffalo has been occurring in some countries due to influences associated with three factors: holsteinization, the substitution of low production buffaloes with high production of other ruminants; mechanization, the substitution of draught animals with tractors; and the poor market demand for buffalo products. According to some countries, buffalo numbers have increased due to the demand for products obtained from buffalo milk and meat on both national and international markets.

Figure A5.3
Swamp buffalo (*Bubalus bubalis*) production systems



EUROPEAN DAIRY AND BEEF PRODUCTION SYSTEM

According to an evaluation of the livestock sector's contribution to the EU greenhouse gas emissions in Europe (Leip *et al.*, 2010), the dairy herd size can be largely increased when a higher part of the total utilized agriculture area is cultivated with fodder maize. The typology developed by Leip *et al.* (2010) identified a number of dairy system clusters, characterized by different levels of intensification: climate constrained systems in northern Europe and mountain areas; extensive systems on grasslands in UK and Ireland; free-ranging subsistence systems in southern Europe; grazing systems in central France, Germany, southern Portugal and Eastern European countries; intensive grass and maize based systems in the main milk production basins of Europe, with higher intensity and maize cultivation in some areas, such as Flanders and the Netherlands.

For cattle meat production, the study of Sarzeaud *et al.* (2007), based on Farm Accountancy Data Network results of 2004, illustrate the diversity of the European situation. Pure dairy and mix dairy-beef systems account for more than 44 percent of the economic value of beef production, with 31 percent of this value associated with cow-calve breeding systems (Charolais, Limousin, Angus, Belgian Blue) and some being associated with sheep production, mainly in UK; while the remaining 25 percent came from finishing units. Forty-four percent of these volumes also integrate breeding activities.

As for dairy production, soil and climate conditions exert a huge impact on the beef livestock system orientation. Breeding systems occupy a constrained area with extensive management (more than 80 percent of the farms had less than 1.6 livestock units per ha). For systems specialized in beef finishing, this proportion is lower than 20 percent. It is close to 50 percent for dairy farming systems.

A Belgian beef production system, with specialized suckling systems in the less fertile area in the south-eastern part of the country, and fattening units in more fertile areas, is illustrated as an example in Figure A5.4. Due to the high cost of the land, production systems remains intensive and is based on the valorisation of the double-muscled Belgian blue breed. This level of intensification is not representative of the average situation in Europe.

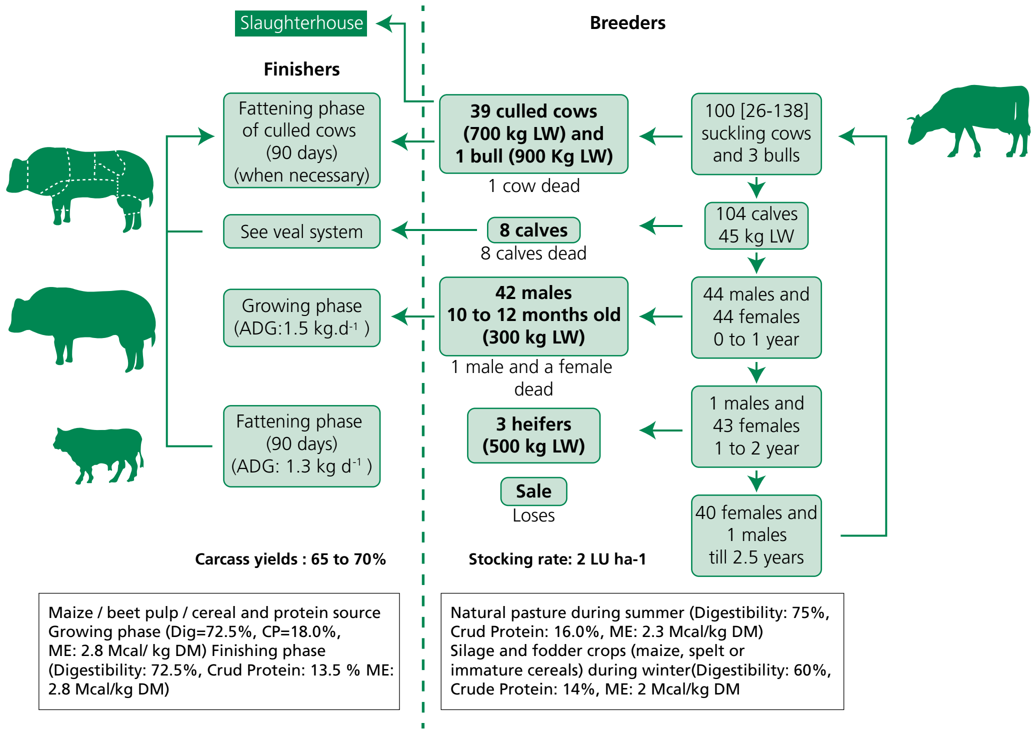
VEAL PRODUCTION SYSTEM IN EUROPE

Figure A5.5 describes the general type of veal production system in Europe. In the European veal industry, there are two types of production systems. By far the largest is the white veal production system in which the calves are mainly milk fed. The less common system is the rosé veal production system in which the calves are mainly grain fed. In both systems, the calves come from dairy farming and enter the veal production system at a starting weight of 45 to 50 kilograms. In 2012-2013, the average veal calf farm housed approximately 780 calves.

In the white veal production system, the calves reach a slaughter weight of 240 to 250 kg within approximately 6 months (25 to 27 weeks). The calves are mainly raised on calf milk replacer and a minor amount of roughage as illustrated in Figure A5.6. In the rosé veal production system, the calves reach a slaughter weight of 250-300 kg between 8 – 11 months. The calves are raised with concentrates and small quantities of calf milk replacer.

A large portion of the manure produced in the Dutch veal production systems is processed in manure processing plants to generate energy. The manure that is not processed is used in arable farming systems.

Figure A5.4
Continental European Breed for Beef production system (Belgian Blue example)

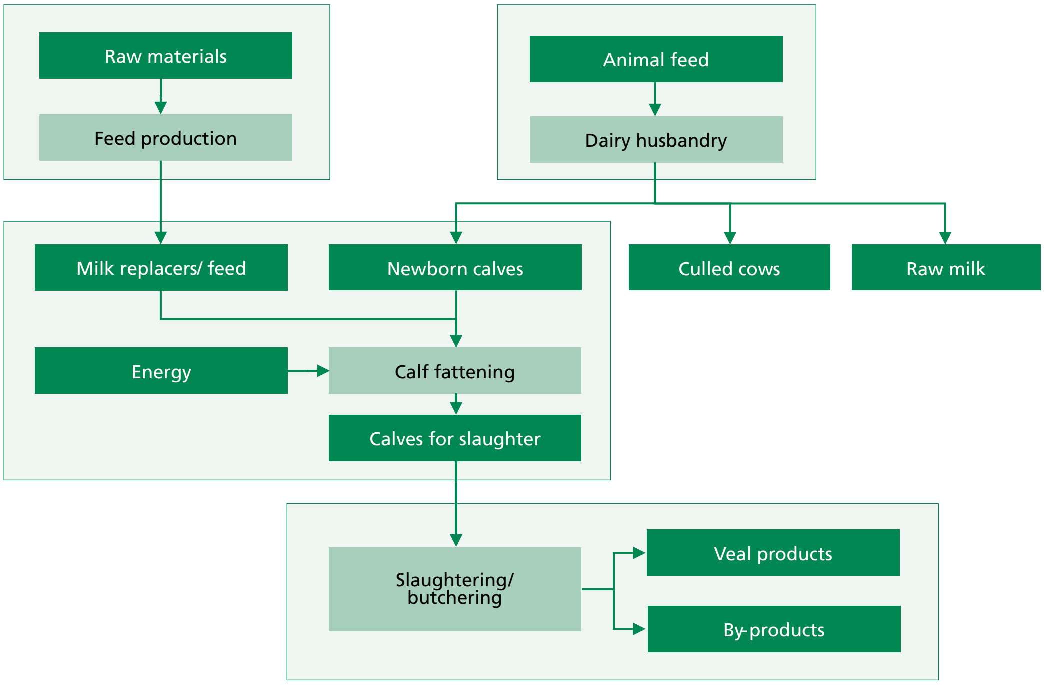


The main inputs of the veal production system are animal feed, electricity, natural gas and water. The digestion process of the calves (enteric fermentation) emits methane. Dinitrogen monoxide is also emitted from excreta and the storage of manure in the stable. Just as in dairy farms, minerals are supplied through animal feed. When excreted, these minerals are an important source of GHG emissions (ammonia, nitrogen, phosphorous) and contribute to environmental impact categories, such as climate change, acidification and eutrophication.

