DRAFT FOR PUBLIC REVIEW

Greenhouse gas emissions and fossil energy demand from small ruminant supply chains

Guidelines for quantification

LIVESTOCK ENVIRONMENTAL ASSESSMENT AND PERFORMANCE PARTNERSHIP

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Table of Contents

FOREWORD

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

The small ruminant[1] sector is of worldwide importance. It comprises a wide diversity of systems that provide a variety of products and functions. In 2011, sheep and goats produced more than 5 million tonnes of meat and 24 million tonnes of milk. Production has increased by 1.7 percent and 1.3 percent per year, respectively, during the past 20 years (FAOSTAT, 2013). This increase was driven mainly by developing countries in Africa and Asia, however Oceania (mainly for meat) and Europe still contribute significantly to production. Production systems can vary from intensive systems, wherein animals are partially or predominantly housed, to extensive systems which rely on grazing and native forages, and transhumance systems that involve large flock movements. Products are not restricted to meat and milk; sheep are also valued for their wool (more than 2 million tonnes of greasy wool was produced in 2011), and goats for their mohair and cashmere. Small ruminants also play a crucial role in sustaining livelihoods in traditional, small-scale, rural and family-based production systems. Across the small ruminant sector, there is strong interest in measuring and improving environmental performance.

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

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

[1] Small ruminants include goats, sheep, cervids and new world camelids (llamas and alpacas). These guidelines focus on goats and sheep. Potential application to other small ruminant species is discussed in Section 2.2 and 10.2.3.

Over the coming months these guidelines will be submitted to public review.[2] The purpose will be to strengthen the advice provided and ensure it meets the needs of those seeking to improve performance through sound assessment practice. Nor is the present document intended to remain static. It will be updated and improved as the sector evolves and more stakeholders become involved in LEAP, and as new methodological frameworks and data become available. The development and inclusion of guidance on the evaluation of additional environmental impacts is also viewed as a critical next step.

The strength of the guidelines developed within the LEAP Partnership across 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.

Lalji Desai

LEAP Chair

February 2014

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

ACKNOWLEDGEMENTS

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

The Technical Advisory Group (TAG) on small ruminants conducted the background research and developed the core technical content of the guidelines. The small ruminants TAG was composed of: Stewart Ledgard (TAG leader, AgResearch, New Zealand), Beverley Henry (Queensland University of Technology, Australia), Marc Benoit (French National Institute for Agricultural Research, France), C. Devendra (Independent Consultant, Malaysia), Jean-Baptiste Dollé and Armelle Gac (Institut de l'Elevage, France), Christopher Lloyd (Organisation for the English beef and sheep industry, EBLEX, UK) and Hans-Peter Zerfas (World Vision, Germany).

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

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

Steering committee members

- Douglas Brown (World Vision)
- Elsa Delcombel (Government of France)
- Lalji Desai (World Alliance of Mobile Indigenous People) – Chair 2013 to 2014
- Jan Grenz (Government of Switzerland)
- Vincent Guyonnet (International Egg Commission / International Poultry Council)
- Dave Harrison (International Meat Secretariat)
- Hsin Huang (International Meat Secretariat)
- Giuseppe Luca Capodieci (The European Livestock And Meat Trading Union)
- Delanie Kellon (International Dairy Federation)
- Lionel Launois (Government of France)
- Pablo Manzano (International Union for Conservation of Nature)
- Nicolas Martin (European Feed Manufacturers' Federation)
- Paul Melville (Government of New Zealand)

- Paul McKiernan (Government of Ireland)
- Frank Mitloehner (University of California, Davis) – Chair 2012 to 2013
- Anne-Marie Neeteson-van Nieuwenhoven (International Poultry Council)
- Frank O'Mara (Irish Agriculture and Food Development Authority, Teagasc)
- Antonio Onorati (International Planning Committee for World Food Sovereignty)
- Lara Sanfrancesco (International Poultry Council)
- Fritz Schneider (Bern University)
- Rogier Schulte (Government of Ireland)
- Henning Steinfeld (Food and Agriculture Organization)
- Bryan Weech (World Wildlife Fund)
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- Rudolph De Jong (International Wool Textile Organization)
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- Elisabeth van Delden (International Wool Textile Organization)

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

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1 GLOSSARY

Abbatoir	An animal slaughterhouse.
Acidification	Impact category that addresses impacts due to acidifying substances in the environment. Emissions of NOx, NH_3 and SOx lead to releases of hydrogen ions (H+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.
Allocation	Partitioning the input or output flows of a process between the product system under study and one or more different product systems.
Attributional	Attributional Life Cycle Assessments focus on describing the environmentally relevant physical flows to and from a product or process.
Background process	Stages of the supply chain which provide goods and services to the foreground system; not under the control of the study commissioner. See also: **Foreground process.**
Biogenic	Derived from biomass, not from fossil sources.
Biomass	Material of biological origin, excluding fossilized material or material embedded in geological formations**.**
Browse	A general term applied to shrubs or trees that are fed on by goats by picking mouthfuls as they move.
Boundary	Set of criteria specifying which unit processes are part of a product system (life cycle).
By-product	Material produced during the processing (including slaughtering) of a livestock or crop product that is not the primary objective of the production activity (e.g. oil cakes, brans, offal or skins).
Capital goods	Goods, such as machinery, equipment and buildings, used in the life cycle of products.
Carbon dioxide equivalent (CO_2e)	Unit for comparing the radiative forcing (global warming potential) of a greenhouse gas expressed in terms of the amount of carbon dioxide that would have an equivalent impact.
Carbon footprint	The level of greenhouse gas emissions produced by a particular activity or entity or product.
Carbon storage	Retaining carbon of biogenic or atmospheric origin in a form other than atmospheric gas.
Carcass	The body after slaughter from which the viscera, skin and head, and some other parts have been removed.
Cashmere	Fine fibre from the Cashmere goat
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 which may contain additives for use as animal feed in the form of complete or complementary feedstuffs.
Consequential LCA	Consequential LCA assessments describe how relevant environmental flows will change in response to different decisions.
Containers and packaging	Containers and packaging that reach consumers.
Co-production	A multifunctional process that produces various outputs such as meat and milk. Production of the different goods cannot be varied, or only varied within a very narrow range.
Co-products	Output from a production activity that generates more than one product (e.g. meat, milk, and, under some circumstances, litter are among the co-products of small ruminant production). The term does not include any services that may also be provided.
Cradle-to-gate	Life cycle stages from the extraction or acquisition of raw materials to the point at which the product leaves the facility
Cull	To reduce the size of a herd or flock by selling or killing a proportion of its members.
Data quality	Characteristics of data that relate to their ability to satisfy stated requirements.
Direct energy	Energy used on farms for livestock production activities (e.g. lighting, heating).
Doe	Mature female goat.
Downstream emissions	GHG emissions associated with processes that occur in the life cycle of a product subsequent to the processes owned or operated by the organization implementing these guidelines.
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). NOTE: Emission factor data is obtained from secondary data sources.
Emissions	Release to air or discharge to land and water that results in greenhouse gases entering the atmosphere. The main GHG emissions from agriculture are carbon dioxide (CO2), nitrous oxide (N_2O) and methane (CH_4).
Eutrophication	Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland accelerate 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.
Ewe	Mature female sheep usually over 2 years of age.
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.
Forage crop	Crops, annual or biennial, grown to be used for grazing or harvested as a whole crop.

Foreground process	The stages of the supply chain under the direct control of the commissioner of the LCA. For product developers and process operators, the foreground data is of special interest because direct changes in the system (changes in materials, designs, processes) have direct effects on the result, while the background system impacts can be influenced only indirectly (by the choices above). See also: **Background process.**
Functional unit	Quantified performance of a product for use as a reference unit. 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.
Global Warming Potential (GWP)	The intensity of a GHG's warming potential, which is different for each gas. The factors used to convert GHGs into CO_2 equivalents are defined by IPCC guidelines and can be found in Section 4.6.
Graze	To feed directly on growing grass, pasturage or forage crops.
Greasy fibre	Untreated fibre straight off an animal (e.g. raw wool, cashmere or mohair).
Greenhouse gases (GHGs)	Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluoro-carbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).
Hogget	Young sheep between a lamb and an adult sheep (a two-tooth from approximately 10–16 months of age).
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 and penetration through the skin, insofar as they are related to cancer.
Impact category	A class representing environmental issues of concern to which life cycle inventory analysis results may be assigned.
Impact category indicator	Quantifiable representation of the contribution of a product unit to the specific impact.
Infrastructure	Product not intended for consumption, with a lifetime exceeding one year. Synonym: Capital goods.
Input	Product, material or energy flow that enters a unit process.
Joint production	A multifunctional process in which production of the various outputs can be varied separately.
Kid	Young male or female goat.
Lamb	A young sheep from birth up until it is classified as a hogget, at approximately 12 months of age, although there is no specific age or time for this change.
Lanolin	Also called wool fat. A yellowish viscous substance extracted from wool, consisting of a mixture of esters of fatty acids; used in some ointments.
LCA	See Life Cycle Assessment.
Life cycle assessment	Compilation and evaluation of inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

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.
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to end of life, inclusive of any recycling or recovery activity.
LCI	See Life Cycle Inventory
Life cycle inventory	Compilation of the exchanges for a unit process. These include purchased input materials, materials extracted from nature (e.g., well water), emissions to the environment, and the output(s) produced.
Material contribution	Contribution of any one source of GHG emissions to a product amounting to more than one percent of its total anticipated life cycle GHG emissions. A materiality threshold of one percent has been established to ensure that minor sources of life cycle GHG emissions do not require the same treatment as more significant sources.
Mohair	Fine, hairy fibre produced by an Angora goat.
Multi-functionality	If a process or facility provides more than one function (i.e. it delivers several goods and/or services) or "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.
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.
Offal	The internal organs of the body removed from the butchered animal (not included in a carcass).
Offsetting	Mechanism for claiming a reduction in GHG emissions associated with a given process or product by removing or preventing the release of GHG emissions in an unrelated process or product.
Output	Product, material or energy that leaves a unit process.
Ozone depletion	Impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example, long-lived chlorine and bromine-containing gases (e.g. CFCs, HCFCs, Halons).
Packing	Process of packing products in the production or distribution stages.
Primary data	Data directly measured or collected data representative of processes at a specific facility or for specific processes within the product supply chain.
Primary packaging materials	Items other than containers/packaging, which reach consumers (including additives for preservation).
Process centre	A facility where products are repackaged into smaller units without additional processing in preparation for retail sale.

Product parts	Cuts of meat for retail sale (e.g., breast/thigh meat, wings, livers).
Product(s)	Any good(s) or service(s). Services have tangible and intangible elements.
Proxy data	Secondary LCI data or unit process used to represent a similar unit process in the product system. For example, using a Chinese unit process for electricity production in an LCA for a product produced in Viet Nam.
Ram	An uncastrated (entire) male sheep.
Raw material	Primary or secondary material used to produce a product.
Reference flow	Quantity of a material from a unit process in the supply chain that is required to produce the functional unit.
Removal	The sequestration or absorption of GHG emissions from the atmosphere, which most typically occurs when CO2 is absorbed by biogenic materials during photosynthesis.
Rendering	A process that converts waste animal tissue into stable, value-added materials.
Replacement rate	The percentage of adult animals in the herd replaced by younger adult animals.
Residual	Material leaving the 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 system calculations. Materials with economic value are not considered residual.
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, sheep, goats, deer, giraffes, antelopes and camels.
Scouring	Treating textiles in aqueous or other media to remove natural fats, waxes, proteins and other constituents, as well as dirt, oil and other impurities.
Secondary data	Information obtained from sources other than direct measurement of the inputs/outputs (or purchases and emissions) from processes included in the life cycle of the product (PAS 2050:2011, 3.41). Secondary data are used when primary data are not available or it is impractical to obtain primary data. Some emissions, such as methane from litter management, are calculated from a model, and are therefore considered secondary data.
Secondary packaging materials	Containers/packaging and materials, which are used in raw materials acquisition, production and distribution but which do not reach consumers
Sink	A natural or artificial reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period.
System boundary	Set of criteria specifying which unit processes are part of a product system (life cycle).
System expansion	Expanding the product system to include additional functions related to co-products.
Tallow	Rendered fat from sheep.
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 — Procedure to assess the uncertainty introduced into the results of a PEF study due to data variability and choice-related uncertainty.

Unit process — The smallest unit of analysis in a life cycle assessment. It is used to keep an account of the exchanges necessary to produce the reference flow of the product output from the operation being modeled. In preparing the LCI model of the system, many unit processes are linked, with the output from each one potentially used as an input exchange for another. Thus the LCI model is a representation of the supply chain necessary to produce the product from the top-most unit process in the model.

Upstream emissions — Emissions associated with processes that occur in the life cycle of a product prior to the processes owned, operated or controlled by the organization undertaking the assessment.

Volatile Solids (VS) — Volatile solids (VS) are the organic material in livestock manure and consist of both biodegradable and non-biodegradable fractions. The VS content of manure equals the fraction of the diet consumed that is not digested and thus excreted as faecal material which, when combined with urinary excretions, constitutes manure.

Waste — Materials for disposal that have no value, and may require further processing as part of the management of the materials. See also: **Residual**.

Water consumption — Water withdrawal minus the return flow to rivers, lakes, aquifers and sea.

Weaning — Removal of lambs or kids from their mothers, usually at about 10–16 weeks.

Wool — The outer coat of sheep consisting of short curly hairs.

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 small 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 life cycle assessment. The main purpose of the guidelines is to provide sufficient definition of calculation methods and data requirements to enable consistent application of LCA across differing small ruminant supply chains.

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

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

The benefits of this approach include:

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

2 SCOPE

2.1 Environmental impact categories addressed in the guidelines

These guidelines cover only the following environmental impact categories: climate change, and fossil energy demand. This document does not provide support towards the assessment of comprehensive environmental performance, nor to the social or economic aspects or small ruminant supply chains.

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

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

The LEAP Animal Feed Guidelines cover additional impact categories: acidification, eutrophication and land use. These categories may be reported for the life cycle stages of small ruminant products. It is intended that in future these guidelines will be updated to include multiple categories.

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

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

Regarding land use, the LEAP Animal Feed Guidelines divided land areas into two categories: arable land and grassland. Appropriate indicators were included in the guidelines as they provide important information about the use of a finite resource (land) but also in view of the follow-on impacts on soil degradation, biodiversity, carbon sequestration or loss, water depletion, etc. Nevertheless, users wishing to specifically relate land use to follow-on impacts will need to collect and analyse additional information on production practices and local conditions.

2.2 Application

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

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

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

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

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

These guidelines have been developed with a focus on sheep and goat production. Their application to other small ruminant species is possible, however, there may be specific circumstances for other species not covered in this document; for example, the co-production of velvet (antlers) and meat by deer would require additional consideration regarding questions of allocation methodology.

3 STRUCTURE AND CONVENTIONS

3.1 Structure

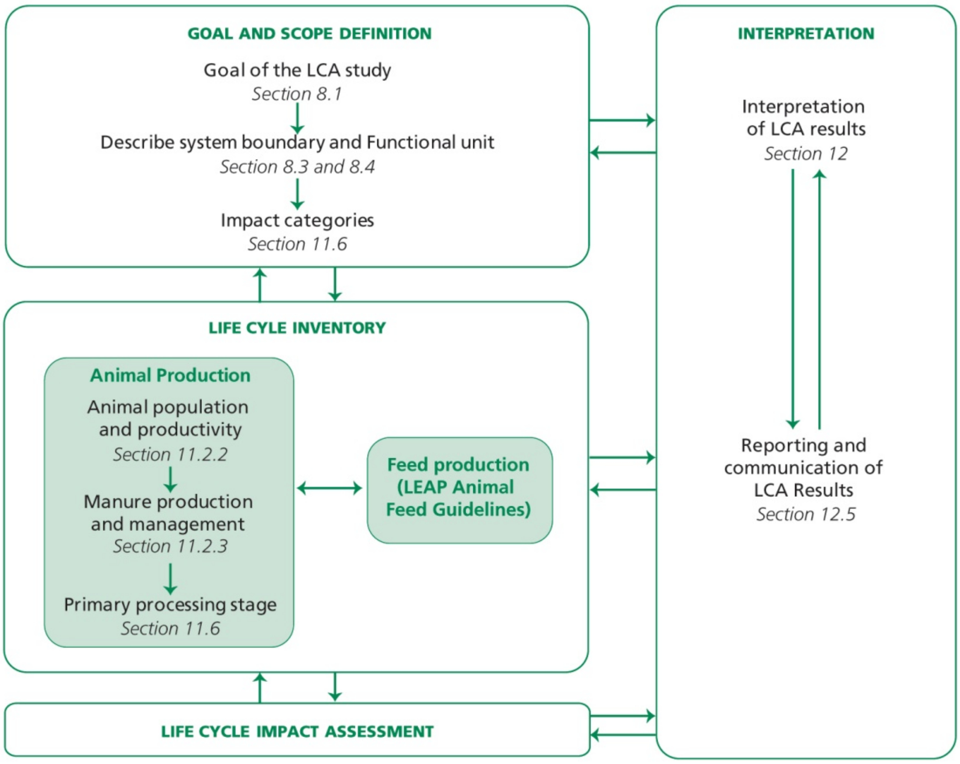
This document adopts the main structure of ISO 14040:2006 and the four main phases of Life Cycle Assessment – goal and scope definition, inventory analysis, impact assessment, and interpretation. Figure 1presents the general relationship between the phases of an LCA study defined by ISO 14040:2006 and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

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

- Section 1212 provides guidance on interpretation and reporting of results and summarizes the various requirements and best practice in reporting.

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

FIGURE 1: MAIN LIFE CYCLE STEPS IN THE SMALL RUMINANT SUPPLY CHAIN



Users of this methodology should also refer to other relevant guidelines where necessary and indicated. The LEAP small 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 but contained in other documents will be specifically cross-referenced to enable ease of use. For example, specific guidance for calculating associated emissions for feed is contained in the LEAP Animal Feed Guidelines.

3.2 Presentational conventions

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

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

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

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

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

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

4 ESSENTIAL BACKGROUND INFORMATION AND PRINCIPLES

4.1 A brief introduction to LCA

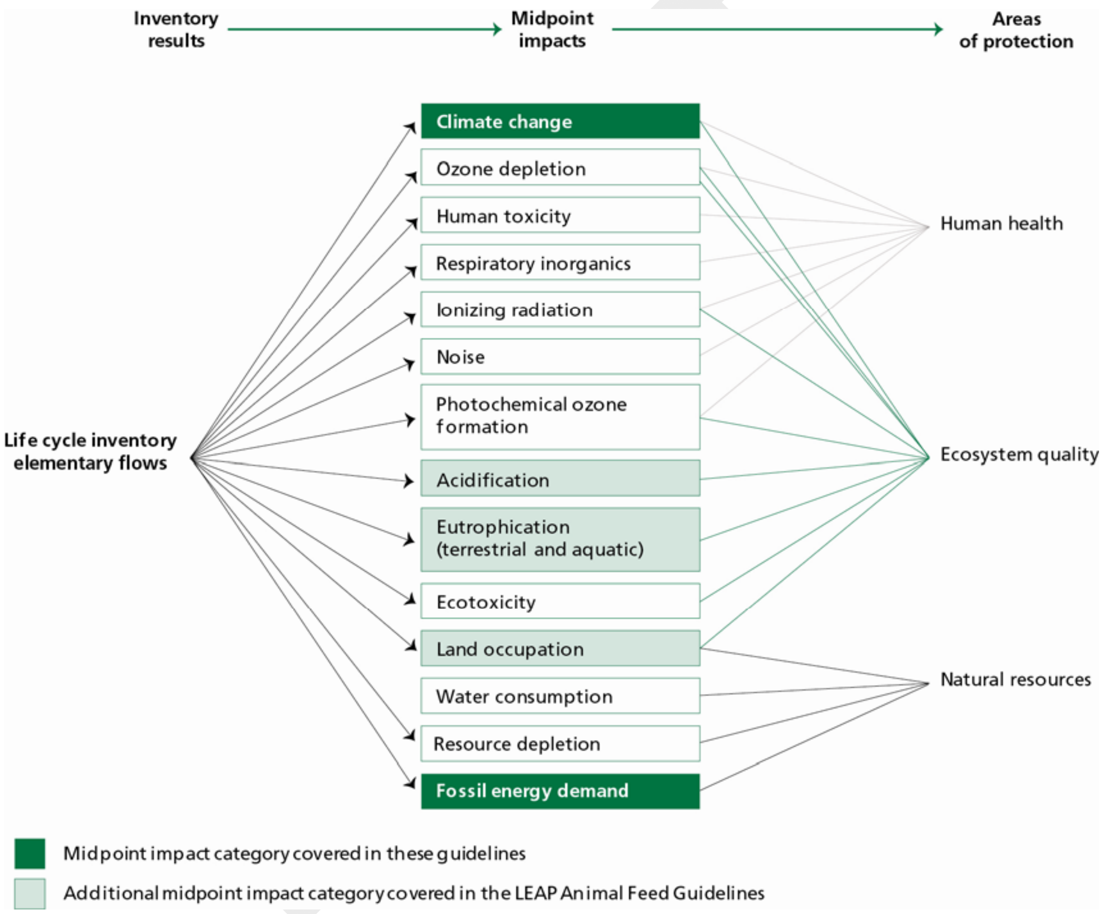
Life cycle assessment (LCA) is recognized as one of the most important methods developed to assess the environmental impact of products and processes. LCA can be used as a decision support tool within environmental management. ISO 14040:2006 defines LCA as a "compilation and evaluation of the inputs,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

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

4.2 Environmental impact categories

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

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



Source: adapted from ILCD, 2010.

