Guidelines for conducting a life cycle assessment of the environmental performance of wool textiles

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International Wool Textile Organisation
Wool LCA Technical Advisory Group

Contents

Foreword

These Guidelines for assessing the environmental performance of wool textiles using a Life Cycle Assessment (LCA) approach have been developed by the International Wool Textile Organisation (IWTO) and Australian Wool Innovation (AWI) with the support of members of the IWTO Sustainable Practices Working Group under the leadership of Dr Paul Swan and Angus Ireland from AWI.

These Guidelines were drafted by members of the Wool Life Cycle Assessment Technical Advisory Group:

- Dr Beverley Henry (Queensland University of Technology)
- Dr Stewart Ledgard (AgResearch New Zealand)
- Dr Barbara Nebel (Thinkstep Pty Ltd)
- Mr Stephen Wiedemann (FSA Consulting)

Expert review and comments by Angus Ireland is gratefully acknowledged.

IWTO makes these Guidelines available for use by stakeholders wishing to conduct a Life Cycle Assessment of wool textiles and clothing. It is assumed that the execution of a Life Cycle Assessment study using these Guidelines will be made by, or in close consultation with, a suitably qualified and experienced practitioner or technical expert. IWTO retains the right to amend or update the Guidelines on availability of new scientific evidence with a view to improving methods for more accurate and defensible assessment of the environmental impacts of wool value chains. The version available will be marked with the date of posting on the website and information on revisions to the previous iterations. It is the responsibility of the user to ensure that the latest version is used and that any time series assessments are adjusted to the latest version of the Guidelines.

These Guidelines are consistent with ISO 14040 and ISO 14044 but should not be regarded as a Standard or Product Category Rules according to requirements for a particular regulatory or reporting program. Therefore, use of these Guidelines cannot be assumed to fulfil any legal obligations related to sustainability reporting. However, as regime-neutral guidance it is expected that elements of these Guidelines may be compatible with some requirements under such programs.

Acronyms and abbreviations

AWI	Australian Wool Innovation
CF	Characterization Factor
CFP	Carbon footprint of a product
CML	Institute of Environmental Sciences (CML) in the Netherlands (http://cml.leiden.edu/research/industrialecology)
CO2-e	Carbon dioxide equivalent
dLUC	direct Land Use Change
EOL	End-of-Life
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IWTO	International Wool Textile Organisation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LEAP	Livestock Environmental Assessment and Performance Partnership
LUC	Land Use Change
LULUC	Land Use and Land Use Change
ME	Metabolizable Energy
N	Nitrogen
NGGI	National Greenhouse Gas Inventory
NGO	Non-Governmental Organization
N2O	Nitrous oxide
NOx	Nitrogen oxides (NO and NO2)
OECD	Organization for Economic Cooperation and Development
P	Phosphorus
PAS	Publicly Available Specification
PCR	Product Category Rules
PEF	Product Environmental Footprint
SETAC	Society for Environmental Toxicology and Chemistry
SOM	Soil Organic Matter
SO2	Sulphur dioxide
TAG	Technical Advisory Group
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compound
WBCSD	World Business Council for Sustainable Development
WRI	World Resource Institute

1 Introduction

1.1 Purpose of these guidelines

General guidance on life cycle assessment is available from several sources that provide background information to persons wishing to conduct a life cycle assessment of wool products. These include:

- International Standards Organisation
  - o ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework (ISO 2006a)
  - o ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines (ISO 2006b)
- British Standards Institute

o PAS 2395:2014 Specification for the assessment of greenhouse gas (GHG) emissions from the whole life cycle of textile products (BSI 2014)

This document Guidelines for conducting a life cycle assessment of the environmental performance of wool textiles ('these Guidelines') has been developed to be consistent with ISO standards and have taken into consideration other internationally recognised standards and guidance (e.g. BSI 2011) for relevant single or multiple impact category life cycle assessment studies, including for a 'carbon footprint' (ISO 2013) or 'water footprint' (ISO 2013), and for partial life cycle assessments, e.g. for the cradle to farm-gate or primary processing stage, of the full supply chain (LEAP 2015a).

Development of these Guidelines also considered the rules, requirements and guidelines for developing an environmental declaration as set out in ISO 14025:2006 (ISO 2006c) and relevant Product Category Rules (PCR) under the International EPD® system (e.g. EPD 2013). These Guidelines align with the objectives of a PCR in aiming to provide more detailed instructions and recommendations for product-specific application than available in a general life cycle assessment standard, and are consistent with many elements of PCRs in specifying rules for life cycle assessment relevant to a nominated product. However, they are not limited to or bound by the rules of a specific program such as EPD®.

1.2 Overview of life cycle assessment

Life Cycle Assessment (LCA), developed in the 1980s, has become the most widely used tool to estimate the environmental performance of a product over its full life cycle from 'cradle to grave'. The aim of the tool is to simplify modelling of the complexities of supply chains to achieve an understanding of environmental impacts and drive continuous improvement. However, simplification of processes can distort or bias results or introduce unacceptable levels of uncertainty, and models have been refined over time to improve representation of supply chains and the accuracy of results. This ongoing method development and emerging expertise in its application, along with limitations on availability of accurate, representative data and difficulty in communicating meaningful outcomes, has led to inconsistency in LCA results and sometimes confusion in interpretation. Efforts to amend and standardise the LCA approach are continuing (e.g. UNEP/SETAC Life Cycle Initiative http://www.lifecycleinitiative.org/).

General guidance for application of the LCA approach is set out in ISO 14044 (ISO 2006a) under sequential steps starting with goal and scope definition, followed by data collection and inventory analysis, and then impact assessment. More recently, LCA based guidelines covering limited impact categories specifically for small ruminants (sheep and goats) (LEAP 2015a) and for textiles (BSI 2014) have been published. Methodological aspects of the LCA approach are described in the following sections of these Guidelines using 'attributional' modelling, with emphasis on the specific application challenges for wool fibre produced from sheep. Appendix A provides a discussion of consequential modelling for understanding of the potential use of LCA for informing decisions on change in production. The attributional approach is more commonly used at present and is appropriate for benchmarking environmental performance of wool, identifying 'hot-spots' in wool supply chains, and monitoring change over time.

1.3 Application of life cycle assessment to wool textile products

1.3.1 Overview of wool textile systems

Wool fibre from sheep is used for a wide range of products including warm outer garments, base layer wear, fashion apparel, luxury interiors and items required to have fire-retardant or insulation properties (IWTO 2014, CSIRO 2008). Wool accounted for only 1.3% of world textile consumption in 2012 (IWTO 2013), but holds a much higher level of importance in terms of unit price and status. The value of a wool fleece and its use category are largely determined by the diameter of the fibre. The merino breed produces the finest wool with grades ranging from ultrafine (<15.0 microns) to broad wool of ≤24.5 microns (Australian Wool Corporation 1990). Other sheep breeds and crossbreeds have higher diameter fibres with this coarser wools (up to 35-45 microns), commonly used for floor coverings. Approximately two thirds of the global wool harvest is used in the manufacture of apparel, about one third in interior products such as carpets, upholstery and rugs, and a small proportion (in the order of 5% of the total) destined for industrial uses such as insulation (IWTO 2014).

The wool supply chain starts with sheep farms which can be found across geographically and climatically diverse regions in around 100 countries. Australia, China and New Zealand rank as the leading producers of greasy wool. Processing and manufacturing are economically important industries in several countries with China being a major wool importer, as well as producer, and the leading centre of processing, spinning and weaving. Italy and the United Kingdom are also significant centres of spinning, knitting and weaving, while manufacturing of wool fabric and apparel occurs across several Asian countries. The stages of the life cycle of wool textiles and apparel are summarised in Figure 1. The diversity of wool supply chains and sheep co-products together with the unique properties and durability of wool resulting from its protein structure make environmental impact assessment more complex than for most, if not all, alternative fibres.
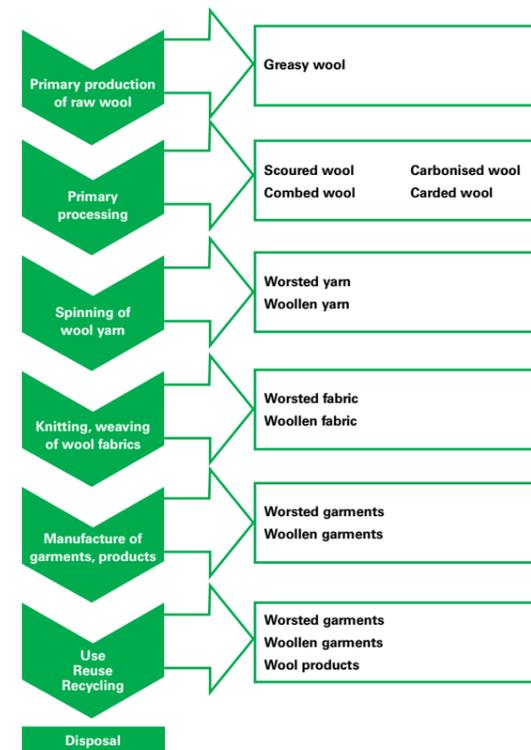

Figure 1. Simplified diagram of stages in the life cycle of wool apparel (Source: Adapted from Henry et al. 2015b).

1.3.2 Challenges in life cycle assessment of wool textiles

For LCA of wool textiles, three questions of methodological and/or data importance highlight the complexity of accurate and consistent quantification of environmental impacts:

- Handling of co-products: Sheep produce not only wool but other commodities with significant economic and social value, notably meat, milk, lanolin and manure-nutrients (LEAP 2015a). The environmental impacts of sheep must be shared between co-products in a way that is fair, practical and reflects, as far as possible, the underlying biophysical processes that generate those impacts.

- Consumer use: Quantitative data on the behaviour of consumers relating to service life, pattern of wear and care of apparel and textiles (e.g. time between cleaning and temperature of washing water) are scarce due to the difficulty and cost of collecting data from many individuals. However, wool textiles are widely recognised as being durable and suited for high quality garments. For example, a conservative estimate of the average life expectancy of trousers is four years for wool or wool-blend fabric compared with two years for cotton blends (Drycleaning Institute of Australia Limited 2014). In addition wool clothing generally requires lower frequency cleaning than garments of other fibres (Laitala et al. 2011.

- Post-first use: Wool textiles are more likely than average to be reused or recycled after the period of first use (Russell et al. 2016). On final disposal to waste streams wool is biodegradable. All of these factors contribute to less negative environmental outcomes over the full life cycle of wool than for other fibres. For precise definition of the system boundary and assessment of life cycle impacts, more reliable and comprehensive statistics on paths of textiles through reuse, recycling and final consignment to waste streams, and robust methodologies to accurately account for the real product streams are a critical need.

The relative contribution to total environmental impact of each stage in the life cycle of wool textiles from raw material production on sheep farms through the steps in processing, manufacture and retail and then to consumer use, reuse, recycling and ultimately disposal will vary across wool products and between supply chains of contrasting efficiency.

1.3.3 Objectives and use of these Guidelines

These Guidelines aim to provide practical methodological guidance on wool LCA methods and information on data requirements and sources to support more consistent and comprehensive assessment of the environmental performance of wool by:

- Promoting use of more realistic and consistent methods for wool LCA;

- Providing guidance for collecting reliable and comprehensive data to account for the diversity of wool production systems, supply chains, product types and consumer use and disposal; and

- Assisting in overcoming inherent difficulties in communicating wool LCA results to stakeholders.

To date there have been few published wool LCA studies that have quantified multiple environmental impacts across the full life cycle of wool textile products. Most LCAs have been restricted to greasy wool production (cradle-to-farm gate) and to assessment of a single impact category, often climate change ('Carbon Footprint'). As more studies are done the need for further guidance and opportunities for refinement will become clearer.

Important note: In Sections 6, 8 and 9 of these Guidelines, some guidance is provided separately for the cradle to farm-gate and the post-farm gate stages of the wool textile life cycle. Both the nature of environmental impacts and the LCA data and methodological challenges differ between the agricultural system producing greasy wool and the later stages of the wool textile supply chain. Disaggregation of these two component areas of the supply chain was, therefore, considered to provide greater clarity but for full life cycle assessment care should be taken to ensure consistent product flow between stages.

2 Terms and definitions

2.1 Terms relating to life cycle assessment

Allocation
Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems [ISO 14044:2006, 3.17].

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

Attributional modelling approach (Attributional LCA approach)
System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule [UNEP/SETAC Life Cycle Initiative, 2011].

Background system
The background system consists of processes on which no or, only indirect, influence may be exercised by the decision-maker for which an LCA is carried out. Such processes are called "background processes." [UNEP/SETAC Life Cycle Initiative, 2011].

Carbon dioxide equivalent (CO2e)
Unit for comparing the radiative forcing of a greenhouse gas (GHG) to that of carbon dioxide [ISO/TS 14067:2013, 3.1.3.2].

Carbon footprint of a product (CFP)
Sum of greenhouse gas emissions and removals in a product system, expressed as CO2 equivalents and based on a life cycle assessment using the single impact category of climate change [ISO/TS 14067:2013, 3.1.1.1].

Consequential data modelling (Consequential LCA approach)
System modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit [UNEP/SETAC Life Cycle Initiative, 2011].

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

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

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

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

Data quality
Characteristics of data that relate to their ability to satisfy stated requirements [ISO 14044:2006, 3.19].

Dataset
A document or file with life cycle information of a specified product or other reference (e.g. site, process), covering descriptive metadata and quantitative life cycle inventory and/or life cycle impact assessment data, respectively. [ILCD Handbook, 2010]. *Note:* May refer to an LCI dataset or LCIA dataset.

Delayed emissions
Emissions released over time rather than as a single, one-time emission, e.g. through prolonged use or final disposal stages, [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].

Direct Land Use Change (dLUC)
Change in human use or management of land within the product system being assessed [ISO/TS 14067:2013, 3.1.8.4].

Direct energy use [for wool production]
Energy used on farms for livestock production activities (e.g. electricity use in farm operations).

Downstream
Occurring along a product supply chain after the point of referral. [Product Environmental Footprint Guide, European Commission, 2013]

Economic value
Average market value of a product at the point of production [Adapted from PAS 2050:2011, 3.17].

Note 1: Averaging is often, but not always, over a 5-year time frame.

Eco-toxicity
Environmental impact category that addresses the toxic impacts on an ecosystem which damage individual species and change the structure and function of the ecosystem. [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].

Note 2: Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.

Elementary flow
Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation [ISO 14044:2006, 3.12].

Emissions
Releases of substances to air and discharges of substances to water and land.

Environmental impact
Any change to the environment, adverse or beneficial, wholly or partially resulting from an organization's activities, or from any part of the life cycle of products or services [Adapted from: ISO/TR 14062:2002, 3.6].

Eutrophication
Excess of nutrients (mainly nitrogen and phosphorus) in water or soil. [Product Environmental Footprint Guide, European Commission, 2013].

Note 1: Measures of eutrophication translate the quantity of substances emitted into a common metric expressed as the oxygen required for the degradation of dead biomass.

Note 2: In water, eutrophication accelerates the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death. In soil, eutrophication favours nitrophilous plant species and modifies the composition of the plant communities.

Extrapolated data
Refers to data from a given process that is used to represent a similar process for which data are not available, on the assumption that it is representative. [Product Environmental Footprint Guide, European Commission, 2013]

Final product
Goods and services that are ultimately consumed by the end user rather than used in the production of another good or service. [GHG Protocol, Product Life Cycle Accounting and Reporting Standard, 2011].

Foreground system
The foreground system consists of processes (called "foreground processes") which are under the control of the decision maker for which an LCA is carried out. [Adapted from: UNEP/SETAC Life Cycle Initiative, 2011].

Functional unit
Quantified performance of a product system for use as a reference unit [ISO 14044:2006, 3.20].

Note: It is essential that the functional unit allows valid comparisons where objects are compared or time series data on the same object are used for benchmarking and monitoring.

GHG removal
Mass of a greenhouse gas removed from the atmosphere [ISO/TS 14067:2013, 3.1.3.6].

Global Warming Potential (GWP)
Characterization factor describing the radiative forcing impact of one mass-based unit of a given greenhouse gas relative to that of carbon dioxide over a given period of time [ISO/TS 14067:2013, 3.1.3.4].

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 [ISO 14064-1:2006, 2.1].

Human toxicity – cancer
Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer [Product Environmental Footprint Guide, European Commission, 2013].

Human toxicity – non cancer
Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation [Product Environmental Footprint Guide, European Commission, 2013].

Impact category
Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned [ISO 14044:2006, 3.39].

Impact category Indicator
Input Product, material or energy flow that enters a unit process [ISO 14044:2006, 3.21].

Land occupation
Impact category related to use (occupation) of land area by activities such as agriculture, roads, housing, mining, etc. [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].

Land use change
Change in the purpose for which land is used by humans (e.g. between crop land, grass land, forestland, wetland, industrial land) [PAS 2050:2011, 3.27].

Life cycle
Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal [ISO 14044:2006, 3.1].

Life Cycle Assessment
Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [ISO 14044:2006, 3.2]

Life cycle GHG emissions
Sum of GHG emissions resulting from all stages of the life cycle of a product and within the specified system boundaries of the product [PAS 2050:2011, 3.30].

Life Cycle Impact Assessment (LCIA)
Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential impacts for a product system throughout the life cycle of the product [Adapted from: ISO 14044:2006, 3.4].

Life Cycle Inventory (LCI)
Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle [ISO 14046:2014, 3.3.6].

Life Cycle Interpretation
Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations [ISO 14044:2006, 3.5].

Material contribution
Contribution from any one source of GHG emissions of more than a threshold proportion, commonly 1%, of the anticipated total GHG emissions associated with the product being assessed [Adapted from PAS 2050:2011, 3.31]

Note: A materiality threshold (often 1%) is used to ensure that very minor sources of life cycle GHG emissions do not demand the same time and effort as more significant sources.

Multifunctionality
If a process or facility provides more than one function, i.e. it delivers several goods and/or services ("co-products"), it is "multifunctional". In these situations, all inputs and emissions linked to the process must be partitioned between the product of interest and the coproducts in a principled manner [Product Environmental Footprint Guide, European Commission, 2013].

Output
Product, material or energy flow that leaves a unit process [ISO 14044:2006, 3.25].