NEW ZEALAND DAIRY FARMS

Dairy farming is very important to the New Zealand economy. The value of dairy exports make up almost a third of New Zealand's annual merchandise exports. There are about 11 500 dairy farms with an average area of 141 ha, and the average herd size is just over 400 animals. Annual milk production averages 3 947 litres (346 kg milk solids) per cow, or 988 kg milk solids per ha. The two main operating structures found on New Zealand dairy farms are 'owner operator' and 'sharemilker', with the former accounting for 65 percent of the farms. Owner operators are farmers who either own or operate their own farms, or who employ a manager to operate the farm for a fixed wage. In the case of sharemilking, the sharemilker owns the herd and any plant and equipment (other than the milking plant) needed to farm the property and receives a percentage of the milk income (typically 50 percent).

Figure A5.5
Veal production System

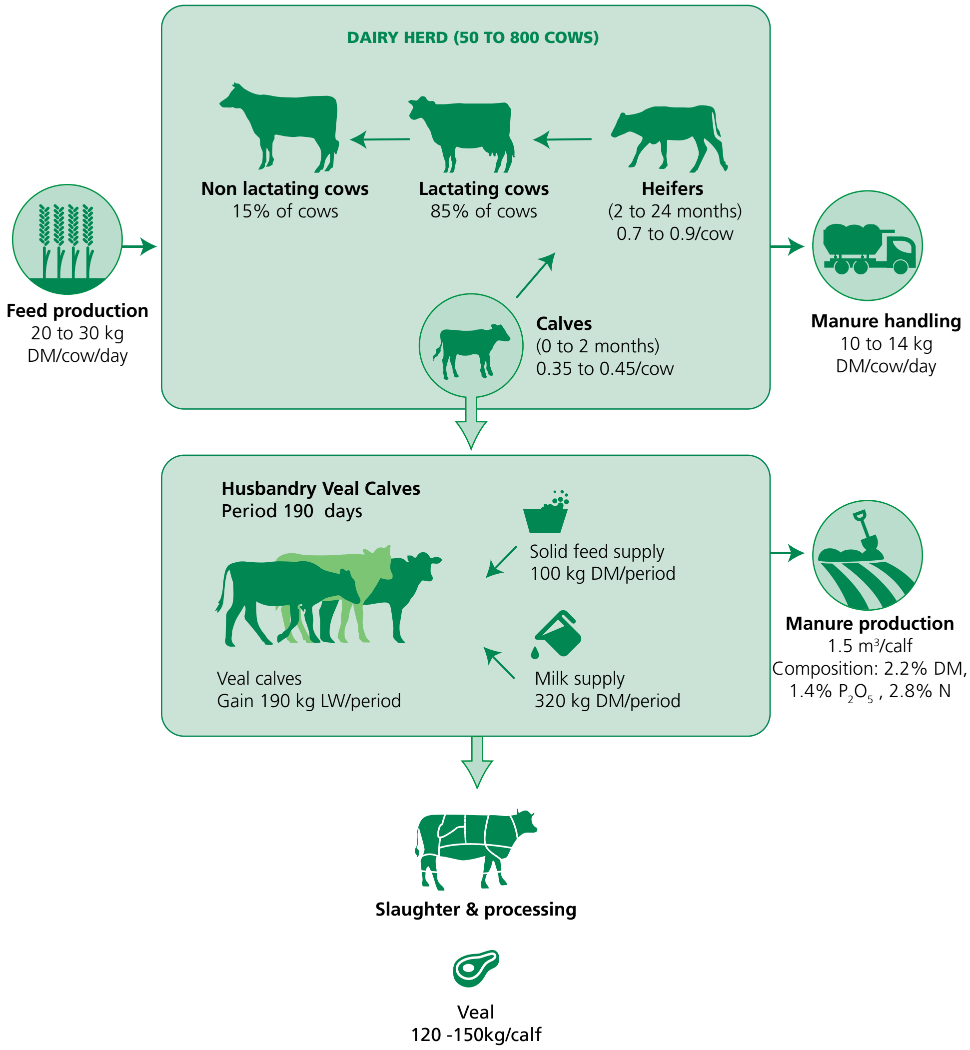


Three breeds (Holstein-Friesian, Jersey, and Friesian/Jersey crossbreed) dominate the dairy herds. About 75 percent of the cows are artificially inseminated. Calving typically occurs in August. Depending on the season, the lactation period ranges from about 250 to 275 days. Annual herd replacement rate is about 20 percent. The cull dairy cows and male calves that are on-sold and 'finished' make an important contribution to the beef supply chain (see Figure A5.7). The dominant feed is pastures, usually consisting of a ryegrass and white clover mix. They are usually grazed *in situ* with seasonal excesses (usually in spring/summer) being made into hay and/or silage. Speciality crops, such as maize for silage, can also be grown on or off the farm in the warmer regions. Other feed supplements, such as palm kernel extract (a by-product of the South East Asian palm oil industry) may also be purchased. The decision is usually based on the cost and other considerations, such as infrastructure and feeding logistics.

Most herds are run outside all year. In areas where pugging damage of the soil in winter can occur, 'stand-of' pads may be used. Full-time housing of cows is extremely rare. Five broad farms production systems can be recognized based on the timing, purpose and amount of imported feed use (the latter consisting of both as purchased supplements and off-farm grazing for dry cows):

1. All grass, self-contained (5 percent of owner-operator herds) farms that rely solely on home-grown pasture, which may be conserved as hay or silage in

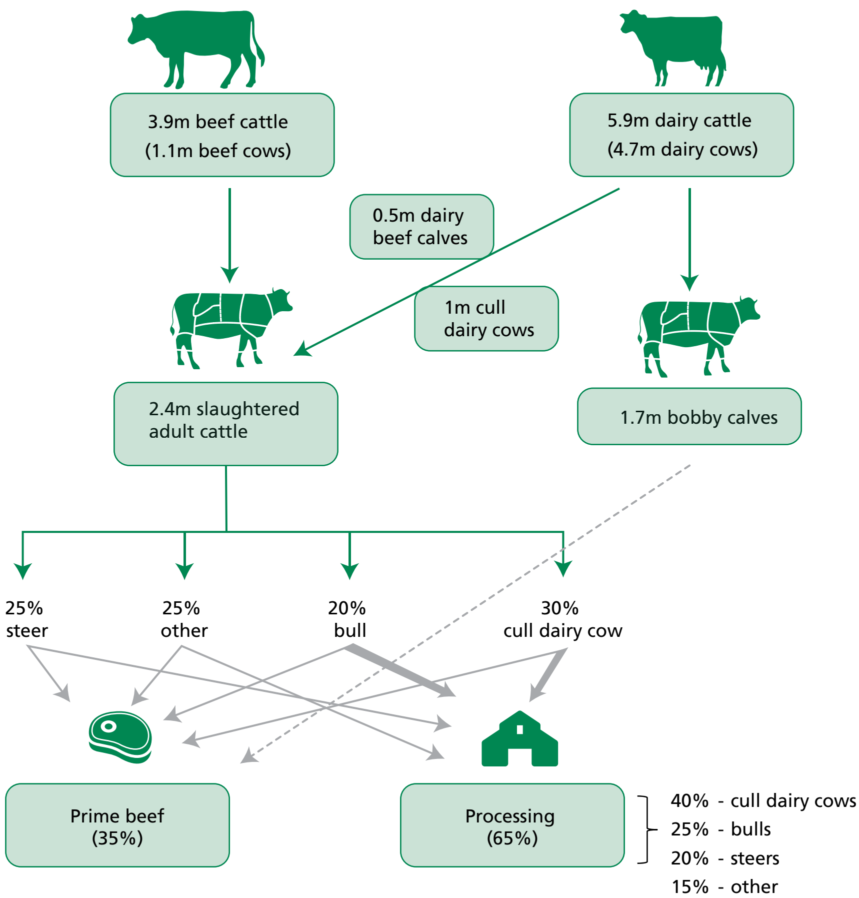
Figure A5.6
Example of Veal production System In the Netherlands



the spring/summer. No supplement feed is purchased, and no cows are grazed off the farm.