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

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

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

The LEAP Animal Feed Guidelines include some more categories and related methodologies (Figure 2). These guidelines do not describe methodologies for other resource use and environmental impact categories, but some relevant methodologies are described for the following:

- land use or land occupation (which should be further subdivided into land suitable or unsuitable for arable production, since it is important to recognize the potential of small ruminants for utilizing land that is otherwise incapable of growing arable crops for direct human consumption);
- water consumption, accounting for blue water use and water scarcity (e.g. Ridoutt and Pfister, 2010; for water footprint methodologies see ISO/TC 14046, 2013);
- resource depletion of non-renewable resources such as minerals and fossil fuels (e.g. Guinée *et al*., 2002).
- eutrophication (e.g. the eutrophication potential method of Guinée *et al*., 2002, or separate eutrophication terrestrial and aquatic methodologies, as in Goedkoop *et al*., 2009).

4.3 Normative references

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

- ISO 14040:2006 *Environmental management – Life cycle assessment – Principles and framework*
  These standards give guidelines on the principles and conduct of LCA studies providing organizations with information on how to reduce the overall environmental impact of their products and services. ISO 14040:2006 define the generic steps which are usually taken when conducting an LCA and this document follows the first three of the four main phases in developing an LCA (Goal and scope, Inventory analysis, Impact assessment and Interpretation).

- ISO14044:2006 *Environmental management – Life cycle assessment – Requirements and guidelines*
  ISO 14044:2006 specifies requirements and provides guidelines for life cycle assessment including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.
- ISO 14025:2006 *Environmental labels and declarations – Type III environmental declarations – Principles and procedures*
  ISO 14025:2006 establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations. It specifically establishes the use of the ISO 14040 series of standards in the development of Type III environmental declaration programmes and Type III environmental declarations.
  Type III environmental declarations are primarily intended for use in business-to-business communication, but their use in business-to-consumer communication is not precluded under certain conditions.
- ISO/TS 14067:2013 *Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication*
  ISO/TS 14067:2013 specifies principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product (CFP), based on ISO 14040 and ISO 14044 for quantification and on environmental labels and declarations (ISO 14020, ISO 14024 and ISO 14025) for communication.
- WRI/WBCSD (2011) *Product Life Cycle Accounting and Reporting Standard*
  The GHG Protocol from the World Resources Institute & World Business Council for Sustainable Development (WRI/WBCSD) provides a framework to assist users in estimating the total GHG emissions associated with the life cycle of a product. It is broadly similar in its approach to the ISO standards, although it lays more emphasis on analysis, tracking changes over time, reduction options and reporting. Like PAS2050, this standard excludes impacts from production of infrastructure, but whereas PAS2050 includes 'operation of premises' such as retail lighting or office heating, the GHG Protocol does not.
- British Standards Institution PAS 2050:2011 *Specification for the assessment of life cycle greenhouse gas emissions of goods and services*
  PAS 2050:2011(BSI 2011) is a Publicly Available (i.e. not standard) Specification. A UK initiative sponsored by the Carbon Trust and Defra, PAS 2050 was published through the British Standards Institution (BSI) and uses BSI methods for agreeing a Publicly Available Specification. It is targeted at applying LCA over a wide range of products in a consistent manner for industry users, focusing solely on the carbon footprint indicator. PAS 2050 has

many elements in common with the ISO 14000 series methods but also a number of differences, some of which limit choices for analysts (e.g. exclusion of capital goods and setting materiality thresholds).

4.4 Guiding principles

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

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

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

Relevance

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

Completeness

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

Consistency

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

Accuracy

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

Transparency

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

5 LEAP AND THE PREPARATION PROCESS

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

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

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

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

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

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

5.1 Development of sector-specific guidelines

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

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

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

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

5.2 The Small ruminants TAG and the preparation process

The Small ruminants TAG of the LEAP Partnership was formed at the start of 2013. The team included selected nine experts in small 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 so ensure credible representation. The TAG was led by Dr Stewart Ledgard of AgResearch, New Zealand.

The role of the TAG was to:

- Review existing methodologies and guidelines for assessment of GHG emissions from livestock supply chains and identify gaps and priorities for further work;
- Develop methodologies and sector specific guidelines for the life cycle assessment of GHG emissions from small ruminant supply chains; and
- Provide guidance on future work needed to improve the guidelines and encourage greater uptake of life-cycle assessment of GHG emissions from small ruminant supply chains.

The TAG met for its first workshop on 12–14 February 2013. The TAG continued to work via emails and teleconferences before meeting for a second workshop, which took place on 5–7 September 2013 in Rome. The eight experts were drawn from six countries: Australia, France, Germany, Malaysia, New Zealand and the United Kingdom.

As a first step, existing studies and associated methods 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.

Our selection of documents for background review in support of the development of these guidelines was driven by the availability of full LCA studies in the small ruminant sector. Our interest was in determining the range of methodological choices that have been used. Our intention was to evaluate as broadly as possible and therefore included peer-reviewed articles, conference proceedings and technical reports. These sources allowed an evaluation of the methodological consistencies and differences for global systems.

The TAG identified 12 studies addressing aspects of the small ruminant supply chain, with eight covering only the cradle-to-farm-gate, four covering the cradle-to-retail gate, and one covering a whole life cycle (meat only). All 12 studies focused on sheep, with one also covering goats. Appendix 1 presents a review of these studies. As a result, it was concluded that no existing approach or study set out fully comprehensive guidance for quantifying GHG emissions and energy use across the supply chain, and that the TAG would need to undertake further work to reach consensus on more detailed guidance. This task built on initial work on a methodology for carbon footprinting of lamb (cradle-to-farm-gate) by LCA researchers (including some in this TAG), which was supported by the International Meat Secretariat and Beef + Lamb New Zealand.

5.3 Period of validity

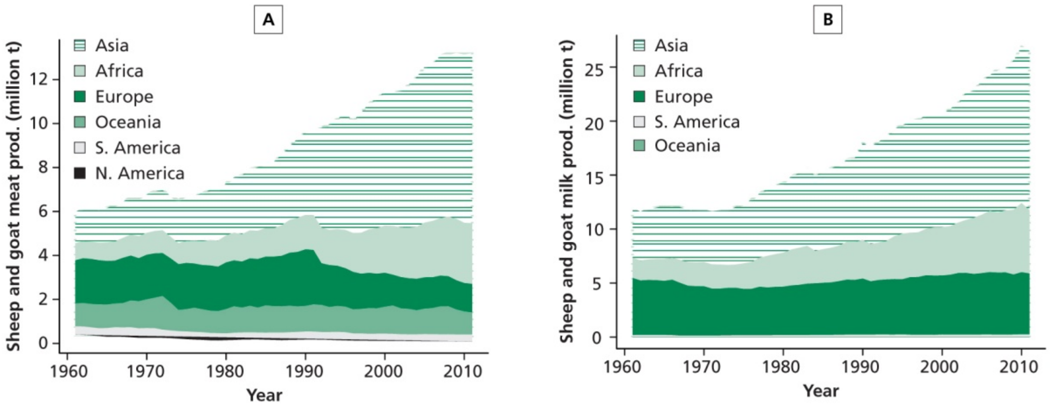
It is intended that these guidelines will be periodically reviewed to ensure the validity of the information and methodologies on which they rely. At the time of development, no mechanism is in place to ensure such review. The user is invited to visit the LEAP website (www.fao.org/partnerships/leap)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

6 BACKGROUND INFORMATION ON SMALL RUMINANT SUPPLY CHAINS

6.1 Background and context

The world populations of goats and sheep in 2011 were 876 and 1 043 million, respectively. A breakdown of their distribution across the main countries shows a dominance of goats in Africa and Asia, although the dominance of specific products varies with most meat production in China, while most milk production occurs in India (Table 6 in Appendix 2). Similarly, for sheep, China is the largest producer of meat, wool and milk, although Australia and New Zealand are the next largest producers of meat and wool (Table 7 in Appendix 2). The various world regions also show differences in terms of their temporal trends in sheep and goat production. The production of both milk and meat from sheep and goats has increased significantly during the past 20 years in Asia, while the increase was lower in Africa (Figure 3). However, production trends were stable to declining in Europe and Oceania.

FIGURE 3: TRENDS IN THE GLOBAL PRODUCTION OF SHEEP AND GOATS (A) MEAT AND (B) MILK ACROSS WORLD REGIONS



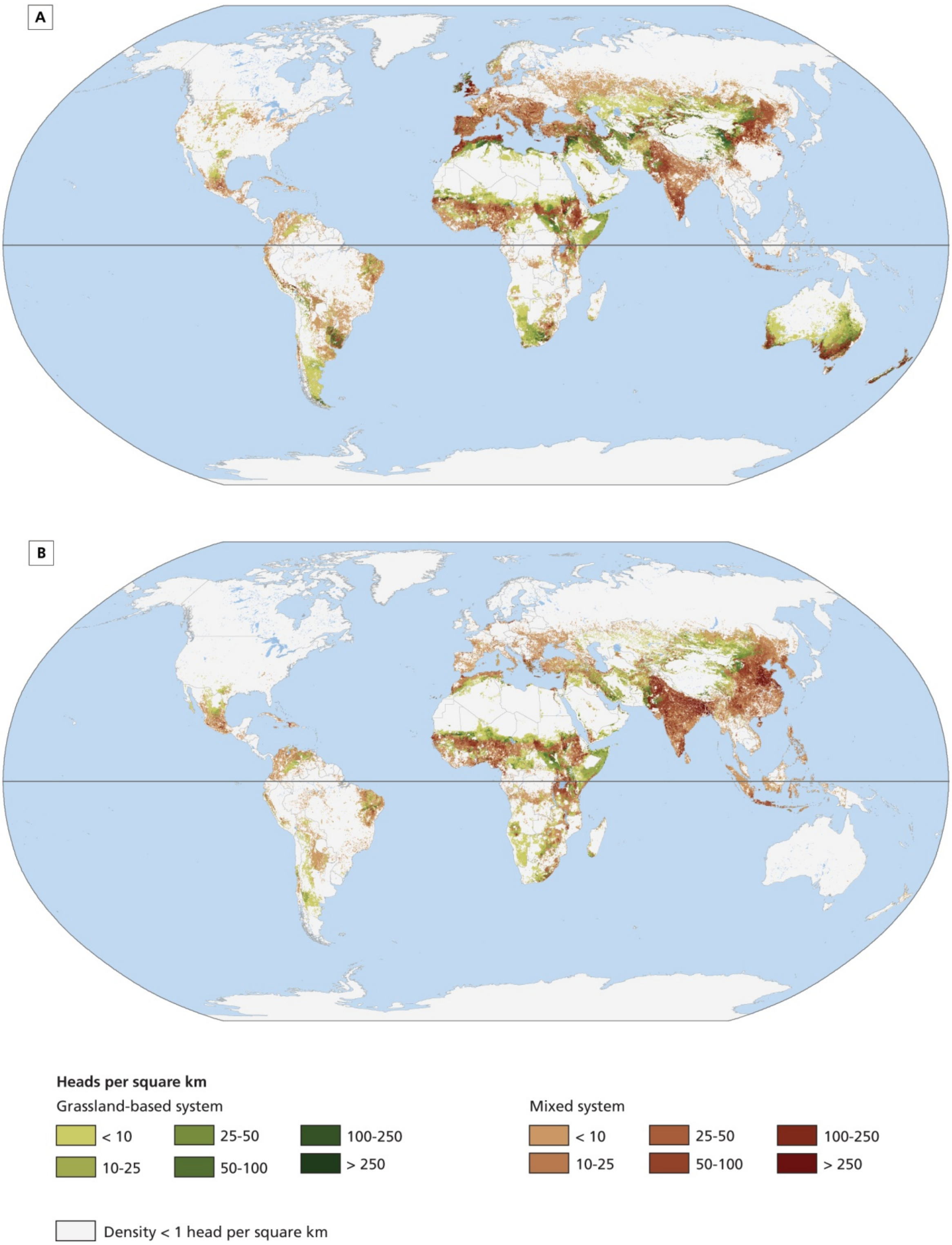
Note: Production is summed between the two species (FAOSTAT, 2013). Regions with low production: meat production for North and South America went from 0.8 and 0.4 million t in 1980 to 0.4 and 0.09 million t in 2011, respectively; milk production for South America and Oceania went from 182 and 0.03 x10^3 t in 1980 to 254 and 0.04 x10^3 t in 2011, respectively.

Both species present a bewildering mix of breeds and play valuable multi-functional roles, especially in small farm systems. Their preferred environments are somewhat different, with goats being more heavily concentrated in semi-arid and arid areas, while sheep thrive best in cooler environments. Goats and sheep play an important socio-economic role in many rural areas. They are capable of utilizing low-quality fibrous feeds (goats more so than sheep) and are highly valued for the multiple products they produce. These include edible products such as meat and milk, and non-edible products such as manure, hides and skins, and natural fibre (mohair, cashmere or wool). With the exception of larger farms where one or the other species may be reared intensively for a particular product, in most small farms and low-input systems, both species may be reared together (often for purposes of diversification).

6.2 Diversity of small ruminant production systems

The agro-ecosystem conditions (climatic, edaphic, biotic) determine which plants exist or can potentially be grown. This in turn determines the quantity, quality and distribution of the feed base, which governs the development of potential animal production systems. Small ruminant production occurs worldwide across a range of Agro-Ecological Zones (AEZ) and presents a wide diversity of systems with different intensities and objectives of production (Figure 4). While a range of constraints to production of small ruminants exist across the AEZs (Devendra *et al.*, 2005), sheep and, in particular, goats are also well adapted to a wide range of conditions and AEZs often unsuitable for alternative food production systems. Additionally, small ruminant production in these landscapes can result in positive environmental benefits through nutrient cycling and maintenance of biodiversity.

Figure 4: Global distribution of (a) sheep and (b) goats from the two main production systems – grassland based and mixed



Note: The color (see legend) indicates the dominant production system and the number of animals in each grid cell. Source: Gerber et al, 2013.

Examples of the diversity of sheep or goat production systems are as follows.

1. *Intensive production systems for meat or milk as the main product with animals housed permanently or through most of the year.* Feed supply can be brought in totally from arable crops or from cut-and-carry pasture and cultivated improved forages. The system is common in humid regions where feed is generally more plentiful.
2. *Extensive to intensive systems with animals reared predominantly on pastures in confined farms.* These may include animals housed for part of the year through to some animals (e.g. lambs) being housed throughout their life, with concentrates being fed during the confinement period. Main products may include meat, milk or fibre.
3. *Extensive systems with animals managed communally for grazing and fed on native forages and residues from crops or trees.* Main products may include meat, milk or fibre (manure may also be a useful co-product).
4. *Very extensive systems where animals are grazed on large areas of unproductive and marginal lands, including rangelands, forest areas and roadsides.* Very low annual rainfall produces a sparse feed-resource base where animals have to seek feed. Inadequate control of numbers can lead to overgrazing and damage to the environment. This system is very common in semi-arid and arid agro-ecological zones.
5. *Nomadic and transhumance systems that involve regular movements of whole flocks (along with families).* These systems are found in agro-ecosystems where crop production is not possible. Grazing and water availability are the main drivers of these movements, which can involve very large flocks.
6. *Rural landless production system.* Several million poor farmers are found in landless small ruminant production systems, especially within systems 3 to 5 above. The poorest are found in vulnerable semi-arid and arid AEZs. In this system, small ruminants play a vital role in ensuring survival through meat and milk, and some income.
7. *Sylvopastoral systems where small ruminant production is integrated with tree cropping.* Residues from trees are often used as feed. These integrated systems are a good example of diversification, which is mainly driven by seasonality and risk.

6.3 Diversity of small ruminant value chains

Value chains play an important role in linking the various stages from production to consumption and waste, including the many services involved. In this context, a life cycle assessment (LCA) approach is appropriate to account for the many stages of resource use and environmental emissions throughout the value chain from raw materials to production, transportation, processing, consumption and waste management. A value chain approach enables identification of potential factors for improvement throughout the life cycle.

In a number of developing countries, small farm owners encounter major problems in coping with a range of difficulties in the face of the complexity and general inefficiency of prevailing marketing chains. Foremost among these is access to a marketing chain. At present in developing countries, inadequate access to market outlets and weak marketing arrangements represent a major constraint to the *production to consumption systems* and to smallholder owners and producers of sheep and goats. The market chain involves rural, peri-urban, urban and international markets, and a major challenge lies in ways to link small farmers with these markets and marketing systems. In Asia, village slaughter centres can be important for increased access to marketing chains by farmers and include socio-economic elements. Rural markets are especially important to rural communities and their households, and are also used for the sale of live animals for slaughter in urban areas. Without improved marketing and transport systems, the prevailing systems constitute major constraints to the sale of animals and products from small farms.

In contrast, in intensive production systems in developed countries, linked value chains are prevalent. They are generally associated with large processing facilities and attempt to gain greater value from the many co-products from small ruminants.

The processing of products from small ruminants can potentially involve many complex stages with multiple end products. These guidelines extend only to primary processing, of which there are a diversity of primary processing systems:

- Specialist abattoirs disassemble animals into a very wide range of meat products and co-products. The latter include hides (for leather), tallow (e.g. for soap, biofuel), internal organs and meat waste (for pet food), blood (e.g. for pharmaceutical products), fibre and renderable material (e.g. for fertilizer).
- Specialist milk processing plants produce a wide range of basic products including cheese, yoghurt, whey and dried milk.
- Specialist fibre scouring plants wash and clean the fibre and may produce co-products such as lanolin.
- Some animals are sold for “backyard” slaughter (sometimes called “wet markets”) primarily for meat products.
- Village slaughter centres (especially in Asia) are associated with the slaughter of a relatively small number of animals to provide meat to villagers. At these centres, the offal and skins are generally sold on and processed at other specialist sites.

Alternatively, primary processed products (e.g. packaged cuts of meat from abattoirs, wool for use in insulation of houses) may be sent directly to wholesale or retailers for direct sale to customers. It is acknowledged that the various stages after primary processing, through to consumption and waste, may result in significant use of energy and refrigerants with associated GHG emissions. However, data requirements for these stages are often difficult to obtain and are usually derived from secondary data in published reports. It was considered impractical to attempt to include these various stages after primary processing in the current guidelines. However, a number of other Specifications or PCRs account for secondary processing and subsequent stages for textiles (e.g. BSI, 2013) and meat (e.g. Boeri, 2013).

A very wide range of secondary processing systems exist, but no attempt was made to account for them in these guidelines. Examples include transforming meat into specialist cuts or to final processed products (e.g. cooked lasagne pre-packed for retailers); carding and spinning fibre into yarns for clothing or carpet production; and addition of further ingredients to basic milk products to produce specialist products such as infant milk products.