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

Primary activity data
Quantitative measurement of activity from a product's life cycle that, when multiplied by the appropriate emission factor, determines the impact arising from a process [Adapted from PAS 2050:2011, 3.34].

Note: Examples of primary activity data include the amount of energy used, material produced, service provided or area of land affected.

Product(s)
Any goods or service [ISO 14044:2006, 3.9].

Product category
Group of products that can fulfil equivalent functions [ISO 14046:2014, 3.5.9].

Product category rules (PCR)
Set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories [ISO 14025:2006, 3.5].

Product system
Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product [ISO 14044:2006, 3.28].

Proxy data
Data from a similar activity that is used to represent the given activity [Adapted from GHG Protocol, Product Life Cycle Accounting and Reporting Standard, 2011].

Note: Proxy data can be extrapolated, scaled up, or customized to represent the given activity.

Raw material
Primary or secondary material that is used to produce a product [ISO 14044:2006, 3.1.5].

Reference flow
Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit [ISO 14044:2006, 3.29].

Releases
Emissions to air and discharges to water and soil [ISO 14044:2006, 3.30].

Reporting
Presenting data to internal management or external users such as regulators, share-holders, the general public or specific stakeholder groups [Adapted from: ENVIFOOD Protocol: 2013]

Resource depletion
Impact category that addresses use of natural resources either renewable or non-renewable, biotic or abiotic [Product Environmental Footprint Guide, European Commission, 2013].

Secondary data
Data obtained from sources other than a direct measurement or a calculation based on direct measurements at the original source [ISO 14046:2014, 3.6.2].

Note: Secondary data are used when primary data are not available or it is impractical to obtain primary data. Some emissions, such as methane from litter management, are calculated from a model and are, therefore, considered secondary data.

Sensitivity analysis
Systematic procedures for estimating the effects of choices made, regarding methods and data, on the outcome of a study [ISO 14044:2006, 3.31].

Soil Organic Matter (SOM)
Content of organic material in soil [Adapted from Product Environmental Footprint Guide, European Commission, 2013].

Note: Soil organic matter derives from plants and animals and comprises all of the organic matter in the soil excluding intact organic matter that has not decayed.

System boundary
Set of criteria specifying which unit processes are part of a product system [ISO 14044:2006, 3.32].

System expansion
Expanding the product system to include additional functions related to co-products.

Uncertainty analysis
Systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability [ISO 14044:2006, 3.33].

Unit process
Smallest element considered in the life cycle inventory analysis for which input and output data are quantified [ISO 14044:2006, 3.34].

Upstream
Occurring along the supply chain of purchased goods/services prior to entering the system boundary [Product Environmental Footprint Guide, European Commission, 2013].

Water Consumption
Water removed from but not returned to the same drainage basin. Water consumption can be because of evaporation, transpiration or integration into a product, or release into a different drainage basin or the sea [ISO 14046:2014, 3.2.1].

Note: Also referred to as freshwater consumption.

Water use
Use of water by human activity including, but not limited to, any water withdrawal, water release or other human activities within the drainage basin impacting water flows and/or quality, including in-stream uses such as fishing, recreation, transportation [ISO 14046:2014, 3.2.1].

2.2 Terms relating to sheep and feed in wool supply chains

Annual forage
Forage established annually, usually with annual plants, and generally involving soil disturbance, removal of existing vegetation, and other cultivation practices.

Carcass
The sheep body after slaughter from which the viscera, skin, head, and some other parts have been removed.

Compound feed/concentrate
Mixtures of feed materials, which may contain additives, for use as animal feed in the form of complete or complementary feedstuffs.

Conserved forage
Conserved forage saved for future use. Forage can be conserved in situ (e.g. stockpiling) or harvested, preserved and stored (e.g. hay or silage).

Crop land
Land on which the vegetation is dominated by large-scale production of crops for sale (e.g. maize, wheat, and soybean production).

Crop product
Product from a plant, fungus or algae cultivation system that can either be used directly as food or feed or as raw material in food, feed processing or fuel production.

Crop residues
Materials left in an agricultural field after the crop has been harvested.

Crop rotation
Growing of crops in a seasonal sequence to prevent diseases, maintain soil conditions and optimize yields.

Cull
To reduce the size of a flock by selling or killing a proportion of its members. **Note:** Cull animals are typically older animals that are sold at the end of life for processing.

Cultivation
Activities related to the propagation, growing and harvesting of plants, including activities to create favourable soil conditions for their growing.

Ewe
Mature female sheep usually over 2 years of age.

Feed
Any single or multiple materials, whether processed, semi-processed or raw, which are intended to be fed directly to food-producing animals [FAO/WHO, Codex Alimentarius CAC/RC 54-2004, 2008].

Feed additive
Any intentionally added ingredient not normally consumed as feed by itself, whether or not it has nutritional value, which affects the characteristics of feed or animal products [FAO/WHO, Codex Alimentarius CAC/RC 54-2004, 2008].

Note: Micro-organisms, enzymes, acidity regulators, trace elements, vitamins and other products fall within the scope of this definition depending on the purpose of use and method of administration.

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
Determinant of 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, and other functions.

Feed ingredient
Component part or constituent of any combination or mixture making up a feed, whether or not it has a nutritional value in the animal's diet, including feed additives. Ingredients are of plant, animal or aquatic origin, or other organic or inorganic substances [FAO/WHO, Codex Alimentarius CAC/RC 54-2004, amended in 2008].

Fodder
Harvested forage, fed intact, either fresh or dried, to livestock.

Forage crop
Crops, annual or biennial, grown to be used for grazing or harvested as a whole crop for feed.

Graze
Feed directly on growing grass, pasturage or forage crops.

Greasy wool
Untreated fibre (raw wool) straight off an animal.

Hogget
Young sheep between a lamb and an adult sheep (a two-tooth from approximately 10–16 months of age).

Lamb
Young sheep from birth up until it is classified as a hogget. There is no specific age or time for this change, but it is normally taken as corresponding to the emergence of the first two adult incisors, which may occur at approximately 12 months of age.

Lanolin
Yellowish viscous substance, also called wool fat, extracted from wool, which consists of a mixture of esters of fatty acids and is used in some ointments.

Natural pasture
Natural ecosystem dominated by indigenous or naturally occurring grasses and other herbaceous species used mainly for grazing by livestock and wildlife.

Note: Also referred to a native pasture. Naturalised pasture may be used to refer to pasture where an exotic species has become established and often dominant.

Ram
Uncastrated (entire) male sheep.

Replacement rate
Percentage of adult animals in the herd replaced by younger adult animals.

Ruminant
Any of various even-toed, hoofed mammals of the sub-order 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.

Note: Ruminants include cattle, sheep, goats, deer, giraffes, antelopes and camels.

Shearing
Process of removing the fleece from a sheep

Note: Shearing may also refer to creation of pile or nap (e.g. of a carpet by cutting the tuft or loops that form the surface or the process of cutting loose fibre from the surface of a woven fabric

Silage
Forage harvested and preserved (at high moisture contents generally >500 g kg-1) by organic acids produced during partial anaerobic fermentation.

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

Wool
The textile fibre obtained from sheep.

Note: Wool may also be used to describe the fibre from other animals, including cashmere from goats, mohair from goats, qiviut from muskoxen, angora from rabbits, and other types of wool from camelids. Features that distinguish wool from hair or fur include being crimped, elastic and growing in staples.

2.3 Terms relating to processing, manufacture, use, recycling of wool textiles

Backing
Secondary layer of material attached to the reverse of a textile as a carrier or substrate or to impart particular properties e.g. heat retention.

Coating
Application of a film to the surface of a textile to impart colour or particular properties e.g. water repelling.

Fabric
Material produced from fibres or continuous filament directly or in the form of yarn, by knitting, weaving or other interlocking process, by fusing using temperature elevation or bonding with a cementing medium.

Fibre
Textile raw material (natural or man-made) generally characterized by flexibility, fineness and a high ratio of

Greige (fabric)
Also known as "grey fabric" and for woven textile products, as "loomstate" textile in its natural, untreated condition, i.e. before washing, bleaching or dyeing.

Knitting
Process of forming a fabric by the intermeshing of loops of yarn.

Non-woven (fabric)
Fabric made directly from a web of fibres or continuous filament, without the yarn preparation necessary for weaving or knitting. **Note:** In a non-woven, the assembly of textile fibres is held together by:

      a) mechanical interlocking in a random web or mat

      b) fusing of fibres, i.e. as with thermoplastic fibres or

      c) bonding with a cementing medium such as starch, casein, rubber latex, cellulose derivatives, or synthetic resin.

Primary packaging materials
Packaging in direct contact with the product.

Professional cleaning
Process for removing soiling or otherwise refurbishing textiles, particularly those susceptible to damage, through the use of specific solvents or other liquids, detergents and other additives, by competent persons.

Repackaging facility
Facility where products are repackaged into smaller units without additional processing in preparation for retail sale.

Scouring
Process of washing wool in hot water and detergent to remove the non-wool contaminants (natural fats, waxes, proteins and other constituents, as well as dirt, oil, and other impurities).

Secondary packaging materials
Additional packaging, not contacting the product, which may be used to contain relatively large volumes of primary packaged products or transport the product safely to its retail or consumer destination.

Spinning
Drawing out, twisting and further treating wool fibres to produce yarn. The further treatment includes, carding, combing, gilling and top making, drawing, roving and sliver formation.

Textile product
Article made from processed fibres. **Note:** Textile products may be made from other natural and man-made fibres. Products may include threads, cords ropes and braids; lace, nets and embroidery; hosiery, knitwear and made up apparel; household fabrics, soft furnishings, upholstery, carpets, rugs, mats; and technical, industrial and engineering textiles.

Texturing
Processing of yarn to introduce durable crimps, coils, loops or other distortions to create different textile surface finishes.

Tufting
Creation of pile or nap (e.g. on a carpet).

Weaving
Formation of textiles by the interlacing of threads passing in one direction (weft) with others at right angles to them (warp). **Note:** Woven textile products are also referred to as "loomstate".

Yarn
Assemblage of staple fibres or continuous filaments forming a continuous strand that can be used to create knitted, woven, braided, non-woven or other textiles.

3 Principles

3.1 General

These principles are fundamental to the application of this guidance and provide a basis for decisions relating to the planning and conducting of a wool LCA. Their application will help to ensure that assessment of environmental performance information is a true and fair account.

3.2 Environmental focus

These Guidelines use a life cycle assessment approach to address the environmental aspects and impacts of a wool textile system. Economic and social aspects and impacts are important but are outside the scope of this guidance. They may be assessed by combining other tools with the environmental life cycle assessment presented in this document.

3.3 Life cycle approach

Assessment of the environmental performance of wool textiles considers all stages of the life cycle from raw material acquisition to final disposal. Assessment may be restricted to one or several life cycle stages, such as cradle to farm-gate or cradle to primary processing. However, if assessments are not based on the full product life cycle they shall not be communicated as comparative assertions.

3.4 Scientific approach

Decisions within a wool life cycle assessment are preferably based on natural, biophysical sciences in a way that reflects causality. If this is not possible, other scientific approaches (e.g. from social or economic sciences) may be used, or international conventions may be referred to. If neither a scientific basis exists nor a justification based on other scientific approaches or international conventions is possible, then, as appropriate, decisions may be based on value choices. Attention should be given to clearly documented justification of decisions based on value judgements.

3.5 Completeness

Completeness refers to the need to have identified and understood all processes and data which provide a significant contribution to the environmental performance being assessed and including them in the inventory.

3.6 Consistency

Assumptions, methods and data are applied in the same way throughout the life cycle assessment to derive results and conclusions in accordance with the goal and scope definition of the study.

3.7 Transparency

Sufficient and appropriate information relevant to the processes, procedures, and assumptions embodied in the reported information are disclosed in order to ensure a proper interpretation of the results and to allow users of the wool life cycle assessment to make decisions with reasonable confidence.

3.8 Accuracy

Ensure that the assessment of environmental performance of wool textiles is accurate, verifiable, relevant and not misleading and that bias and uncertainties are reduced as far as is practical. The accuracy of quantitative information may depend on specific sampling methods and qualitative information but is subject to a level of uncertainty that can be quantified.

3.9 Fairness

Ensure that reporting of the environmental performance of wool textiles based on this guidance allows the user to clearly understand the scope of the study and limits of confidence in the results.

4 Product definition

4.1 Overview of product group

These Guidelines specify requirements for the assessment of the environmental impacts of wool textile products across wool supply chains using a life cycle approach. This first iteration of the Guidelines focusses on wool textile for apparel and sets out the requirements for attributional life cycle assessment of a sub-set of environmental impact categories that have been shown in past studies or are identified in significant LCA approaches to be of importance for wool production systems. Future development is planned to expand the guidance to cover additional impact categories and, following international consensus on methodology, to develop guidance for conducting consequential LCA studies.

These Guidelines build on previous standards and guidance for life cycle assessment as outlined in the Introduction, including:

- ISO 14044:2006 Environmental management - Life Cycle Assessment - Requirements and Guidelines
- ISO/TS 14067:2013 Carbon footprint of products – Requirements and guidelines for quantification and communication
- ISO 14046:2014 Environmental management - Water footprint - Principles, requirements and guidelines.
- PAS 2395:2014 Specification for the assessment of greenhouse gas (GHG) emissions from the whole life cycle of textile products.
- LEAP (2015a) Greenhouse gas emissions and fossil energy demand from small ruminant supply chains: Guidelines for quantification.

4.2 Product definition

Clear, unambiguous definition of the product under assessment is essential in LCA studies. Apparel frequently has multiple components and materials which can substantially affect the cradle-to-grave environmental impacts. The first version of these Guidelines targets the component of textiles made from the wool of sheep, while recognising that full environmental performance of a garment with non-wool materials, such as zippers, buttons, finishes and trims, will require additional data and analysis. Reporting of the results of an LCA study based on these Guidelines shall clearly specify whether the assessment refers to the wool textile component alone or to all parts, including non-wool parts, of a finished product.

4.3 Product system

These Guidelines take into account the full life cycle of wool textile products. The assessment is commonly conducted in a modular fashion across stages, in which case assessment of each stage shall provide information for a subsequent stage in a way that ensures that the reference flow is consistent through the supply chain i.e. that there is material balance between outputs of one stage and inputs to a subsequent stage (ISO 2013). All relevant activities shall be included in the modularised stages so that the processes from production of greasy wool through to recycling and final disposal, including transport and energy use within and between stages, are included in accounting.

5 Goal and scope

A wool textile LCA may be conducted to meet a range of objectives. For example, the goal of an LCA may be to benchmark the environmental performance of an organisation's wool products across multiple impact categories as a basis for undertaking performance tracking, and/or to set improvement targets and monitor progress against them. In some cases the goal may be linked to a specific impact category such as reducing greenhouse gas emissions for production of a garment type, or identifying the emissions hotspots in the supply chain in order to prioritise investment in efficiency and mitigation. The intended audience of a wool LCA is also an important consideration. The objectives may include reporting to internal or external stakeholders on one or several environmental impacts. These Guidelines do not provide detailed guidance on communication, although Annex D recommends key factors for consideration in conveying the results of wool LCA studies and lists additional references. These Guidelines are not intended for comparative assertions, product declarations, or labelling.

5.1 Goal

The goal of the study shall be clearly defined as a critical first step in an LCA. The goal is based on careful analysis of the purpose of the study and in order to help ensure that any conclusions drawn are consistent with its scope and its conduct.

ILCD (2010) recommends the following factors be considered in the goal definition of an LCA:

- Subject of the analysis;
- Key properties of the assessed system: organisation, location(s), dimensions, products, sector, and position in the value chain;
- Purpose for performing the study and decision-context;
- Intended use of the results, e.g. for internal decision-making or to be shared externally with third parties;
- Limitations due to the method, assumptions and choice of impact categories; in particular, clear description of limitations to conclusions on broad environmental performance associated with narrow assessment of impact categories;
- Target audience of the results;
- Need for critical review;
- Relevant stakeholders.

An iterative process with interpretation against the defined goal at each step in the LCA shall be undertaken to check alignment of data and methods. Interpretation shall consider the principles of LCA (Section 3) including lack of bias, completeness and accuracy, and should include sensitivity checks and uncertainty analysis.

5.2 Scope

Along with the goal definition, the scope of the study shall be defined as part of the first stage of an LCA. The scope identifies the product and system to be analysed, the functional unit, system boundary, and impact categories to align with the goal. These factors determine the breadth and level of detail of the LCA. The scope definition affects data collection and details of method choices. It shall be reviewed and, where necessary, revised in consideration of data limitations, uncertainty or method adjustment identified during the iterative process of the study as described above.

5.3 Functional unit

In undertaking an LCA for wool textile products, the quantity and quality of the product being assessed shall be specified in the description of the scope. The functional unit shall be defined to represent the primary unit by which the study reports impacts, and should represent the product or service produced by the system and should be determined in relation to the purpose and specific situation of a study.

The functional unit shall reflect the service provided by the product, including expected lifetime of the product. A full LCA study shall include consideration of reuse after the first use phase where applicable and the end-of life of the product. Where studies investigate only a segment of the supply chain (e.g. cradle to farm-gate) the functional unit may be a product flow across the system boundary, such as a kilogram of greasy wool. In addition to the functional unit which applies to the final product, it is important to define reference flows to provide a quantitative reference for intermediate products. In order to ensure input and output data are normalised in a mathematically consistent way, functional units and reference flows shall be clearly defined and measurable (ISO 14044: 2006). For example, the reference flow (and functional unit for a cradle to farm-gate partial LCA) is a unit weight of greasy wool at the farm-gate. Examples of functional units are set out in Table 1.

Table 1. Examples of functional units or reference flows in published guidelines or LCA studies.