2. Feed is purchased for dry cows, including those grazing off the milking area (25 percent of herds). Approximately 10 percent of total feed is imported.
3. Feed is purchased for dry cows and to extend lactation in the autumn (40 percent of herds). Up to 20 percent of total feed is imported.
4. Feed is purchased (20 to 30 percent of total feed) for dry cows and to extend both ends of lactation (25 percent of herds).
5. Feed is purchased (over 30 percent of total feed) for year round feeding, including for dry cows (5 percent of herds).

Figure A5.7
Structure of New Zealand beef production and export (2011-2012)



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Appendix 6

Calculation of feed energy requirements for draught power and allocation between draught power and meat production

Lawrence (1985) provides the following relationship for calculation of metabolizable energy requirements for draught power:

Where: E is extra energy used for work (kJ); F is distance travelled (km); M is live weight (kg); L is load carried (kg); W is work done while pulling loads (kJ); H is vertical distance moved (km); A is energy used to move body weight 1 m horizontally (J); B is energy used to move 1kg of applied load 1 m horizontally (J); C is efficiency of mechanical work (work done/energy used); and D is the efficiency of raising body weight (work to raise body weight/ energy used). F, M, L, W and H can be easily estimated or measured and the constants A, B, C and D have been reported as 2.0 J/kg/m, 2.6 J/kg/m, 0.3 and 0.35, respectively (Lawrence, 1985). The quantity of the animal's ration required to provide this additional energy is calculated from the ME content (kJ/kg) of the ration as: Feed (kg) = E/ME (kJ/kg).

$$E = AFM + BFL + \frac{W}{C} + \frac{9.81HM}{D}$$

Harrigan and Roosenberg (2002) provide estimates for the draught force needed for different activities, such as ploughing, disking and harrowing. These forces range from 580 N/m implement width for harrowing to over 7 000 N/m implement width for moldboard ploughing (15 cm depth, medium soil). The work, W, is calculated as draught force multiplied by distance. Typical speeds for tillage tools is near 3.2 km/h. Animals will typically work for 5 to 5.5 hours per work day, with between 100 and 150 work days per year. For ploughing Lawrence (1985) estimates 10 kg load (the downward load on the yolk) for ploughing and 1.9 kg for pulling a cart. For this example, 2 kg is assumed for the load, on average. Swamp buffalo, which are predominantly owned by smallholder operations, are primarily used for draught and meat. These animals may live 14 to 18 years or longer. For purposes of an example calculation of an allocation fraction between meat and draught power provided by an animal over its lifetime, we assume an average daily draught force of 750 newtons (N) for 5 hours. With the average speed, this results in a work term, W = 16(km)*750N = 12MJ /day. If the terrain is relatively flat, then the vertical distance moved in a day's work may be 50 m, as an example. Finally, assuming a body weight of 500 kg, it is possible to calculate the daily energy requirement as:

$$E = 2 * 16 * 500 + 2.6 * 16 * 2 + \frac{12000}{0.3} + \frac{9.81 * (0.05) * 500}{0.35} = \frac{56.78MJ}{day}$$

Table A6.1: Feed consumed for growth of buffalo after bulbul (2010)

Body weight (kg)	Age (days)	Average daily growth (kg/day)	Dry matter intake (kg)*	Dry matter consumed (kg)
22	0	0.3		
100	260	0.5	0.4	104
150	100	0.5	0.8	80
200	100	0.5	1	100
250	100	0.5	1.1	110
300	100	0.5	1.1	110
400	200	0.5	1.4	280
500	200	0.5	1.4	280
			Cumulative dry matter for growth	1064

* Consumption above maintenance requirements to achieve average daily growth.

The lifetime energy requirement (assuming 12 active years beginning at 2 years of age) is then 56.78*125 work day/ year * 12 year = 85 176MJ or 20 343 Mcal. Tatsapong *et al.* (2010) present a series of rations for buffalo with different levels of crude protein, the lowest, with 5 percent crude protein consists of 66.2 percent rice straw, 26.12 percent cassava pulp, 4.32 percent soybean meal, 3.42 percent molasses and vitamins and minerals. This ration has an energy density of 2.14 Mcal/kg dry matter, which translates to approximately 9 506 kg of ration consumed for draught power in the animal's lifetime. Bulbul (2010) presents the nutrient requirements for growth of buffalo as ranging from 0.8 to 1.4 kg dry matter/500g gain (excluding maintenance requirements) depending on the animals weight as shown in the Table A6.1.

The allocation fraction is then calculated as:

$$AF_{draught} = \frac{9506}{9506 + 1064} = 0.90$$

Because the maintenance ration is not included in the calculation of the allocation fraction, the final estimate of environmental burden assigned to draught power and meat is calculated when the total emissions associated with both activities have been estimated. This includes calculation of all the feed consumed, enteric and manure emissions and other ancillary emissions that may be associated with the production system.

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Appendix 7

Example of manure as co-product

In cases where manure generates net revenue for an operation, it is considered a co-product of the production system and shall receive a share of upstream burdens. Is this example, a biophysical approach is considered for calculating the allocation ratio for manure for a dairy system in which the main products are milk, meat and manure. The demographics of the farm are presented in Table A7.1 below. Table A7.2 presents the dry matter intake for each animal class on the farm. In this example springers are animals within 60 days of first calving. Table A7.2 also presents the weighted net energies for growth and lactation of the different rations for each animal class, which is used to calculate the feed requirements for growth and lactation respectively.

For the example, it assumed that the daily milk production is 29 kg of fat- and protein-corrected milk (FPCM). Further, it is assumed that all cull animals are sold to the beef sector, and that only fully grown animals are culled. Bull calves and surplus heifer calves are also sold to the beef sector. The allocation fractions ae calculated as the ratio of feed consumed of reach purpose divided by the total feed consumed for production of the three co-products. Note that this calculation only gives the allocation ratio, and that feed consumed for maintenance during the animals' lives is allocated based on these allocation fractions.

Given the rations in Table A7.2, the feed consumed by lactating animals in one year is: 730*29*365 = 7,733,696 kg /yr. The feed consumed to produce the calves (based on net energy for pregnancy) is 614 calves*217(kg dry matter/calf)) = 133,225 kg feed / yr. Similarly, for culled cows the feed consumed for growth to the sale weight is: 256 (culls)*2290 (kg feed for growth / cull) = 586,349 kg feed/yr.

Table A7.1: Herd demographics and manure production

	Head	Weight (kg)	Total Manure (kg/day)*	Volatile Solids (kg/day)	Dry matter intake (kg/day)	Cumulative feed to reach cull weight**
Average number milking cows	730	703	69	7.5	24.98	
Average number dry cows	116	748	38	4.2	11.5	
Average number heifers < 5 months	106	91	8.5	0.935	4.1	
Average number heifers > 4 months and unmated	360	179	22	3.2	9.6	
Average number mated and pregnant heifers	233	363	26	0.286	11.5	
Heifers calving	277	612				
Culls	256	680				2,290
Calves sold	614	45				217
Cows calving per year	681					
Heifer calves reared	319					

* Average manure production taken from ASAE (2005).