6.4 Multi-functionality of small ruminant supply chains

Small ruminant production systems generate a range of goods and services, thus providing a wide range of contributions towards economic, social, food security, and agronomic and ecological objectives.

For many poor and vulnerable people, small ruminants play an important role in the four dimensions of food security (availability, access, stability and utilization) and are crucial to nutrition, providing high-quality proteins and a wide diversity of micronutrients. Where people have no access to banks and other financial services, small ruminants allow them to store and manage wealth, and are thus an important buffer in times of crisis.

In mixed crop-livestock systems, small ruminants often contribute to productivity, as manure is used to fertilize the soil and maintain organic matter, and herds are used to control weeds.

Small ruminants also play an important role in cultural and religious events. Among these is the Tabaski, celebrated by the Muslims of West and Central Africa, which requires the ritual sacrifice of animals.

Finally, small ruminants can contribute effectively to the management of landscapes and preserved ecosystems. In some areas (e.g. mountainous regions), small ruminants contribute to the cultural landscape, providing ecosystem services through encroachment control, conservation of biodiversity, and the presence of traditional agricultural activities and infrastructure.

6.5 Overview of global emissions from small ruminants

Globally, sheep and goats are responsible for about 6.5 percent of the livestock sector's emissions (475 million tonnes CO_2-equivalents) (Gerber *et al.*, 2013; Opio *et al.*, 2013). The global average GHG emission intensity of milk is lower for goats than for sheep (5.2 vs. 8.4 kg CO_2-eq/kg product, respectively), mainly because goats have higher milk yields on average at the global level. The corresponding GHG emission intensity of meat is very similar between the two species (23.3 vs. 23.4 kg CO_2-eq/kg product for goats and sheep, respectively). For both milk and meat, emission intensity tends to be lower in developed than developing regions. However, this should not be interpreted as suggesting an overall environmental superiority of developed country production systems, as noted in Section 2.2. Enteric fermentation and feed production largely dominated the sources of GHG emissions along the supply chains in these studies, accounting for 55 percent and 35 percent of emissions from small ruminants, respectively. In regions where natural fibre production (wool, cashmere, mohair) is economically important, a substantial share of emissions can be attributed to these products (especially when the economic value is used to allocate emissions between edible and non-edible products).

Gerber *et al.* (2013) also show that emission intensities vary greatly between production units, even within similar production systems, leaving much room for improvement. If the bulk of the world's small ruminant producers adopted technologies and practices already used by the most efficient producers in terms of emission intensity, it would result in significant reductions in emissions. A major driver of GHG emission intensity is the efficiency of feed conversion into product, which is determined by potential animal productivity, as well as feed availability and quality through the year. Manure management also has an important effect on GHG emissions. Opportunities for reducing GHG emission intensity include improved animal breeding, feeding, health and reproduction. Management practices to improve production and quality of feed sources, including through efficient use of manure for better nutrient capture and recycling, can also enhance animal productivity. However, the potential for reducing GHG emission intensity are dependent on local climatic and feed conditions. Indeed, in some ecosystems, small ruminants may be one of the only options landholders have to utilize low quality forage for production of protein for human consumption. In some grassland and rangeland systems there is also potential for increased carbon sequestration in vegetation and soils.

PART 2:

METHODOLOGY FOR QUANTIFICATION OF GREENHOUSE GAS EMISSIONS AND FOSSIL ENERGY DEMAND OF SMALL RUMINANT PRODUCTS

7 DEFINITION OF PRODUCTS AND PRODUCTION SYSTEMS

This document is intended to provide guidelines for users to calculate the GHG emissions and removals for small ruminant (sheep and goats) products over the key stages of the cradle-to-farm-gate or the cradle-to-primary processing gate. The guidelines are based on use of an attributional life cycle assessment (LCA) approach. It is expected that the primary users will be individuals or organizations that have a good working knowledge of LCA.

7.1 Products description

These guidelines cover the cradle-to-primary processing gate and the main products generated comprise one or more of:

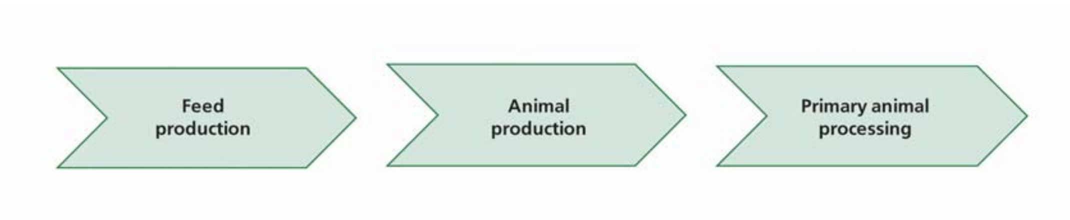
- meat products, with possible co-products such as tallow, skins and renderable material;
- clean fibre (i.e. wool, mohair or cashmere) and possible minor lanolin co-product;
- milk products such as cheese, yoghurt and milk powder, with possible co-products such as whey.

These products are produced from a very diverse range of production systems around the globe.

7.2 Life cycle stages: modularity

A life cycle assessment of primary products can be conducted by dividing the production system into modules that relate to the different life cycle stages. The three main stages can be summarized as feed production (including feed processing, milling and storage), animal production (including animal breeding) and primary animal processing (Section 8.4) (Figure 5). The feed production stage covers the cradle-to-animal's mouth stage and includes a range of feeds including processed concentrates, forage crops, pastures, shrubs and trees (see the LEAP Animal Feed Guidelines). The animal production stage covers the cradle-to-farm-gate stage and the main products generated are live animals, fibre (e.g. wool for sheep and mohair or cashmere for goats) and/or milk.

FIGURE 5: MODULAR SCHEME OF SMALL RUMINANT PRODUCTION CHAINS



8 GOAL AND SCOPE DEFINITION

8.1 Goal of the LCA study

The first step required 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 to serve the goal of GHG emission management by determining the carbon footprint of products, understanding the GHG emission hotspots and prioritizing emissions-reduction opportunities along supply chains. LCAs provide detailed information on a product's environmental performance and can serve performance tracking goals as well as setting progress and improvement targets. They could also be used to support reporting on the environmental impacts of products, although these guidelines are not intended for comparison of products or labelling of environmental performance.

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

Seven aspects shall be addressed and documented during the goal definition (European Commission, 2010):

- Subject of the analysis
- Key properties of the assessed system: organization, location(s), dimensions, products, sector, and position in the value chain;
- Purpose of performing the study and decision-context;
- Intended use of the results: will they be used internally for decision-making or shared externally with third parties?
- Limitations due to the method, assumptions, and choice of impact categories: in particular, limitations to broad study conclusions associated with exclusion of impact categories shall be addressed;
- Target audience of the results;
- Comparative studies to be disclosed to the public and need for critical review;
- Commissioner of the study and other relevant stakeholders.

8.2 Scope of the LCA study

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 so as 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 life cycle inventory, as described in more detail in Section 10.1.

These guidelines refer only to two environmental impact category (climate change characterized through GHG emissions, and reported as CO2 equivalent and fossil energy demand) and therefore should not be used to provide an indicator of overall environmental effects of the production systems and products. Care is therefore needed in the reporting and communication of the results of assessments based on these guidelines to avoid misinterpretation of the scope and application of the results.

8.3 Functional unit

The functional unit defines the form and units used to specify a product. Different functional units are appropriate when different downstream system boundaries are specified (e.g. farm gate, processing plant, retail, post-consumption to grave). Recommended functional units for different main product types are given in Table 1. Where meat is the product type, the functional unit when the animal leaves the farm shall be **live-weight**. At the stage of leaving the meat-processing plant (or abattoir) the functional unit 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 offals (e.g. liver, kidney, heart) and green offals (e.g. stomach and intestines) are increasingly being harvested and should be included. In developing countries, the meat-processing site may vary from processing plants to "backyard" or cottage industry processing (sometimes termed "wet market"), and a higher proportion of the animal may be harvested for human consumption. Note that the "product-weight" includes bone retained within the animal parts for human consumption (primary processing plants for small ruminants typically leave bone in many of the meat cuts). The relative bone content has been estimated at approximately 18 percent of a sheep's carcass-weight in UK studies (Kim Matthews, EBLEX UK data). Ideally, the bone content of the total meat product would be defined, but this is rarely measured. However, it shall be stated when the functional unit includes bone-in, and if the bone content is outside the usual range for the carcass component it shall be described and an estimate of the bone content provided. 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 (Appendix 3). No distinction is made between different cuts of meat, including edible offal, and they shall be treated as equivalent (with no specific allocation method used for different cuts). An example of the relative content by weight of different meat cuts and co-products is given in Box 4 in Section 11.6.3.

Where fibre is the main product type, the functional unit shall be **greasy weight** (as shorn off the animals) at the farm gate or **clean weight** after it leaves a scouring plant. The scouring plant is the only primary processing stage covered by these guidelines (see Section 8.4).

Where milk is the main product type, the functional unit shall be the weight of the milk as it leaves the farm gate corrected for fat, protein and lactose content (**energy-corrected milk**). The latter standardizes the milk after adjustment for differences associated with animal type, breed and production. To provide comparison with dairy cow milk, the following equation from the IDF (2010a) methodology is recommended for energy-corrected milk (ECM):

$$\text{kg ECM} = \text{kg milk} \times (0.1226 \times \text{fat\%} + 0.0776 \times \text{true-protein\%} + 0.0621 \times \text{lactose\%})$$

Where crude-protein % is used instead of true-protein %, the relevant multiplier is 0.0722 (instead of 0.0776). This equation standardizes the milk to 4 percent fat, 3.3 percent protein and 4.8 percent lactose. Research indicates that lactose % can vary during the lactation season and with species (e.g. Park and Haenlein, 2006), and therefore it is desirable to account for lactose % in the equation for ECM. However, if data on lactose % are unavailable, a default value of 4.8 percent lactose shall be used for sheep and goats. After the milk primary processing stage there are a wide range of possible products and the appropriate functional unit reported shall be the weight of the specific product (**milk product weight**).

TABLE 1: RECOMMENDED FUNCTIONAL UNITS FOR THE THREE DIFFERENT MAIN PRODUCT TYPES FROM SMALL RUMINANTS ACCORDING TO WHETHER THEY ARE LEAVING THE FARM OR THE PRIMARY PRODUCT PROCESSING GATE

Main product type	Cradle-to-farm-gate	Cradle-to-primary processing gate
Meat	Live-weight (kg)	Meat product(s) (kg)
Fibre	Greasy weight (kg)	Clean weight (kg)
Milk	Energy-corrected milk (kg)	Milk product(s) (kg)

8.4 System boundary

8.4.1 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. A full LCA would include processing, distribution, consumption and final disposal; 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 small ruminants (Figure 6). It covers the main stages of the cradle-to-farm-gate, transportation of animals to primary processor, and then 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 of the cradle-to-primary processing gate. The feeds stage is covered in detail in the associated LEAP Animal Feed Guidelines document and covers the cradle-to-animal's 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 lambs/kids and nutrients directly fed to animals; covered in detail in Section 11.2).

The animal production stage covers all other inputs and emissions associated with animal production and management not covered by the LEAP Animal Feed Guidelines. It is important to ensure that 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 as well as those used directly for meat/milk/fibre production. This may involve more than one farm if animals are traded between farms prior to going to processing.

The primary processing stage shall be limited to the primary milk-processing factory, the scouring or cleaning stage for fibre, and animal slaughter (backyard, village slaughter centre and abattoir) for meat processing. It includes all transportation steps within the cradle-to-primary processing gate.

The choice of basic milk, meat products and clean fibre 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. 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. sweetened fruit yoghurt, lasagne). For fibre, a range of secondary processing options exist depending on the end product, for example, yarn/fibre spinning, dyeing, knitting/weaving and garment-making; spinning and carpet or rug making; or direct use as insulation or absorbent for contaminants such as oil spills.

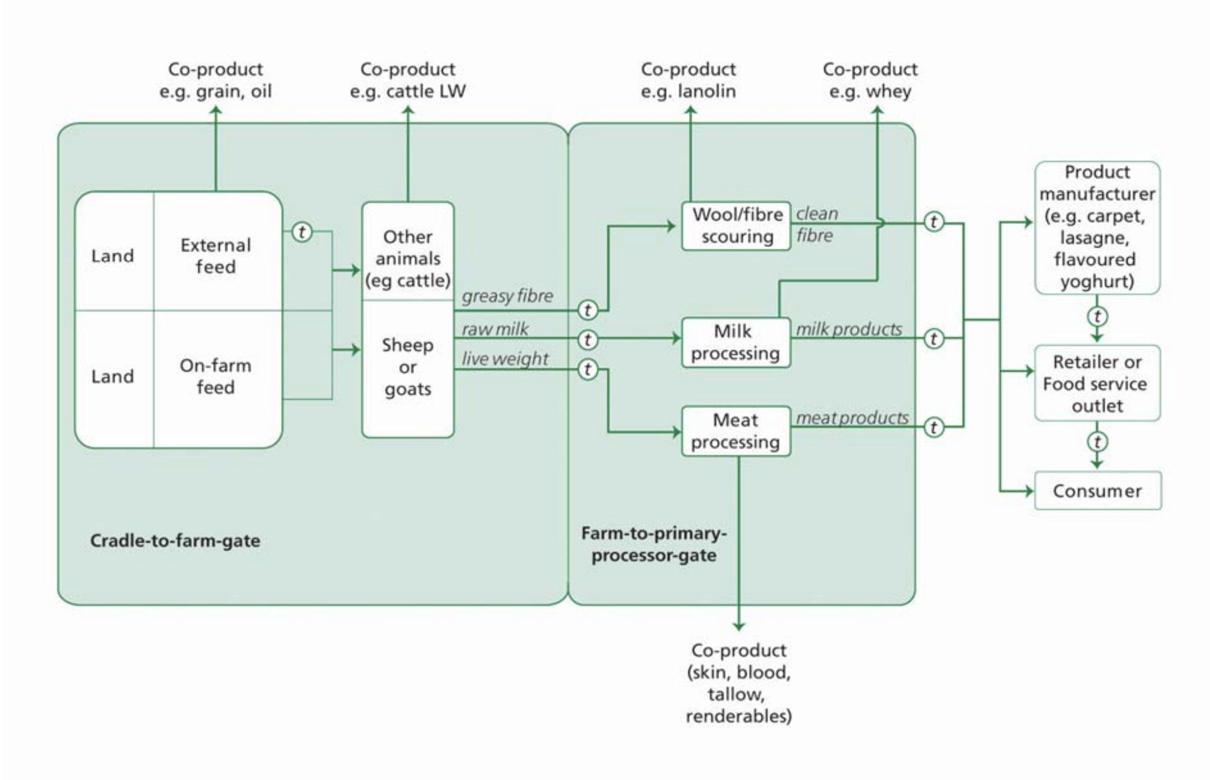
Several available product category rules (PCRs) extend beyond the system boundary covered in these guidelines and include the post-primary processing supply chain for meat (Boeri, 2013) and fibre (Rossi, 2012). There are no PCRs for processed milk products from small ruminants, but there are for dairy cow milk products (e.g. Sessa, 2013b). There are no PCRs for carpets, but some early LCA publications exist for carpets (e.g. Petersen and Solberg, 2004; Potting and Blok, 1995) that illustrate some of the non-fibre constituents and additional processes. There is a draft Specification under development for textile products (BSI, 2013).

Figure 6 illustrates a range of co-products produced from the farm to primary processing gate, which fall outside the system boundary covered by these guidelines. There are no PCRs related specifically to these co-products. However, there are some relevant LCA publications for leather (Joseph and Nithya, 2009; Mila i Canals *et al*., 1998; Mila i Canals *et al*., 2002), biofuel from tallow (Thamsiriroj and Murphy, 2011), thermoplastic from blood meal (Bier *et al*., 2012) and products from rendering animal processing byproducts (Ramirez *et al*., 2011).

a) Scoping analysis

Frequently a scoping analysis based on a relatively rapid assessment of the system can provide valuable insight into areas which may require additional resources to establish accurate information for the assessment. Scoping analysis can be conducted using secondary data to provide an overall estimate of the system impact. Furthermore, based on existing literature reviews in the small ruminant sector (Appendix 1), it is relatively clear that for production systems it is extremely important that the following factors are assessed with high accuracy: the ration, the feed conversion efficiency, 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 is important.

FIGURE 6: SYSTEM BOUNDARY DIAGRAM FOR THE LIFE CYCLE OF SHEEP OR GOATS COVERING THREE MAIN PRODUCTS (FIBRE, MILK AND MEAT)



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 "sheep or goats" box may include up to several phases of movement of animals between different farms/areas/systems before progress to primary processor.

8.4.2 CRITERIA FOR SYSTEM BOUNDARY

Material system boundary: Which entities and processes are included in the assessment? What is the analysed company's sphere of influence? Which entities and processes are excluded from the assessment, and for what reasons? A flow diagram of all assessed processes should be drawn indicating where processes were cut off. For the main transformation steps within the system boundary, it is recommended that a material flow diagram is produced and used to account for all of the material flows, e.g. within the processing stage the live weight is defined and shall equate the sum of the mass of the products produced.

Spatial system boundary and stages: The cradle-to-farmgate stage includes feed and animal components. The LCA of feeds is covered in detail in an associated document (LEAP Animal Feed Guidlines) 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, animals may graze/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 cover all emissions associated with land use and land-use-change.

The animal components cover all other inputs and emissions in the small ruminant supply chain not covered by the LEAP Animal Feed Guidelines. This includes emissions associated with small ruminant production and management. The latter includes accounting for the fate of excreta; however, it is important to avoid double counting if excreta is captured as manure and represents a direct input for feed production (manure emissions from transport and application are included in the LEAP Animal Feed Guidelines). Animal production may involve more than one farm if animals are traded between farms prior to going to processing (e.g. lambs/kids 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.

For the meat processing stage, there shall be no differentiation between the various products that are edible by humans therefore impacts are divided evenly by mass over all such products from the small ruminant supply chain because there are no significant biophysical or nutritional differences between them (Section 11).

The primary processing stage is limited to animal slaughter (backyard, village slaughter unit and 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 on-selling to large abattoirs near the 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.

The system boundaries covered shall include the feed production, animal production and primary processing stages.

8.4.3 MATERIAL CONTRIBUTION AND THRESHOLD

In determining whether to expend resources and effort to include specific inputs, a 1 percent cut off threshold for mass and energy should be adopted; larger thresholds shall be explicitly documented and justified by the project goal and scope definition. Inputs to the system that represent less than 1 percent of the mass or less than 1 percent of the energy required for a specific unit process (activity) in the system can be excluded from the analysis. Instead, a scoping analysis (Section 8.2) can be used to provide an estimate. An exception to this exclusion is made in cases where significant environmental impact is associated with a small mass input (e.g. some material may be present in small quantities, yet still have a relatively large environmental impact; these should be included). A minimum of 95 percent of the impact for each category shall be accounted for.

8.4.4 Time boundary for data

Documentation for temporal system boundaries shall describe how the assessment deviates from the one-year time frame. By how many years is the temporal scope extended for the model parameters?

The time boundary for data shall be representative of the time period associated with the average GHG emissions for the products. For products from small ruminants, a period of 12 months shall be used, since this length of time is typical for the breeding cycle of sheep and goats.

In some cases where there may be considerable inter-annual variability in inputs, production and emissions, it may be necessary for the one-year time boundary to be determined using data averaged over 3 years to meet criteria of representativeness. An averaging period of 3 to 5 years is commonly used to smooth the impact of seasonal and market variability on agricultural products.

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 life cycle inventory; however, the operation or occupation of, or other activities utilizing capital goods shall be accounted. However, for studies in which the goal and scope include assessment of alternate systems for which there may be significant differences in infrastructure requirements, capital goods production shall be included.

8.4.6 Ancillary activities

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

8.4.7 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 (Section 8.4.4). Delayed emissions from soil and vegetation may be considered in the LEAP Animal Feel Guidelines. The PAS 2050:2011 provides additional guidance regarding delayed emissions calculations for interested practitioners (BSI, 2011).