WOOL PRODUCT	EXAMPLE FUNCTIONAL UNIT/REFERENCE FLOW	REFERENCE
Fibre	1 kg greasy wool	Wiedemann et al. (2015a), LEAP (2015a)
	1 kg clean wool	LEAP (2015a)
Yarn	1 kg yarn	
Textile	1 kg textile	
Apparel (socks)	1 pair socks (medium size; weighing 0.0817 kg excluding packaging) with 1 year of use and 52 washes per year	Henry et al. (2015b)
Apparel (long-sleeve base layer garment)	1 garment (men's size; 0.250 kg excluding packaging) with 1 year of use and 52 washes per year	Henry et al. (2015b)
Apparel (Merino knitted sweater)	1 sweater (weighted average 0.265 kg, without accessories) with 5 years of use and 15 washes per year over this life time	Bevilacqua et al. (2011)

5.4 System boundary

5.4.1 Determining the system boundary

The system boundary is defined during the goal and scope phase of the LCA. A full LCA shall include all aspects of the supply chain from raw material production (greasy wool) through to the end-of-life of the functional unit, including recycling and end-of-life processes such as composting or incineration. In a modularised approach, it is important to ensure that all material inputs and emissions are counted for the relevant stages, and that no double counting occurs.

Figure 2 illustrates a general system boundary for a representative wool textile life cycle. Stages within the system are summarised here and described in later sections of these Guidelines.

The life cycle of a wool garment may be assumed to encompass the following steps:

- Production of greasy wool (the raw material) including all inputs to the fleece such as the breeding sheep (rams and ewes), energy for shearing, and inputs for feed production such as irrigation, nutrients (fertiliser), pesticides and other chemicals;

- Production of clean wool, which typically takes place at a scouring plant involving use of cleaning chemicals (e.g. detergents, bleaching agents and acids), freshwater consumption, energy use and wastewater processing;

- Yarn and textile production typically through steps of spinning, knitting or weaving, dyeing and finishing, encompassing freshwater consumption, direct and indirect energy use, chemical use, wastewater treatment and textile production waste management;

- Product manufacture processes including cutting, assembly, finishing and packaging of the product, direct and indirect energy use, chemical use, freshwater consumption; **Note:** These Guidelines do not include production of items for embellishment of wool textile products such as trims and buttons.

- Transport within and between production steps starting at inputs for greasy wool production on-farm and continuing across all stages to final product completion;

- Transport of the final product including distribution to retail outlets or directly to consumers (e.g. through online purchasing), and, where applicable, including transport of a consumer to the retail outlet;

- Use stage, including washing, drying, ironing, dry-cleaning where applicable, encompassing freshwater consumption, energy use, detergent and other chemical use;

- Reuse (commercial e.g. charity sales, or non-commercial e.g. passing-down to family or friends);

- Recycling (closed-loop or open-loop), including energy, water and chemical use, and transport;

- End-of-life disposal characteristically by landfill or incineration, but sometimes including composting, and including end-of-life disposal of packaging.
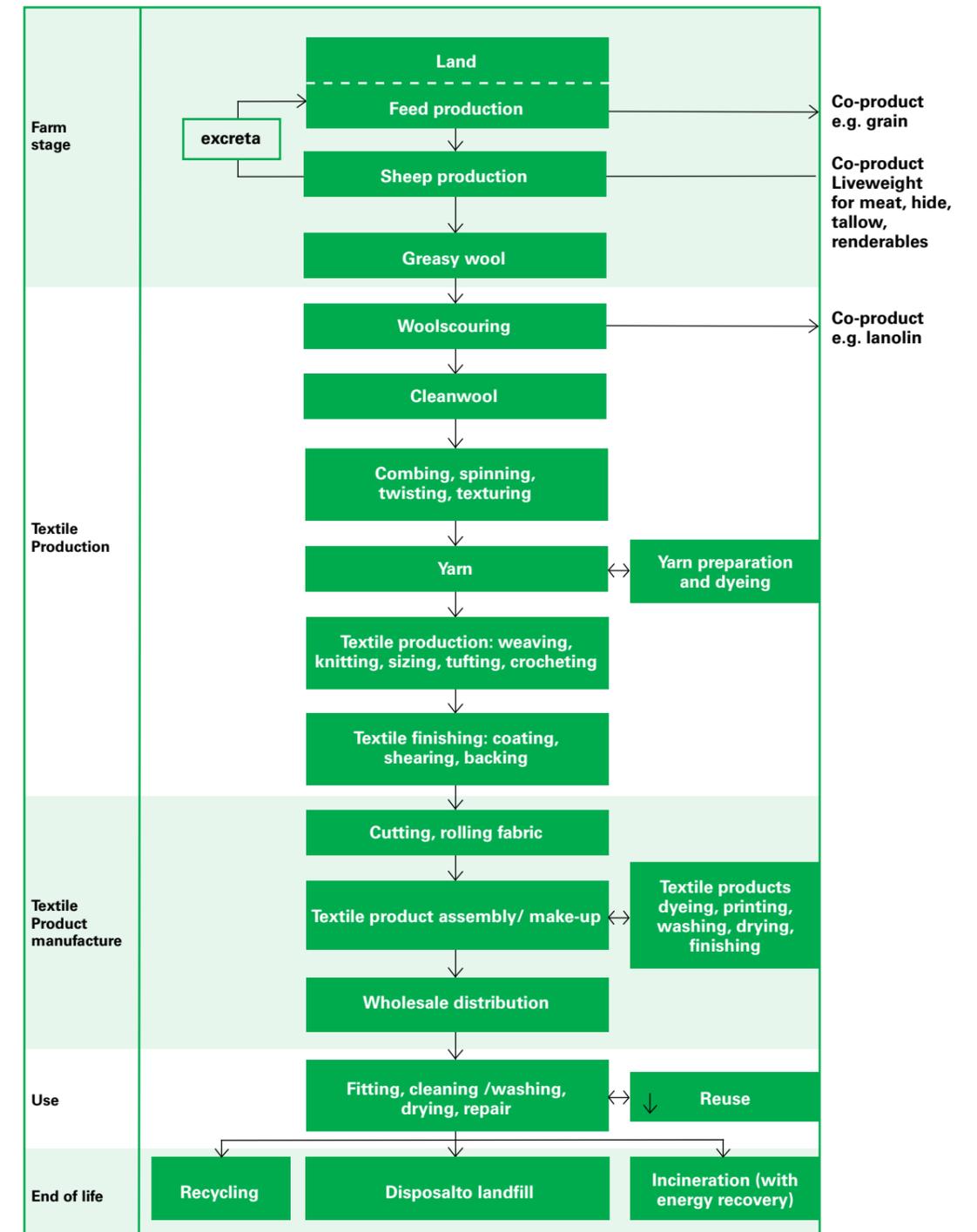

Figure 2. System boundary diagram for the life cycle of textile produced from wool from sheep (excluding inputs, outputs and emissions). Transportation can occur between any of the various stages outlined. (Source: Henry et al. 2015b; adapted with permission from BSI 2014).

5.4.2 Scoping analysis and materiality

While an LCA study ideally includes all relevant transfers in the inventory and minimises the uncertainty in all life cycle stages contributing to each impact category, the data requirements to do this can be prohibitively time consuming and expensive. For practical reasons a decision may be made in LCA to exclude very minor contributions. Exclusion of any process due to its being immaterial should be determined by a scoping analysis based on a relatively rapid assessment of the system. The scoping analysis may be conducted using secondary data to provide an overall estimate of a limited number of supply chain stages to determine the relative impacts of each stage. Where contributions from inputs or processes are <1% of total impacts these may be excluded. However, a minimum of 95% of the total impact for each category shall be accounted for. For example, excluded processes or inputs at the sheep farm stage, may include embedded inputs in buildings or other long-life farm infrastructure such as fencing. The system boundary should be defined using a flow diagram, indicating where processes were cut off. A material flow assessment is also recommended to track the mass flow of wool and co-products through each stage of the supply chain.

5.4.3 Overview of data requirements

Detailed data are important for the first stage in the wool supply chain, greasy wool production on sheep farms, which typically contributes more than 50% of the total for important impacts such as climate change over the life cycle of textile products. Data may extend over more than one farm if sheep are traded between farms prior to shearing. Because of the substantial contribution of this stage, the quality of data relevant to feed production and animal production is an important determinant of the accuracy of assessment.

Agricultural systems producing greasy wool are typically open and dynamic, and involve many transfers between the production system and the environment. Often, these transfers cannot be directly measured as part of an LCA study, so that modelling is required to determine impacts. For example, many impacts associated with wool production are largely governed by the amount of feed consumed by sheep but feed intake is very difficult to measure in grazing situations and is typically modelled in LCA research. Modelling of feed intake and the related impacts, which include emissions of the greenhouse gas, methane, from enteric fermentation, drinking water volumes and manure production, requires robust data on animal numbers, and a good understanding of live weight and reproductive status of the flock, as well as the characteristics of the feed.

In the post-farm stages, energy efficiency, transportation modes and distances, waste discharge and fate of the product following purchase by a consumer are important in determining key impacts, and these shall be accurately assessed. Data on consumer use and practices for reuse, recycling and end-of-life may cover multiple countries and non-commercial as well as commercial transactions. For some of these processes, impact modelling currently relies on limited surveys which may not be representative and reporting should include an analysis of confidence in these inventory data.

5.4.4 Time boundary for data

Accurate accounting requires a minimum of 12 months of data for the primary stages of the supply chain, to account for seasonal variation in production, and climate related impacts. At the sheep farm, a longer period of accounting (3 to 5 years) may be warranted to ensure a representative production year is selected. For example, production in some parts of the world may be heavily influenced by drought.

5.4.5 Capital goods and ancillary inputs

The production of capital goods (buildings and machinery) with a lifetime greater than one year may be excluded in the life-cycle inventory. Capital goods whose life span is less than one year shall be included for assessment, unless the contribution to resource use or emissions falls below the 1% cut off threshold (See Section 5.4.2).

All consumables and ancillary inputs (such as veterinary medicines, servicing, executive air travel or accounting or legal services) shall be included if relevant and material. To determine if these activities are relevant, an input-output analysis may be used as a scoping analysis.

5.4.6 Delayed emissions from vegetation and soils

All emissions during the life cycle of the wool product are assumed to occur and be fully accounted within the time boundary for data, i.e. within the period as determined by the goal and scope of the study but a minimum of one year). The method for assessment of delayed emissions presented in LEAP (2015b) and BSI (2011) should be followed or, if an alternative method is used this shall be justified.

5.4.7 Offsets

For climate change impact assessment, offsetting, i.e. investment in a mechanism outside the boundary of the textile product system for compensating all or for a part of the product GHG emissions, shall not be included in the LCA. However, GHG removals within the boundaries of the product system that are part of production, e.g. carbon sequestration in shelter belts in pastures grazed by wool sheep, should be included in the assessment according to methods set out in ISO/TS 14067 (ISO 2013). Where assessed, as well as being included in the LCA, they shall also be reported separately under an "additional information" section with detailed documentation of methodology and assumptions used.

6 Environmental impact categories and resource use in wool LCA

A wide range of potential resource use and environmental impact categories have been identified in LCA standards. For example, ILCD (2011) has 3 resource indicators (land use, resource depletion-water and resource depletion-abiotic), climate change and 10 other indicators related to human health and ecosystem quality. Not all impact categories are equally relevant to each stage of the supply chain of wool products or have an equivalent level of consensus on methodology across the life cycle of wool. The priorities and status of impact categories is also discussed.

6.1 General information on impact categories in wool LCA

6.1.1 Review of LCA impact category selection

In LCA the selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration (ISO 2006b). Table 2 provides a list of impact categories or resource use indicators used in LCA and their adoption in programs most relevant to wool LCA. The reference documents describe other requirements, most of which can be defined as inventory indicators rather than environmental impact indicators. Note that some documents cited refer to the authors of a certain impact category, e.g. WMO 2011 for Ozone Depletion, and others quote the common name that is used in LCA tools and LCA literature, e.g. CML 2001 or ReCiPe. An interim recommendation has been made for most impact categories and resource use indicators based on an assessment of technical accuracy and the degree of consensus in international textile LCA programs and these recommendations will be updated over time. Appendix A2 provides additional description of some key impact categories.

Table 2. Impact categories and resource use indicators important for LCA of wool products. Methods used in the most commonly reported programs are also listed with an interim recommended approach for wool textile LCA.

CATEGORY	INTERIM RECOMMENDATION	PCR 2013:12[1]	SAC[2]	EU-PEF[3]
Climate Change (CO2-e using GWP100)	ISO/TS 14067:2013 (ISO 2013; Myhre 2013)	CML[4]	IPCC 2007	IPCC 2007
Abiotic Resource Depletion elements (ADP elements)	CML (van Oers et al. 2002)	CML	CML (van Oers et al. 2002)	Not required
Abiotic Resource Depletion fossil (ADP fossil)	CML (van Oers et al. 2002)	Not required	CML (van Oers et al. 2002)	CML (van Oers et al. 2002)
Eutrophication aquatic	CML	CML	Redfield (1934)	Struijs et al. 2009 as implemented in ReCiPe
Eutrophication terrestrial	CML	CML	Redfield (1934)	Seppälä et al. 2006; Posch et al. 2008
Acidification Potential	CML (Seppälä et al.; 2006; Posch et al. 2008)	CML	CML	CML (Seppälä et al. 2006; Posch et al. 2008)
Photochemical Ozone Creation Potential (POCP)	CML	CML	TRACI 2.1 (Bare 2002)	Van Zelm et al. 2008 as applied in ReCiPe
Ozone Depletion Potential (ODP)	WMO 2011 as implemented in CML	Not required	Montreal Protocol (WMO 2011)	WMO 2011
Human toxicity – cancer effects	USEtox (Rosenbaum et al. 2008)	Not required	EU-SVHC, SARA 313, AAFA, CA-Prop 65[5]	USEtox model (Rosenbaum et al. 2008)
Human toxicity – non-cancer effects	USEtox (Rosenbaum et al. 2008)	Not required		USEtox model (Rosenbaum et al. 2008)
Eco-toxicity for aquatic freshwater	USEtox (Rosenbaum et al. 2008)	Not required		USEtox model (Rosenbaum et al. 2008)
Resource Depletion Water	Pfister et al. 2009	Not required	Pfister et al. 2009	Swiss Ecoscarcity model (Frischknecht et al. 2008)
Resource Depletion fossil fuels	CML (Guinee et al. 2002)	Not required		CML
Land Occupation	Wiedemann et al. 2015a	Not required	m²-yr land occupied	Not required
Land transformation	ISO/TS 14067:2013 (ISO 2013)	Not required	Land use change inventory (m²)	Soil Organic Matter (SOM) model (Milà i Canals et al. 2007)
Particulate Matter/Respiratory Inorganics	TRACI 2.1 (Bare 2002) or RiskPoll model (Humbert 2009)	Not required	TRACI 2.1 (Bare 2002)	RiskPoll model (Humbert 2009)
Ionising Radiation – human health effects	ReCiPe (Goedkoop et al. 2008) or ILCD (2011)			Human Health effect model (Dreicer et al. 1995)

[1]**PCR 2013:12:** PCR 2013:12 Textile yarn and thread of natural fibres, man-made filaments or stable fibres, Version 1.01, International EPD® System.

[2]**SAC:** Sustainable Apparel Coalition (2013) Product Category Rule Guidance 2013, Institute for Environmental Research and Education

[3]**EU PEF:** EU. (2013). 2013/179/EU Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations.

[4]**CML:** Unless otherwise indicated, CML refers to the 2001 baseline Version: April 2013.

[5]**EU-SVHC** (Substances of Very High Concern); **SARA 313** (US EPA Release Inventory Chemical List Section 313); **AAFA** (American Apparel and Footwear Association Restricted Substances List); **CA-65** (California Office of Environmental Health Hazard Assessment).

ISO 14044:2006 (ISO 2006b) allows for selection of impact categories according to the goal and scope of the study, and published LCAs have frequently quantified only a limited number of impacts. Several of these studies (e.g. LEAP 2015a, Bevilacqua et al. 2011) have reported a single-impact, particularly climate change impact ('Carbon Footprint'), or the Water Footprint (ISO 2014). In the EPD scheme, many PCRs have pre-selected impact categories to be included.

The main objective of these Guidelines is to provide guidance for wool textile LCA studies that are robust, scientifically credible and as accurate as possible within data and methodology limitations. It is also desirable that the LCAs may be harmonised with major international schemes. Hence, impact categories described for SAC (2013), PCR 2013:12 and EU PEF (2013) were reviewed (Tables 2 and 3). Requirements vary between these schemes.

Table 3. Comparison of impact categories required by SAC, EU-PEF and PCR 2013:12

IMPACT CATEGORY	SAC	EU – PEF	PCR 2013:12
Climate Change	X	X	X
Acidification – atmospheric	optional	X	X
Eutrophication - terrestrial	X	X	X
Eutrophication – aquatic	X	X	X
Photochemical Ozone Creation Potential	optional	X	X
Stratospheric Ozone Depletion	optional	X	
Abiotic Depletion Fossil	X	X	
Abiotic Depletion Elements	X	X	
Resource Depletion Water	X	X	
Land Occupation	X[1]		
Land transformation	optional	X	
Soil losses	optional		
Eco-toxicity for aquatic freshwater	X	X	
Human Toxicity – cancer effects	X	X	
Human Toxicity – non-cancer effects	X	X	
Particulate Matter/Respiratory Inorganics	optional	X	
Ionising Radiation – human health effects			X

[1]Agriculture only; not required for man-made fibres

An overview of the most relevant impact categories or resource use [mid-point] indicators listed in Table 2 is given below as background and guidance for selection of impact categories in wool LCA. The climate change, eutrophication potential, water consumption and land occupation indicators are most important at the sheep production stage. They are expressed as mid-point impact categories.

Resource depletion – fossil fuels (Primary Energy Demand): Fossil fuel use is a useful indicator of depletion of a finite resource. Non-renewable primary energy demand contributes to climate change, an environmental issue of high public and institutional interest, and widely recognised as an extremely pressing global environmental issues of our time.

It is also linked to other environmental impact categories related to human health and air quality (Ecotoxicity and Human Toxicity) and to Climate Change. Resource depletion - fossil fuels (Also called Fossil Fuel use or Primary Energy Demand) is typically relatively low for the greasy wool production phase compared to the raw material stage of alternative fibres. However, in intensive farming systems with relatively high inputs, heavy metals from high fertiliser use can be a significant contributor to some impact categories (e.g. human health-cancer and non-cancer; Chobtang et al. 2015).

