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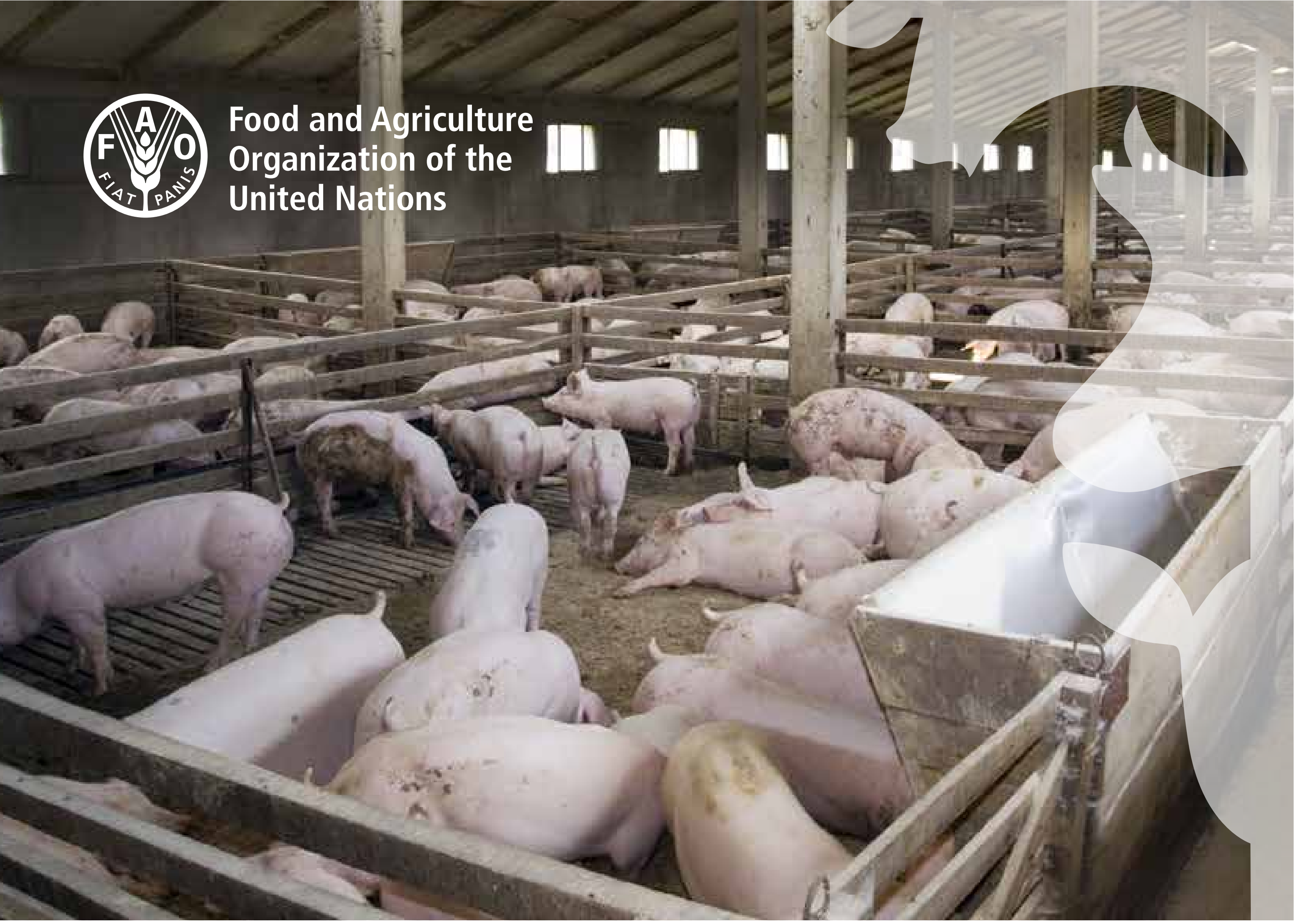