8.4.8 Carbon offsets

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

8.5 Impact categories

These guidelines are primarily based on assessment of GHG emissions. The total GHG emissions for individual gases are summed along the system boundary. Individual gases are then multiplied by the relevant characterization factor to convert them all into a common unit of carbon dioxide equivalents (kg CO_2eq). The characterization factors shall be based on the Global Warming Potentials of the specific gases over a 100-year time horizon using the most recent IPCC factors which can be found in the latest IPCC guidance documentation. Because characterization factors change as our understanding evolves, it is important to note in the report documentation what specific sources were used for them.

The fossil energy demand should also be calculated, since all inputs of fossil fuels have to be determined as part of the data collection requirements for assessing GHG emissions. This is captured in the impact category called Cumulative Energy Demand and sub-category of non-renewable energy resources, and uses the Lower Heating Value of the fuel for its characterization factor (Huijbregts et al., 2006). It shall account for the embodied primary energy for the production and combustion of the various energy sources and may draw on recognised databases such as Ecoinvent (Frischknecht et al., 2005). Fossil energy demand for the production and use of electricity, which will be specific for a particular country, shall also be included.

The LCA of products should account for a range of resource use and environmental impact categories. It is intended that in future these guidelines be updated to include multiple categories *(*Section 5.3).

9 MULTI-FUNCTIONAL PROCESSES AND ALLOCATION

One of the challenges in LCA has always been associated with 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 and explained, including 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 situations where system separation or expansion is not used, the allocated inputs and outputs should equal unallocated inputs and outputs.

9.1 General principles

The ISO 14044 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: i.e. they should reflect the way in which the inputs and outputs are changed 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, for example allocation of process energy between small ruminant meat and other non-human edible products, the allocation procedures should follow the ISO 14044 allocation hierarchy. When allocation choices significantly affect the results, a sensitivity analysis shall be performed to ensure robustness of conclusions.

Below is a list of commonly used procedures for addressing multi-functional processes, as stated, for example, in ISO 14044 (2006, Section 9). Allocation can be based on other relationships such as:

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

Avoided burden or system expansion can be based on:

- displacing average;
- displacing marginal;
- differentiating whether one is dealing with a determining or non-determining product flow, or an avoided burden followed by sharing of credit.

9.2 A decision tree to guide methodology choices

A decision tree diagram to help decide on the appropriate methodology for dealing with co-products is given in Figure 7. This involves a three-step approach and the principles involved in working through it are as follows:

Step 1: Avoid allocation by subdividing the processing system into three categories.

A production unit is defined here as 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 different animal herds (sheep, goats, cattle, deer), or the individual processing lines in a manufacturing facility.

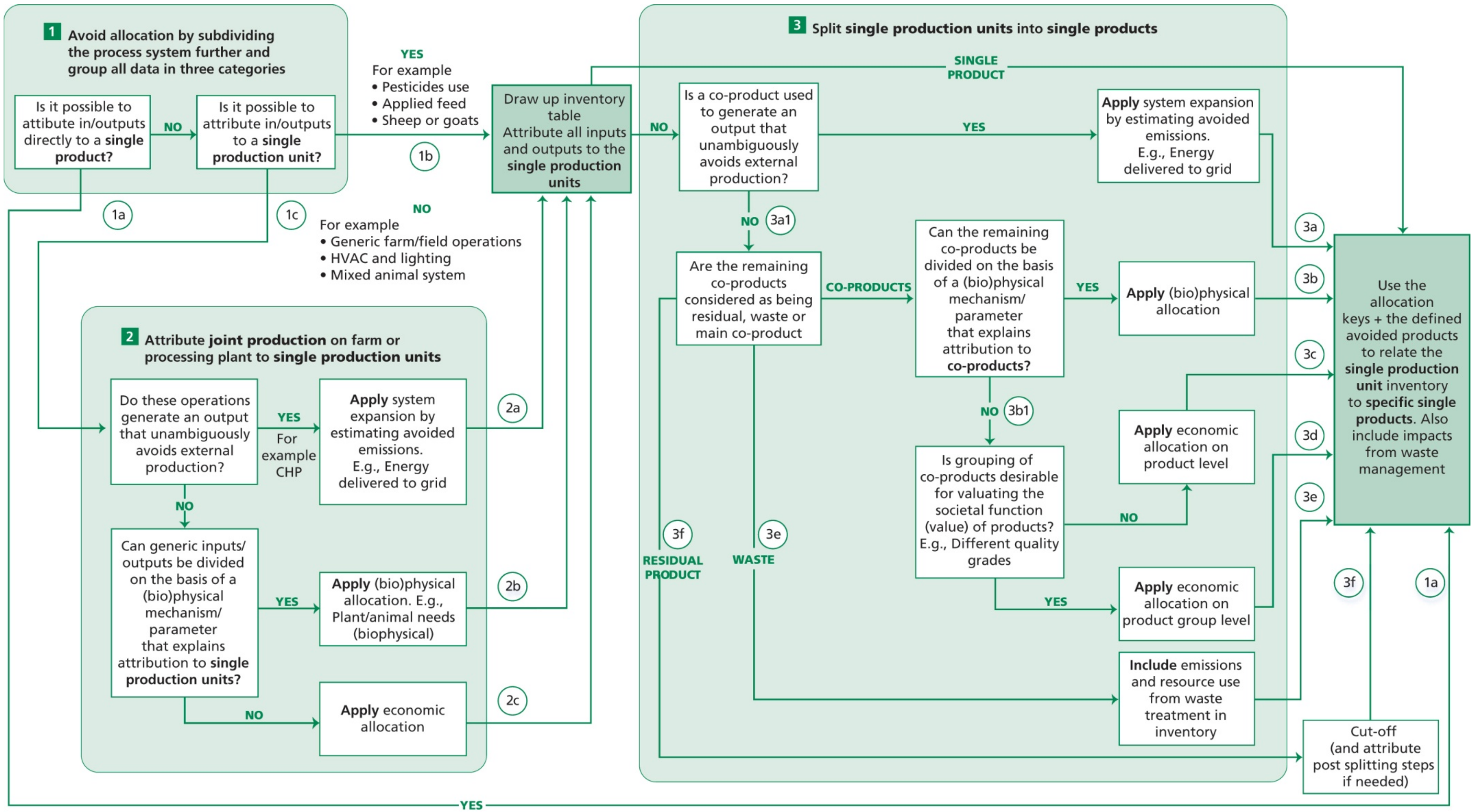
In the first step (ISO step (1a) subdivision) all processes and activities of a farm/processing facility are divided into three categories: the condition is that inputs/emissions are easily divided over the processes and that enough information about the inputs/emissions is available.

flow 1.a. Inputs/activities that should be directly assigned to a single 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.b. Inputs/activities that should be assigned to production units that can provide single or multiple co-products, e.g. input of pesticides or energy inputs of operations of a barn or manufacturing facility, or feed for a specific animal type at a farm.

flow 1.c. Inputs/activities of a nonspecific nature in a farm or processing facility such as heating, ventilation, climate control, internal transport in a manufacturing facility or farm that cannot be directly attributed to production units. For example energy to pump drinking water for multiple animal species in a small-scale, multi-species operation.

FIGURE 7: 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.

Step 2. Attribute joint production to production units

In theory, all joint production systems are separable, where sufficiently detailed data exist, and should normally follow path 1a. Nevertheless, situations exist where this is impractical, and in step 2 (Figure 7) the generic processes should be attributed to production units on the basis of ISO steps 1b, 2 and 3. For example sheep, goats, cattle, alpaca and deer may be all raised in a single 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/Step 2. For some production systems, the 1b path to box 3 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.

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

If an output generated by the production unit unambiguously avoids external production, apply substitution (system expansion). There is one important condition for system expansion: that the avoided co-product shall be fully equivalent. This means that you shall be very certain and clear about the avoided production and that there should be no, or minimal interference with other production systems. The result of this step will be an avoided product in the inventory for the unit process; however, at the inventory level there is no corresponding reduction in the emissions or exchanges with the environment. The credit for the substitution will arise in subsequent calculations.

When system expansion is not possible, the second question is whether a physical allocation is possible. The condition here is that the products should have similar physical properties and serve similar goals or markets, or that known processing or biophysical relationships can be used to assign inputs and outputs of a single production unit to each product. 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 step will be a splitting of some inventory flows between the production units, and if the resultant unit process is multifunctional, these inventory flows will be allocated to single co-products in the next step of the procedure (box 3 in Figure 7).

If inputs in a multiple production system benefit all products and cannot be specifically assigned to production units, the allocation should be preferably based on a physical property or mechanistic algorithm (flow 2b in Figure 7).

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 multifunctional, these inventory flows will be allocated to single co-products in the next step of the procedure (Box 3 in Figure 7).

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

After performing steps 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. Step 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. In the case of a multifunctional production unit, the first approach is to employ system expansion. The same rule holds as the one defined above for production units, so only in very clear situations of avoidance, such as connection to an electricity grid, system expansion should be applied. Any flow arising from 3a will follow this path. When system expansion is not possible, the remaining outputs must be classified as co-products, residual products or wastes. Existing standards state that a footprint should not get a credit for sold electricity (or natural gas) that is incorporated into grid factors (WRI 2011; BSI 2011). Therefore it is not valid, according to these existing standards, to provide a credit using system expansion (or other method) for sold electricity/gas. Further, system expansion does not provide a footprint for the avoided product that can be used in another LCA (for a downstream system). This guidance strongly encourages other methods for allocation, in particular when there is a danger for improper interpretation at policy level when several LCAs are combined to obtain an aggregated view of the larger system; specifically, if an animal production system uses system expansion, and a later crop production analysis assumes the credit for use of manure, there will be a 'double credit' in the combined system.

Outputs of a production process are considered as residual if (flow 3f):

- they are sold in the condition in which they appear in the process and contribute very little to the turnover of the company (total value of the flow less than 1 percent);
- the upstream and production process that produce the outputs are not deliberately modified for the outputs, and has a subsequent use. There may be value-added steps beyond the boundary of the small ruminant system under study, but these activities do not impact the small 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 it carries no economic value or 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. For the small ruminant sector, the most common process falling in this category is wastewater treatment at processing facilities and, in some cases, manure sent to a landfill. Manure exported off-farm is discussed below.

All other co-products are subject to allocation, leading to flows 3b, 3c and 3d in Figure 7. Assignment to these flows depends upon whether physical, biophysical or mechanistic allocation is possible (3b), or whether an economic allocation at a single product (3c) or product group level (3d) is applied.

The condition for determining whether physical allocation is appropriate is that the products should have similar physical properties and serve similar functions or markets, or a straightforward mechanistic algorithm can be identified, or that biophysical relationships can be used to assign inputs and emissions to each product. When physical allocation is not feasible (interactions too complex to accurately define a mechanistic relationship) or is not allowed (dissimilar properties or markets), the last option is economic allocation.

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 can be grouped before allocation between them and other inedible co-products such as hide, blood and renderables.

9.2.1 Allocation of transport

Estimating environmental impacts of transportation entails two allocation issues: allocation of empty transport distance covered by transport means and allocation of the load fraction of transportation means. The allocation of empty transport distance is often already included in the models used when the secondary life cycle inventory (LCI) data for transportation were created. However if primary data for transport are derived, the LCA practitioner shall make an estimate of the empty transport distance. In the absence of other information, a worst-case estimate should be applied here, meaning inclusion of 100% extra transport for empty return. Allocation of empty transport kilometres shall be done on the basis of the average load factor for the transport under study. If no supporting information is collected, it shall be assumed that 100% extra transport is needed for empty return.

If products are transported by a vehicle, resource use and emissions of the vehicle shall be allocated to the transported products. A means of transport has a maximum load. This maximum load is expressed in tonnes. However the maximum weight can only be achieved if density of the loaded goods allows it. Therefore allocation of transport emissions to transported products shall be done on the basis of mass share ***unless*** the density of the transported product is significantly lower than average so that the volume restricts the maximum load.

9.3 Application of general principles for small ruminant systems and processes

In practice, dealing with multi-functional processes and the choice of allocation method is a contentious issue in LCA studies and for small ruminants there are a number of steps where allocation decisions are required. Thus, this guidelines document goes into some detail on each of these steps and gives recommendations on the preferred allocation methodology for each one (Section 11.2.5 and 11.6). The recommended methods, based on use of the decision tree, are summarized in Table 2.

Cradle-to-farm-gate: Within the cradle-to-farm-gate stage there are a number of allocation decisions associated with feeds; these are described in the LEAP Animal Feed Guidelines. 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;
- where small ruminants produce multiple products of meat, milk and fibre.

In ruminant livestock systems, the major determinant of GHG emissions is enteric methane and excreta N_2O emissions, and the driver of these is feed intake. 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 (i.e. step 1c in Figure 7, since this is not a single production unit) is based firstly on separation of activities between species and then on determination of feed intake for each species (i.e. step 2b in Figure 7). Remaining shared inputs (e.g. energy use for water provision and animal movement) are allocated according to relative feed intake between species.

At a 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 value for the target small ruminant species based on relative feed intake to determine that species' total emissions.

TABLE 2: 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 SMALL RUMINANT PRODUCTS

Source/stage of co-products	**Recommended method***	**Basis**
Animal species (within farm)	1. Separate farm activities 2. Biophysical causality	First, separate the activities specific to an animal species. Then, determine emissions specific to feeds relating to the sheep or goats 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.
Meat, fibre, milk (within farm)	1. Separate activities 2. Biophysical causality	First, separate activities specific to products (e.g. electricity for shearing or milking). Then use biophysical allocation according to energy or protein requirements for animal physiological functions of growth, fibre production, milk production, reproduction and maintenance.
Milk processing to milk products	1. Separate activities 2. Mass of fat + protein	First, separate activities specific to individual products where possible. Then use allocation based on the relative amount of fat + protein in the milk products
Fibre processing to clean fibre and lanolin	1. Separate activities 2. Economic	First, separate the activities specific to individual products where possible. Then use economic allocation based on a minimum of three years of recent average prices.
Meat processing to meat and non-meat products	1. Separate activities 2. Economic	First, separate the activities specific to individual products where possible. Then use economic allocation based a minimum of three years of recent average prices.

Note: * 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.

For sheep or goats (i.e. which are a single production unit and therefore follow step 1b), the allocation between meat, milk and fibre co-products shall be based on biophysical allocation according to feed requirements for production of the products (described in detail in Section 11.2.5; steps 3a1 and 3b in Figure 7). This aligns with the IDF (2010a) methodology for allocation between milk and meat for dairy cows. Previous studies have shown that the choice of allocation method for meat, milk and fibre co-products can have a significant effect on reported GHG emissions (e.g. Ledgard *et al*., 2011; Gac *et al*., 2012). As noted previously, where 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 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).

Manure exported off-farm: In some situations, part or all of the excreta from animals may be collected and sent off-farm. In practice, this is of minor importance in most small ruminant systems and detailed discussion on options for handling manure exported off-farm are given in Appendix 4. It is the strong recommendation of these guidelines that the default method for manure should be to consider it as a *residual* at the farm gate. This is most applicable when manure has essentially no value as it leaves the farm gate. In such cases, emissions linked to the production and storage on-farm of manure would go to the other co-product(s) of live-weight, milk and greasy fibre. Appendix 4 outlines other options including system expansion relating to energy or fertilizer, or treating manure as a co-product, residual or waste.

Primary processing: For the milk primary processing stage (a single production unit following steps 1b, 3a1 and 3b in Figure 7), allocation between co-products shall be based on the relative mass of fat + protein. The use of this approach for dairy products aligns with that used in recent publications for milk products from dairy cows (Flysjö *et al*., 2011; Thoma *et al*., 2013b), and meets the requirements for similarity of products in Figure 7. However, for fibre and meat-processing systems the products have very different end uses (except in meat processing for offal and meat cuts, which are seen as having the same function and are considered together in the same product group of "edible meat products"); therefore, economic allocation is considered the most appropriate approach using Figure 7 (i.e. steps 3b1 and 3c or 3d). It is recognized that some co-products may be identified as being of no economic value after primary processing (and in Figure 7 would be classified as a residual; step 3f), but that they may be collected and used for secondary processing (e.g. used for burning for energy or used for producing blood-and-bone meal). However, in that case the product, having undergone secondary processing, is considered to fall outside the system boundary for these guidelines.

10 COMPILING AND RECORDING INVENTORY DATA

10.1 General principles

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

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

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

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

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):

- **Representativeness**: qualitative assessment of the degree to which the data set reflects the true population of interest. Representativeness covers the three following dimensions:
    a) time-related 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, LCA practitioner shall document the data sources, the data quality, and any efforts made to improve data quality.

10.2 Requirements and guidance for the collection of data

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

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

For projects where significant primary data is to be collected, a data management plan is a valuable tool for managing data and tracking the process of LCI data set creation, including metadata documentation. The data management plan should include (WRI 2011, 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 and that have a documented Quality Assessment (Section 10.3);
- data from previous projects that have a documented Quality Assessment;
- data published in peer-reviewed journals or from generally accepted LCA databases that are regarded as reliable sources of information;
- data presented at conferences or otherwise publicly available (e.g., internet sources);
- data from industrial studies or reports can be considered.

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 to GHG emissions. Foreground processes, here defined as those processes under the direct control of, or significantly influenced by, the study commissioner, are depicted in Figure 6 under feed, water and animals. Raw material acquisition represents background data. For 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, methane emissions from animal rumen fermentation and manure management. In cases such as this, when a model is used to estimate the emission, the input data used for the model shall be measured.

The practicality of measured data for all foreground processes is also related to the scale of the project. As an example, if a national-scale evaluation of the small ruminant sector is planned, it is impractical to collect farm-level data from all small 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 to ensure compatibility with the study goal and 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 respect geographic relevance (e.g. for crop yield in relation to climate and soils) and align to the defined goal and scope of the analysis. Each data source should be acknowledged and uncertainty in the data quality noted.

Prior work (e.g. Appendix 1) has identified the main hotspots and primary data (or modelled estimates using primary input data) 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. c. 80 percent in Ledgard *et al.*, 2011) and animal enteric methane can represent around 50-70 percent of cradle-to-farm-gate emissions. Thus, animal population and productivity, and feed quality data are key primary activity data needed to calculate enteric methane emissions. Similarly, methane and N_2O 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 calculate them. Where manure is collected from animals, methods of storage and use can have a significant effect 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. 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). In a whole life cycle analysis, Ledgard *et al.* (2011) showed that transportation accounted for up to 5 percent of total GHG emissions, including shipping of product up to 20,000 km to distant markets. The study showed that all emissions associated with meat processing (abattoirs) represented 3 percent of total life cycle emissions, of which fuel use, electricity use and wastewater processing were the dominant contributors.

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

Secondary data refers to life cycle inventory data sets generally available from existing third-party databases, government or industry association reports, peer-reviewed literature, or other sources. It is normally used for background system processes, such as electricity or diesel fuel which may be consumed by foreground system processes. When using secondary data it is necessary to selectively choose the data sets which will be incorporated into the analysis. Specifically, life cycle inventory for goods and services consumed by the foreground system should be geographically and technically relevant. 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 GHG emissions, 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 calculation of the 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, a relevant electricity emission factor for the country or site of use should be used that accounts for the relevant 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.
- They should be used only for processes in the background system. When available, sector-specific data shall be used instead of proxy LCI data.
- They shall fulfill the data quality requirements specified in this guide (Section 10.3).
- They should, where available, be sourced following the data sources provided in this guide (e.g. Section 11.2.2 for animal assessment and in Appendices 3 and 5).
- 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 data sets 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 is sufficiently representative of the given process in the product's life cycle. LCI data gaps can result in inaccurate and erroneous results (Reap *et al.*, 2008). When missing LCI is set to zero, the result is bias towards lower environmental impacts (Huijbregts *et al.*, 2001).

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

The use of proxy data sets – background LCI data sets which are the most similar process/product for which data is available – is common. This technique relies on the practitioner's judgment, and is therefore, at least arguably, arbitrary (Huijbregts et al. 2001). Using the average of several proxy data sets has been suggested as a means to reduce uncertainty compared to the use of a single data set (Mila i Canals et al. 2011). Mila i Canals et al. 2011 also suggest that extrapolation from one data set to bridge the gap may also be used. For example, data from goat and sheep production could be extrapolated for production of other small ruminants (e.g. deer, llama, alpaca), based on expert knowledge of differences in feed requirements, feed conversion ratios, excreta characteristics, and fibre or antler 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 as a means of bridging data gaps. In this approach the monitor value of the missing input is analysed through the input-output tables and then used as a proxy LCI data set. This approach is of course subject to uncertainty and has been criticized (Finnveden *et al.*, 2009).