Climate change: The climate change indicator has a number of contributing greenhouse gases (GHGs) and emissions of each are summed along the supply chain. Estimation of net greenhouse gas emissions includes the photosynthetically bound carbon (also called biogenic carbon) and the release of that carbon during the use or end-of-life phase as CO_2 and/or CH_4. The aggregated impact is calculated by applying a characterization factor, most commonly the Global Warming Potential for a 100-year time-frame to give a equivalence units, mass of CO_2- equivalents. These Guidelines adopt the standard in ISO/TS 14067:2013 whereby if an LCA does not apply the latest IPCC GWP value (currently IPCC 2013) to calculate the climate change impact, this shall be stated and justified in the LCA report (ISO 2013).

Eutrophication potential: The methodology for estimating eutrophication potential differs across a range of publications, with most recognising one or more of nitrogen (N), phosphorus (P) and oxygen-depleting organic (e.g. chemical oxygen demand or COD) sources. A method for Eutrophication Potential using all these sources was defined by Guinée et al. (2002). A number of methods have been evaluated for specific countries or regions and a review of these methods by ILCD (2011) resulted in a recommendation of Marine or Aquatic Eutrophication based on only N inputs to water and Terrestrial or Freshwater Eutrophication based on only P inputs to water. These methods and their associated characterisation factors (Goedkoop et al. 2009) were based on validation in European waterways, which makes extrapolation to other countries uncertain. The current recommendation is to use these methods as a default approach, although ideally a local validated characterisation would be preferred where available. However, it is recognised that extensive sheep production systems are associated with relatively low per-hectare emissions and in catchments where such systems dominate the freshwater eutrophication potential could be determined by N and/or P, ideally spatially-dependent information for the catchment/region/nation.

Resource depletion – water (Consumptive water use): The method used to estimate fresh water consumption is based on the quantity of 'blue' water use (from ground and surface waterways) that is withdrawn and not returned within the catchment. Water consumption can be due to evaporation, transpiration, integration into a product or release into a different drainage basin or the sea. To be expressed as an indicator of environmental impact, requires application of a water scarcity index based on regional water availability (Ridoutt and Pfister 2010, Pfister et al. 2009, ISO 2014).

Land occupation: Land occupation refers to the area of land use associated with all sources contributing to production. Environmental impacts associated with use of land may include depletion in resource availability or change in biodiversity, carbon stocks and soil quality. Assessment of these impacts or stress on availability of land resources for alternative social and economic use (e.g. urban development or conservation) cannot be assessed from an aggregation of areas of occupied land of different quality. Separating land types using net primary productivity (NPP) or a simplified indicator such as arable vs non-arable land is needed as a minimum basis for analysis (e.g. Wiedemann et al. 2015b) but no consensus method is yet available (Koellner & Scholz 2007, Mattila et al. 2011). In all cases, the environmental impact or resource use is expressed per functional unit.

6.2 Impact categories: Cradle-to-farm-gate stage of wool production

For sheep production systems resource use indicators relating to land occupation and freshwater consumption are important because the impact can be relatively large. In major production regions, area of land use associated with sheep grazing is frequently high. Sheep farming can also potentially cause significant depletion of water resources through animal drinking and use for irrigation of pasture or feed crops. Impacts on water quality and eutrophication potential can also occur. However, methods for these impact indicators are currently often generic and cannot reflect site-specific impacts, especially for water quality and eutrophication. Regionalised characterisation factors are now available for water use and methods are being examined by researchers and with a view to improvements in future (e.g. Reap et al. 2003).

In summary, the most relevant impact indicators for the cradle to farm-gate stage of the life cycle of wool are:

1. Climate change
2. Freshwater consumption
3. Non-renewable primary energy demand (fossil fuel use)
4. Eutrophication potential
5. Land occupation

In all cases, the environmental impact or resource use is expressed per functional unit.

6.3 Impact categories: Post farm-gate stages of the wool supply chain

Of the impact categories listed in Table 2, Climate change, Abiotic Resource Depletion, Eutrophication Potential, Acidification Potential, Photochemical Ozone Creation Potential and Ozone Depletion Potential are relevant to most manufacturing processes, and are generally included in LCA studies.

Based on the analysis above, the following impact indicators are recommended for wool LCA in the post-farm gate stages:

1. Climate change
2. Freshwater consumption
3. Non-renewable primary energy demand
4. Eutrophication potential
5. Acidification potential
6. Photochemical ozone creation potential
7. Ozone depletion potential
8. Human toxicity and ecotoxicity

This list incorporates the most important indicators identified for cradle to farm-gate production of wool (Section 6.2) except for land occupation. Atmospheric acidification and photochemical ozone creation potentials as well as eutrophication (discussed above) can be significant for processing, manufacture and use of wool textiles and should be included in assessments because they are closely connected to air, soil, and water quality and capture the environmental burdens associated with commonly regulated emissions such as NOx, SO2, VOC, and others. Ozone depletion potential should be included because of its high political relevance, which eventually led to the worldwide ban of more active ozone-depleting substances; the phase-out of less active substances is due to be completed by 2030. The indicator is, therefore, included for reasons of completeness.

An evaluation of human toxicity and ecotoxicity may also be undertaken. USEtox™ is currently the best-available approach to evaluate toxicity in LCA and the consensus methodology of the UNEP-SETAC Life Cycle Initiative. The precision of the current USEtox™ characterisation factors is within a factor of 100 to 1,000 for human health and 10 to 100 for freshwater ecotoxicity (Rosenbaum, et al., 2008). This is a substantial improvement over previously available toxicity characterisation models, but still significantly higher than for the other impact categories noted above. Given the limitations of the characterisation models for each of these factors, results are reported as 'substances of high concern'. They should not be included in results for comparative assertions.

7 Multi-functionality and allocation to co-products

7.1 General principles for allocation in textile LCA

Principles for handling co-products in LCA as set out in ISO 14044:2006 (ISO 2006b) and elaborated in LEAP (2015a,b) for livestock systems and in BSI (2014) for textile supply chains are summarised below. The choice of method for handling co-production in multifunctional systems, such as wool textile supply chains, frequently has a significant impact on the final calculated impacts across the co-products. These Guidelines add to published information in Standards and protocols by providing specific guidance regarding allocation choices at each major stage in the production system. This guidance reflects recent research (Wiedemann et al. 2015a) and aims to support consistency in application of generic rules to wool LCA studies using a defensible methodology.

ISO 14044:2006 (ISO 2006b) recommends avoiding allocation where possible, by:

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

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

Of these options, expanding the product system may be highly informative for wool LCA when applied with a consequential modelling approach (See Appendix A2) but is generally considered not compatible with attributional LCA and is not recommended or described further in these Guidelines.

System separation is the first recommended step where multiple products arise from a single system. In the case of wool production at the farm level, other products that can be separated and accounted for separately may include products from other livestock species, or feed products from crops grown on the farm. These processes shall be separated and accounted for independently from wool production.

Where system separation is not possible, ISO 14044:2006 recommends, in order of preference, the following methods for handling co-products in LCA:

1. The inputs and outputs of the system should be partitioned among co-products or functions in a way that reflects the underlying physical relationships between them; or

2. Where physical relationships alone cannot be established or used as the basis for allocation, inputs should be allocated among the products and functions in a way that reflects the other relationships between them, e.g. according to the relative economic value of the products.

In the application of ISO 14044:2006, the following requirements for allocation shall be met (ISO 2006b):

- Inputs and outputs shall be allocated to different products according to clearly stated procedures that shall be documented and explained.

- The sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation.

- Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of any departure from the selected approach.

LEAP (2015a,b) provides specific guidance for handling co-products in small ruminant (sheep and goat) supply chains relevant to wool as in Table 5. Where allocation cannot be avoided biophysical allocation is preferred for the cradle to farm-gate stage dealing with mixed animal species on-farm and for important co-products (greasy wool, live-weight (for meat) and milk) from sheep or goats. Economic value is recommended for allocation between clean wool and lanolin products from the primary processing (scouring) stage.

PAS 2395 (BSI 2014) follows the hierarchy approach of ISO 14044 (ISO 2006b). Where allocation cannot be avoided, PAS 2395 has a general recommendation for textile supply chains that mass allocation be used for co-products that have similar characteristics and/or functionality, and economic allocation (calculated over a period of not less than one year) is applied in the case of co-products that differ in characteristics and/or functionality. However, in the case of animal fibres such as wool, PAS 2395 specifies that biophysical allocation (calculated over a one-year period) shall be used at the cradle to farm-gate stage and for accounting for mixed animal species on farms.

Table 4. Recommended methods for dealing with multi-functional processes and allocation between co-products for the cradle to farm-gate and primary processing stages in the life cycle of sheep or goat products. (Source: LEAP 2015a).

SOURCE/STAGE OF CO-PRODUCTS	RECOMMENDED METHOD*	BASIS
Animal species (within farm)	1. System separation 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. System separation 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.
Fibre processing to clean fibre and lanolin	1. System separation 2. Economic	First, separate the activities specific to individual products where possible. Then use economic allocation possibly based on five years of recent average economic value.

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. Specifically, it is recommended that biophysical causality and economic allocation are used in sensitivity assessment, and that market price fluctuations be included as a tested parameter in all economic allocation (Food SCP RT, 2013, p. 28).

Based on the consensus approach in ISO standards and recently published international guidance relevant to wool production from sheep, these Guidelines recommend that, where allocation cannot be avoided, biophysical causality shall provide the basis for dividing environmental impacts between co-products in the cradle to farm-gate stage of the supply chain. Where applicable, economic allocation should be applied to quantify impacts and resource use for post-farm gate stages of wool LCA. In all cases the approach adopted shall be documented and justified, including through use of sensitivity analysis. Methods applied in dividing multifunctional processes should be consistent within and between the datasets used. Furthermore, it should be ensured that the sum of the allocated inputs and outputs should equal unallocated inputs and outputs.

Section 7.2 provides specific guidance for allocation methodology for handling co-products in LCA for each supply chain stage in the life cycle of wool products.

7.2 Handling co-products in wool LCA supply chains

7.2.1 Cradle to farm-gate

Within the cradle to farm-gate stage of wool production, there may be allocation decisions associated with feeds, and the methods set out in LEAP (2015b) for animal feeds should be applied as appropriate. In mixed animal systems, co-production shall be accounted for as in Table 5, i.e. by firstly, separating any activities specific to each species and then determining impacts specific to feeds for the sheep system and impacts relating to other inputs such as energy or diesel requirements, using biophysical causality to estimate the proportion for each animal species. If other methods are used they shall be fully described and justified.

The major co-products from sheep in addition to fibre are live weight (meat) and, in some cases, milk. Allocation shall follow an approach closely aligned to the underlying biophysical processes occurring. For allocating between wool and live weight, we recommend using an approach based on protein allocation in the animal. A suitable biophysical modelling approach has been described by Wiedemann et al. (2015a). However, for ease of application where full biophysical modelling is not possible, it is recommended that a protein mass allocation (PMA) method is applied. PMA provides results that are a reasonable proxy for the more detailed biophysical protein allocation models (Wiedemann et al. 2015a).

Example – Protein mass allocation of wool and live weight:

$$Wool_{PM} = Wool\ Mass_{Greasy} \times Clean\ wool\ concentration \times Wool_{Dry\ mass} \qquad \text{Equation 1}$$

Where

$Wool_{Dry\ mass} = 84\%$, and assuming clean wool is 100% protein

$$Live\ weight_{PM} = Live\ weight\ mass \times protein\ concentration \qquad \text{Equation 2}$$

Where

Protein concentration may be determined using the regression of Sanson et al. (1993) or applying a default of 18%:

$$Wool_{Alloc} = Wool_{PM} / (Wool_{PM} + Live\ weight_{PM}) \qquad \text{Equation 3}$$

If milk is also produced, a similar approach can be used by determining the total protein mass of milk, and including this in the allocation equation.

7.2.2 Scouring

During scouring of greasy wool, both lanolin and clean wool are produced. Allocation at this point can be determined by separating the system at the point where grease and dirt is removed from wool as a residual product. At this point, no impacts are allocated to the material, and further processes used to produce lanolin are allocated to the lanolin product. If system separation is not feasible, economic allocation should be applied, and where possible this should be based on five years of recent average economic value.

7.2.3 Textile production and textile product manufacture

Steps in production of textile products from clean wool at the end of the first processing stage of the life cycle characteristically give only one product of economic value and no allocation decisions are required, i.e. 100% of the environmental impact is allocated to the wool functional unit.

7.2.4 Reuse and recycling

PAS 2050:2011 (BSI 2011) provides a simplified method of calculating environmental impacts over the cycle of use and reuse of products that may be applied to wool textile products that are reused. This method is given in Appendix C.1.

PAS 2050:2011 (BSI 2011) also provides a method for accounting for use of recycled material. While this guidance was developed only for climate change impact, the approach can, in principle, be applied to other impact categories. PAS 2050:2011 recommends that in the case of closed-loop recycling (e.g. where recycled wool textile products maintain the same inherent properties as the virgin material input) the impacts arising from use of recycled wool as raw material shall be specified using the closed-loop approximation method (also called the end-of-life approach). If the recycled wool textile product does not maintain the same inherent properties as the virgin material input, the [environmental impact] shall reflect the product specific recycled content and/or recycling rate based on the cut-off method (Appendix C.2, C.3).

An alternative to the simple approach in PAS 2050:2011 developed by Wolf and Chomkhamsri (2014) has been recommended for adoption in EU PEF Product Category Rules (Appendix C.4). Data requirements for the integrated method are more demanding. Until broader international consensus is reached and more representative data are available, it is recommended that wool LCA studies should use the most comprehensive approach possible. A detailed description of data completeness and quality shall be reported and a sensitivity analysis should be undertaken. These Guidelines will be updated to reflect methodology development for wool textile recycling and reuse which are important in the wool life cycle (Russell et al. 2016).

8 Data requirements for wool LCA

8.1 Principles for data quality

ISO standards (ISO 2006a,b) require that the data used to create the inventory model in LCA be as precise, complete, consistent, and representative as possible having regard to the goal and scope of the study. In practice, time and budget constraints are also an important consideration. Data quality principles are outlined as follows:

- **Precision:** For LCA, data could be measured, calculated, taken from literature or estimated. Measured primary data of the highest possible precision is preferred, followed by calculated data, literature data, and estimated data. Where modelling is required, the goal is to model all relevant foreground processes using measured or calculated primary data.

- **Representativeness:** expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data are not available and the impact on results is minor (e.g. <10% of the total for an impact category), best-available proxy data should be employed.

- **Completeness:** The objective is to capture all relevant data associated with processes within the goal and scope of the study. This requirement is judged on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. Therefore, all relevant process steps should be considered and modelled to represent the specific situations with regard to the goal and scope. Any missing data on material and energy flows must be noted and treated according to ISO14044 clause 4.2.3.6.3 (ISO (2006b)) practice as follows: 'the treatment of missing data is documented and, for each unit process and for each reporting location where missing data are identified, the treatment of the missing data and data gaps should result in a "non-zero" data value that is explained, a "zero" data value if explained, or a calculated value based on the reported values from unit processes employing similar technology.'

- **Consistency:** refers to modelling choices and data sources. The objective is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts. To ensure consistency, all primary data should be collected with the same level of detail, while all background data are sourced from a valid, up-to-date database. Allocation and other methodological choices must also be applied consistently throughout the model, as explained in Section 8.

- **Reproducibility:** expresses the degree to which third parties would be able to reproduce the results of the study based on the methodology and data values contained in the study report. The objective is to provide enough transparency within the report so that third parties are able to approximate the reported results. In practice, provision of data to third parties may be limited and transparency managed through exclusion of confidential primary data and access to the same background data sources. A clear description of the data quality is essential in the LCA study report. Details including checks carried out to validate the data should be supplied.

Under ISO 14044 (ISO 2006b), data quality analysis is an optional element of life cycle impact assessment and provides understanding of the study's reliability in terms of significance, uncertainty and sensitivity of the impact assessment results. The following techniques may be utilised:

- **Gravity analysis:** allows identification of data that make the greatest contribution to results.

- **Uncertainty analysis:** helps determine how uncertainties in data and assumptions can progress and affect reliability of results.

- **Sensitivity analysis:** helps determine how changes in data and methodological choices can affect the results.

8.2 Data sources

8.2.1 Cradle to farm-gate

The data requirements for LCA are highly dependent on the goal and scope of the study. This is particularly important for wool textile LCA studies which may focus on wool produced at national, regional or case-farm levels where sheep production systems can be extremely variable.

At national and regional levels there can be wide diversity in farm production systems and this makes it difficult to make accurate estimates for the 'average' system or product. Some studies have divided farms within countries or regions into 'typologies' that account for system variability. For example, New Zealand farms have been divided into high country (merino), hill country and intensive rolling/flat farm systems and further sub-divided according to major climate zones and whether sheep are farmed with cattle or with mixed cropping enterprises (Beef+LambNZ 2011; Ledgard et al. 2011). European studies have typically examined sheep farm systems ranging from year-round grazing of pastures through to farms where sheep are indoors with feed brought in (e.g. Ripoll-Bosch et al. 2013). In such cases, it is important to obtain representative farm data for the different typologies and wool types and to integrate or weight the data according to the relative production from the different typologies. In practice, this has typically been done based on the use of data from large numbers of surveyed farms from each farm typologies (e.g. Ledgard et al. 2011; Ripoll-Bosch et al. 2013), a combination of regional statistics and farm survey data (e.g. Wiedemann et al. 2015b), or from a limited number of representative case study farms in each farm category (e.g. Wallman et al. 2011).

Primary data (i.e. directly measured or calculated from collected data) should be used for as much farm specific information as possible. This should cover all 'foreground' processes, e.g. those associated with animal production and farm inputs at the farm production level. In practice, the required farm data on inputs, processes and outputs will result in the need for some estimation of key driving factors or processes, e.g. a critical determinant of the main GHG emissions from sheep is the amount, type and quality of the feed consumed by sheep. While the type of feed can be identified from recorded data and the quality of the feed based on measured data (or published data for the feed type relevant to the specific location, climate and management), the amount of feed intake can be very difficult to measure in grazed pasture systems. In the latter case, this is typically estimated indirectly using accepted models (published, peer-reviewed, country-specific and validated) based on primary data for animal live-weight and production as described in Section 9. Primary data on the animal population associated with wool production are critical and this should be based on an equilibrium population that covers all animal classes (including all breeding and replacement animals) and ages present over a 12 month period.