***Calculated* using net energy for growth based on US National Research Council (Thoma, *et. al.*, 2013).

Table A7.2: Example rations by animal class

Feed	Open Heifers	Bred Heifers	Springers	First-Calf Heifers	Mature Cows	Dry Cows
corn			2.45	5.96	5.96	2.45
oats	1.22	0.61				
molasses				0.95	0.95	
ddg, dry				2.86	2.86	
cottonseed				1.02	1.02	
wheat mill run			1.22	1.80	1.80	1.22
canola meal				1.43	1.43	
supplement				0.44	0.44	
corn silage	3.08	2.31	3.85	3.39	3.39	3.85
alfalfa hay	4.08	5.31	4.08	4.08	4.08	4.08
almond hulls	1.22	3.27		3.06	3.06	
Total	9.61	11.50	11.61	24.98	24.98	11.61
Net Energy for Growth (Mcal /kg)	0.94	0.86	1.06	1.09	1.09	1.06
Net Energy for Maintenance (Mcal /kg)	1.39	1.30	1.54	1.67	1.67	1.54
Net Energy for Lactation (Mcal /kg)				1.59	1.59	

Table A7.3: Feed consumed to provide heat increment for manure production

	Head	Total Manure (kg/day)	Volatile Solids (kg/day)	Kg feed for heat increment
Average number milking cows	730	69	7.5	1,089,321
Average number dry cows	116	38	4.2	123,920
Average number heifers < 5 months	106	8.5	0.935	23,672
Average number heifers > 4 months and unmated	360	22	3.2	275,151
Average number mated and pregnant heifers	233	26	0.286	16,950
Total				**1,529,014**

In case manure is not considered a co-product, the allocation fraction for milk is given by: 7,733,696 / 8,453,174 =0.915.

Emmans (1994)in both single-stomached and ruminant animals, the heat increment of feeding is considered to be linearly related to five measurable quantities. For both kinds of animals three of the quantities, with their heat increments in parentheses, are urinary N (wu; kJ/g has shown that the heat increment associated with production of manure is 3.8MJ/kg fecal organic matter (or volatile solids). The calculation for the feed required to provide the heat increment for digestion is, for example, for lactating cows:

730(head)*7.5 (kg volatile solids/head/day)*365 (days/yr)*3.8 (MJ/kg volatile solids)/ (1.67 (Mcal/kg feed)*4.184(MJ/Mcal) = 1,089,321 kg feed consumed by lactating cows. This is summarized in Table A7.3.

Finally, the allocation fraction for milk, meat and manure is calculated as:

$$AF_{milk} = \frac{7{,}733{,}696}{9{,}982{,}188} = 0.775$$

$$AF_{meat} = \frac{719{,}478}{9{,}982{,}188} = 0.072$$

$$AF_{manure} = \frac{1{,}529{,}014}{9{,}982{,}188} = 0.153$$

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Appendix 8
Meat processing

Wiedemann and Yan (2014) suggest a combination of physical allocation based on utilizable protein and energy in the primary products coupled with system expansion for minor co-products. They argue that a strictly physical allocation across all co-products gives unreasonably high allocation fractions to some of the minor co-product; an issue corrected through the coupling with system expansion.

Gac *et al.* (2014) present a similar analysis of the meat processing facility, but use a European Union regulatory framework for the definition of the classes of co-products. They recommend an allocation based on dry matter content of the different co-products. This is favoured over other options because of the value of the materials based on protein and fat content for both human food uses as well as other uses: "the allocation on the dry matter content has the following advantages: this criterion combines all of the physico-chemical characteristics of interest (in particular lipids and proteins); it is relevant for the different uses and markets (food, chemistry, leather) and for all animal co-products, irrespectively of their destination; it provides stable figures, few dependent of the economical context."

Blonk Consultants (2013) propose yet a different grouping of co-products from bovine slaughter. They consider meat and organs as food grade, splitting blood into sterile and non-sterile (considered as a residual), but include bones with the food grade category and hides as a residual. In addition, several parts are considered waste (e.g. spine, brains, hooves and horns). They agree that differentiation among different food grade components is not appropriate. They also discuss a hierarchy for allocation decisions that is essentially identical to that adopted by the LEAP partnership for large ruminants (and reproduced in the main body of this chapter). For the slaughterhouse co-products, they recommend using 'ingredient value' for minor co-products, which can be converted to food grade ingredients. The ingredient value is the value after further processing of the slaughterhouse co-products, and is suggested to be similar to a system expansion substitution for these products, which seems to align with the recommendation of Wiedemann and Yan (2014) above. However, this interpretation does not match well with the recommendation from the Veal Product Category Rule (Blonk Consultants, 2013).

For slaughtering economic allocation shall be applied using the following categorization of slaughter products

- Fresh meat (allocation on the basis of average price of full package)
- Other Food grade products (allocation on the basis of average price of package)
- Other products (no allocation)

In comparisons and external communication, the other allocation options (mass and energy) shall be explored as part of the sensitivity assessment. Also, here no environmental impact will be allocated to the category other products.

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Appendix 9

Average cattle and buffalo herd parameters

Table A9.1: Average cattle and buffalo herd parameters

Parameters	North America	Russian Federation	Western Europe	Eastern Europe	North Africa and near East	East and SE Asia	Oceania	South Asia	Latin America and the Caribbean	Sub-Saharan Africa
Dairy cattle: Weights (kg)										
Adult cow	747	500	593	518	371	486	463	346	551	325
Adult bull	892	653	771	673	477	326	601	502	717	454
Calves at birth	41	33	38	36	20	28	31	23	38	20
Slaughter female	564	530	534	530	329	256	410	87	540	274
Slaughter male	605	530	540	530	367	243	410	141	540	278
Rates (%)										
Replacement adult cow	35	31	31	27	15	28	22	21	21	10
Fertility	77	83	83	84	73	80	80	75	80	72
Death rate female calves	8	8	8	8	20	15	10	22	9	20
Death rate male calves	3	8	8	8	20	15	10	50	9	20
Death rate other	3	4	4	4	6	6	4	8	9	6
Age at first calving (years)	2.1	2.3	2.3	2.2	3.4	2.5	2.1	3.1	2.6	4
Beef Cattle: Weights (kg)										
Adult cow	649	0	529	530	431	501	403	350	419	271
Adult bull	843	0	688	689	563	542	524	505	545	347
Calves at birth	40	0	35	35	29	33	27	23	28	20
Slaughter female	606	0	529	530	445	223	403	73	392	349
Slaughter male	565	0	529	530	478	218	403	68	400	288
Rates (%)										
Replacement adult cow	14	0	15	15	21	16	22	21	14	11
Fertility	93	0	93	93	75	90	93	75	73	59
Death rate female calves	11	0	10	10	18	15	10	22	14	19
Death rate male calves	11	0	10	10	18	15	10	50	14	19
Death rate other	4	0	3	3	7	7	3	8	6	7
Age at first calving (years)	2	0	2.3	2.3	2.8	2.5	2.1	3.1	3.4	3.9

(Cont.)