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

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

10.3 Data quality assessment

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

10.3.1 DATA QUALITY RULES

Criteria for assessing LCI data quality can be structured by representativeness (technological, geographical, and time-related), completeness (regarding impact category coverage in the inventory), precision/uncertainty (of the collected or modelled inventory data), and methodological appropriateness and consistency. Representativeness addresses how well the collected inventory data represents the "true" inventory of the process for which they are collected regarding technology, geography and time. For data quality, the representativeness of the LCI data is a key component and primary data gathered shall adhere to the data quality criteria of technological, geographical, and time-related representativeness. Table 3 presents a summary of requirements for data quality. Any deviations from the requirements shall be documented. Data quality requirements shall apply to both primary and secondary data. For LCA studies using actual farm data and targeted at addressing farmer behaviour, ensuring that farms surveyed are representative and the data collected is of good quality and well managed is more important than detailed uncertainty assessment.

TABLE 3: 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 the past three years and 5-7 years for secondary data sources. • The representative time period on which data is based shall be documented.

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, system boundaries, etc. During the data collection process, data quality of activity data, emission factors, and/ or direct emissions data shall be assessed using the data quality indicators. WRI/WBCSD has published additional guidance on quantitative uncertainty assessment[3] which includes a spreadsheet to assist in the calculations.

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

Secondary data for background processes can be obtained from, 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 – for example, if use of European electricity grid processes in other 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).

[3] http://www.ghgprotocol.org/calculation-tools/all-tools

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

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

10.4.1 Secondary activity data

See Section 10.2.2.

10.4.2 Default/proxy data

See Section 10.2.2.

10.4.3 Inter- and intra-annual variability in emissions

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

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11 LIFE CYCLE INVENTORY

11.1 Overview

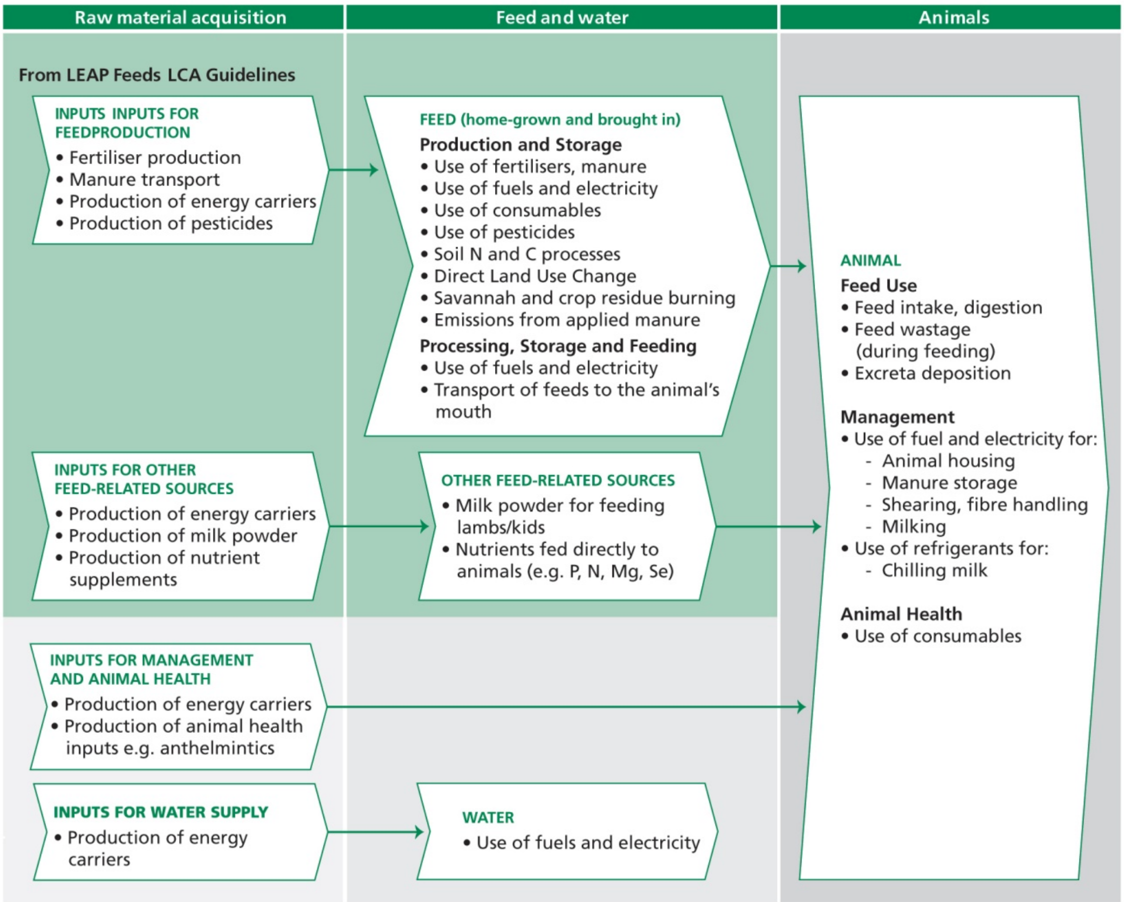
The life cycle inventory (LCI) analysis phase involves the collection and quantification of inputs and outputs throughout the life cycle stages covered by the system boundary of the study (Figure 6). This typically involves an iterative process (as described in ISO 14044: 2006), with the first steps involving data collection using principles as 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 allocation for different co-products); and aggregation of data, ensuring all significant processes, inputs and outputs are included within the system boundary.

The system boundary (Figure 6) has pre and post farm gate stages.

11.2 Cradle-to-farm-gate

The cradle-to-farm-gate stage consists of three main processes of raw material acquisition, water and feed production, and use for animal production (Figure 8). Most raw material acquisition is associated with the production of feeds. Note that these guidelines only provide limited background information related to animal feeds because these are covered in the separate LEAP Animal Feed Guidelines document. Thus, animal feeds information is presented largely for context, but also because of the strong linkage between feeds and animal production.

FIGURE 8: PROCESSES THAT CONTRIBUTE TO GHG EMISSIONS AND FOSSIL ENERGY DEMAND 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 blue background refers to inputs, processes and emissions covered by the LEAP Animal Feed Guidelines and not part of the current guidelines.

Water supply to animals is important for their survival and energy inputs are often required for the provision (e.g. for pumping and reticulation) and/or transport of water. The GHG emissions associated with this and other sources of energy use shall be included. There is also a small contribution to resource use and GHG emissions associated with the production and provision of animal health inputs, which may include treatments for infectious diseases, internal and external parasites, reproductive diseases and metabolic diseases (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 illustrating the various steps involved is presented in Figure 9.

At the cradle-to-farm-gate stage, previous research has shown that the largest single source of GHG emissions is methane from digestion of feeds in the rumen of goats and sheep. For example, Ledgard *et al*. (2011) estimated enteric methane at 57 percent of the total life cycle emissions for lamb from New Zealand consumed in England. Thus, it is important to obtain an accurate estimate of feed intake by small 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.

11.2.1 Feed assessment

The production, conservation and use of feeds can represent a significant contributor to the total resource use and GHG emissions from small ruminant products. Thus, it is important to accurately identify the number and types of feeds used, which can vary markedly in different small ruminant production systems, as discussed in Section 6.2. Determination of the amount of each feed used is described in detail in Section 11.2.2.

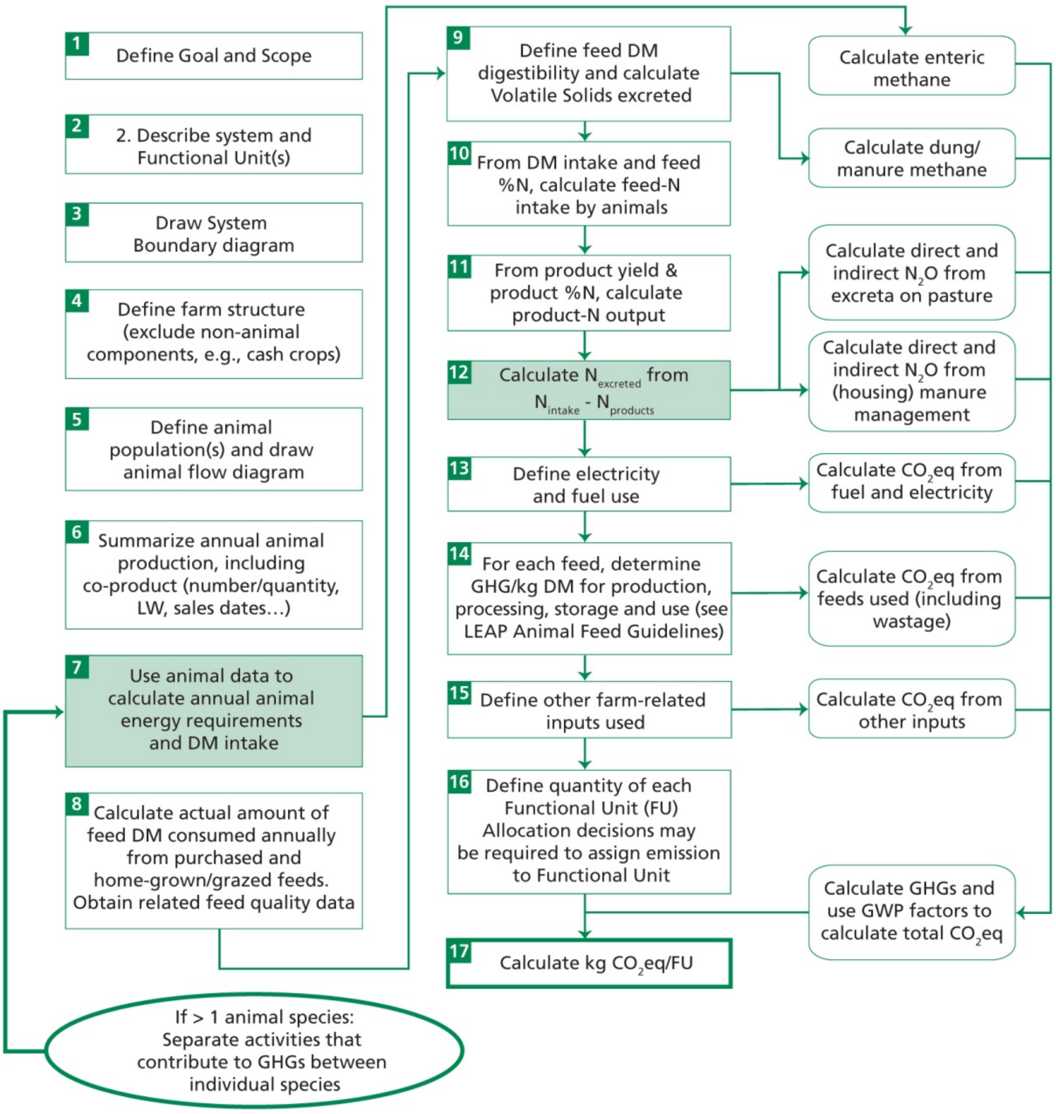
Feed types can vary from annual crops (where the feed source may be harvested grains, whole crop silage/hay or forage crops grazed *in situ*) through to perennial plants. The latter includes pastures, range forages, browse and tree cuttings. A summary of the typical composition (dry matter, energy, protein, fibre and phosphorus concentrations) of a very wide range of these feed types is given in NRC (2007; Tables 15.11 and 15.12). Primary data on the composition of the main feed sources used shall be obtained for use in the LCI analysis wherever possible, but the NRC tables provide default values when primary data cannot be obtained.

a) Calculating environmental impacts of feed production

The LEAP Guidelines document on the LCA of feeds describes the methodology for calculation of GHG emissions associated with the production, processing and storage of animal feeds. The main raw materials and processes that must be accounted for in determining the emissions of feeds are given in Figure 8. Key contributors to GHG emissions are inputs of fertilizers, manures and lime (including relevant manufacturing, transport and application stages); fuel used for production, processing and transport; crop residues (that produce N_2O 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 stage and, therefore, these aspects are covered in the LEAP Animal Feed Guidelines (see also BSI, 2011 for methods).

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

FIGURE 9: FLOW DIAGRAM AS A GUIDE TO THE PROCEDURE FOR DETERMINING THE CARBON FOOTPRINT OF SMALL RUMINANT PRODUCTS FOR THE CRADLE-TO-FARM-GATE STAGE



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

When default published values for GHG emissions 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.

In practice, there is wastage of feed at various stages between harvest and storage (covered in the LEAP Animal Feed Guidelines), and during feeding to animals, and this shall be accounted for. For example, if there is 30 percent wastage between the amount fed to animals 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 N_2O emissions during storage shall be accounted for.

As noted in Section 6, a large proportion of sheep and goats globally are managed in extensive systems with grazing of perennial pastures or browsing on mixed forage systems, including shrubs. Some important features of these feed types, in contrast to annual crops and concentrates, are 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 means that a single average dataset will be less accurate than if a seasonal or monthly profile of plant analyses is used and linked with seasonal or monthly estimates of animal feed intake.

The amount of feed used shall be based on the calculated intake by the animals over a one-year period. Thus, for a feed that is harvested and brought to the animals (e.g. a concentrate), the annual amount of dry matter feed used (plus any allowance for wastage) shall be calculated and multiplied by the emissions per kg feed (i.e. kg CO_2-equivalent/kg dry matter). In some extensive systems in Asia and Africa, and in Australia during periods of extended drought, cuttings from trees would also represent a feed that is harvested and brought to animals. In such cases, there is a need to account for any inputs used in their production, as well as for the harvesting and transport of feed to the animals, to determine any feed-related emissions. Where that tree has multiple uses (e.g. for fruit production for sale as well as for a source of forage), the GHG emissions from the total inputs to the tree shall be allocated between the two uses, or if they are a very low value waste product, no production-related emissions would be allocated to them (described in the LEAP Animal Feed Guidelines).

Cereal straw or other plant residues may be used for bedding in housed animal systems. In such cases, GHG emissions associated with the harvest and transportation steps of such products shall need to be accounted for.

11.2.2 ANIMAL POPULATION AND PRODUCTIVITY

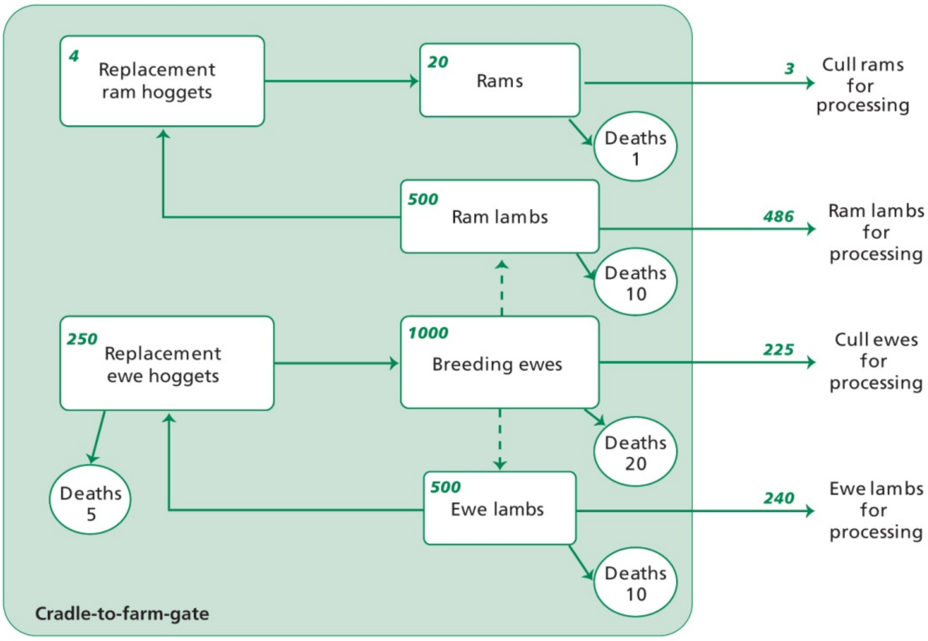
The calculation of animal-derived GHG emissions (e.g. enteric methane, excreta N_2O) requires data on total feed intake and some feed quality parameters. In most small ruminant production systems it is not possible to obtain direct data on feed intake. This applies particularly to farm systems with direct grazing or browsing of perennial forage plants. Thus, feed intake is commonly determined indirectly using models that calculate feed requirements according to animal numbers and their productivity.

Most models used for calculation of feed requirements derive intake from the energy requirements for animal processes of growth, reproduction, fibre production, milk production, activity (i.e. grazing/walking) and maintenance (e.g. IPCC, 2006; NRC, 2007). This requires data on relevant animal numbers and productivity.

To account for total GHG emissions from animal products over a one-year time period, it is necessary to define the animal population associated with the production of the products (e.g. see Figure 10 for a simplified sheep population example). This requires accounting for the number of breeding female and male animals, replacement female and male animals, and surplus (i.e. not required for maintenance of the flock) animals 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 (i.e. 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 numbers of replacement animals could be calculated);
- fertility (i.e. lambing or kidding %, equivalent to the number of animals weaned as a proportion of the number of breeding adult ewes/does, as well as lambs/kids produced from growing replacements e.g. ewe hoggets);
- death rate;
- average age at first lambing/kidding.

FIGURE 10: SIMPLIFIED EXAMPLE OF A SHEEP POPULATION ILLUSTRATING RELATIVE NUMBERS OF BREEDING AND REPLACEMENT SHEEP ON-FARM AND SURPLUS SHEEP SOLD FOR MEAT PROCESSING



Note: Based on breeding ewe flock of 1 000, 100 percent lambing, 25 percent replacement rate, 2 percent death rate and first lambing at 2 years of age.

From the base animal population data, an annual stock reconciliation needs to be derived that accounts for the time of lambing/kidding and time of sale of surplus animals. Ideally, a monthly stock reconciliation would be used. The benefit of having a tier-2 methodology (using 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 lambs 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.

The population data may need to be extended to include animals transferred between farms. For example, growing "store" lambs may be sold or moved to another farm for finishing to final live-weight before sending off for processing. In this case, 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 source farms, and where these data are unavailable, it will be necessary to use regional data for the specific animal classes on the contributing farm(s). Simplifications may be necessary for minor contributors such as accounting for breeding rams or bucks. These are often sourced off other farms, but can be accounted for by assuming they are derived from within the base farm system (e.g. Figure 10). Ideally the transport component of externally sourced ram/bucks would be included in the calculations.

Calculation of animal productivity also requires average data on male and female adult live-weight, live-weight of animal classes at slaughter, fibre production and milk production (for milking sheep or goats). Average birth weight is also required, but a reasonable default value for lambs is 9 percent of the adult ewe live-weight or about 7 percent for goats.

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 was unavailable then an example of sheep flock and goat herd parameters for different regions of the world is given in Appendix 5.

a) 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) of ruminants from animal population and productivity data. Many of these have similar driving functions (e.g. maintenance requirements based on 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 sheep or goats have been published, and used in the National Greenhouse Gas Inventory (NGGI) for that country, 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. However, the equation for energy requirements for fibre growth shall be adjusted to account for the efficiency of ME requirements for fibre growth using 157 MJ/kg fibre (NRC, 2007; not the current IPCC value of 24 MJ/kg fibre, which is simply based on energy content of wool). It is acknowledged that use of the IPCC (2006) model requires application of the sheep model for goats, and that it may give lower estimates than some other models such as NRC (2007) and CSIRO (2007). The recommended order of preference is:

1. country-specific models used in the country NGGI;
2. other models that have been peer-reviewed and published that are applicable to the region and country;
3. IPCC (2006) model;
4. IPCC default tier-1 values (this should be seen as a last resort).

Determination of metabolizable protein requirements by animals is required for systems where fibre is an important product, so that allocation between fibre and co-products (e.g. meat) can be calculated (Section 11.2.5). The above information on energy requirements also applies for protein requirements, including the hierarchy of methods. However, IPCC (2006) does not include calculations for protein requirements and therefore option 3 will be the NRC (2007) metabolizable protein requirement models for sheep or goats.

b) 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 the animal product(s). This is only likely to apply where animals are permanently housed and all feed is brought to them. However, in most cases, small ruminants obtain feeds from a number of sources, including by grazing or browsing, and it is not 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, as outlined in Section 11.2.2.