Secondary data (i.e. not directly measured but obtained from relevant published or recorded expert data) are generally used for 'background' processes for which the wool producer is not directly responsible, e.g. those associated with the off-farm production of inputs that are used on the farm. However, the use of secondary data can be acceptable for 'foreground' processes where primary data are unavailable and where the contribution to resource use and environmental emissions is not material. Secondary data should be sector-specific, recent (e.g. within the past 5 years) and meet data quality requirements (ISO 2006b, LEAP 2015a; See also Section 7.1). Some widely used sources of secondary data are from recognised databases, such as Ecoinvent (http://www.ecoinvent.ch/), ELCD (http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm) and Agri-footprint (http://www.agri footprint.com). However, data from such sources should be modified as needed to ensure relevance to the country or region of the study.

Data quality as well as sources should be specified in all reporting of results from an assessment of the environmental performance of wool and wool products. The requirements for data quality should meet the key areas described in ISO 14044 (ISO 2006b) and LEAP (2015a) and outlined in Section 7.1 above. Thus, the quality of data should be based on consideration of representativeness, precision, completeness, consistency, reproducibility and uncertainty analysis. For wool, which is from diverse animal-based production systems, the representativeness of the data is critical. Representativeness refers to elements of time (the age of the data and period of time over which it was collected), technology (reflecting the relevant technologies and sheep production system) and geography (geographical areas in relation to the scope of the study). The technology and geographical representativeness relates to the appropriate coverage of the farm typologies outlined earlier.

Data for sheep production for use in determining potential environmental impacts per kg wool shall cover a sufficient period to represent the production cycle for wool and associated co-products. Wool growth and characteristics (fibre length, diameter and volume) for mature coarse-wool sheep fluctuates through the year with growth being highest in summer and least in winter. Wool growth is affected by feed intake but controlled by the endocrine system in response to day-length (e.g. Sumner 2010). Similarly, farm data shall cover all relevant classes of sheep (breeding, replacement and growing sheep) involved in the production of wool and related co-products (e.g. live-weight sold for meat). Consequently, data collected shall cover a minimum of a full year, although in areas with large annual variability in climate and production it is appropriate to obtain an average for 12 months but based on 3-5 years data to ensure representativeness.

For minor inputs, flows or outputs, cut-off criteria (e.g. where the contribution is <1%, See Section 5.4.2) may be identified to guide investment in obtaining data for LCA. Cut-off criteria shall not be used to exclude particular flows.

8.2.2 Post farm-gate data

Post farm-gate stages include processes such as textile production, textile product manufacture, use of the wool product and end of life (see Figure 2). Transport to, within and from these processes shall also be included. There may be substantial variability in the types of final product and hence in the textile production processes. The data requirements for post farm-gate processes are dependent on the goal and scope of the study. Primary data for each foreground process should be collected for specific systems modelled in the LCA, with consideration to using recent information to reflect current technologies. It is recommended that foreground data should be no more than two years old and that the time period represented by data should be reported. Sensitivity analysis should be conducted where the technological representativeness of data is not known.

For the background system, if data from primary sources are not accessible, secondary data may be utilised. For example, for some processes such as the production of electricity, diesel or other generic datasets, secondary data from reliable databases or literature may be used. Documentation for secondary data should be provided for transparency.

To ensure reliability of data, primary data may be collected using specifically adapted data templates and spreadsheets. Cross-checks concerning the plausibility of mass and energy flows should be carried out on the data received. Validation involving, for example, mass balances, energy balances and/or comparative analyses of release factors are generally required. Other validation measures such as comparing collected or estimated data with published data should be undertaken as required.

In addition to requirements for data quality under ISO standards (ISO 2006a,b) as described in Section 8.1, there may be specific requirements under different PCRs. For example, data representativeness is addressed in the International EPD® System's PCR 2013:12, requiring that the data shall be representative for the year/time frame for which the EPD is valid (maximum three years). Consistent with recommendations in these Guidelines, the Sustainable Apparel Coalition PCR Guidance (SAC 2013) requires primary foreground data to be no more than two years old at the time of publication and that sensitivity analysis be conducted where technological representativeness of secondary data used is unknown.

Note: Representative data for 'typical' processing and manufacture facilities have not been sufficient to provide a default dataset for wool LCA to date, but may be appended to future iterations of these Guidelines. Such data could be used for validation checking but their use in an LCA study should be accompanied by a sensitivity analysis.

9 Life cycle inventory

9.1 Overview of Life Cycle Inventory

A data inventory of all inputs (including raw materials and energy sources), outputs (including emissions to air, soil or water) and products (including co-products and wastes) must be collected for all stages of the product supply chain covered by the goal and scope of the LCA. As noted in Section 7, primary data is required for foreground processes while secondary data may be used for background processes. The inventory shall consist of measured data and, where it is not possible to take direct measurements of inputs or outputs, modelled estimates based on primary data inputs to the modelling process. Options for dealing with data gaps include use of proxy data or extrapolated data. Proxy datasets include the use of background life cycle inventory (LCI) values based on a similar process or product, while extrapolated data may be estimated from related processes or products. Such secondary data should not account for more than 20% of the total contribution to any one impact category and uncertainty associated with such data should be outlined (LEAP 2015a). All major datasets should preferably be recorded with relevant uncertainty estimates, e.g. a mean and standard deviation. Such data may then be used in a Monte Carlo analysis to characterise the uncertainty of quantified impacts. Where there are several potential options for estimating a process (e.g. different methods of allocation between co-products), a sensitivity analysis should be conducted and results presented to illustrate the effects of method choice.

The LCI analysis involves an iterative process as outlined in ISO 14046 (ISO 2014) covering collection and validation of data, relating the data to each process and reference flow or functional unit (including allocation for co-products as required), and aggregation for calculation of specific emissions or resource use for each environmental impact category.

9.2 Cradle to farm-gate stage

9.2.1 Overview of data inventory for the cradle to farm-gate stage

The main inputs and activities that represent sources of emissions or resource use for the cradle to farm-gate impact categories discussed in detail in these Guidelines are given in Table 6. These are predominantly the inputs and activities associated with animal production, feed production and the production and use of the main farm inputs. The energy use includes fuel use associated with all transportation steps, e.g. transport of raw materials for production of inputs, transport of inputs to the farm, feed movement to and within the farm, and animal movement.

Previous research with sheep systems and LCA across the life cycle of lamb to the consumer stage showed that the cradle-to-farm-gate stage dominated (commonly >80%) climate change, eutrophication, and land occupation, while for fossil fuel demand this stage accounted for almost 50% (Ledgard et al. 2011; Wiedemann et al. 2015b). These studies also showed that within the cradle-to-farm-gate stage, the major determinants were feed production and animal feed intake. For example, for climate change the methane emissions from animal rumen fermentation contributed 71% of farm-related total GHG emissions (Ledgard et al. 2011). Excreta from sheep and the related manure management may also be a significant contributor to on-farm GHG emissions and eutrophication. Thus, it is critical to obtain accurate estimates of feed production, feed intake by animals, excreta production and manure management.

Table 5. Recommended methods for dealing with multi-functional processes and allocation between co-products for the cradle to farm-gate and primary processing stages in the life cycle of sheep or goat products. (Source: LEAP 2015a).

IMPACT CATEGORY	EMISSION/ RESOURCE USE	SOURCE (INPUT/ACTIVITY)
CLIMATE CHANGE	Methane	□ Animal rumen fermentation □ Animal excreta/manure □ Feed production wastes (anaerobic storage) □ Biomass burning □ From energy use (including for inputs, e.g. fertilisers)
	Nitrous oxide	□ Animal excreta/manure □ Nitrogen fertilisers □ Crop residues □ Indirect sources from nitrogen leaching, runoff or volatilisation of ammonia-N □ From energy use (including for inputs, e.g. fertilisers)
	CO2	□ From energy production and use (including for inputs, e.g. fertilisers) □ From soil after urea application □ From soil after lime application □ Land use and land use change
EUTROPHICATION	N to water	□ Leaching/runoff from land (including from inputs, e.g. excreta, manure, fertiliser) □ N loss via soil erosion
	Ammonia	□ From volatilisation from excreta/manure & N fertiliser
	NOx	□ From fuel combustion
	P to water	□ Leaching/runoff from land (including from inputs, e.g. excreta, manure, fertiliser) □ Releases associated with P fertiliser manufacturing □ P loss via soil erosion
FRESHWATER CONSUMPTION	Water (quantity; from surface or ground water)	□ Animal drinking water □ Water content of animal products □ Animal respiratory losses □ Net evaporation from water storage sources used for animals or irrigated crops □ Water withdrawal and evapo-transpiration (ET) for irrigation of feeds □ Water withdrawal and evaporation from production of energy sources and inputs
LAND OCCUPATION	Land (area; non-arable or arable)	□ Land used for all activities (including feed production, animal containment, production of inputs)

9.2.2 Feed production

The first requirement is to determine the quantity of each of the feed types consumed by sheep and the main feed quality characteristics. These are then related back to production of the different feeds and their associated inputs and emissions. Feed types can vary greatly from grasslands through to crops such as cereals or brassicas that may be grazed directly, made into silage or go through various processing stages and made into concentrates for supplementary feeding to animals. The LEAP guidelines for animal feed supply chains (LEAP 2015b) provide detailed guidance on accounting for environmental emissions and resource use from feeds including processed feeds as well as specific information on determining an LCI for feeds. A range of default data are provided in LEAP (2015d).

The main purchased inputs that contribute to emissions from feed (including manufacturing, transport and application stages) are fertilisers, manures and lime. The other major contributor is fuel used for feed production, processing and transport. Additionally, resource use and emissions associated with production and sowing of seeds for feed production should be accounted for.

Use of irrigation water for crop production is often a dominant contributor to freshwater consumption, while N2O emissions from crop residues and CO2 emissions from land use change may be significant contributions to the climate change impact category. Primary data should be obtained for the main feeds. For brought-in feeds where primary data cannot be accessed, default data from databases such as Agri-footprint (http://www.agri-footprint.com/) may be used with adjustments for location of supply.

Emissions and resource use associated with feeds shall account for the total amount of feed purchased or provided. In practice, this will be more than that consumed by animals, due to wastage, which can be up to 30% when fed out in the field onto the ground. Plant residues, such as cereal straw, may be used for bedding for housed sheep and emissions associated with harvesting and transportation to the farm shall be accounted for.

Globally, many sheep are outdoors throughout the year and graze on perennial plants including pastures, herbs and shrubs. Such plants can vary markedly in feed quality during the year and the accuracy of estimates of animal feed requirements and of calculations of the amounts of N and P that will be consumed and excreted by animals depends on obtaining reliable data on the quality of feeds (e.g. metabolizable energy, crude protein contents and digestibility).

9.2.3 Sheep population, productivity and feed intake

Accurate data are required for all classes of sheep that contribute to the equilibrium farm flock and their production of wool and co-products (e.g. live-weight sold for meat), i.e. including the breeding ewes and rams as well as all replacements required to maintain a stable population (Figure 3). All of these sheep produce wool, although lambs generally produce less wool of a finer fibre diameter which may have a different end use than wool from older breeding sheep. Multiple farms may need to be accounted for, e.g. some breeding animals reared on a different farm to the main production farm or surplus animals raised off-farm and shorn before being sold for meat processing.

Sheep productivity data are required for use in models for estimating feed requirements. The minimum data required include live-weight of breeding ewes and rams (e.g. winter weights), live-weight of animal classes at slaughter, age of growing animals when sold for slaughter, average birth weight (or use default of 9% of mature weight) and wool production.

In most cases, and particularly in grazing sheep systems in the absence of housing and brought-in feed, feed intake is not measured and, therefore, must be calculated. Due to the significance of feed intake in determining environmental emissions, feed intake shall preferentially be calculated using recognised peer-reviewed models based on use of annual data for animal numbers and productivity to estimate energy requirements associated with animal growth, reproduction, wool growth, walking and maintenance. LEAP (2015a) provided a hierarchy of acceptable models in order of suitability:

- Country-specific models used in a country's national GHG inventory;
- Other peer-reviewed published models applicable to the region and country; and
- The IPCC (2006) model.

The IPCC model does not account for requirements for wool growth and is generally less suitable than models such as NRC (2007) and CSIRO (2007). Application of these models requires representative data on the energy and protein concentrations of the different feeds consumed. The use of such models in accounting for brought-in feeds, feed wastage, grazing and feed quality is described in LEAP (2015a).
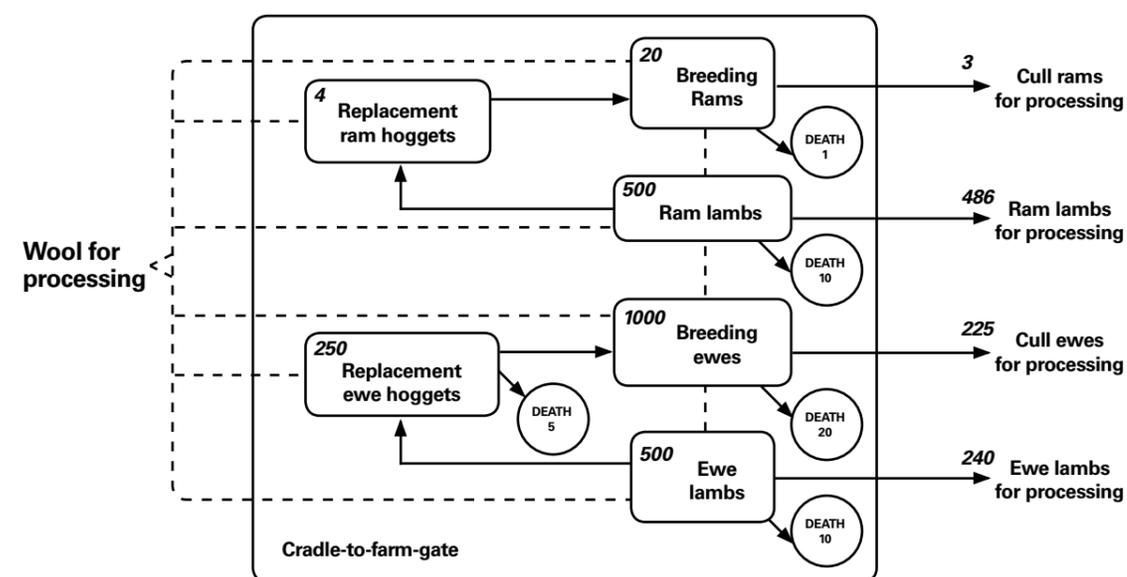
Figure 3. Simplified diagram of a sheep population illustrating relative numbers of breeding and replacement sheep on-farm and surplus sheep sold for meat processing. The population is based on a flock of 1000 breeding ewes, with 100% lambing, 25% replacement rate, 2% death rate and first lambing at 2-years-age. All sheep classes contribute to wool production which is generally harvested by shearing sheep once or twice a year. Wool may also be harvested from hides of sheep during the meat processing stage. (Source: Henry et al. 2015b).

9.2.4 Animal excreta and manure management

The amount of N and P excreted by sheep is calculated by difference based on the total feed intake with concentrations N and P in that feed and the output of N and P in products (wool and live-weight sold for meat). Similarly, the amount of volatile solids in excreta (which determines excreta methane emissions) can be calculated from the dry matter intake in feed less the component digested corrected for ash content in the manure, using data on feed dry matter digestibility concentration.

When sheep are housed or contained and their manure is collected and stored, the method of storage shall be defined since it determines the appropriate emission factors for methane emissions from volatile solids and nitrous oxide emissions (direct and indirect) from manure (IPCC 2006).

9.3 Post farm-gate stage

9.3.1 Overview of data inventory for the post farm-gate stage

Key inputs and outputs are required for all steps in the supply chain following production of greasy wool, including processing and manufacture of wool textiles and wool products, consumer use and end-of-life scenarios, including reuse and recycling. A wide range of possibilities are possible, particularly for consumer decisions on use, reuse and recycling practices. The description in these Guidelines should not be seen as an exhaustive list of possible scenarios but as guidance on what should be considered in conducting a wool LCA. Inputs and outputs and consequently environmental emissions and depletion of resources vary at every stage of the supply chain between companies, sites, products and consumers. The guidance in these Guidelines is intended to drive the accuracy, consistency and comprehensiveness of wool LCAs but does not cover all possible inputs and outputs that may be relevant or scenarios that contribute to environmental impact categories.

Table 4 of PAS 2395:2014 (BSI 2014) provides a comprehensive, general list of inputs and materials required for textile production and use and is a useful reference for identifying requirements in LCI.

9.3.2 Processing and Manufacture

9.3.2.1 Scouring and top making

For the first stage of the wool processing, 'scouring and topmaking', the input is greasy wool after shearing and the functional output 'wool top' which is a semi-processed product of fibres in a form ready for spinning. In the first sub-process, scouring, the wool is washed to remove wool grease, dirt and other impurities. In the top-making step, carding, gilling and combing the wool removes vegetable matter and short fibres to produce a uniform product with aligned fibres that can be spun.

In this step, key inputs that shall be accounted for are greasy wool, packaging materials, electricity, water and detergents and other chemicals, such as those used for pH control of the water. Key outputs are wool top, waste, sludge and wastewater.

The LCI should also account for by-products of the production of wool top from greasy wool: burrs; noils; sweepings; and lanolin.

9.3.2.2 Shrink resist treatment

The shrink resist treatment following scouring and topmaking chemically etches the cuticle of the fibre before applying a polymer to prevent felting and impart shrink resistance to wool to enable machine washability.

There are different processes available for the shrink resist treatment. The key inputs and outputs which can vary significantly shall be collected as primary data for the specific supply chain and recorded as part of the LCI. Chemicals used shall be aligned to selected impact categories.

9.3.2.3 Top dyeing and spinning

Dyeing of the wool top follows the shrink resist treatment. Steps in the dyeing process normally include: dyeing the top; washing and drying of dyed top; and re-combing the dyed top. The dyed wool top is then spun into yarn for knitting or weaving into fabric.