Table A9.1: *(Cont.)*

Parameters	North America	Russian Federation	Western Europe	Eastern Europe	North Africa and near East	East and SE Asia	Oceania	South Asia	Latin America and the Caribbean	Sub-Saharan Africa
Buffalo: Weights (kg)										
Adult female	650	650	648	559	500	380	n/a	485	650	n/a
Adult male	800	800	800	700	610	398	n/a	532	900	n/a
Calves at birth	38	38	38	38	32	24	n/a	31	38	n/a
Slaughter female	350	440	352	481	310	190	n/a	215	400	n/a
Slaughter male	350	440	352	380	309	190	n/a	135	475	n/a
Rates (%)										
Replacement female	10	20	10	20	16	20	n/a	20	10	n/a
Fertility	76	68	76	68	69	57	n/a	53	75	n/a
Death rate female calves	8	8	8	8	18	29	n/a	24	7	n/a
Death rate male calves	8	8	8	8	18	28	n/a	44	7	n/a
Death rate other	4	4	4	4	6	6	n/a	9	2	n/a
Age at first calving (years)	2.5	3.6	2.5	3.2	3.1	4	n/a	4	3	n/a

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Appendix 10

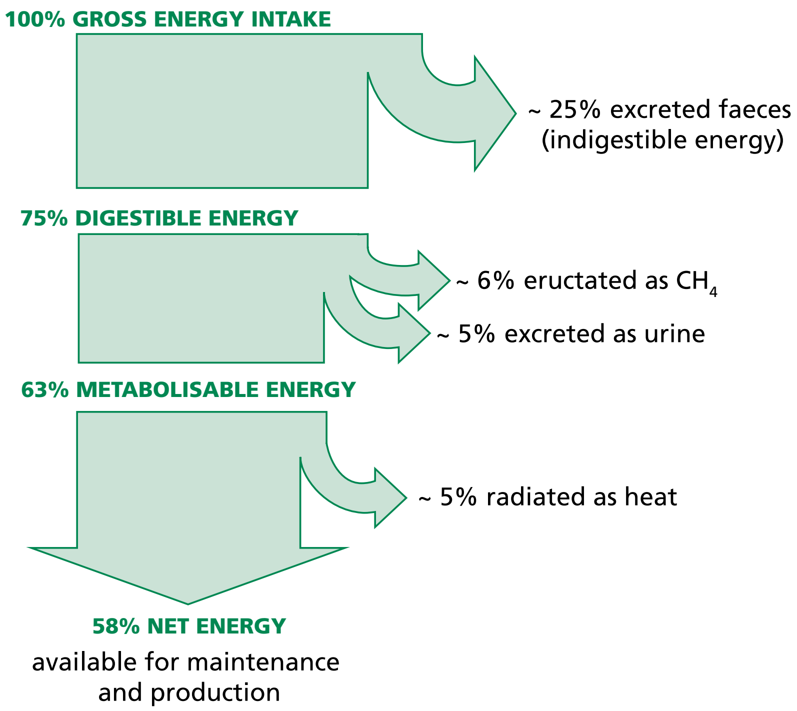
Calculation of enteric methane emissions from animal energy requirements

BACKGROUND

Section 11.2.2 outlines the procedure for calculating feed intake from energy requirements of large animals. These calculations are based on net energy (NE) as used in IPCC (2006) or metabolizable energy (ME) intake.

However, the procedures for calculating enteric methane are usually described as a percentage of gross energy (GE) intake. Thus, there is a need to convert NE or ME to GE. Figure A10.1 shows the relationship between these, where GE can be partitioned to manure energy and enteric methane energy and NE.

Figure A10.1
Diagram showing the flow of the different sources of energy for ruminants, based on a high-quality feed with a digestibility of 75 percent



Source: Lassey (2007).

CALCULATION OF GROSS ENERGY

The main additional data needed are the percentage feed digestibility. A summary of the range of values for different feed types is given later in this Appendix.

IPCC (2006) uses NE and gives the following equation for the ratio of NE for growth to the digestible energy consumed (REG):

$$REG = \left[1.164 - (5.16x10^{-3})DE\% + (1.038x10^{-5})(DE\%)^2 - \frac{37.4}{DE\%}\right]$$

where DE% is digestible energy as a percentage of gross energy in the feed.

Similarly, the following equation is used for the ratio of net energy for maintenance to the digestible energy consumed (REM):

$$REM = \left[1.123 - (4.092x10^{-3})DE\% + (1.126x10^{-5})(DE\%)^2 - \frac{25.4}{DE\%}\right]$$

From these, the gross energy (GE in MJ/day) is calculated using:

$$GE = \left[\frac{\frac{(NE_m + NE_a + NE_l + NE_w + NE_p)}{REM} + \frac{(NE_g)}{REG}}{\left(DE\%/_{100}\right)}\right]$$

where the subscripts m, a, l, w, p, and g refer to maintenance, activity (walking), lactation, work, pregnancy and growth, respectively.

The relationships for net energy estimation are as follows (all with units of MJ/day):

$$NE_m = Cf_i(BW)^{0.75}$$

$$NE_a = C_a(NE_m)$$

$$NE_l = Milk(1.47 + 0.4Fat)$$

$$NE_w = 0.1(NE_m)(hours)$$

$$NE_p = 0.1(NE_m)$$

$$NE_g = 22.02(WG)^{1.097}\left(\frac{BW}{C_g * MW}\right)^{0.75}$$

Where the coefficients Cfi, Ca and Cg are from the table A10.1 depending on specific conditions. BW is the animal body weight (kg), Milk is daily milk production (kg); Fat is the milk fat content (percentage); hours is the hours of work per day (h); WG is daily weight gain for the animal class (kg/day); and MW is the mature weight of an adult female of the species (kg).

Table A10.1: Coefficients for **calculating net energy for maintenance for cattle and buffalo**

Animal Class	Cf_i	Animal Class	C_g	Situation	C_a
Non-lactating cows	0.322	Female	0.8	Stall (little activity)	0.00
Lactating cows	0.386	Castrates	1.0	Pasture (moderate activity)	0.17
Bulls	0.370	Bulls	1.2	Grazing large areas	0.36

Source: (IPCC, 2006).

From GE, the methane emissions can be calculated from the GE intake using:

kg methane/mature animal/year = gross energy intake (MJ/year) x 0.065/55.65, or
kg methane/animal(<1 year-old)/year = gross energy intake (MJ/year) x 0.045/55.65

where the values of 0.065 and 0.045 refer to the 6.5 percent and 4.5 percent loss factors for methane of gross energy intake, and 55.65 is the energy content of methane in MJ/kg. The IPCC methane loss factor for feedlot cattle with a 90 percent concentrate diet is 3 percent (IPCC, 2006). The use of feed additives, such as methane inhibitors, in the dairy and cattle diets further reduces the methane loss factor, but total reductions will be lower for these diets, as emissions on high concentrate diets are already low as compared to high forage diets.

Typical ranges for values of DE percentages are: concentrates: (75-85 percent), pasture (65-75 percent) and low-quality forage (45-65 percent).

In practice, DE percentages will vary during the year and an example of this from the New Zealand GHG Inventory for average dairy cattle feed in New Zealand in winter, spring, summer and autumn at 81.0 percent, 79.3 percent, 74.5 percent and 78.1 percent, respectively (Pickering and Wear, 2013). Corresponding ME concentrations are 11.9 percent, 11.8 percent, 10.8 percent and 11.3 MJ ME/kg DM, respectively.

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Appendix 11
Water footprint and animal agriculture

Water is a key factor for animal production and competitiveness between countries and regions. Historically, animal agriculture has not managed water because it has been believed that water is abundant and inexpensive. Water sources appear as a major competitive advantage in discussions about animal agriculture. Preserving the quantity and quality of water is of strategic importance for maintaining the competitiveness of animal agriculture and ensuring the sustainable production of animal protein. The best management practices and their environmental, social and economic impacts that are necessary to achieve sustainability are described in Figure A11.1.

Estimates of how much water is consumed by a livestock herd or to produce one kg of meat or milk remain scarce. Such information needs to be made available to the public and water resource managers. In this way, animal agriculture can become less controversial and demonstrate that, despite being water-intensive, it has at its disposal practices and programmes for increasing water efficiency. Studies have begun to provide such estimates, using a variety of methods. Two current methods are noteworthy: Water Footprint Network and Life Cycle Assessment.

In the past, the public and the animal-production sector did not know about these types of methodologies and their premises; how to interpret the results; or how to use them in decision making. The lesson that has been learned is that, regardless of the method used to calculate the water footprint and its premises, a strategy should exist for reporting results and describing the production system of reference, geographic area and time series. Only in this way, will the results have the potential to be used in decision-making, and water footprint values be internalized by actors and used to improve the water efficiency.

Currently, the challenges to calculating the water footprint for animal agriculture are:

- lack of concern about water use and water management in farms and production chains;
- lack of data, which increases assumptions, uncertainties and conflicts;
- fewer interactions between agriculture and livestock sectors;
- absence of a systemic vision for actors and decision makers;
- aversion of some actors to the water footprint assessment; and
- limited understanding of the methodology by actors and the public.