Calculation of feed intake from the energy requirements of an animal that consumes a number of feed types will commonly require several steps. The following describes the process using metabolizable energy (ME).

The first step is to define the measured amount of feed intake from any supplied feed sources brought into the farm from an outside source (e.g. where concentrates are provided as a supplement). This needs to account for the total amount of the particular feed(s) provided and adjust for the level of feed consumption and wastage (i.e. using a utilization percentage). Some examples of losses by wastage are 5-10 percent when feed is provided to animals in specialized feeding facilities through to 20-40 percent when fed by spreading out on ground or pasture (DairyNZ, 2012). The first calculation step 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):

$$MEintakeother = \text{Total ME requirement} - (DMintake \times MJ\ ME/kg\ DM)feed1 - (DMintake \times MJ\ ME/kg\ DM)feed2$$

The difference ($MEintake_{other}$) will be the amount of energy consumed from other feed sources, for example, from grazing pasture or browsing a mix of shrubs and 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:

$$DM\ intake_{other} = MEintake_{other} / (MJ\ ME/kg\ DM)_{other}$$

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 sheep or goats, there is a need to have an accurate average estimate of the concentrations of dry matter, metabolizable energy (MJ ME/kg DM), digestibility (kg digestible DM/kg total DM) and nitrogen (g N/kg DM). While these will be necessarily averaged values, the most accurate data available for the specific system or regional system should be used. The latter two parameters are used in the calculations of emissions from excreta for methane and N_2O, respectively. These feed compositional parameters can be obtained from feed measurements from the farm system(s) studied, average published data relevant to the agro-ecological zone being studied, or published national or global data for the relevant feeds. For forage or browse 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 (2007).

c) Animal enteric methane emissions

According to IPCC (2006), an average of 6.5 percent (±1%) of gross energy intake is lost as enteric methane from the rumen of mature sheep and 4.5 percent from lambs (< 1 year old). Goats are assumed to have the same methane loss factors. Data for cattle generally indicate that this loss factor is higher for lower digestibility feeds, but there are limited data for development of scaling factors for small ruminants and therefore the single emission factors shall be used.

Determination of the amount of methane emitted from each animal class requires multiplication of the total net energy (NE) or ME intake by each animal class (as described in Section 11.2.2) by methane emission factors. However, a first step is the conversion of total NE (or ME) intake to gross energy intake, using data on feed percentage digestibility (see Appendix 6; IPCC, 2006). The annual quantity of methane emitted for each animal class is then calculated using the following equations:

$$kg\ CH4/mature\ animal/year = gross\ energy\ intake\ (MJ/year) \times 0.065 / 55.65$$

$$kg\ CH4/animal(<1\ year\text{-}old)/year = gross\ energy\ intake\ (MJ/year) \times 0.045 / 55.65$$

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

Thus, annual enteric methane emissions per animal per year are calculated using the above equation and the gross energy intake for one year for each animal class and integrating them up 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 .If a user of these guidelines is unable to access sufficient basic data to apply the above approach, then a tier-1 emission factor could be used based on the IPCC (2006) default values of 8.5 kg and 5 kg CH_4/animal/year for sheep in developed countries, and sheep in developing countries and goats, respectively (based on live-weights of 65 kg, 45 kg and 40 kg, respectively). However, the use of tier-1 factors mean that the user has no ability to account for carbon footprint reductions associated with improvements in animal productivity.

11.2.3 Manure production and management

a) Methane emissions from animal excreta and manure

Methane emissions from animal excreta and manure are estimated by first calculating the amount of volatile solids produced. This represents the amount of feed consumed corrected for the component digested by animals and the non-volatile ash component that remains. The equations for calculating volatile solids in IPCC (2006; Equation 10.24) can be simplified to:

$$\text{kg volatile solids} = [\text{kg DM intake by animals} \times (1.04 - \text{DMD})] \times 0.92$$

where DMD is the dry matter digestibility expressed as a fraction. For example, the % DMD for perennial pastures in New Zealand varies throughout the year, from about 74 percent in summer to 84 percent in winter (Pickering *et al.*, 2011). The 0.92 factor in the above equation is based on a default of 8 percent ash content of manure (i.e. using 1 – [%ash/100]), which should be modified if measured or if country-specific values differ from this default.

The methane emission factor calculations for the volatile solids vary according to the manure management system and climate (IPCC, 2006). If the tier-2 approach cannot be used, generic tier-1 emission factors are given by IPCC (2006; Table 10.15) for sheep and goats in developed or developing countries, and different temperature regimes. Where country-specific emission factors have been peer reviewed, published and integrated into the national GHG Inventory, then these shall be used instead

b) Nitrous oxide emissions from animal excreta and manure

Nitrous oxide emissions occur by direct emissions from excreta, indirectly from ammonia released from excreta into the atmosphere and deposited back onto soil, and from nitrate leached to waterways. A tier-2 approach shall be used whereby the amount of N excreted by animals is calculated using the animal 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 N concentration of the diet (weighted according to the relative proportions of different feed types "t" in the diet) to get the amount of N consumed:

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

N output in product(s) (i.e. meat, fibre, milk) is then subtracted from the N consumed to calculate the amount of N excreted:

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

Data on the average N concentration of a wide range of different feed sources is given in the LEAP Animal Feed Guidelines and NRC (2007), but this shall be over-ridden by measured values (i.e. primary data) or country-specific peer-reviewed published values, if available. The N 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 N:

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

The values for protein concentration of products should be based on measured values or country-specific peer-reviewed published values, where possible. Typical default values for the protein concentration of meat (live-weight gain basis), clean wool (dry weight basis; scoured wool typically has about 16 percent water) and milk from sheep are 21 percent, 100 percent and 5.8 percent, respectively (e.g. Pulina *et al*., 2005). Corresponding typical values for goats for meat, clean fibre and milk are 21 percent, 100 percent and 3.0 percent, respectively.

Direct N_2O emissions from excreta deposited on soil during grazing or browsing are calculated by multiplying the annual amount of N excreted by the IPCC (2006) emission factor of 0.01 kg N_2O-N/kg N excreted (see Figure 11 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. When excreta is collected and processed via a manure management system, the storage-related emissions are to be included in this analysis. Where the stored manure is transported away and applied to land growing a crop or pasture, the emissions associated with transport and application (after adjustment for N lost by volatilization) are found in the LEAP Animal Feed Guidelines and not within the current LCA Guidelines.

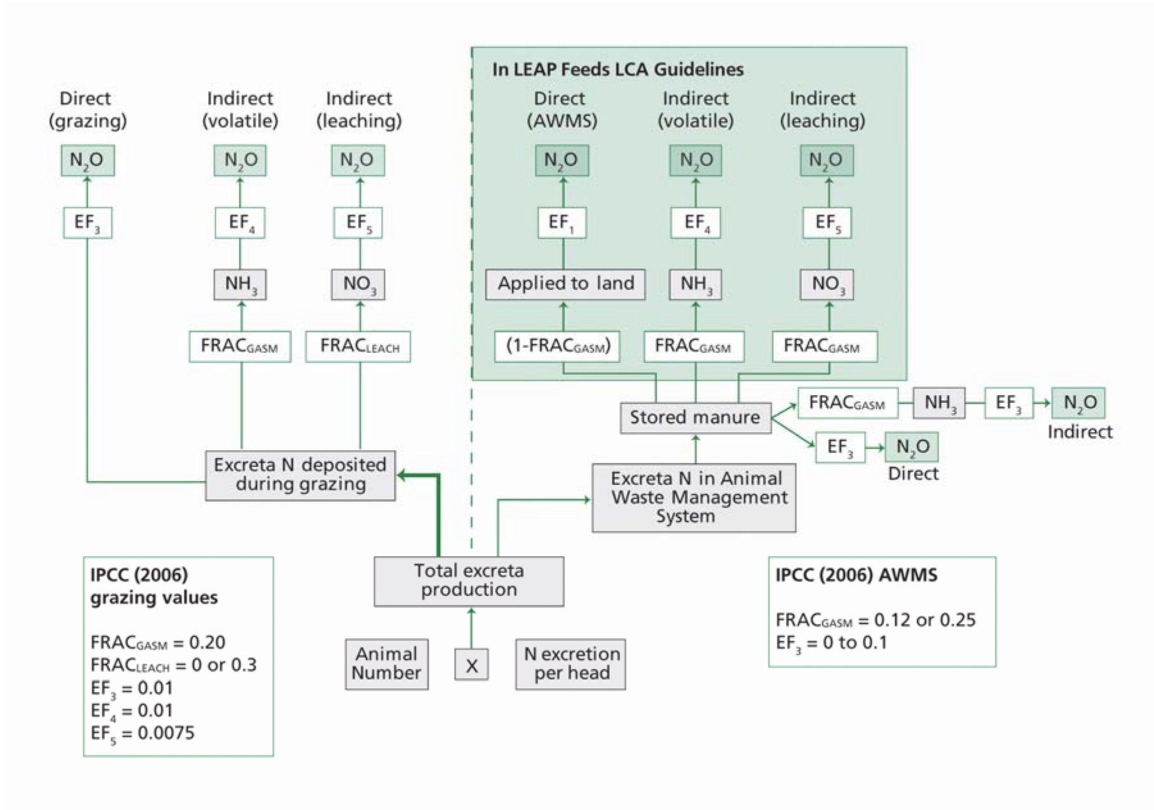
For calculation of N_2O emissions from manure during storage, the relevant IPCC (2006) emission factors shall be used. For example, direct N_2O emission factors in kg N_2O-N/kg N from storage vary from nil for uncovered anaerobic lagoons, 0.005 to 0.01 from aerobic ponds (being less with forced aeration),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

Indirect N_2O emissions from ammonia emissions during storage first require an estimate of the amount of ammonia emitted. This can be calculated using country-specific factors that have been published and integrated into the national GHG Inventory or the IPCC (2006) default ammonia loss factors ($FRAC_{GASM}$) for excreta-N deposited in deep-bedding or solid storage animal-housing manure management systems of 25 percent and 12 percent, respectively. Ammonia-N loss is then multiplied by the IPCC (2006) emission factor (EF_4) of 0.01 kg N_2O-N/kg N excreted.

Indirect N_2O emissions from ammonia loss and N leaching from excreta deposited directly to land during grazing shall be calculated as shown in Figure 11. Country-specific factors that have been published and integrated into the national GHG Inventory shall be used and, if not available, the IPCC (2006) default factors shall be used. Calculations first require an estimate of the amounts of ammonia loss and N leaching from excreta deposited on land. The default IPCC (2006) loss factor for $FRAC_{GASM}$ is 20 percent of N excreted, and for $FRAC_{LEACH}$ is 30 percent (for soils with net drainage, otherwise 0 percent) of N excreted. 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 leached, respectively.

The total N_2O emissions from excreta and manure are calculated by summing the direct and indirect N_2O emissions, after adjustment for the N_2O/ N_2O-N ratio of 44/28.

Figure 11: Summary of approach for calculating N_2O emissions from animal excreta and the animal waste management system (AWMS) using IPCC (2006) activity factors (FRAC refers to fraction of N source contributing) and emission factors (EF in kg N_2O-N/kg N)



Note: 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).

11.2.4 Emissions from other farm-related inputs

The other main inputs on-farm that contribute to GHG emissions 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 animals and milk powder used for rearing lambs or kids are 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). Note that any operations associated with the production, storage and transportation of animal 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 animal movement, removal of wasted feed associated with provision of feeds to animals on-farm and other farm-specific activities (e.g. visit by veterinarians).

The total amount use of a particular fuel type 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, milk collection (for milking goats and sheep) and shearing of fibre from animals (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.

In some extensive production systems, nutrients required to avoid deficiency by animals (e.g. phosphorus, magnesium, sodium) may be delivered directly to animals rather than being applied to land for uptake by plants used as animal feeds. In such cases, this may represent a significant contribution to total GHG emissions and shall be accounted for, as described in the LEAP Animal Feed Guidelines.

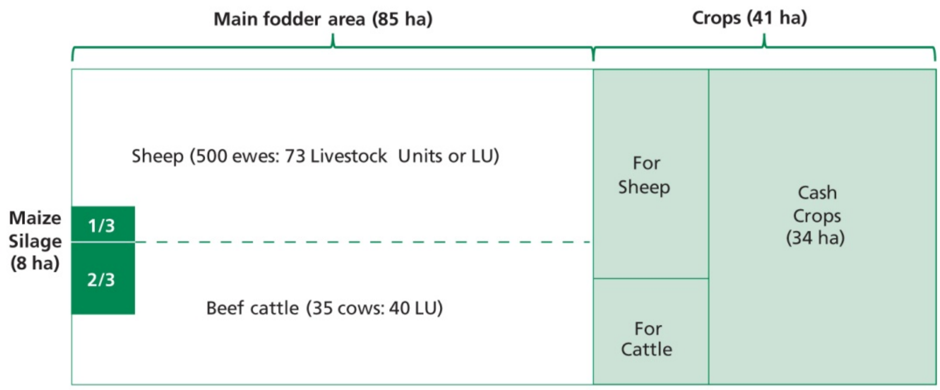
Where there is a significant use of consumables in farm operations, the GHG emissions associated with their production and use should be accounted for. This would generally be estimated from published data or from appropriate databases (e.g. Ecoinvent). However, in practice these will often constitute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

11.2.5 MULTI-FUNCTIONAL PROCESSES AND ALLOCATION OF GHG EMISSIONS BETWEEN CO-PRODUCTS

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

Many farms present a mixture of animal species (e.g. sheep, goats, cattle, deer) which are often farmed together. Where possible, it is recommended to separate activities of the farm system for the different animal species where specific uses can be defined (e.g. use of summer forage crops to finish lambs only, or use of nitrogen fertilizer specifically for pasture growth to feed beef cattle). For the remainder of the GHG emissions 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 the sheep or goats under study shall be calculated as outlined in Section 11.2.2. Emissions associated with other non-feed shared activities (e.g. fuel used for animal movement, drain cleaning, hedge cutting, fencing maintenance, etc.) shall be allocated between animal species using a biophysical allocation approach. Preferably, this should be based on calculation of the total feed intake for each of the different animal species and allocation based on the relative feed intake between species (see Box 1).

Box 1: Example of calculation of multi-functional processes and allocation in a French mixed sheep and cattle farm



The figure above describes the farm system (based on Benoit and Laignel, 2011). The area identified as being used for cash crops is excluded in the calculation of GHG emissions 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. The table below describes a process used in France to apportion GHG emissions between cash crops and animal species for the Case Study farm.

Source/stage of co-products	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 (kWh/LU) used to build specific allocation keys
Manure fertilizers	Amounts known for each crop and forages	Split between cash crop and feeds for animals, i.e. system separation
Manure application		
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 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 (where a livestock unit or LU equates to one cattle eating 4 750 kg DM; see table below).

	Sheep production	Cattle production	Cash crops	Total
References in buildings on areas	1 GJ/LU + 0.9 GJ/ha of fodder area +0.4GJ/ha crop	1.8 GJ/LU + 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. hectares 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, thereby allowing 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 allocate it 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 type (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 jointly graze pasture on the farm and are jointly fed pasture 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 DM intake) for sheep and cattle. In this case, the allocation factor (A) was calculated using:

$$A\ (\%) = 100 \times \text{Sheep total DM intake} / (\text{Sheep total DM intake} + \text{Cattle total DM intake})$$

In this farm, A = 100x347/(347+190) = 65% (where 347 and 190 are t DM intake calculated for sheep and cattle respectively). Thus, 65 percent of farm-related GHG emissions (or fossil energy demand) that could not be separately estimated or derived via system separation would be attributed to sheep.

b) Allocation between meat, milk and fibre production

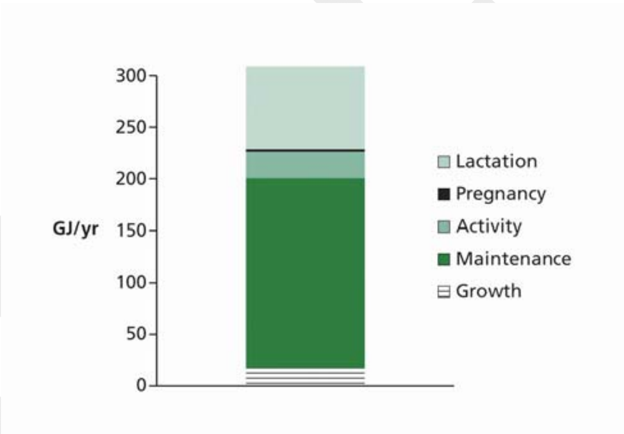
Small ruminants produce meat, milk and fibre. However, in most production systems the focus is on one main product, or one product may provide the largest proportion of economic returns for the producer. For dairy cows where the main product is milk and where there is a meat co-product, a biophysical allocation approach is most widely used (e.g. Thoma *et al.*, 2013a), and is recommended in the IDF (2010a) methodology. The same approach shall be used for sheep or goats where the main product is milk. Using a tier-2 approach, the energy requirements for milk and meat production are calculated according to an internationally acceptable methodology (Section 11.2.2.a; since energy is the main determining requirement for these products). The allocation ratio for milk, relative to milk plus meat (plus fibre if it is also a minor co-product), is then calculated from the ratio of the energy requirement for milk production to the energy requirement for milk, meat (i.e. animal growth component) and fibre (if relevant) production (see Box 2):

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

Box 2: Example of calculation of biophysical allocation between milk and meat for goats in Kenya

This example refers to a dual-purpose goat system based on 100 breeding does producing 8 775 kg milk sold (and the same amount being fed to kids) and 3 440 kg live-weight sold for meat (from surplus kids and cull does and bucks). It was based on data from Bett et al. (2009).

A goat population structure was prepared and production data was used to calculate energy requirements using the IPCC (2006) model. Results for the goat population showing the relative breakdown between functions are given in the figure below.



The ratio (R) of energy requirements for sold-milk production (half of the total was sold, with the rest fed to kids) relative to meat production (based on the requirements for growth) was calculated using:

R = energy req. sold-milk/(energy req. sold-milk + energy req. growth) = 40.3/(40.3+17.4) = 0.70

Thus, the allocation percentage for milk and meat was 70 percent and 30 percent, respectively.

For sensitivity analysis of the effect of allocation method, the corresponding allocation percentage for milk using economic allocation was 45 percent and using protein-mass was 50 percent.

This equation is rearranged to calculate the corresponding allocation % to meat and fibre. Where milk or meat is the main product from the production system, biophysical allocation based on energy requirements shall be used. However, where fibre is an important product, biophysical allocation based on protein requirements shall be used. The latter recommendation is based on the fact that fibre production is largely determined by protein requirements and not energy requirements. Additionally, most energy-based models are relatively weak in accounting for fibre production and simply include fibre production within the energy requirements for maintenance, or use a crude estimate of energy content of fibre (e.g. IPCC, 2006; in Section 11.2.2.a, it is recommended that the energy requirement for fibre is changed to 157 MJ/kg fibre).

Thus, where fibre is an important co-product the allocation ratio for fibre, relative to fibre plus meat (plus milk if it is also a minor co-product), is then calculated from the ratio of the metabolizable protein requirement for fibre production to the metabolizable protein requirement for fibre, meat (i.e. animal growth component) and milk (if relevant) production using:

Allocation % to fibre = 100 x [protein req. for fibre/(protein req. for fibre + protein req. for meat + protein req. for milk)]

This equation is rearranged to calculate the corresponding allocation percentage to meat and milk co-products. Box3 provides an illustration of application of this approach for a New Zealand farm system.

BOX 3: EXAMPLE OF CALCULATION OF BIOPHYSICAL ALLOCATION BETWEEN FIBRE AND MEAT FOR SHEEP IN NEW ZEALAND

In North Island, New Zealand, Romney-cross sheep graze on hill country with cattle. On average, for this farm class the sheep are stocked at 5.6 sheep/ha/year and produce 207 kg live-weight sold/ha/year and 30.8 kg wool/ha/year (Beef + Lamb New Zealand survey data). It is based on data from Ledgard *et al*. (2009, 2011).