Key inputs for these steps to be accounted in the LCI in addition to the wool top (with shrink resist treatment are the chemicals required for the dyeing process, energy and water requirements.

9.3.2.4 Knitting or weaving

After spinning, yarn is converted to fabric for apparel or interiors using either knitting or weaving processes.

Key inputs that shall be accounted for in this step are the dyed yarn, energy, chemicals such as oils and lubricants for machinery and all packaging and labelling used for the final fabric. Key outputs in addition to the fabric include any waste yarn and packaging materials.

9.3.2.5 Final processing and manufacture

For garment production, the final stage includes cut and sew, finishing, folding and packaging. For products knitted in one piece, such as socks, the cut and sew step is omitted. After manufacture, the garments are normally inspected and any possible defects repaired. Commonly, a hangtag is added, the garment is folded, given a size sticker and packaged prior to transportation to the warehouse.

Key inputs for this stage vary but may include thread, size/content labels, buttons, zips, packaging materials including hang tags and electricity. Data to estimate emissions and resource use for any trims used in manufacturing a wool textile product should be obtained from reliable sources and shall be described where applicable. There are a wide range of possible trims and specific guidance is not included in these Guidelines. The Sustainable Apparel Coalition (http://apparelcoalition.org/) is developing a database of inventory data suitable for LCA of apparel and interior textiles that is anticipated to provide default input data. Key outputs of the final processing and manufactures steps, in addition to the garment or other product, include waste from cut and sew and packaging materials. Data for these by-products and their fate shall be included in the LCI and impact modelling.

9.3.2.6 Warehouse and distribution

Transport modes and distances from farm to warehouse are major inputs to the LCI and modelling of emissions and resource use.

Before distribution, the energy use in the warehouse and or distribution centre per kg of products shipped shall be taken into account. For the different distribution possibilities, modelling scenarios should be used to estimate emissions and resource use. These could include online distribution, where the product is delivered directly to the customer, and retail distribution, including transport of the customer to and from the retail outlet.

9.3.3 Use phase

The consumer use phase has been shown to have a significant impact on the full life cycle impacts of textile products (e.g. Henry 2015b). However, it is generally also the stage of the life cycle with the least reliable data and, therefore, has high uncertainty.

Key factors influencing the impact assessment for the use phase are:

- Service life of the product
- Frequency of wear
- Type of cleaning e.g. drycleaning, washing, airing
- Number of washing cycles per life time
- Temperature and volume of water for washing
- Amount and type of detergent used
- Use of a dryer vs clothesline

Key inputs during the use phase are water, detergent and energy, while the key output is wastewater.

Critical information for accurate accounting of the use phase of wool products is the lifetime of use (including reuse) before recycling or disposal. As a durable and high value fibre, wool is more likely to be reused through sale to commercial take-back schemes, donations to charities or passing on as family heirlooms. These options extend the life beyond the period of use by the first owner. In contrast to recycled products, the extended life of reused wool garments does not involve environmental impacts and resource use for reprocessing. Appendix C.1 provides some guidance on the calculation of environmental impacts associated with reuse based on PAS 2015 (BSI 2011).

Due to the difficulty in obtaining representative data for the large number of individual consumer decisions in reuse this phase has frequently been ignored in textile LCAs. However, due to the variable but potentially significant impact on environmental impacts for apparel products and the potential for influencing consumer (and possibly industry) practices towards improved sustainability it is recommended that this stage be accounted for in wool LCA where data are available. Research and surveys currently being conducted, is expected to provide more accurate and representative data on consumer behaviour in relation to service life/durability, frequency of wear and care of wool garments e.g. http://www.iwto.org/; http://www.nzmerino.co.nz/).

9.3.4 End-of-life stage

Inputs such as energy or water and emissions of greenhouse gases shall also be accounted for at the time of final disposal of wool products. In addition to accounting for emissions occurring in the end-of-life stage of wool, any chemicals emitted to soils and water such as dyes shall also be considered and should be estimated. Information on the fate of wool at end-of-life is important to accurately account for impacts, including the climate change impact category. End-of-life scenarios for wool textiles include, landfill and composting.

If landfill is assumed as the end of life scenario, a proportion of anaerobic decomposition of the wool may occur resulting in methane production. Greenhouse gas emissions occur due to methane production either as directly loss to the atmosphere or as carbon dioxide following capture and flaring. Alternatively methane may be captured for energy generation, depending on type and management of the landfill facility. An alternative method of disposal due to the biodegradability of wool, is composting with capture of nutrients and release of embedded carbon as carbon dioxide.

In accounting for GHG emissions, the carbon sequestered in the wool during growth will eventually be released back to the atmosphere. These biogenic carbon emissions should be modelled consistent with ISO/TS 14067 (ISO 2013). Since the lifetime of wool products is less than the time horizon for evaluating GHG effects (100 years), end-of-life is modelled simply as a direct release of the carbon sequestered in the product as a CO2-e emission to air. However, where biogenic carbon storage is for more than 10 years, as may occur for high quality garments such as a woollen overcoat or with products from open-loop recycling such as insulation, mattress pads, the period of storage may be recorded separately in the LCA study report.

Where wool products are recycled either using closed-loop or open-loop processes all inputs and outputs shall be included in the inventory analysis for the quantification of environmental impacts and resource use. Appendix C provides guidance on calculation and allocation issues for accounting for environmental impacts associated with closed-loop and open-loop recycling based on PAS 2015 (BSI 2011) or the more comprehensive integrated approach (Appendix C.3). Development of standardised accounting methodology for recycling of textile products is an ongoing area of work and these Guidelines will be updated as methods develop.

10 Life cycle impact assessment

10.1 Overview of LCIA

Life cycle impact assessment (LCIA) of products frequently reports on a combination of mid-point indicators of environmental impacts and resource use. For wool production and wool textiles, several source documents (e.g. LEAP 2015a, EU 2013, SAC 2013) provide impact assessment guidance for a number of different categories and indicators. Efforts to achieve harmonisation or alignment between approaches are ongoing but inconsistencies remain. These Guidelines make recommendations for impact assessment for a limited number of categories/resource use indicators and stages of the supply chain that are of most significant in the life cycle and where there is broad consensus on a standardised approach. Table 2 and Appendix A provide further guidance on progress towards a harmonised or consensus approach.

In reality, the impact categories listed in Table 2 represent impact potentials. This means they are approximations of environmental impacts that could occur if the emissions would: (a) follow the underlying impact pathway; and (b) meet certain conditions in the receiving environment. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit. LCIA results are, therefore, relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

For good practice consistent with these Guidelines, LCIA shall be calculated in relation to the functional unit and shall include the following elements:

- Selection of impact categories, category indicators and characterization models (See Section 6 as well as Section 9);
- Assignment of LCI results to the selected impact categories;
- Calculation of category indicator results which may involve calculations for individual supply chain stages, their sum across the supply chain and characterisation (e.g. applying GWP factors to GHG emissions results).

The selection of impact categories, category indicators and characterization models shall be justified and shall be consistent with the goal and scope of the LCA, which may include consistency with requirements of a specific regime PCR if part of the goal of the LCA. Inventory results included in an impact assessment such as water consumption shall be identified and related to selected category indicators.

It is the responsibility of the user of these Guidelines to ensure familiarity with the requirements for different schemes and selection of impact categories and assessment methods consistent with those requirements where reporting under a particular program or initiative. It is intended that these Guidelines be updated in line with ongoing developments in LCIA and associated LCA methodologies and data sources applicable to wool to ensure accurate up-to-date guidance is provided.

10.2 Climate change

The climate change impact shall be assessed as the sum of the calculated potential climate change impact of each GHG emitted and removed by the product system calculated by multiplying the mass of each GHG released or removed by the 100-year GWP in units of 'kg CO2-e per kg emission' as given in the latest report of the IPCC. If the latest IPCC GWP values are not used, this shall be stated and justified in the LCA report. Emissions or removals of GHGs for each source or sink shall be calculated by summing the results of the activity data multiplied by the relevant emission factor using country-specific values or if country factors are not available then by the default IPCC (2006) emission factors.

10.2.1 Emissions from feed production

Amounts of feed production wastes and biomass burnt are multiplied by relevant emission factors (e.g. from IPCC 2006) to quantify methane emissions from these sources. Similarly, quantities of N fertiliser use and crop residues (above- and below-ground) incorporated into soil are multiplied by relevant nitrous oxide emission factors.

10.2.2 Emissions from the animal

Animal rumen methane emissions would be calculated from gross energy intake, estimated from total feed energy or dry matter intake, for each animal class and default IPCC emission factors of 6.5% of gross energy intake for mature sheep or 4.5% for lambs. Similarly, excreta and manure methane emissions are determined from activity data on volatile solids, while nitrous oxide emissions are determined from activity data on the amounts of N in excreta and manure (IPCC 2006; LEAP 2015a).

Indirect emission pathways are associated with losses of nitrogen via leaching or runoff. Studies must account for the mass of nitrogen lost via these pathways. Similarly, indirect emissions also arise from volatilisation of ammonia-N, and emissions from both sources can be determined by estimating the mass flow using a nutrient balance, and then calculating emissions using appropriate emission factors.

10.2.3 Emissions and removals from Land Use and Land Use Change

Direct land use change (LUC, e.g. changes between forest, grassland and arable land use) can result in large changes in carbon stocks in plant biomass and in soil carbon level. In the supply chain for wool textiles it can be an important indicator for the cradle to farm-gate stage of the supply chain but a minor category for the subsequent stages. For example, direct LUC is relevant to wool produced on sheep farms where forest has been cleared for pasture, tree planting has occurred on sheep farms (e.g. as shelter belts, Henry et al. 2015a), or there has been a shift from grassland to cultivation for feed crops. Net GHG emissions associated with direct LUC shall be estimated using a recognised international method such as PAS 2050 (BSI 2011) or ISO/TS 14067 (ISO 2013). For example, PAS 2050 provides accounting methods for both biomass and soil carbon change including default values for country/region differences in soil carbon stocks associated with different land uses. However, in view of the greater uncertainty in estimating net emissions due to direct LUC these methodologies recommend that the GHG emissions are reported separately.

Land use, through management practices, can also result in changes in soil carbon and hence contribute to net GHG emissions. For example, cultivation of soil for crops may release CO2 to the atmosphere and conversely carbon sequestration may occur in soils converted from cultivation to well-managed grassland especially if initially in a degraded state. Accounting for soil carbon emissions or sequestration generally requires the use of process models which should be selected from peer-reviewed scientific publications, be well-accepted in the field of soil science and be validated using long-term measurements. If these criteria cannot be met estimated emissions or removals may be based on default carbon stock values in IPCC (2006) (LEAP 2015b). However, as for Direct LUC, in view of the greater uncertainty estimates of soil carbon emissions or removals shall be reported separately.

10.2.4 Emissions associated with primary energy production and use

Use of fossil fuels and electricity is important for quantification of indicators of primary energy demand and climate change (greenhouse gas emissions). The amounts of these energy sources used for all operations along the supply chain, including uses associated with feed and animal production, shall be included in the inventory for LCIA. Primary data on actual use shall be collected where possible. If primary data are unavailable, then fuel use may be calculated from the operating periods for various activities and hourly fuel use data for

the type of operation. To calculate GHG emissions, the amount of each fuel used is multiplied by the relevant country-specific GHG emission factor. The amount of electricity use for all activities for on-farm production (e.g. for sheep shearing), processing, manufacturing, use and recycling should be multiplied by the country-specific emission factor that accounts for all non-renewable and renewable sources of electricity production.

10.2.5 Emissions associated with consumables and capital goods

The production of infrastructure (buildings and machinery) with a lifetime greater than one year may be excluded from the inventory and LCIA, as defined in PAS 2050 (BSI 2011). All consumables and at least those capital goods with a life span of less than one year should be included, unless they have been excluded based on the 1% cut-off threshold for materiality (see Section 5.4).

10.3 Freshwater consumption

Calculation of freshwater consumption should be performed by constructing water balances for each major process throughout the supply chain. Freshwater consumption may occur via multiple pathways within a water balance. In addition, other non-consumptive outputs (such as drainage or release back to the same water basin) may also occur and should not be classified as consumptive uses. The sources contributing to water consumption for the wool production stage are summarised in Table 4 and discussed in detail below. Sources of water consumption for processes along the supply chain are listed in Section 9.3. For some stages, notably the consumer use phase, there is a high uncertainty associated with freshwater consumption due to high variability in practices between individual consumers and between different household water supplies and appliances. LCIA for freshwater consumption should apply the best available data, e.g. on consumer washing practices and appliance efficiency, from local surveys or reliable sources. The LCIA report shall describe the source and quality, including representativeness of the inventory and LCIA.

Wool production is the major contribution to freshwater consumption in the wool supply chain. Water consumption directly associated with animals includes respiratory losses, excretion via urine and manure, and output in products. Of these, respiratory losses and output in products are invariably consumptive uses. Excretion via urine and manure may be handled in different ways depending on fate modelling. In dry climates, much of this water is likely to evaporate after excretion, or may be taken up by a plant and then transpired, and this water is considered a consumptive use analogous to irrigation. In wet climates, it could be shown that some water excreted in urine and manure flows back into the same water basin, thus representing a non-consumptive flow. This should be confirmed by animal/grazing system water balance modelling. The quantity of drinking water consumed should ideally be based on measured data or using published regional/country data. However, if these are unavailable there are a number of published models that could be used which relate water intake to factors such as animal production, climatic conditions, and feed type and composition. Evaporation losses from water sources specifically made for animal drinking water or irrigation shall be estimated using water balances for these water supply systems (Wiedemann et al. 2015c).

Evapotranspiration from irrigated feed sources is often a large contributor to freshwater consumption. Thus, it is important to get primary data on the quantity of irrigation water applied to the various feed sources for sheep. This is then linked to site-specific models to estimate evapotranspiration from irrigated water used to grow feed.

There can also be minor water withdrawal and evaporation from production of various energy sources and inputs. Some studies have indicated that hydro-electricity can be a significant source of evaporation from dammed water bodies (Herath et al. 2011). Primary activity data should be used for significant contributors, otherwise secondary data from credible, accepted publications or databases can be used for estimation of minor contributors.

10.4 Land occupation

Land occupation refers to use of land as a resource for production of the functional unit e.g. m2 per kg wool textile. However it is important to recognise that aggregating land of different quality and productivity does not provide a meaningful indicator of the impact of production. At a minimum, the area of arable land and non-arable land should be reported separately to provide an indicator of the stress on a finite resource. Much of global wool production occurs in extensive semi-arid rangeland environments where few alternative production activities are viable. Reporting of land occupation should include qualification of the area of actual or potential use for cultivation since this land type is under the greatest competitive demand.

The land occupation indicator is frequently of highest significance for the cradle to farm gate stage of wool textile LCA. Where possible, quantification of land occupation shall use primary data on the area of land associated with the main activities of feed production, and animal containment and management. The land area associated with feed production should be differentiated into land capable or not capable of supporting arable cropping. The calculated land area for animals shall include all farm areas required for the sheep production, including laneways and animal holding yards. Land associated with the background processes (e.g. fertiliser manufacturing) should be estimated, and this is likely to be based on secondary data from publications or accepted databases.

10.5 Eutrophication

Freshwater eutrophication is assumed to be determined solely by P using the ReCiPe method (Goedkoop et al. 2009; ILCD 2011). Farm system analyses indicate that P fertiliser manufacturing can also be a significant contributor (Chobtang et al. 2015) and this is estimated from the rate of P fertiliser used multiplied by an emission factor. Similarly, the ReCiPe method for aquatic eutrophication assumes that it is determined solely by N. As well as direct N losses to waterways there can be an indirect contribution from ammonia and NOx. Their contribution is based on estimation of the amounts of ammonia and NOx emitted (primarily from animal excreta, manure and N fertiliser) multiplied by an emissions factor that attempts to account for their indirect contribution on deposition to waterways (e.g. Goedkoop et al. 2009).

The sources of N and P loss that should be accounted for in wool production are defined in Table 6. At the feed production and farm levels, the main N loss to waterways is from N leaching and, to a lesser extent, N runoff associated with land use practices. The recommended method for estimating N and P losses to waterways is to use a country-specific model that has been validated, published and widely used. For example, in New Zealand the OVERSEER® nutrient budget model (Wheeler et al. 2003) estimates N losses based on N in animal urine, dung, manure, fertiliser and back-ground soil sources, modified by soil and climate factors. That well-validated model is used by local government in New Zealand to regulate N losses in a range of catchments. Where a country-specific model is unavailable, a simple Tier-1 method could be used based on multiplying the amounts of fertiliser or manure N or P by 'fate factors', such as the method described for Europe by Goedkoop et al. (2009).

Emissions associated with background processes (e.g. fertiliser manufacturing) should be estimated, and may use secondary data (adjusted for the appropriate country of origin) from publications or accepted databases (see Section 8.1).

10.6 Primary energy demand

The total amount of fossil fuel energy use (including coal, petroleum, gas etc) for all activities across the supply chain, including electricity, transport, heating, cleaning, shall be calculated relative to the functional unit, taking into account efficiencies in energy conversion. These data shall be consistent with the inputs to calculate greenhouse gas emissions associated with fossil fuel use (See section 10.2.4) and the climate change impact. Further guidance is provided in Appendix A.

10.7 Other impact categories and resource use indicators

Inventory analysis for impact categories and resource use indicators not listed above in Sections 10.2 to 10.6 shall be analysed using methods and units referenced in Table 2 according to the goal and scope of the LCA study and the Principles set out in Section 3. The approach for other impact categories and indicators should be consistent with that described in Sections 10.2 to 10.6. At this time it was concluded that no clearer guidance was able to be provided than available in the publications referenced. However, it is intended to include additional impact categories and resource use indicators in this Chapter of the Guidelines as experience with wool LCA expands understanding of specific wool textile requirements and relevant data become available.

11 Interpretation of LCA results

11.1 General guidance on interpretation of LCA results

Interpretation of the results of an LCA provides a process of checking that the assessment conforms to the goal and scope in aspects such as selection and quality of data and methods for calculation of the environmental impact for selected categories. Thus, interpretation may initiate an iterative process to improve the assessment to meet the goals of the study. The end point of the interpretation after ensuring that the goals have been met is a report setting out the conclusions and any recommendations for mitigating impacts and improving environmental performance. General guidance on interpretation of the results of an LCA study is provided in Clause 4.5 and Annex B of ISO 14044:2006.