Knowledge of water consumption by animal agriculture is an opportunity for:

- providing water-use data for large ruminants production systems;
- ensuring availability of water quantity and quality;
- estimating the water consumption of blue water by animal-production systems in different regions and conditions to facilitate water management, promote water-use efficiency and establish best water practices;
- reducing conflicts between production systems and the public;
- identifying vulnerable areas;
- formulating policies and setting goals for reducing water demand; and
- formulating zoning and water management programmes.

Figure A11.1

Best management practices and their environmental, social, economic impacts

WATER MANAGEMENT IN ANIMAL AGRICULTURE

DIMENSION	BEST MANAGEMENT PRACTICES	POSITIVE IMPACTS
GREEN WATER	• Know all environmental legislation related to its activity and the management of water resources and soil. • Utilize inputs considering all environmental, technical, and productive conditions, and analyse soil fertility. • Utilize soil conservation practices, including winter cover crops, and appropriate till age practices. • Have a nutrient management plan. • Consider agricultural and ecological zonings.	**ENVIRONMENTAL** - conserve soil, water, and downstream quality, increase the carbon fixation by the soil, reduce the GHG emission, and preserve landscape, biodiversity and wildlife. **SOCIAL** - document environmental and water management, raise the level of information and knowledge about the importance of water, maintain a good relationship with neighbours. **ECONOMIC** - have an agriculture plan, increase the land production, reduce the cost with soil degradation and erosion.
BLUE WATER	• Know all environmental legislation related to its activity and the management of water resources. • Know the water fluxes in the farm (water map). • Installation of water meters. • Have actions and indicators to evaluate water consumption by animals and services. • Do not allow animals to consume water from rivers, streams, lakes and ponds. • Diets must be properly formulated in order to avoid excessive intake and excretion of nutrients. • Have an irr igation project and efficient equipment. • Monitor water system to maintain cleanliness and eliminate leaks; • Always check if there is an occurrence of cracks, infiltration and leaks in water systems. • Follow the manufacturer's technical equipment recommendations • Distribute equipment and water sources in a correct way in the facility and space.	**ENVIRONMENTAL** - reduce the use of water, energy, and nutrients, produce indicators to evaluate the water efficiency, give water security to the farm and to watershed. **SOCIAL** - document environmental and water management, facilitate the process to take the water and environmental licenses, reduce the conflict between production, watershed community, and stakeholders, raise the level of information and knowledge about the importance of water, maintain a good relationship with neighbours and environmental agencies, assist policy makers to better understand animal-water-environment linkages so as to improve policy design and decision-making. **ECONOMIC** - offer water in quantity and quality to the herds, upgrade feed management, have a water plan, improve the production and sanitation in the farm and the herds, reduce the water cost and the water pricing.

Appendix 12

Data needed to calculate water footprint at the dairy farm level

On farm:

- Quantity of electricity
- Quantity of diesel
- Quantity of withdrawal water (often need to be estimated)
- Type of water (tap water, well water, etc.)
- Percentage manure/slurry
- Days of full grazing

Crops and pasture (on and off farm):

- Irrigation water
- Quantity of nitrogen, phosphorus and potassium used for each crop
- Type of mineral fertilizer

Animals:

- For each type of animal:
  - Number of animals
  - Type of feed and quantity
  - Composition of concentrate
- Type, quantity and live weight of sold animals
- Quantity of milk sold

Type of milking parlour

Appendix 13
U.S. Water Footprint Example

The Innovation Center for U.S. Dairy commissioned the U.S. milk comprehensive LCA. The goal of this study (Henderson *et al.*, 2013) was to assess overall environmental impacts of milk production in the United States, taking spatial differences (e.g. feeding practices and crop production practices) into account. The study built on data collected during US Dairy greenhouse gas (GHG) study (Thoma *et al.*, 2010), where data were collected at the state, regional, and national levels.

The functional unit was one consumed kilogram of fat- and protein-corrected milk (FPCM), as defined by the IDF (2010). In this example, however, we focus only on the impacts up to the farm gate (impacts associated with milk production), not milk processing, distribution and consumption. Allocation between milk and beef was based on a causal, feed-centred approach that traced energy in feed, resulting in a typical allocation ratio of 89 percent and 11 percent for milk and beef respectively.

Rations are critical connection between milk production and feed. As noted above, feed production is often the dominant contributor to many life cycle impacts. Thoma *et al.* (2010) surveyed US milk producers, and were able to capture 80 percent of the ration dry matter (DM) using 11 feeds, with the remainder modelled as a feed mix. To calculate the water inventory at the dairy level, the regional ration and the state-by-state supply of feed were considered. A matrix approach (Henderson *et al.*, 2013) was employed to link consumption of feed in one state to production of that feed in other states, based on a feed transport model. It is critical to realize that crop production practices vary from location to location, largely due to climatic differences. For example, water requirements for corn grain production vary widely between states from over 1 000 litres to 0.3 litres / kg DM.

Data collection included state-based yield, irrigation rate and the fraction of produced feed each state supplies to the others. Also, included was water used on the dairy producing farm: dairy wash water and cow drinking water.

In this LCA study, only consumed water (which is withdrawn from a basin and not returned) was included in the water inventory. Green water, largely natural precipitation was not considered, as using green water for crop production does not constitute a withdrawal nor does it deprive other users.

Life Cycle Impact Assessments at the endpoint level allows the quantification of impacts related to water consumption on human health and ecosystem quality, but for the purposes of this demonstration calculation, we focus only on water stress (Pfister, Koehler and Hellweg, 2009). Connecting water inventory to impact is critical: using 1 litre of water in water-stressed and water-rich regions will have different effects.

WATER FOOTPRINT INVENTORY AND IMPACT ASSESSMENT

Figure A13.1 shows the map of the U.S. water stress index for 18 HUC (hydrologic unit code)-2 level watersheds. It is clearly shows the differences in watersheds water competition. The figures below illustrate the variation in water consumed (water inventory, Figure A13.2) and water stress impact (Figure A13.3), disaggregated ac-

Figure A13.1
Water stress index (WSI) for USA watersheds

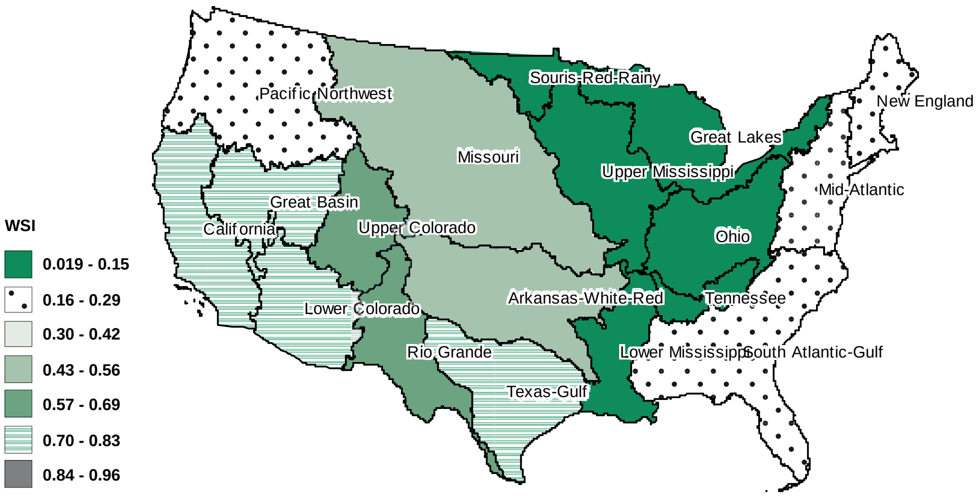


Figure A13.2
Water use inventory at the national level

Watershed-level inventory is shown on the y-axis (L H_2Oe/ kg FPCM); milk production on the x-axis; rectangle area represents overall contribution.