Farm survey data were used to define a sheep population structure and sheep production. The data were incorporated into a protein requirement model (based on the Australian Feeding Standards model; CSIRO 2007) to determine protein requirements.

Of the total metabolizable protein requirements, 17 percent was required for wool production and 29 percent for sheep growth, pregnancy and lamb production. The remaining protein requirement was for flock maintenance.

The ratio (R) of protein requirements for wool production relative to meat production (based on the total requirements for growth) was calculated using biophysical allocation as:

R = protein req. wool / (protein req. wool + protein req. growth) = 17/(17+29) = 0.37

Thus, the allocation percentages for wool and meat were 37 percent and 63 percent, respectively.

Sensitivity analysis was carried out to examine the effect of other methods of allocation. This resulted in calculated values for the allocation percentage for wool using biophysical allocation based on energy requirements (and using 157MJ/kg wool) or economic allocation of 16 and 19 percent, respectively.

In practice, there are relatively few small ruminant production systems where fibre is the main product and returns the highest proportion of revenue. These include specialist ultra-fine wool sheep in Australia and some goat systems for specialist cashmere and mohair production. It is acknowledged that the use of a biophysical allocation approach based on protein requirements for fibre, meat and milk is still in a state of development (with no scientific publications on the topic). On this basis, use of a protein requirement model may not always be possible. Therefore, a less-preferred alternative option is use of energy requirements only. The recommended hierarchy for calculating biophysical allocation is:

1. where milk is the dominant product this shall be based on energy requirements, but where fibre is a dominant or important co-product it shall be based on protein requirements;
2. use energy requirements for all product evaluations.

If the second option is used, it shall be accompanied by an explanation and justification of the method used for the assessment.

In conformance with ISO/TS 14067 (2013), 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. For example, system expansion, 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).

11.3 Transportation

This section refers to transportation stages covering transport of animals, fibre or milk from the site of production to the site of primary processing, and any internal transport within the primary processing site(s) to the output loading dock (see Section 11.6). It also includes transportation of inputs such as water within the farm, and animals between different farms, contributing to their production prior to 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. Regarding return empty transport, allocation of empty transport kilometres shall be done on the basis of the average load factor of the transport, representative for the transport under study. If no supporting information is collected, it should be assumed that 100 percent extra transport is needed for empty return. Allocation of transport emissions to transported products shall be done on the basis of the mass share, unless the density of the transported product is significantly lower than average such 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 animals occur (e.g. by shipping to middle-Eastern countries), 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. Where refrigerated transportation is used, the typical rate of loss of refrigerant and associated GHG emission factor shall be included.

11.4 Inclusion and treatment of land-use-change

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

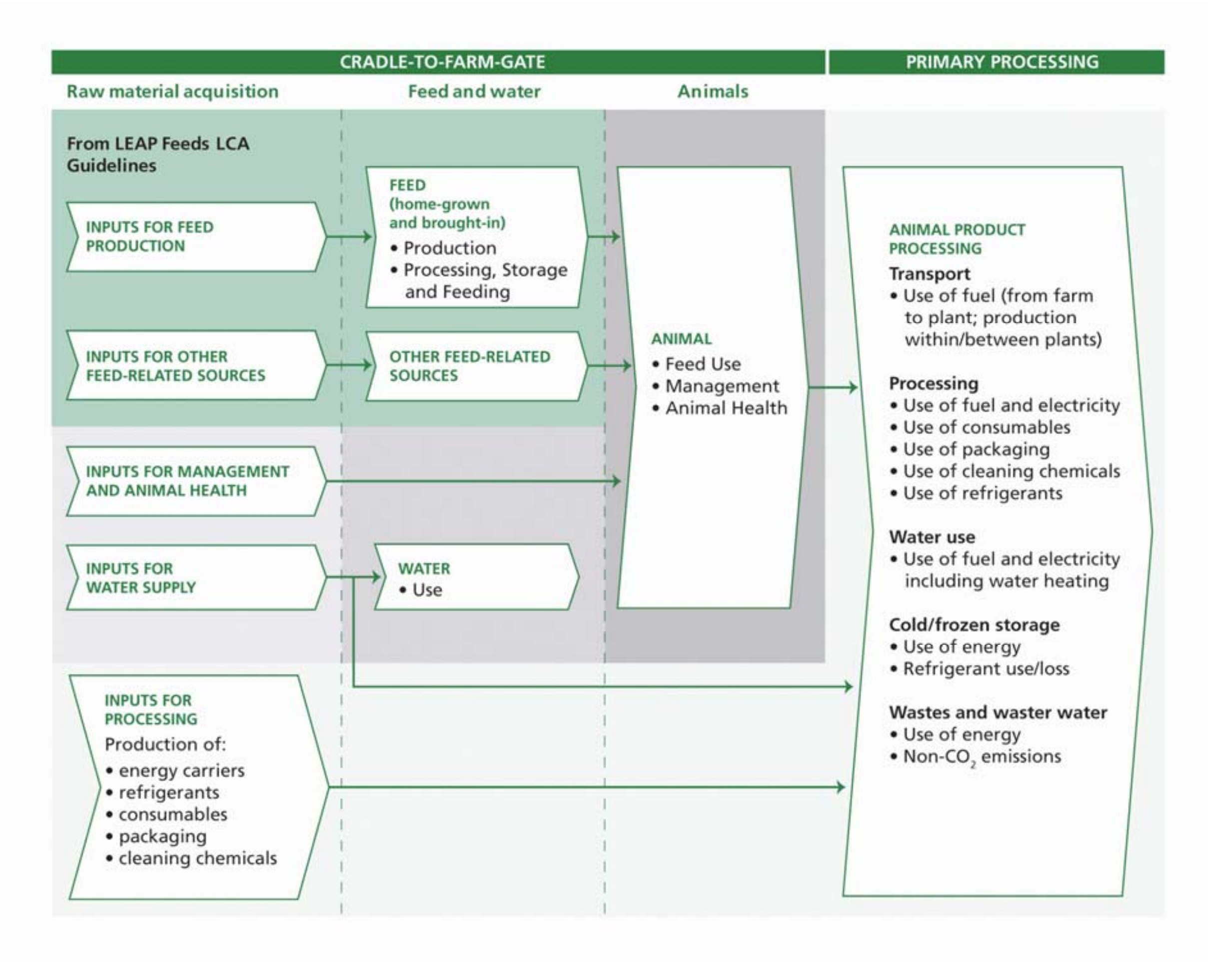
11.5 Biogenic and soil carbon sequestration

Biogenic and soil carbon sequestration can be important for some small ruminant systems. However, since this relates only to the feed production stage, the specific methods are covered in the LEAP Animal Feed Guidelines. As these guidelines note, biogenic and soil carbon sequestration shall be included in the final GHG emissions value. Where no data relating to soil carbon sequestration are available, the LEAP Animal Feed guidelines provide default values for temperate climate. The last option is to assume zero change in soil carbon.

11.6 Primary processing stage

The three primary products of milk, fibre and meat are covered in these guidelines. For all products, there are a number of generic processes that contribute to GHG emissions. These are summarized in Figure 12 and include transportation (of products 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 GHG emissions with their primary processing.

FIGURE 12: PROCESSES THAT CONTRIBUTE TO GHG EMISSIONS AND FOSSIL ENERGY DEMAND WITHIN THE SYSTEM BOUNDARY OF THE CRADLE-TO-PRIMARY-PROCESSING-GATE



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

11.6.1 Milk processing

The milk collected from goats or sheep 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 industry to large multi-process facilities. IDF (2010a) and DairyCo (2010) provide an outline of processes and methods for LCA-based carbon footprinting of dairy cow milk, but there are no corresponding reports or PCRs for goat or sheep milk processing.

The main processes that need to be accounted for are processing of milk, production and use of packaging, refrigeration, water use and wastewater processing, and within-plant transportation (Figure 12). The milk-processing stage includes the use of resources including energy, water and consumables (e.g. detergents, cleaning chemicals).

a) Data collection and handling of co-products

Representative data need to be collected from the milk-processing plant(s) for the defined one-year period on the amount of milk (and its fat and protein content) entering the plant and the amount and 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 also need to be collected on the resources used for processing. Ideally this would be collected for each unit process so that it can be allocated according to the products produced. However, these are rarely available. In some cases, data may be available that can be attributed to 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 such cases a method for allocation of resource use and emissions between the products is required. The IDF (2010a) has defined a physico-chemical method for allocation between dairy cow milk co-products, but this is untested for goat or sheep milk. Thus, a simpler approach is recommended for used based on the relative fat + protein content of the co-products produced (Thoma *et al*., 2013a).

Packaging is generally a relatively small contributor to total GHG emissions (<1%) 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 GHG emissions should include the production of the packaging as well as the raw materials. Where glass bottles are used for liquid milk, the rate of re-use should be accounted for in the calculations. The guidelines produced by DairyCo (2010) provide useful information related to the range of packaging materials and factors to include in the calculation of GHG emissions associated with their production and use. Similarly, many other consumables and cleaning chemicals are used in the processing of dairy products, and secondary data sources from databases such as Ecoinvent will generally be used for their production and use. This also applies to refrigerants, although use of primary activity data on the type and amount of refrigerants used is desirable.

b) Calculating GHG emissions from milk processing

Activity data are required on the amounts of the various resources used. Energy use must 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 GHG emission factors to calculate the total emissions. For refrigerants, Forster *et al.* (2007, Table 2.14) provide a list of GWP (100-year) factors for a wide range of refrigerants, which should be updated to coincide with future revisions by IPCC.

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 GHGs produced (e.g. methane from anaerobic treatment systems). Emission factors for methane and N_2O 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_2-equivalents according to the latest GWP factors from IPCC. The calculation of total GHG emissions must include adjustment for allocation between the various co-products, as outlined in Section 9.3.

11.6.2 FIBRE PROCESSING

The fibre collected from goats (i.e. cashmere, mohair) or sheep (i.e. wool) may be used for a wide range of purposes, including clothing, carpet-making and housing insulation. Again, there is a wide diversity in the processes used to produce these products ranging from cottage industry to large-scale commercial processing. An outline of processes and methods for LCA-based carbon footprinting are covered in draft PCRs on textile yarn and thread of natural fibres (EPD, 2012), and woven fabrics of wool or animal hair (EPD, 2011) that are relevant for cashmere and wool processing.

The present guidelines refer only to the primary processing stage of scouring or cleaning of the fibre. The cleaned fibre may then go on to other stages, such as yarn-making for textiles (with secondary processing or for direct use by a consumer), carpet-making, or low-value uses such as insulation or absorbents.

Fibre collected from small ruminants often contains grease, suint, soil and plant material (which for wool can amount to 20-40 percent of the weight of the raw greasy wool), and this is commonly removed by scouring to produce clean fibre. During the scouring process lanolin may be extracted, as it represents a useful co-product. The main processes that need to be accounted for in fibre scouring are the use of cleaning chemicals (e.g. detergents, bleaching agents and acids), water, within-plant transportation and wastewater processing (Figure 12). The primary processing stage includes the use of resources such as energy, water and consumables.

a) Data collection and handling of co-products

Representative data need to be collected from the fibre-scouring plant(s) for the defined one-year period on the amount of greasy fibre entering the plant and the amount of clean fibre, lanolin and residue (vegetable matter and dirt, which usually goes to waste) generated. A material flow diagram of input and output products should be produced to account for a minimum of 99 percent of the mass.

Data on all resources used shall be collected, with important resources being electricity, water and cleaning chemicals. The main energy resource used is usually electricity. Primary data on electricity use shall, therefore, be collected. Where possible, the data should be collected to allow allocation according to the products produced (e.g. electricity use for final purification of the lanolin). Where data are only available for a whole processing plant, a method for allocation of resource use and emissions between the products is required. In most cases, the clean fibre and lanolin can be considered as the main products, with the residue as a valueless waste. However, in some cases the residue may be further processed to a conditioner or fertilizer, and in such cases should be treated as a co-product.

A relatively large volume of wastewater can be generated during the scouring process and data shall be collected on the volume and composition (e.g. Chemical Oxygen Demand and nitrogen concentration) of the wastewater and the method of wastewater processing.

To account for the lanolin co-product a system expansion approach could be used whereby any product displaced by the lanolin could be determined. However, there are no published studies to guide such an analysis. For consistency with Figure 8 and the other LEAP Guidelines, economic allocation between co-products is recommended. In practice, the recovery of lanolin from greasy wool amounts to about 2-7 percent by weight (higher for finer wool), therefore, most of the resource use and GHG emissions will be allocated to the wool. Goat fibres generally have a lower grease content than sheep wool, therefore, lanolin becomes a minor co-product and possibly a residual if $<1\%$ overall value (see Figure 7).

b) Calculating GHG emissions from fibre processing

The total GHG emissions are calculated from the sum of the emissions associated with resource use and wastewater processing. Calculation of GHG emissions associated with electricity use shall account for total embodied emissions, recognizing the relative energy sources used for electricity production in the country where the primary processing occurs. Emissions from use of other resources shall also be determined using activity data and relevant GHG emission factors to calculate the total emissions.

Data on wastewater quantity and composition are used, in conjunction with GHG emission factors according to the method of wastewater processing (IPCC, 2006), to calculate GHG emissions from wastewater processing.

Total GHG emissions shall be allocated between the various co-products, as outlined in Section 9.3.

11.6.3 Meat processing

Primary processing of sheep or goats for meat production can occur in facilities ranging from backyards to large-scale commercial processing abattoirs. This can result in a wide range of co-products, including hides (for leather), tallow (e.g. for soap, biofuel), pet food, blood (e.g. for pharmaceutical products), fibre and renderable material (e.g. for fertilizer).

A PCR (Boeri, 2013) has been produced 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).

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).

a) 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 sheep or goat 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 relative quantity of all co-products (e.g. blood, gut contents), and therefore secondary data would be required, or could be aggregated across several minor co-products. An indication of the approximate relative weight of products for a lamb is: meat 52 percent, hide 6 percent, wool 4 percent, blood 5 percent, tallow 3 percent and renderable material 30 percent (see also Box 4).

Data are required on the use of the various resources. Energy use is a major contributor to total GHG emissions 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 large component of the processing GHG emissions. Thus, data shall be collected on the volume and composition (e.g. Chemical Oxygen Demand and nitrogen concentration) of the wastewater and method of wastewater processing. Some resources such as consumables and refrigerant use are relatively small and typically constitute a minimal proportion of the total GHG emissions (e.g. <1%). Thus, secondary data on use of these resources are acceptable.

Potentially, a system expansion approach could be used whereby product displaced by the various non-meat products could be determined. However, there are no published studies to guide such an analysis. In view of the range of products and their usefulness for various purposes, it is recommended to consider a system expansion approach in future when more relevant published research is available. The PCR (Boeri, 2013) recommended the use of economic allocation. Similarly, the present guidelines recommend the use of economic allocation. However, it is noted that some co-products may be identified as of no 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).

An example of the effects of economic allocation compared to mass allocation for the average lamb from New Zealand abattoirs in mid-2009 (see Box 4) shows a much higher allocation to meat using economic allocation than when mass allocation was used. Box 4 also shows the large variation in price per kilogramme between different cuts of meat. The present guidelines recommend treating all meat components as the same per-kg (i.e. no separate economic allocation between meat cuts).

Some abattoirs process multiple animal species (e.g. cattle and sheep). In such cases there is a need to allocate emissions according to species. This shall be based on the relative number and live-weights of the animal species processed. However, this approach will need to account for relative differences in requirements (such as 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 energy use cannot be apportioned between meat processing and rendering, some adjustment may be appropriate to account for the greater energy requirements for rendering (e.g. 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. For example, Lovatt and Kemp (1995) obtained specific fuel use/tonne meat processed at eight-fold and two-fold higher for fuel and electricity use, respectively.

Box 4 Example of variation in the mass and economic value of components of an average New Zealand lamb leaving an abattoir effects on allocation calculations (data provided by NZ Meat Industry Association 2009)

Data in the table below were based on a summary of the average weight of different meat cuts and co-products from lamb leaving an average abattoir in New Zealand in mid-2009. The associated average relative economic value of the different components is also given and this is used to calculate the average allocation to meat. The weighted average value across all edible components was used, thereby assuming no difference in "value" between the different edible components when applying economic allocation. The table shows that in practice there was more than an eight-fold difference in price per kilogramme between the lamb rack and neck cuts of meat. It also illustrates the relatively large difference in economic value of the co-products.

	Average mass of component (kg)	Component % of total mass	Price per-kg relative to leg meat	Component as % of total economic value
Meat:				
Neck	0.54	1.5	0.21	0.8
Shoulder	4.6	12.7	0.51	16.1
Rack	1.21	3.4	1.73	14.3
Breast and shank	1.46	4.1	0.47	4.8
Loin	1.43	4.0	1.04	10.2
Legs	4.68	13.0	1.00	32.1
Other meat	2.43	6.7	0.38	6.4
Edible offal	2.0	5.5	0.28	3.9
Co-products:				
Hide/skin	2.21	6.1	0.28	4.3
Wool	1.59	4.4	0.27	3.0
Blood	1.76	4.9	0.01	0.1
Inedible offal	0.65	1.8	0.14	0.6
Rendering/tallow	11.54	32.0	0.04	3.5

Thus the economic allocation percentage (EA) for meat relative to the total returns for the lamb was calculated using:

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

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

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

The results from these calculations for % allocation to meat using economic or mass allocation were 88 percent and 51 percent, respectively.

b) Calculating GHG emissions from meat processing

Calculation of GHG emissions 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 GHG emission factors for the method of wastewater processing (IPCC, 2006) to calculate GHG emissions from wastewater processing. 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 GHG emissions from them accounted for using the IPCC (2006) method for waste. Total GHG emissions 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, Ledgard *et al*. (2011) found from a survey of NZ sheep meat-processing plants that the relative contributors to GHG emissions from electricity for chilling/freezing was 18 percent, other energy use (particularly for water use and heating) 47 percent, wastewater processing 26 percent and other sources 9 percent.

11.6.4 ON-SITE ENERGY GENERATION

In some primary 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 net energy use would be used in the analysis. Where there is a surplus of energy generated within the primary processing system and sold outside the system under study, the present guidelines recommend the use of system expansion. This is in line with ISO 14044 (2006).

12 INTERPRETATION OF LCA RESULTS

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

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

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

12.1 Identification of key issues

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

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

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

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

12.2 Characterizing uncertainty

This section is related to Section 9, data quality. Several sources of uncertainty are present in LCA. First is knowledge uncertainty which reflects limits of what is known about a given datum, and second is process uncertainty which reflects the inherent variability of processes. We can reduce knowledge uncertainty by collecting more data. We may reduce process uncertainty by breaking complex systems into smaller parts or aggregations, but inherent variability cannot be eliminated completely. Third, the characterization factors that are used to combine the large number of inventory emissions into impacts also bring uncertainty into the estimation of impacts. In addition, there is bias introduced if the LCI model is missing processes, or may have larger flows than actually present.

Variation and uncertainty of data should be estimated and reported. This is important because results based on average data (i.e. the mean of several measurements from a given process – at a single or multiple facilities) or using LCIA characterization factors with known variance do not reveal the uncertainty in the reported mean value of the impact. Uncertainty may be estimated and communicated quantitatively through a sensitivity and uncertainty analysis and/or qualitatively through a discussion. Understanding the sources and magnitude of uncertainty in the results is critical for assessing robustness of decisions that may be made based on the study results. When mitigation action is proposed, knowledge of the sensitivity to, and uncertainty associated with the changes proposed provides valuable information regarding decision robustness, as described in Table 4. At a minimum, efforts to accurately characterize stochastic uncertainty and its impact on the robustness of decisions should focus on those supply chain stages or emissions identified as significant in the impact assessment and interpretation. Where reporting to third parties, this uncertainty analysis shall be conducted and reported.