The results of the quantification of environmental impacts shall be interpreted according to the goal and scope of the LCA study and shall:

- include a quantitative and/or qualitative assessment of uncertainty;
- identify and document in detail the selected allocation methods in the wool LCA study; and
- identify the limitations of the study.

This life cycle interpretation phase shall comprise the following steps:

a) identification of the significant issues based on the results of the quantification of the environmental impacts according to data and methods used in the LCI and LCIA phases;

b) an evaluation that considers completeness, sensitivity and consistency checks; and

c) conclusions, limitations, and recommendations of the study.

11.2 Identification of key issues

Identification of significant issues in the wool LCA study starts with identifying the most important impact categories and life cycle stages, and the sensitivity of results to data quality and methodological choices. 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 (LEAP 2015a). In addition, any explicit exclusion of supply chain activities shall be included in the report including those assessed as being immaterial. At this point, a series of checks should be performed in the foreground processes.

The following checks are proposed for reviewing modelled processes at the cradle to farm-gate stage of wool textile production.

LIVESTOCK MODELS

a) Are livestock numbers, ages, growth rates and wool production data clearly provided in the inventory tables?

b) Do the animal numbers, reproductive rates, sale numbers and mortality numbers in the flock model confirm that the flock is being modelled as a steady-state?

c) Have product flows including live weight, wool and milk (if the latter is relevant) been clearly documented so that allocation assumptions can be understood?

d) Have intermediate, modelled output data such as feed intake been clearly reported in the inventory?

e) Have feed intake estimates been subject to sensitivity checks?

f) Is the level of production achieved from the flock discussed and compared with regional or industry averages? Do the flock datasets and characteristics match the goal and scope? For example, if the study aims to produce results for a general wool supply chain, were farm data collected from representative flocks in terms of flock performance?

GREENHOUSE GAS ESTIMATION

a) Have all estimation models and assumptions been clearly documented?

b) Has uncertainty (for example uncertainty associated with emission factors) been taken into account via sensitivity analysis or uncertainty analysis?

c) Have all GHG sources been taken into account, including indirect sources, and sources from treatment of wastes (e.g. waste water, solid wastes sent to land-fill).

d) Have net emissions from land use (LU) and direct land use change (dLUC) been determined and reported, with appropriate sensitivity and/or uncertainty analysis results? Are the assumptions made in this assessment representative of the industry?

e) Are major energy uses documented clearly in the inventory for each stage of the supply chain?

f) Are all major purchased inputs included in the inventory, including inputs that may be used in small volumes but are energy intensive to produce, such as cleaning chemicals, dye, veterinary products etc been included in the inventory?

WATER MODELS

a) Have water balances been provided for each sub-system in the supply chain, to demonstrate that all flows have been characterised, and that the researchers have clearly and correctly differentiated between water flows and water consumption?

b) Has the water system been adequately described, and is it clear that losses in water supply systems have been considered and accounted?

c) Have modelled results, such as water balances, been verified by comparison with similar data in the literature?

d) Have water flows within background systems, such as inputs from purchased feed, been included?

e) Has the study demonstrated how representative (or otherwise) the water consumption in the study is, and how well this matches the goal and scope of the study? Critical factors to consider are the representativeness of irrigation use on-farm, because a small number of farms may use a very large amount of water, resulting in skewed results if these farms are under, or over represented in the dataset.

EUTROPHICATION MODELS

a) Are nutrient sources and flows documented – for example using a nutrient balance, to demonstrate completeness?

b) Where a nutrient model is used, has this model and all necessary assumptions and input data been sufficiently described?

c) Have appropriate, regionally specific nutrient fate factors or models been applied?

d) Do the results from the LCA correspond suitably with the published research regarding nutrient losses and eutrophication in the region where the study has been completed?

e) Have all potential sources contributing to eutrophication been included at each stage?

f) Has a suitable sensitivity analysis been completed, outlining the key inventory data, and model assumptions that influence eutrophication?

Completeness is checked based on consistency of the data with the goal and scope of the study, and by ensuring that, at each supply chain stage, the relevant processes or emissions contributing to the impact have been included. Sensitivity checks should be conducted to assess the extent to which specific methodological choices influence the results and the extent to which implementing alternative, defensible choices would affect the results. This is particularly important with respect to allocation choices. Where possible, sensitivity checks should be conducted for each phase of the LCA study, i.e. the goal and scope definition, the life cycle inventory model, and impact assessment.

Consistency checks should be structured to ensure that the principles, assumptions, methods and data are consistent with the goal and scope throughout the study. This check should encompass consistency of: (a) data quality along the life cycle of the product and across production systems; (b) methodological choices (e.g. allocation methods) across production systems; and (c) the application of the impact assessments steps with the goal and scope. Consistency checks should include all foreground processes and background processes that contribute more than 5% to any one impact category.

11.3 Characterising uncertainty

Sources of uncertainty in LCA may include: (a) uncertainty in data access and quality; (b) process uncertainty which include the inherent variability, e.g. in wool production systems; (c) understanding of how to translate processes into environmental impacts; and (d) omission of processes in the impact assessment which may bias the results of the wool LCA study.

Variation and uncertainty of data should be estimated and reported, including where results are based on average data or on characterization factors with known variance that do not show the uncertainty in the reported mean value of the impact.

If the results of the wool LCA study are to be reported to third parties, the uncertainty analysis shall be conducted and reported. Some LCA software packages include a Monte Carlo analysis to characterise the uncertainty in estimated impacts contributed by uncertainty in data inputs.

Uncertainty due to methodological choices such as modelling principles, system boundaries, cut-off criteria, and other assumptions e.g. such as averaging time may be characterised through scenario assessments (e.g., comparing the impact calculation using different allocation methods).

11.4 Sensitivity Analysis

Detailed LCA studies are made up of thousands of individual data points, assumptions and methodological choices to describe the outputs and impacts from a supply chain. However, often results are governed by a relatively smaller number of data points or assumptions. These key data points, assumptions, and related methodological choices must be subject to a sensitivity analysis, which aims to identify and communicate the significance of the particular choices made in the study. This is done by first identifying the impact hotspots in the supply chain, then identifying the key processes or data points that influence these hotspots.

Checking model sensitivity can be described with the following example. Greater than 50% of greenhouse gas emissions from wool production typically arise from enteric methane and manure from sheep farming. Enteric methane is typically modelled, and is governed by sheep feed intake and the selected emission factor or model applied. Both the modelling of flock feed intake and the choice of emission factor or model are sensitive processes. A sensitivity check should be performed to confirm that: a) the model used to predict feed intake is appropriate; b) the inventory data and model assumptions used to predict feed intake are correct; c) the assumptions used to predict feed intake align with the production output (in terms of wool, live weight and if relevant, milk); and d) the model used to predict emissions produces comparable results to the scientific literature for enteric methane measurement. Key indicators such as feed intake for individual animals and the whole flock should be cross checked with referenced studies. If substantial differences exist between the results and the output from other published studies or models, then further investigation and explanation will be required.

Checking data sensitivity can be described with the following example. Eutrophication impacts may be strongly influenced by the quality of discharge water from the processing of wool. Appropriate sensitivity checking may include checking the representativeness of the inventory data regarding waste water discharge (volume) and waste water quality (nutrient load). If the data were collected as part of the study, or were provided as non-verified primary data from a facility, the researcher should ensure the data cover an appropriate time scale (i.e. 12 months) and values should be checked against industry averages. The sensitivity of the assumptions may be tested by re-running the model with 'industry average' nutrient load data for comparison.

11.5 Conclusions, Recommendations and Limitations

The final step in interpretation is to derive conclusions from the results that relate to the goal and scope definition, to recommend appropriate actions, e.g. for reducing impacts and improving environmental performance, and to address the limitations to of the study due to uncertainty and relevance to the goal and scope.

Conclusions in the context of the goal and scope of the wool LCA study should identify and summarise hot spots in the supply chain for each impact category. Where possible the potential for improvement with mitigation options due to management interventions should also be included. Comparisons of the relative environmental merits of different products are not encouraged due to the difficulty in ensuring results do not in part reflect differences limitations in data quality and the impact of methodological choices. However, ISO 14044:2006 (ISO 2006b) requires that if the study is intended to support comparative assertions, then the possible contribution of inconsistencies in functional units, system boundaries, data quality, or impact assessment shall be evaluated and communicated.

Recommendations made as part of the interpretation of the wool LCA study shall strictly relate to the goal of the study and be logical and reasonable and shall be accompanied by limitations in order to avoid their misinterpretation beyond the scope of the study.

11.6 Preparing a study report for wool LCA results and critical review

According to ISO 14044:2006 (ISO 2006a), and as described in LEAP (2015a), 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 a comprehensive discussion of the limitations including:

- Potential for trade-offs due to selection of limited environmental impact categories;
- Positive environmental impacts, notably at the on-farm stage, e.g., on biodiversity, landscape, carbon sequestration;
- Multi-functional outputs other than production (e.g., social, spiritual, nutrition);

The following elements should be included in the LCA report:

- Executive summary including overview of the goal and scope, main results, recommendations, and the assumptions and limitations of the study;
- LCA study title, date, and other identifying information such as responsible organization or researchers and intended users;
- Goal of the study, notes on methodology, e.g. consistency with these guidelines;
- Functional unit and reference flows;
- System boundary;
- Materiality criteria and cut-off thresholds;
- Allocation method(s) and justification;
- Description of inventory data: representativeness, averaging periods (if used), and assessment of quality of data;
- Description of assumptions or value choices made for each stage of the life cycle, with justification;
- LCI modelling and calculating LCI results;
- Results and interpretation of the study including conclusions, limitations and any trade-offs;
- Whether or not the study was subject to independent third-party verification.

ISO 14044:2006 (ISO 2006a) states that internal review and iterative improvement should be carried out for any LCA study. In addition, third-party verification and/or external critical review should be undertaken. If intended for the public release, third-part verification shall be undertaken and a communication plan shall be developed to establish accurate communication that is adapted to the target audience and defensible. Public communication is not covered in detail in this Guidance but a summary of relevant issues is given in Appendix D.

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Appendix A Life Cycle Assessment methods

A.1 ISO 14040 and 14044

A standardised framework and defined inventory methodology for conducting a Life Cycle Assessment (LCA) was first agreed internationally by LCA practitioners from several agencies in North America and Europe and experts from the International Organization for Standardization (ISO) in the 1990s. This framework which is summarised in Fig. A.1, was formalised in international standards ISO 14040 (ISO 2006a) and ISO 14044 (ISO 2006b) which then provided the authoritative principles, requirements and guidance for environmental assessment according to the life cycle or cradle-to-grave method.

ISO 14040 describes the principles and ISO 14044 specifies the methodological requirements and provides guidelines for conducting an LCA. The phases in an LCA study include:

- definition of the goal and scope of the LCA;
- the life cycle inventory analysis (LCI);
- the life cycle impact assessment (LCIA);
- the life cycle interpretation;
- reporting and critical review of the LCA;
- limitations of the LCA;
- relationship between the LCA phases; and
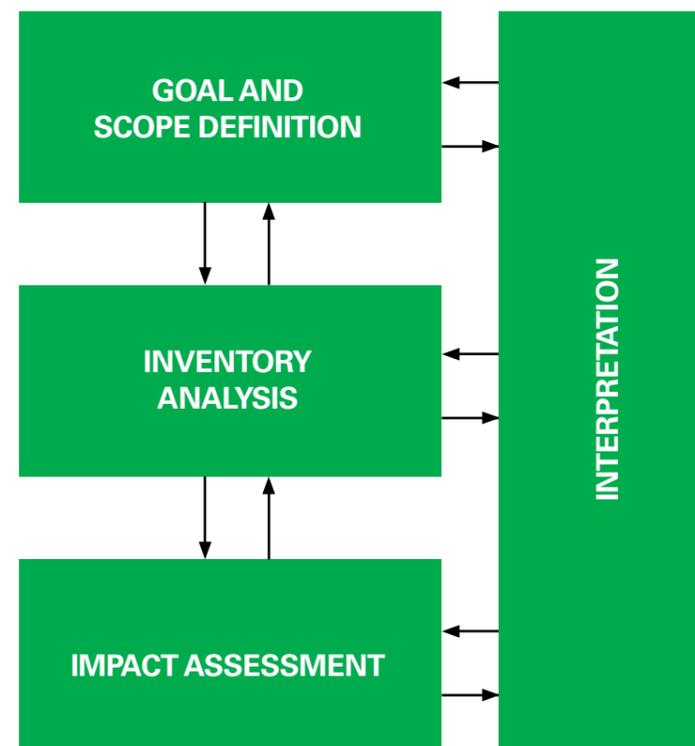- conditions for use of value choices and optional elements.

Figure A.1. Stages of a life cycle assessment (ISO 14044:2006)

The generic guidelines set out in ISO 14044 allow for an LCA for specific goods (e.g. wool textiles) and services to conform to the standard by applying appropriate data and assumptions. More detailed guidance for impact categories of specific focus (e.g. ISO/TS 14067 (ISO 2013) for Carbon Footprint of products and ISO 14064 for the water footprint of products (ISO 2014) have also been developed. However, to ensure consistent application of the standard, Product Category Rules (PCRs), may be developed to ensure data sources and quality and methodological choices and assumptions are appropriate and LCA results are credible and comparable between similar nominated products and over time. Recent publications provide LCA-based guidelines covering part of the life-cycle (partial-LCA) and limited impact categories specifically for small ruminants (sheep and goats) (LEAP 2015a) and for textiles (BSI 2014) have been published. The Guidelines set out in this document for wool textile LCA serve a similar purpose to a PCR but are intended to be regime-neutral, i.e. to be applicable under different programs or schemes of interest to a user.

A.2 Attributional and Consequential Life Cycle Assessment

ISO 14044 (ISO 2006b) sets out general guidance for application of LCA under a sequential process from goal and scope definition through to impact assessment in a way that could be applied to either of the two major LCA models, attributional and consequential. In an attributional modelling approach inputs and outputs are attributed to the functional unit of a product system to provide a point-in-time assessment that is most suited to benchmarking environmental performance, identifying hot-spots in the supply chain and/or monitoring change in impacts over time. Consequential data modelling, on the other hand includes only activities in a product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit (UNEP/SETAC 2011).

Most published studies conforming to ISO 14044 have been attributional LCAs, but interest is growing in conducting consequential LCA studies to examine the marginal environmental effects of a change in production of a product. The Guidelines for LCA of wool textiles in this document are for an attributional approach due to the much stronger history in use and greater consensus in method and interpretation. However, recognising the interest in, and future potential for wider use of consequential LCA, an overview is provided here of the two approaches with a description of how the fundamental choice between them influences methodology, results and interpretation of a study with the aim of providing an understanding of potential future directions. Table A1 sets out some assumptions in each approach, noting that each has positive aspects and can provide information of value for their respective purposes. Importantly, however, mixing attributional and consequential modelling produces results that have no clear meaning. This summary is derived from descriptions given in Appendix 16 of LEAP (2015c) and is based on publications listed therein.

Table A1. Key assumptions and features of attributional and consequential modelling approaches in LCA.

APPROACH	ATTRIBUTIONAL MODELLING	CONSEQUENTIAL MODELLING
Modelling approach	System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.	System modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.
Focus	Usually a clearly defined, single product system	Changes throughout whole Economy
Question the approach aims to answer when future-oriented/alternative scenarios are assessed	Baseline scenario is the Product System as it is, now or in the future. The question is "What is the potential environmental impact attributable to certain product delivered in a given point in time?"	Baseline scenario is the World as it is, now or in the future, without any action. The question is "What are the net impacts associated to a change (in a product system) relative to the baseline scenario, where that change does not take place?" The baseline scenario is not assessed per se – only the effect of the change is assessed.
Question the approach aims to answer when future-oriented/alternative scenarios are assessed	What is the potential environmental impact attributable to a certain product delivered in a given point in time (t1) if the product were designed and/or produced and/or consumed and/or managed differently at the end of its life? Alternative scenarios can be modelled on the basis of the assumptions made by a practitioner on e.g. alternative raw materials chosen, project variants, alternative production processes, consumption patterns, product end-of-life options. Sensitivity analysis is often used to compare alternative scenarios in a static manner. As long as the assessment scope is relative to a single product system, no induced effects on other product systems can be captured.	What is the potential environmental impact of a decision likely to result in a change in demand or in supply of a product? Most of the activities affected by the decision are included, i.e. excluding constrained activities, but including first-order rebound effects.
Modelling Assumptions	Linear emission profiles attached to LCI datasets. Effects on the economy are not captured	Linear, static model. Producers are price-takers. Markets clear. Ceteris paribus relative to other decisions and 3 the overall technology and productivity of the rest of society.
Co-products	Unit process outputs defined according to a normative rule, for example, all products generating revenue for the process might be considered as co-products.	Products are normally classified either in determining products or non-determining products.
Solving multi-functionality	To be avoided as far as feasible via subdivision or reporting at multi-product level (that is, system expansion to include additional functionality – ISO 14044:206), otherwise partitioning according to a normative rule.	System expansion and substitution.
Crediting of avoided burden and accounting for rebounds	Usually not allowed.	Obligatory.
Background system data	Average technology mix.	Marginal technologies.
Reference standards/guidelines	SO 14040:2006, ISO 14044:2006, ILCD Handbook Situation C2 guidelines (EC 2010), UNEP/SETAC Life Cycle Initiative, Global Guidance Principles for Life Cycle Assessment databases (2011).	ISO 14040:2006, ISO 14044:2006, ILCD Handbook Situation B guidelines (EC 2010), CALCAS project guidelines on consequential LCA (Weidema et al 2009), UNEP/SETAC Life Cycle Initiative, Global Guidance Principles for Life Cycle Assessment databases (2011).

In summary, attributional modelling involves a clearer entry into life cycle assessment with fewer 'assumptions' needed, and enables benchmarking of environmental performance and hot-spot identification to facilitate development of efficient mitigation strategies. Modelling the marginal effects of change in production or possible effects of substitutions on other sectors requires a 'consequential' approach. Currently, there is insufficient agreement on methodology for broad acceptance of consequential modelling, but it is anticipated that Guidelines for consequential LCA for wool, including how to handle co-products and by-products, will be developed in future. This will help to overcome the inherent limitations associated with attributional LCA that constrain use of results for predicting the influence of future changes in supply and demand of wool textile products.