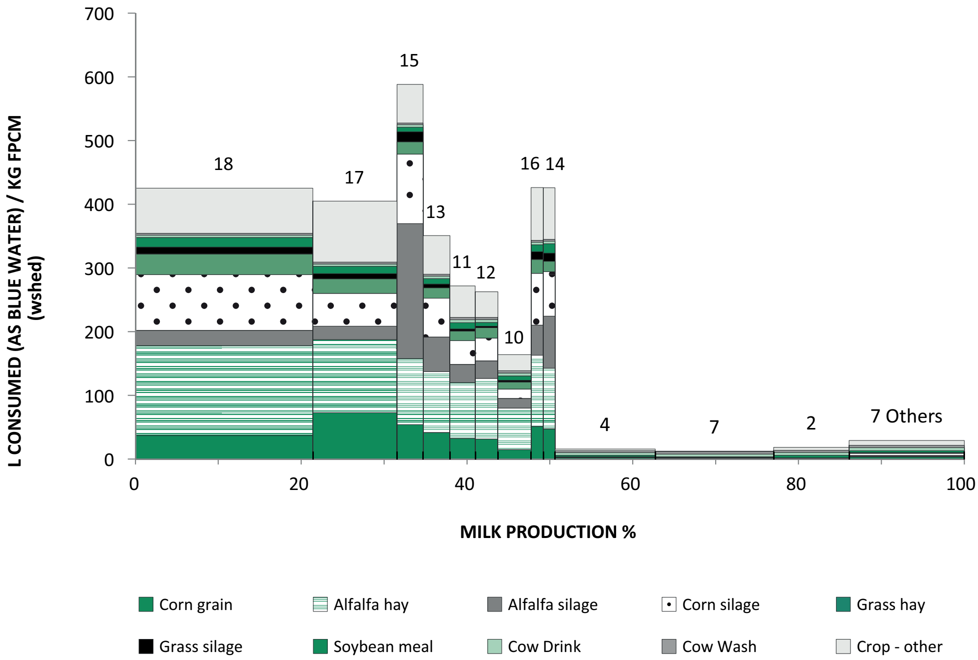
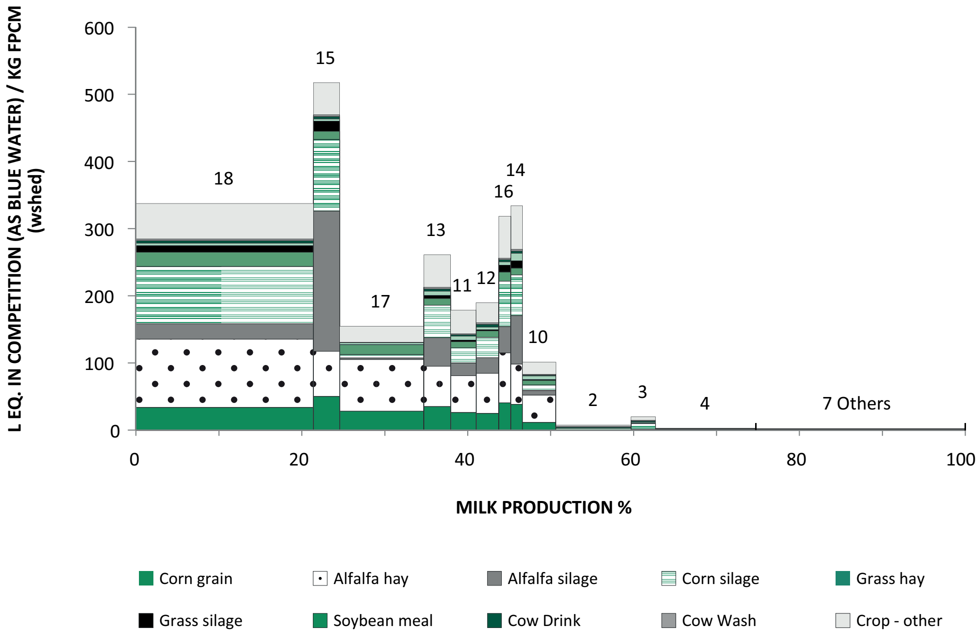


Figure A13.3
Water use impact at the national level

Watershed-level stress is shown on the y-axis (L H_2Oe/ kg FPCM); milk production on the x-axis; rectangle area represents overall contribution to water stress.



cording to feed crop as well as on-farm activity by US watershed (see Figure A13.1 for watershed numbers). To reflect the mix of national production, variable-width graphs were used. These show a watershed-level inventory (or impact) on the y-axis, and the milk production fraction on the x-axis. Watersheds are sorted according to descending area: the product of both the watershed level inventory or impact and that watershed's milk production importance.

Because data are shown disaggregated according to feed, we see in Figure A13.2 that the main contributors to water inventory are, generally, hays and silages grown locally in watersheds with water scarcity. Water for drinking and parlour washing tend to be relatively small. Even areas with abundant water tend to purchase commodity crops that require some irrigation. The watershed-level water consumption ranges from 588 to 12 litres H_2Oe / kg FPCM, and the water stress are 517 to 0.9 litres H_2Oe / kg FPCM.

Depending on climatic conditions, feed supply and rations, just a few watersheds are significant contributors to the national-level milk water inventory. Watersheds may be significant at the national level through high milk production fractions, but moderate water inventories, moderate production with high water inventory. In the case of inventory, 95 percent of the water consumption is due to 50 percent of milk production; for impact 98 percent of water stress is due to 50 percent of production.

The national average water consumption at farm gate is 18 litres H_2Oe / kg FPCM, and the impact is 121 litres H_2Oe/ kg FPCM.

Overall, this analysis shows the importance of using spatially differentiated values in the water footprint. In contrast to other environmental impacts (e.g. GHG or land use), the amount of water required to produce feeds varies greatly across geographies. This shall be coupled with information about sources of feeds to accurately capture the water use, and impact, associated with milk production.

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Appendix 14

Assessing carbon soil sequestration in tropical regions

The gases responsible for the greenhouse effect and global warming are carbon dioxide (CO_2), Methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6). The largest emissions are of CO_2 and it has the greatest impact on global warming. The increasing concentration of CO_2 in the atmosphere is the result of burning fossil fuels, deforestation and misuse of agricultural soils. Although agriculture contributes to the increase in greenhouse gas emissions, it also presents a great potential for mitigation through carbon sequestration in the soil. Through photosynthesis plants convert atmospheric CO_2 into vegetable mass, and the suitable management of this mass can retain some of the carbon in the soil. This mechanism is classified as 'carbon sequestration' of the atmosphere by soil (Lal, 2004a, 2004b, 2004c).

Carbon is stored on Earth in fossil biomass and geological carbon (mineral coal, petroleum and gas), in the soil (organic and inorganic carbon), in the atmosphere, and in oceans. An estimated 560 x 10^{15} g (560 gigatonnes (Gt) or petagrama (Pg) = 10^{15} g) of organic carbon are contained in terrestrial biota (plants and animals), whereas soils contain about 2500 x 10^{15} g (Lal, 2008).

According to Lal (2004b), worldwide soil organic carbon sequestration potential is estimated to be 0.01 to 0.3 Gt carbon/year on 3.7 billion ha of permanent pasture, which is equivalent to a sequestration potential of 4 percent of the total GHG emissions.

To achieve carbon sequestration in the soil, it is essential that the agro-ecosystem be characterized by a cropping system with high biomass production and slow decomposition of plant residues. This results in more efficient soil cover, which reduces CO_2 emissions and other GHGs (NO_2 and CH_4) to the atmosphere. The quantity and quality of plant residues accumulated in the soil, along with crop rotation with green manure species increases the supply of nutrients, particularly, carbon and nitrogen, in the soil, which also contributes to the negative balance of greenhouse gas emissions.