TABLE 4: GUIDE FOR DECISION ROBUSTNESS FROM SENSITIVITY AND UNCERTAINTY

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

12.2.1 MONTE CARLO ANALYSIS

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

12.2.2 Sensitivity analysis

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

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

12.2.3 Normalization

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

12.3 Conclusions, Recommendations and Limitations

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

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

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

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

12.4 Use and comparability of results

It is important to note that these guidelines refer only to a partial LCA and that where results are required for products throughout the whole life cycle then it is necessary to link this analysis with relevant methods for secondary processing through to consumption and waste stages (e.g. EPD 2012; PAS 2395 2013Draft). Results from application of these guidelines cannot be used to represent the whole life cycle of small ruminant products. However, they can be used to identify hot-spots in the cradle-to-primary-processing stages (which are major contributors to emissions across the whole life cycle) and assess potential GHG reduction strategies. In addition, the functional units recommended are intermediary points in the supply chains for virtually all small ruminant sector products and therefore will not be suitable for a full LCA. But 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 minimise the risk of misinterpretation.

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

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

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

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

12.6 Report elements and structure

The following elements should be included in the LCA report:

- Executive summary typically targeting a non-technical audience (e.g. decision-makers), including key elements of goal and scope of the system studied and the main results and recommendations while clearly giving assumptions and limitations;
- Identification of the LCA study, including name, date, responsible organization or researchers, objectives of/reasons for the study and intended users;
- Goal of the study: intended applications and targeted audience, methodology including consistency with these guidelines;
- Functional unit and reference flows, including overview of species, geographical location and regional relevance of the study;
- System boundary and unit stages (e.g. to farmgate and farmgate 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: 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 LUC;
- LCI modelling and calculating LCI results;
- Results and interpretation of the study and conclusions;
- Description of the limitations and any trade-offs;
- If intended for the public domain the report should also state whether or not the study was subject to independent third-party verification.

12.7 Critical review

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

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

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

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

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APPENDICES

Appendix 1: Greenhouse gas emissions from small ruminants: A review of existing methodologies and guidelines

Introduction

Greenhouse gas (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*., 2011). 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, 2010b) 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 use of life cycle assessment (LCA) to account for all GHG sources and to determine the extent of emissions on a product basis.

The purpose of this brief review is to summarize existing methodologies and guidelines for calculating GHG emissions from small ruminants.

GHG methodology guidelines for small ruminants

There have been two international methodology reports relating to small ruminants or sheep specifically. Gerber *et al*. (2013) published a report on the carbon footprint of livestock that included beef, sheep and goats for a range of agro-ecology regions and production systems around the world. This was based on methodology developed by staff in the FAO and covered the cradle-to-farm-gate, meat-processing and transportation-to-retailer stages of the life cycle.

Beef + Lamb New Zealand and the International Meat Secretariat initiated development of a "straw-man" document entitled *A common carbon footprint methodology for the lamb meat sector* (Ledgard, 2011) that involved contributions from various international industry and sheep LCA research groups, including the English Beef and Lamb Executive (EBLEX), Adrian Williams (Cranfield University, UK), Ronald Annett (AFBI, Northern Ireland), the Institut de l'Elevage (France), Hybu Cig Cymru (HCC Wales) and Quality Meats Scotland. This document was confined to the cradle-to-farm-gate stage of the lamb life cycle. It followed a similar approach to that of the IDF (2010b) common methodology for milk production, with the intention of including a number of recommendations on methodology aspects where specific methodology choices are required (e.g. system boundary, functional unit and allocation methods).

Only a few publications or reports have estimated the total GHG emissions from sheep production, and only one study for deer (Lieffering *et al*., 2011) and one for goats (Gerber *et al*., 2013) could be found via a detailed literature search. Table 5 provides a summary of the published sheep studies with carbon footprint estimates for lamb and the variation in components of the methodology used. Studies varied in the extent of their system boundary and therefore in the relevant functional unit.

TABLE 5: SUMMARY OF THE CARBON FOOTPRINT OF LAMB FROM PUBLISHED STUDIES AND METHODOLOGIES USED

Reference	Data source	System boundary	Functional unit (FU)	Allocation method(s)	Enteric methane	Carbon footprint ($kg\ CO_2$-eq/FU)
International:						
Ruminants: Gerber *et al.* (2013)	FAO country data	RDC[1]	1 kg CW[2], 1 kg FPCM[3]	Economic, protein content	Tier 2	15-31[4] (4.7-9.0[5])
Lamb: Ledgard (2011)	Representative data	Farm gate	1 kg LW	Biophysical/economic	Tier 2	n.a.[6]
Country-specific:						
Australia: Peters *et al.* (2010)	1 case farm	Farm gate	1 kg CW	Mass	Tier 2	10.5
Australia: Eady *et al.* (2012)	1 case farm	Farm gate	1 kg CW	System expansion/ biophysical/economic	Tier 2	12.6
England: EBLEX (2012)	57 case farms	Farm gate	1 kg LW	Economic	Tier 2	6-20[7]
France: Gac *et al.* (2012)	Farm survey (104)[8]/model	Farm gate	1 kg LW	Mass	Tier 1	12.9
France: Benoit and Dakpo (2012)	Farm survey (1180)	Farm gate	1 kg CW	Mass	Tiers 1 and 2	11.9 (15-82)[9]
NZ: Ledgard *et al.* (2011)	Farm survey (437)/model	Life cycle[10]	1 kg meat	Biophysical/economic	Tier 2	19
Spain: Ripoll-Bosch *et al.* (2013)	Farm survey (3)	Farm gate	1 kg LW	Economic	Tier 2	19-26
Sweden: Wallman *et al.* (2012)	10 case farms	RDC	1 kg CW	Mass/economic	Tier 2	16
UK: Williams *et al.* (2008)	UK model	RDC	1 kg CW	Economic	Tier 2	14.1
Wales: Edwards-Jones *et al.* (2009)	2 case farms	Farm gate	1 kg LW	Economic	Tier 1	8-144[11]

Note: [1] to retail distribution centre; [2] carcass-weight; [3] fat and protein corrected milk; [4] range for small ruminant CW across regions globally; [5] range for small ruminant FPCM across regions globally; [6] generic methodology only (no specific analyses included); [7] average and range across 57 case farms; [8] bracketed values refer to number of farms in surveys; [9] range across 1 180 farms (or -7 to 62 if carbon sequestration was included); [10] whole life cycle (i.e. cradle-to-grave); and [11] high on peat soils.

The study of Eady *et al*. (2012) 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 NZ system (Ledgard *et al*., 2011) included mixed sheep and cattle farming and used biophysical allocation to allocate between each animal type (i.e. 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).

There is only one published carbon footprint study for goats, which showed similar or slightly lower values than from lamb or sheep meat (Gerber *et al*., 2013). The principles for estimating the carbon footprint for goat products are likely to be similar to those for sheep. Indeed, a specific study on enteric methane emissions by goats in respiration chambers on different diets showed an average of 6.6 percent of energy loss as methane (Bhatta *et al*., 2008). This is similar to that from other animal studies and to the IPCC default value of 6.5 percent. Nevertheless, comparative animal studies on enteric methane emissions indicated significant differences between sheep and deer fed the same diet, with average values of 18.4 and 16.5 g methane/kg dry matter intake, respectively (Swainson *et al*., 2008).

In conclusion, the estimates of the carbon footprint of lamb shown in Table 5 showed wide variability and much of this variability can be attributed to differences in methodology used. This highlights the importance of developing a common methodology to be able to identify real differences in GHG emissions between farm systems and products, and to identify GHG reduction opportunities.

Product category rules

The generic GHG methodology guidelines refer to product category rules (PCRs) and recommend that these are used where they have been produced. A detailed search revealed that there are no specific PCRs for sheep or goat 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 small ruminants.

GHG footprinting tools covering small ruminants

There are a number of GHG footprinting tools that are being used or available for use on farms for evaluation of the GHG footprint of small 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 UK-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 small ruminants and their products for comparison of production and processing systems.

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Appendix 2: Small ruminants: Main producing countries

Table 6: Relative number of goats (in grassland vs. mixed production systems) and of goat meat and milk production across countries globally, 2011

Country	Goats (thousand head)		Goat meat (thousand tonnes)	Goat milk (thousand tonnes)
	Grassland-based systems	Mixed systems		
Top 20 countries (for herd)				
China	22178	129036	1890	277
India	2232	121298	599	4760
Pakistan	13404	42590	286	759
Nigeria	2159	47788	289	-
Bangladesh	0	44208	199	2496
Sudan (former)	20411	22113	97	1072
Iran (Islamic Republic of)	18447	7061	163	306
Ethiopia	2081	14283	68	53
Somalia	12820	1751	65	501
Kenya	6363	7510	47	197
Indonesia	320	12997	71	281
Mongolia	11133	2114	48	71
United Republic of Tanzania	2112	10424	35	108
Niger	7381	3857	66	278
Burkina Faso	1470	9239	35	106
Brazil	3637	6620	29	148
Mexico	1985	6884	44	162
Mali	3742	4963	75	703
Yemen	2232	5630	42	56
Uganda	161	7638	33	-
Remaining countries	66412	108655	1045	4758

Sources: Gerber *et al*. (2013) for grassland vs. mixed production systems and FAOSTAT (2013) for goat meat and milk production.

TABLE 7: RELATIVE NUMBER OF SHEEP (IN GRASSLAND VS. MIXED PRODUCTION SYSTEMS) AND SHEEP MEAT, MILK AND WOOL PRODUCTION ACROSS COUNTRIES GLOBALLY, 2011

Country	Sheep (thousand head)		Sheep meat (thousand tonnes)	Sheep milk (thousand tonnes)	Greasy wool (thousand tonnes)
	Grassland-based systems	Mixed systems			
Top 20 countries (for herd)					
China	68590	83025	2050	1529	393
Australia	47434	53667	564	-	368
India	2138	60330	293	-	43
Iran (Islamic Republic of)	36090	17648	96	449	60
Sudan (former)	23865	25929	215	390	55
New Zealand	12015	27864	465	-	166
United Kingdom	4894	30066	301	-	67
Nigeria	1235	30304	168	-	-
South Africa	16850	8291	124	-	41
Turkey	5534	19536	230	893	47
Pakistan	6228	18522	158	36	42
Spain	1287	21230	135	520	22
Ethiopia	1635	19099	88	58	8
Syrian Arab Republic	11702	7882	183	706	21
Algeria	10268	8641	253	320	26
Morocco	4076	12793	144	38	55
Brazil	5847	9659	84	-	12
Russian Federation	5233	10063	171	1	53
Peru	4858	9950	35	-	10
Somalia	13117	1577	70	590	-
Remaining countries	127899	190774	2402	4241	553

Sources: Gerber *et al.* (2013) for grassland vs. mixed production systems and FAOSTAT (2013) for sheep meat, milk and wool production.

Appendix 3: Summary of carcass-weight: live-weight ratios (as percentages) for goats and sheep for different regions

TABLE 8: AVERAGE RATIOS OF CARCASS-WEIGHT TO LIVE-WEIGHT FOR GOATS AND SHEEP FOR DIFFERENT GLOBAL REGIONS

Region	Goats	Sheep
North America	52	52
Russian Federation	43	45
Near East and North Africa	43	48
Western Europe	43	45
Eastern Europe	44	45
East and South East Asia	48	49
Oceania	45	50
South Asia	43	48
Latin American countries	44	49
Sub-Saharan Africa	48	45

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

Carcass-weight (CW), 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 CW.

The variation in these average default CW values of 43-52 percent for goats and 45-52 percent for sheep probably reflects differences in method of calculation from the literature that it was derived from (e.g. hot versus cold CW), as well as differences associated with key factors of age, breed, weight, gender and diet. For example, in a review of New Zealand data, the hot-CW:LW ratio averaged 44 percent (range 40-48 percent) for lambs and 39 percent for ewes/rams (Muir *et al*., 2008), while for Northern Ireland it was 46 percent for lambs reared on pasture and 49 percent for lambs reared on concentrates (Annett and Carlson, 2011).

Appendix 4: Allocation options for manure exported off-farm

In some situations, part or all of the excreta from animals may be collected and sent off-farm. The following is based on the decision tree shown in Figure 7. Unless a system separation approach is adopted for manure, that is following flow 1a, or substitution (following flow 3a), a decision associated with the classification of manure as either a co-product, waste or residual must be made in box 3 of the decision tree. It is the strong recommendation of these guidelines that the default manure method should be to consider it as a *residual* at the farm gate. This results in a clean separation of the system where all post-farm emissions from use of the manure are assigned to that use, while all on-farm management is assigned to the main product from the farm (animal live-weight and fibre).

Substitution: When manure is used directly to produce energy, system expansion may be used to unambiguously substitute for the energy displaced from the external economy. The primary question will be whether marginal or average energy products are substituted.[4] For the purposes of these guidelines, if system expansion/substitution is used, then the average energy product (e.g. national electricity grid mix of primary energy sources) shall be substituted. Combustion ash must also be evaluated as a potential co-product, residual or waste, and associated emissions properly accounted for. In addition, clear documentation of the substitution shall be included in the report and, following other extant standards if energy is sold, then no credit as a substitute product is allowed. However, in the latter case, the energy shall be considered as a co-product and an appropriate allocation chosen through use of the decision tree.

Manure may be sold off-farm as a fertilizer replacement. This option of substitution as fertilizer shall only be considered where clear evidence can be provided about specific replacement of fertilizer products, and justification shall be provided to document the equivalence of the substitution. Utilization of manure as fertilizer also results in different emissions from the field other than inorganic fertilizers. Therefore, substitution shall require assignment of the field emissions to the animal product, with a subsequent substitution credit of both the production and field emissions associated with the substituted inorganic fertilizer.

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 these two co-products. In this case, physical allocation based on physical parameters is clearly not appropriate (since it is a completely different product to the other co-products, such as meat). Thus, an economic allocation shall be adopted. There shall be no credit for

[4] Blonk *et al*. (2010) show that, in practice, this is not immediately obvious for an electricity grid. The grid is fed by multiple production units and how should the avoided production/consumption mix be determined if your type of electricity production is a part of the mix. BSI (2011) defines a practical approach by simply stating that the average country production mix should be applied.

avoided fertilizer production in this situation, because the option for system substitution is path 3a, not 3c. As a co-product, it would have a functional unit, which would be 1 kg manure with a defined set of characteristics (i.e. dry matter, digestibility and nitrogen concentrations).

Residual: This applies when manure has essentially no value as it leaves the farm gate. This is equivalent to system separation, in that activities associated with conversion of the residual to a useful product occur outside of the system boundary for the small ruminant production system. In such cases, emissions linked to its production would go to the other co-product(s) (including emissions on storage), while subsequent emissions from transport and use (e.g. on a crop) would go to that subsequent use (i.e. outside the system boundary of these guidelines).

Waste: If manure is classified as waste-only in situations where it is disposed by landfill, incineration without energy recovery or sent to a treatment facility, then all on-farm emissions shall be assigned to the animal products of live-weight and greasy fibre. In such cases, emissions associated with the final disposition of manure are within the system boundary and must be accounted for and assigned to the animal products. In the case of manure as a waste, there shall be no substitution credit for its use as fertilizer since this falls under path 3a, not 3e.

References

Blonk, H., Kool, A., Luske, B., Ponsioen, T., & Scholten, J. 2010. Methodology for assessing carbon footprints of horticultural products. A study of methodological issues and solutions for the development of the Dutch carbon footprint protocol for horticultural products. Blonk Milieu Advies, Gouda, the Netherlands

Appendix 5: Average sheep flock and goat herd parameters for different regions of the world

Parameters	North America	Russian Federation	Western Europe	Eastern Europe	North Africa and Near East	East and South East Asia	Oceania	South Asia	Latin America and the Caribbean	Sub-Saharan Africa
Sheep: weights (kg)										
Adult female	80	49	62	44	41	47	70	35	59	38
Adult male	108	101	82	85	55	65	98	45	81	51
Lambs at birth	4	3	4	3	3	4	4	3	3	3
Slaughter female	27	21	29	21	26	26	35	24	29	24
Slaughter male	27	21	29	21	26	26	35	24	29	24
Rates (%)										
Replacement female	21	23	29	22	21	16	24	18	20	17
Fertility	92	95	91	90	83	77	100	81	91	76
Death rate - lambs	19	17	18	18	25	31	9	24	18	33
Death rate - other	8	2	3	5	12	14	4	12	12	13
Age at first lambing (years)	2.1	1.9	1.6	1.8	1.4	1.6	1.8	1.6	2	1.5
Goats: weights (kg)										
Adult female	64	55	59 (61)*	50	37 (40)	44 (34)	50	32 (31)	35 (37)	29 (31)
Adult male	83	100	88 (91)	100	53 (56)	53 (43)	81	42 (39)	50 (60)	36 40)
Kids at birth	6.4	2.2	4.0 (4.6)	5	2.7 (3.2)	3.9 (2.1)	3.6	2.7 (2.4)	3.5 (3.7)	2.2 (2.3)
Slaughter female	36	30	26	30	32	27	38	25	27	19
Slaughter male	36	30	26	30	32	27	38	25	28	19
Rates (%)										
Replacement female	30	18	17	18	19	24	21	19	24	16
Fertility	85	90	87	90	87	88	87	81	80	87
Death rate - kids	18	5	4	5	31	37	12	15	14	27
Death rate - other	9	2	2	2	7	16	6	5	5	7
Age at first kidding (years)	1.4	1.3	1.3	1.3	1.6	1.1	1.4	1.8	1.5	2

Note: * Numbers in brackets refer to the parameters for meat animals. *Source*: Gerber *et al*. (2011).

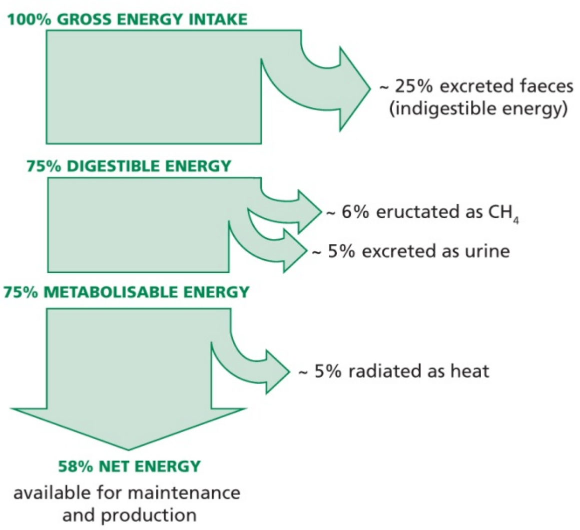
Appendix 6: Calculation of enteric methane emissions from animal energy requirements

Background

Section 11.2.2.b outlines the procedure for calculating the energy requirements for animal class (e.g. lambs, hoggets, ewes, rams for sheep) according to metabolic requirements for the relevant categories of growth, maintenance, activity (walking), reproduction, wool production and milk production. 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. shows the relationship between these, where GE can be partitioned to manure energy and enteric methane energy and net energy.

FIGURE 13: DIAGRAM SHOWING THE FLOW OF THE DIFFERENT SOURCES OF ENERGY FOR RUMINANTS, BASED ON A HIGH-QUALITY FEED WITH A DIGESTIBILITY OF 75%



Source: Lassey (2007).

Calculation of gross energy

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

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

$$REG = [1.164 – (5.160 \times 103 \times DE\%) + (1.038 \times 10\text{-}5 \times DE\%2) - (37.4/DE\%)]$$

where DE% is digestible energy as a % 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):

$$REM = [1.123 – (4.092 \times 103 \times DE\%) + (1.126 \times 10\text{-}5 \times DE\%2) - (25.4/DE\%)].$$

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

$$GE = \left\{ \frac{[NEm + NEa + NEl + NEr]}{REM} + \frac{[NEg + New]}{REG} \right\} \div (DE\%/100)$$

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

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

$$\text{kg } CH_4\text{/mature animal/year} = \text{gross energy intake (MJ/year)} \times 0.065/55.65\text{, or}$$

$$\text{kg } CH_4\text{/animal(<1 year-old)/year} = \text{gross energy intake (MJ/year)} \times 0.045/55.65$$

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.

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

In practice, DE % will vary during the year and an example of this from the NZ GHG Inventory for average sheep pasture in New Zealand in winter, spring, summer and autumn at 73.8 percent, 77.7 percent, 68.1 percent and 66.1 percent, respectively (Pickering, 2011). Corresponding ME concentrations are 10.8 percent, 11.4 percent, 9.9 percent and 9.6 MJ ME/kg DM, respectively.

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