A.3 Description of some key environmental impact categories

Some key LCA environmental impact categories are described below with commonly used units and a key reference as a source of additional information. LCA studies may also report resource use indicators such as freshwater consumption and land use which are important for wool textiles and these are described in Section 6.2 if the Guidelines.

Other impact categories, such as those related to noise and dust, tend to have strong local impacts but weak global impacts and are often excluded in LCA by the textile industry (Chevalier et al. 2011). The exclusion can be attributed to the lack of availability of well-developed assessment methodology for their quantification.

Climate Change (kg CO_2 equivalent): A measure of all greenhouse gas emissions across the supply chain. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare. (IPCC 2013, ISO 2013)

Abiotic Resource Depletion (ADP elements, ADP fossil; kg Sb equivalent, Mj): The consumption of non-renewable resources leads to a decrease in the future availability of the functions supplied by these resources. Depletion of mineral resources and non-renewable energy resources are reported separately. Depletion of mineral resources is assessed based on ultimate reserves. (van Oers, de Koning, Guinée, Huppes 2002).

Eutrophication Potential (kg PO_4^{3-} equivalent): Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition. (Guinée et al. 2002, Goedkoop et al. 2009, ILCD 2011).

Acidification Potential (kg SO_2 equivalent): A measure of emissions to the atmosphere that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials. (Guinée, et al. 2002).

Photochemical Ozone Creation Potential (POCP, kg C_2H_4 equivalent): A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops. (Guinée, et al. 2002).

Ozone Depletion Potential (ODP, kg CFC-11 equivalent): A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants. (Guinée, et al. 2002).

Human toxicity, Eco-toxicity (Comparative toxic units CTU_h, CTU_e): A measure of toxic emissions which are directly harmful to the health of humans and other species. (Rosenbaum et al. 2008)

Water Scarcity Footprint (WSF, Litres H_2O equivalent): A measure of the stress on a region due to fresh water consumption as calculated by applying the water stress index (WSI). The WSI is the ratio of total annual freshwater withdrawals to hydrological availability with values ranging from 0 (no water stress) to 1 (high water stress). It is multiplied by the water consumption value to indicate which portion of consumption contributes to water deprivation. (Pfister, Koehler, Hel 2009)

Primary Energy Demand (PED, MJ): A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account. (Guinée, et al. 2002)

The impact categories listed above represent impact potentials. They are approximations of environmental impacts that could occur if the emissions: (a) actually follow the underlying impact pathway; and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory captures only that fraction of the total environmental load that corresponds to the functional unit. LCIA results are, therefore, relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

A.4 Other Standards and Guidelines

A.4.1 LEAP Guidelines

The Livestock Environmental Assessment and Performance (LEAP) Partnership, a multi-stakeholder initiative of the Food and Agriculture Organisation of the United Nations is developing guidelines for livestock chains with the goal of improving the environmental sustainability of the livestock sector through better metrics and data. Objectives in the development of the LEAP guidelines were:

- 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.

The guidelines for assessment of greenhouse gas emissions and fossil energy use from small ruminant supply chains (LEAP 2015a) aim to contribute to a harmonised international approach to the assessment of environmental performance of sheep and goat supply chains. The initial focus is on greenhouse gas emissions and energy use but there is recognition of the strong global interest in measuring and improving environmental performance of wool production systems more broadly. The Guidelines for small ruminants are also supported by guidelines for assessment of the environmental performance of animal feeds supply chains, development of databases and tools for feed, and development of principals for the assessment of livestock impacts on biodiversity.

A.4.2 PAS 2395:2014

Used in conjunction with one of the specified base methodologies (ISO/TS 14067:2013; WRI/WBCSD GHG Protocol Product Standard; PAS 2050:2011), PAS 2395:2014 aims to provide a robust, repeatable assessment of GHG emissions from the whole life cycle of textile products. The PAS sets out requirements supplementary for the assessment of greenhouse gas (GHG) emissions from the life-cycle of any products manufactured substantially from textiles with the goal of aiding consistent application of these generic methodologies to the textile products sector by providing:

- textile product focus for aspects of the assessment where supplementary requirements are permitted and could prove beneficial to assessment outcomes;

- rules or assessment requirements that are directly relevant to the main sources of emissions from textile products;

- clarity on how to uniformly apply specific elements of assessment methodologies within the textile products industrial sector; and

- enhanced synergy between the assessment outcomes provided by different methodologies.

For some calculations in the base methodologies, PAS 2395 provides supplementary requirements and additional guidance on those elements that have been found to present particular difficulties when undertaking GHG emissions assessments on textile products, such as during the use stage and at recycling. Recognising the global nature of trade in textile products the development of PAS 2395 sought to ensure that the supplementary requirements provided were applicable wherever used by consulting experts from different regions of the world and different segments of the textile industry. PAS 2395 addresses the single impact category of Climate Change (i.e. global warming potential, GWP). It does not assess other environmental impacts such as non-GHG emissions, acidification, eutrophication, toxicity, biodiversity impacts or labour standards, or other social and economic aspects of the provision of textile products and associated with the life cycle of such products. Therefore, the PAS stresses that an assessment of the GHG emissions of textile products using PAS 2395 in conjunction with PAS 2050, ISO/TS 14067 or WBCSD GHG Assessment Protocol, does not provide an indicator of the overall sustainability of these products, such as may result from more comprehensive life cycle assessment.

A.4.3 International EPD® System Product Category Rules

Environmental product declarations (EPDs) are being developed in a range of countries under various voluntary and legislated schemes. An EPD® (www.environdec.com) is a standardized tool under ISO 14025:2006 to communicate the environmental performance of a product or system, based on an LCA approach.

Product Category Rules (PCRs) for a range of products have been developed in the framework of the International EPD® System. The International EPD® System is a system of environmental declarations based on a hierarchic approach following the international standards:

- ISO 9001, Quality management systems
- ISO 14001, Environmental management systems
- ISO 14040, LCA - Principles and procedures
- ISO 14044, LCA - Requirements and guidelines
- ISO 14025, Type III environmental declarations

Appendix B Summary of published wool LCA studies

PCRs specify further and additional minimum requirements on EPDs of the defined product group complementary to the internaitonal standards. PCRs are specified for core "gate-to-gate" modules and also provide rules for which methodology and data to use in a full LCA, i.e. life cycle parts up-stream and down-stream of the core module. The PCR also has requirements on the information given in the EPD, e.g. additional environmental information. A general requirement on the information in the EPD is that all information given in the EPD, mandatory and voluntary, shall be verifiable.

An example of a PCR that applies to wool is that for *Textile yarn and thread of natural fibres, man-made filaments or staple fibres* (Product group: UN CPC 263 and 264) dated 2014-02-26.

While LCA is the most commonly used tool to assess the environmental performance (resource use and emissions to the environment) of a product, there are relatively few published studies for wool fibre, textiles and clothing (Table A.1). Many of these studies are for partial LCA, frequently for the cradle to farm-gate stage of the supply chain (the production of greasy wool as the raw material input to wool textiles and clothing). The majority of these studies quantify only a single impact category, the climate change impact (Global Warming Potential (GWP) reported as carbon dioxide equivalent emissions of greenhouse gases per unit mass of greasy wool. These studies are of value in identifying the contribution of the raw material production and the potential for improvement with change in on-farm management practices, but do not represent an assessment of environmental performance and are not suitable for comparison across different fibres or textiles.

Table B1. Summary of the scope of publicly available wool LCA studies and the impact categories that were evaluated in each assessment (adapted from Henry et al. 2015b).

PUBLISHED LCA STUDY	FUNCTIONAL UNIT	SYSTEM BOUNDARY	IMPACT CATEGORIES
Eady et al. (2009)	1 kg fine greasy wool	To farm-gate	GWP
Eady et al. (2012)	1 kg 19.5 µ greasy wool	To farm-gate	GWP
Brock et al. (2013)	1 kg 19 µ greasy wool	To farm-gate	GWP
Wiedemann et al. (2015a)	1 kg greasy wool	To farm-gate	GWP, ED, LU
Potting & Blok (1995)	1 sq m carpet	Pre-farm to disposal	Most CML[1] indicators
Barber & Pellow (2006)	1 t dry wool top	Pre-farm to wool top at spinning mill	GWP2, ED
Brent & Hietkamp (2003)	1 kg dyed yarn	Pre-farm to dyed yarn	Most CML indicators[1], GWP[2], LU, WU
Petersen & Solberg (2004)	Wool carpet	Post farm-gate to use	GWP
Murphy & Norton (2008)	1 sq m insulation	Farm to disposal	GWP, ED, AP, EP
Bowyer (2009)	Wool broadloom carpet	Pre-farm to disposal	GWP, ED, AP, EP, HTP, ETP, WU, ODP, smog, indoor air quality, habitat alteration
Bevilacqua et al. (2011)	1 wool sweater	Pre-farm to disposal	GWP[2]
Henry et al. (2015b)	1 pair socks	Pre-farm to disposal	GWP, WU, ED
	1 men's base layer garment	Pre-farm to disposal	GWP, WU, ED

GWP_{100} = global warming potential, 100 year time-frame (kg CO_2-e)

AP = acidification potential (kg SO_2 eq.)

EP = eutrophication potential (kg PO_4 eq.)

ODP = ozone layer depletion potential (kg CFC-11 eq.)

ADP = abiotic depletion potential (kg antimony eq.)

HTP = human toxicity potential (kg 1,4 - dichlorobenzene eq.)

ETP = ecotoxicity potential (kg 1,4 - dichlorobenzene eq.)

POCP = photochemical oxidant creation potential (kg ethylene eq.)

Resource use

ED = Fossil energy demand (MJ)

LU = Land use (ha)

WU = Water use (L)

[1] CML impact categories (LCA Institute of Environmental Sciences NL)
[2] GHG emissions exclude sheep enteric CH_4 and N_2O

Appendix C Additional published guidance on End-of-Life calculations

C.1 Treatment of environmental impacts associated with reuse

The following calculation is adapted from PAS 2050:2011 which gives an equation for GHG emissions. The PAS states that where a product is reused, the [environmental impact] per instance of use or reuse shall be assessed on the basis of:

$$Impact = \frac{a+f}{b} + c + d + e$$

Where:

a is the total life cycle impact of the product, excluding use-phase;

b is the anticipated number of reuse instances for a given product;

c is impact arising from an instance of refurbishment of the product to make it suitable for reuse;

d is impact arising from the use phase;

e is impact arising from transport returning the product for reuse;

f is impact arising from disposal.

C.2 Recycling: Closed-loop approximation method

The following calculation is adapted from PAS 2050:2011 which gives an equation for GHG emissions. The PAS states that if the recycled wool textile product maintains the same inherent properties as the virgin material input, the [environmental impact] arising per unit (E) from that material shall reflect the product specific recycling rate based on the calculation given in the closed-loop approximation method (also called the end-of-life approach).

$$E = (1 - R_2) E_V + R_2 E_R + (1 - R_2) E_D$$

Where:

R_2 = proportion of material in the product that is recycled at end-of-life;

E_V = impact arising from virgin material input, per unit of material;

E_D = impact arising from disposal of waste material, per unit of material;

E_R = impact arising from recycled material input, per unit of material.

C.3 Recycling: Open-loop approximation method

The following calculation is adapted from PAS 2050:2011 which gives an equation for GHG emissions. The PAS states that if the recycled wool textile product does not maintain the same inherent properties as the virgin material input, the [environmental impact] arising per unit (E) from that material shall reflect the product specific recycled content and/or recycling rate based on the following calculation:

$$E = (1 - R_1) E_V + R_1 E_R + (1 - R_2) E_D$$

Where:

R_1 = proportion of recycled material input;

R_2 = proportion of material in the product that is recycled at end-of-life;

E_R = emissions and removals arising from recycled material input per unit of material;

E_V = emissions and removals arising from virgin material input per unit of material;

E_D = emissions and removals arising from disposal of waste material per unit of material.

C.4 Integrated End-of-Life method

An integrated formula for modelling reuse, recycling and energy recovery in LCA studies recently reported by Maki Consulting provides a more comprehensive useful alternative to the methods developed by PAS 2050:2011. The integrated approach has not yet been published in the peer reviewed literature but is being considered for future adoption by the Sustainable Apparel Coalition if the revised Material Sustainability Index in is extended beyond the materials production stage.

$$E = (1 - R_1) \times E_V + R_1 \times Q_{sin} / Q_{pin} \times E^{\S}_V + R_2 \times (E_{recyclingEOL} - E^*_V \times Q_S / Q_p) + R_3 \times$$
$$(E_{ER} - LHV \times X_{ER,elec} \times E_{SE,elec} - LHV \times X_{ER,heat} \times E_{SE,heat}) + (1 - R_2 - R_3) \times E_D$$

Where:

E is the resources consumed and emissions for the acquisition of the primary/virgin material and of the secondary material used as recycled content as well as the EOL stages of the analysed product's life cycle, related to 1 kg of the material in the analysed product;

E_V is the resources consumed/emissions for the acquisition of virgin material (per kg primary material);

$E^{\S}_V$ is the resources consumed/emissions for the acquisition of the virgin material substituted by the secondary material that is used as recycled content for the analysed product (per kg primary material);

E^*_V is the resources consumed/emissions for the acquisition of the virgin material substituted by the secondary material (also termed recyclate) obtained from EOL treatment of the analysed product (per kg primary material). If only closed-loop recycling takes place, $E^*_V = E^{\S}_V = E_V$;

$E_{recyclingEOL}$ is the resources consumed/emissions for the EOL treatment of the analysed product, including collection, sorting, transportation, recycling processes etc. until the first type of recyclate is obtained that can be used to replace a primary material (per kg secondary material).

E_D is the resources consumed/emissions for disposal of the various waste materials from the EOL product, that are obtained due to direct landfilling, reject, wastes generate during recycling or energy recovery processes (e.g. ashes, unusable slags), including transporting, conditioning, storage etc. of the material or product (per kg treated material).

E_{ER} is the resources consumed/emissions to operate the energy recovery process, including transporting, conditioning, storage etc. of the material or product (per kg treated material).

$E_{SE,heat}$; $E_{SE,elec}$ are the avoided resources consumed/emissions for the specific substituted primary energy sources for heat and electricity, respectively (per MJ primary energy carrier).

R_1 is the recycled content of the analysed product, i.e. secondary material (that has been recycled in a previous system) used as input for its production (Dimensionless ($0 \leq R_1 \leq 1$)). Note: $1 - R_1$ is hence the content of primary material in the analysed product.

R_2 is the recyclate obtained from EOL treatment of the analysed product that can be used in subsequent product systems instead of a virgin material, i.e. the proportion of the material contained in the analysed product that will be used as recycled content in another product system. R2 takes into account any inefficiencies in the collection and recycling processes (Dimensionless ($0 \leq$ R2 $\leq$ 1)).

R_3 is the proportion of material in the analysed product that is used for energy recovery (e.g. incineration with energy recovery) at EOL (Dimensionless ($0 \leq$ R3 $\leq$ 1)).

LHV is the Lower Heating Value of the material in the EOL product that is processed for energy recovery (MJ/kg material).

$X_{ER,heat}$; $X_{ER,elec}$ represent the efficiency of the energy recovery process (i.e. the ratio between the energy content of output (both heat and electricity, respectively) and the energy content of the material in the product that is used for energy recovery). X_{ER} takes into account the inefficiencies of the energy recovery process (Dimensionless ($0 \leq X_{ER} \leq 1$)).

Q_S / Q_p; Q_{sin} / Q_{pin} are the crediting and debiting correction factor ratio for any differences between the secondary material and the primary material. Depending on the policy preference, this can be either the relative substitution factor, i.e. how much primary material the secondary material substitutes (the theoretically correct factor) or the relative technical quality (e.g. fibre length, tensile strength or other measure) (Dimensionless ($0 \leq Q_S / Q_p \leq 1$)).

Full explanation of the derivation and application of the EOL formula can be found in Wolf, M.A., and K. Chomkhamsri (2014) The "Integrated formula" for modelling recycling, energy recovery and reuse in LCA, unpublished document. Maki Consulting and PPP International Trader LP. Berlin Germany. Accessible at: http://maki-consulting.com/wp-content/uploads/2013/05/White-paper-Integrated-approach_Wolf&Chomkhamsri2014_Final.pdf)

Appendix D Issues for communication of wool LCA

Quantification of a product environmental impact or environmental performance needs to be based on the application of ISO 14040 and ISO 14044, and product category rules as specified in these Guidelines may be appropriate to ensuring consistency with these standards. A key purpose of LCA communication is for consumers and other stakeholders in wool textile products to make informed choices. LCA-based environmental performance information can, therefore, influence behaviour towards environmental sustainability through textile choice, during the use stage or in making decisions on recycling and final disposal.

A study report for wool LCA has the purpose of documenting the results of the quantification of the environmental impact of a wool textile product within the goal and scope of the study and should clearly present the purpose of the study and demonstrate that the provisions of these Guidelines as representative of international standards have been met.

The results and conclusions of the LCA study shall be documented in the study report without bias. The assumptions, data, methods and results and the life cycle interpretation shall be transparent and presented in sufficient detail to allow a reader to fully understand the limitations and complexities of the CFP study. The goal and scope of the LCA shall be defined in the study report in a way that allows the results and life cycle interpretation to be used in a manner consistent with the conduct of the assessment.

If the LCA study is to be made publicly available, regardless of the communication option selected, the communication report should preferably be verified by a third party in accordance with ISO 14025:2006 (ISO 2006) based on quantification procedures that have undergone an external critical review according to ISO 14044:2006 or be supported by a detailed report to enable external experts to independently evaluate confidence in the results.

Note: 'Publicly available' would normally refer to a communication which is deliberately placed in the public domain or intended to be available to consumers, for instance through an intentional publication or through an open internet site. Communications which are, for instance, exchanged between businesses or posted on a restricted access internet site would not normally be classified as publicly available even if they subsequently enter the public domain through the unforeseen actions of a third party.