The carbon balance of the soil is greatly influenced by human activity, particularly the removal of natural vegetation and patterns of land use in pastures, agricultural, industrial and urban areas. During the last three centuries, the combined losses of biomass from natural soils and soil loss due to deforestation and cultivation have emitted an estimated 170 x 10^{15} g of carbon. Continued deforestation for agriculture in the tropics results in additional emissions of about 1.6 x 1015 g of carbon per year (Segnini *et al.*, 2008). According to the 4th Assessment Report to the IPCC (Smith *et al.*, 2007), 1.5 gigatonnes CO_2e of carbon could be sequestered annually if a broad range of grazing and pasture improvement practices were applied to all of the world's grasslands. It is estimated that improved grazing management practices in grasslands could sequester about 409 million tonnes CO_2e of carbon per year (or 111.5 million tonnes carbon per year over a 20-year time period), globally (Gerber *et al.*, 2013).

Carbon stocks in the soil are dependent on the amount of organic matter present in it, and this, in turn, is directly related to the soil's chemical, physical and biological characteristics. This reservoir of carbon contains almost 3.3 times more carbon than the atmosphere, which has approximately 760 x 10^{15} g. Thus, the amount of carbon in soils is more than four times the amount of carbon in the terrestrial biota and over three times that of the atmosphere. The oceans hold around 38 400 x 10^{15} g, and geologic carbon contains 4 130 x 10^{15} g. However, the carbon reservoir that is the easiest to manage is soil carbon in terms of sequestering carbon from the atmosphere (Lal, 2008).

Carbon stocks vary according to the types of soils and soil profiles, the total biomass production and amount of soil organic matter. According Boddey *et al.* (2012) in some ecosystems, the natural soil fertility is low, and plant primary production is limited, but with the application of lime and fertilizers to agricultural lands, pasture or planted forests, primary production could significantly exceed that of the native vegetation. Grazing land and pasture management practices that increase soil carbon stocks can significantly mitigate CO_2 emissions and may present opportunities for profitable investment in mitigation (Gerber *et al.*, 2013) through carbon credits.

A further 176 million tonnes CO_2e of sequestered emissions (net of increased N_2O emissions) per year over a 20-year time period, was estimated to be possible by sowing legumes in some grassland areas. Thus, a combined mitigation potential of 585 million tonnes CO_2e was estimated from these practices, representing about 8 percent of livestock supply chain emissions (Gerber *et al.*, 2013). The implementation of other production systems, such as integrated forest-livestock systems and crop-livestock-forest sytsems, as well as management practices, such as minimum tillage and avoiding soil disturbances, can be options for reducing greenhouse gas emissions. However, it is necessary for carbon quantification methods to be efficient enough to deliver better estimates of carbon inventories. More importantly, these instrumental methods need to verify the precision and accuracy of the findings and generate minimal waste (Segnini *et al.*, 2008).

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Appendix 15
LCA data modelling approaches

The scientific literature is replete with papers comparing the LCA data modelling approaches. In particular, much attention was catalysed by scholars on the pros and cons of attributional and consequential modelling approaches because they are often seen in competition by representatives of the different schools of thought. Although attributional and consequential modelling approaches are the mainstream practices, additional approaches exist and are emerging, especially to support decision making. For a comprehensive overview, see De Camillis *et al.* (2013).

This annex pinpoints some key features of attributional and consequential approaches in order to provide the reader of LEAP guidelines with some basic information to understand differences in epistemology, basic assumptions and modelling rules.

Even if attributional and consequential approaches are seen as equally legitimate perspectives, the LEAP Partnership acknowledges that mixing attributional and consequential approaches delivers results that have no clear meaning. This was indeed highlighted by Ardente *et al.* (2013) and more recently reiterated by Plevin *et al.* (2014) and Pelletier *et al.* (2015).

DESCRIPTION OF THE DATA MODELLING APPROACH

Attributional 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" (UNEP/SETAC Life Cycle Initiative, 2011).

The attributional LCA data modelling approach attempts to provide information on what portion of global burdens can be associated with a product (and its life cycle). In theory, if one were to conduct LCAs of all final products with attributional modelling, one would end up with the total observed environmental burdens worldwide (UNEP/SETAC Life Cycle Initiative, 2011).

Consequential approach

"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." (UNEP/SETAC Life Cycle Initiative, 2011).

FOCUS

Attributional approach

Usually a clearly defined, single-product system

Consequential approach

Changes throughout whole economy

QUESTION THE APPROACH AIMS TO ANSWER WHEN BASELINE SCENARIO IS ASSESSED

Attributional approach

Baseline scenario is the product system as it is, now or in the future.

The question that the approach strives to answer is "What is the potential environmental impact attributable to a certain product delivered in a given point in time ($t_{o\text{-BaselineA}}$)?" (De Camillis *et al.*, 2013)

Consequential approach

"Baseline scenario is the World as it is, now or in the future, without any action. The question that the approach aims is to answer is "what are the net impacts associated to a change (in a product system) relative to the baseline scenario, where that change does not take place?". In this way, the baseline scenario is not assessed per se – only the effect of the change is assessed." (Brandão and Weidema, 2013).

QUESTION THE APPROACH AIMS TO ANSWER WHEN FUTURE-ORIENTED/ALTERNATIVE SCENARIOS ARE ASSESSED

Attributional approach

What is the potential environmental impact attributable to a certain product delivered in a given point in time (t_1) if the product were designed or/and produced or/and consumed or/and managed differently at the end of its life? (De Camillis *et al.*, 2013)

Alternative scenarios can be modelled on the basis of the assumptions made by a practitioner, for example, on alternative raw materials chosen, project variants, alternative production processes, consumption patterns and product end-of-life options.

Sensitivity analysis is often used to compare alternative scenarios in a static manner. As long as the assessment scope is relative to a single product system, no induced effects on other product systems can be captured (De Camillis *et al.*, 2013).

Consequential approach

What is the potential environmental impact of a decision likely to result in a change in demand or in supply of a product?

Most of the activities affected by the decision are included, i.e. excluding constrained activities, but including first-order rebound effects (Brandão and Weidema, 2013).

MODELLING ASSUMPTIONS

Attributional approach

Linear emission profiles attached to LCI datasets. Effects on the economy are not captured (De Camillis, Zamagni and Bauer, 2013).

Consequential approach

"Linear, static model. Producers are price-takers. Markets clear. Ceteris paribus relative to other decisions and the overall technology and productivity of the rest of society" (Brandão and Weidema, 2013).

CO-PRODUCTS

Attributional approach

Unit process outputs defined according to a normative rule, for example, all products generating revenue for the process might be considered as co-products.

Consequential approach
Products are normally classified either in determining products or non determining products.

SOLVING MULTI-FUNCTIONALITY
Attributional approach
To be avoided as far as feasible via subdivision or reporting at multi-product level, i.e. system expansion to include additional functionality (ISO 14044:2006), otherwise partitioning according to a normative rule (Pelletier *et al.* 2015).

Consequential approach
System expansion and substitution (Pelletier *et al.* 2015).

CREDITING OF AVOIDED BURDEN AND ACCOUNTING FOR REBOUNDS
Attributional approach
Usually not allowed (De Camillis *et al.*, 2013)

Consequential approach
Obligatory (Brandão and Weidema, 2013)

BACKGROUND SYSTEM DATA
Attributional approach
Average technology mix (De Camillis *et al.*, 2013)

Consequential approach
Marginal technologies (Brandão *et al.*, 2014)

REFERENCE STANDARDS/GUIDELINES
Attributional approach
- *ISO 14040:2006* (ISO, 2006a)
- *ISO 14044:2006* (ISO, 2006b)
- *ILCD Handbook Situation C2 guidelines* (European Commission, 2010)
- *Global Guidance Principles for Life Cycle Assessment Databases* (UNEP/SETAC Life Cycle Initiative, 2011)

Consequential approach
- *ISO 14040:2006* (ISO, 2006a)
- *ISO 14044:2006* (ISO, 2006b)
- *ILCD Handbook Situation B guidelines* (European Commission, 2010)
- *CALCAS project guidelines on consequential LCA* (Weidema *et al.*, 2009)
- *Global Guidance Principles for Life Cycle Assessment Databases* (UNEP/SETAC Life Cycle Initiative, 2011)

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