VERSION 1

Environmental performance of pig supply chains

Guidelines for assessment

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Foreword

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

The livestock sector has expanded rapidly in recent decades and growth is projected to continue as a result of sustained demand, especially in developing countries. In 2013, 113 million tonnes of pig-meat carcass was produced globally; and 98 percent of pig-meat production originated in three regions: Asia accounted for 57 percent, Europe for 24 percent and the Americas for 17 percent. It is interesting to note that China contributes about 48 percent of global pig-meat production, followed by the USA with 10 percent (FAOSTAT, 2015). Increasing populations, greater purchasing power and urbanization have been strong drivers of that growth. The pig sector is very diverse in structural terms: along with large-scale commercial operations, traditional small-scale, rural and family-based pig systems play a crucial role in sustaining livelihoods. Increasing demand for pig products will also result in additional pressure on natural resources. This is of particular concern because the livestock sector already has a major impact on natural resources in using 35 percent of total cropland and 20 percent of green water for feed production (Macleod *et al.*, 2013). Global pig-related emissions have been estimated to account for 700 million tonnes of CO_2 equivalent per annum – about 9 percent of the livestock sector – half of which comes from feed production (Macleod *et al.*, 2013). There is hence growing interest in the pig sector and other sectors in measuring and improving the environmental performance of pig supply chains.

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

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

These guidelines underwent a public review. The purpose of the review was to strengthen the advice provided and ensure it meets the needs of those seeking to improve performance through sound assessment practice. The present document is not intended to remain static. It will be updated and improved as the sector evolves and more stakeholders become involved in LEAP, and as new methodological frameworks and data become available. The development and inclusion of guidance on the evaluation of additional environmental impacts is another critical step.

The effectiveness of the guidelines developed in the LEAP partnership for the various livestock subsectors stems from the fact that they represent a coordinated international cross-sector effort to harmonize measurement approaches. Ideally, harmonization will lead to greater understanding, transparent application and communication of metrics, and – especially in the pig sector – real and measurable improvements in performance.

Hsin Huang, International Meat Secretariat – 2016 LEAP chair

Rogier Schulte, Teagasc; Paul McKiernan, Government of Ireland – 2015 LEAP co-chairs

Lalji Desai, WAMIP – 2014 LEAP chair

Frank Mitloehner, University of California, Davis – 2013 LEAP chair

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

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

The TAG on pig production conducted the background research and developed the core technical content of the guidelines. It was led by: Greg Thoma (Leader, Arkansas University, USA), Yaosheng Chen (Co-leader, Sun Yat-Sen University, China) and Hongmin Dong (Co-leader, Chinese Academy of Agricultural Sciences). The members were: Airton Kunz (Embrapa, Brazil), Miguel Angel Aparicio Tovar and Paula Gaspar (Universidad de Extremadura, Spain), Balram Sahu (Pathe Pathshala, the Peoples' University on the Move, India), Ben Lukuyu (ILRI, Kenya), Gonzalo Becoña (Plan Agropecuario, Uruguay), Ilias Kyriazakis (University of Newcastle, UK), Jean-Luc Farinet (CIRAD, France), Jeffery Escobar (Novus, USA), John Hermansen (Aarhus University, Denmark), Mariscal Landin Gerardo (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Mexico), Paolo Masoni (The Italian network on LCA, Italy), Valentina Fantin (ENEA, Italy), Peadar Lawlor (Teagasc, Ireland), Sandrine Espagnol (Institut du porc, France), Stephen Wiedemann (FSA Consulting, Australia), and TC Wang and Hui Zhang (Anyou International, China).

The LEAP secretariat coordinated and facilitated the work of the TAG, guided and contributed to the content and ensured coherence among the various guidelines. It is hosted at FAO. The members were: Carolyn Opio (Coordinator), Camillo De Camillis (LEAP Manager), Félix Teillard (Technical officer), and Aimable Uwizeye (Technical officer).

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

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Although not directly responsible for the preparation of these guidelines, the other TAGs of the LEAP partnership contributed indirectly to the preparation of this document.

MULTI-STEP REVIEW PROCESS

The initial draft guidelines developed by the TAG over 2015 went through an external peer review before being revised and submitted for public review. Lisbeth Mogensen (Aarhus University, Denmark) and Karoline Reckmann (University of Kiel, Germany) peer reviewed these guidelines in 2016. The LEAP Secretariat reviewed this technical guidance before its submission for both external peer review and public review. The LEAP Steering Committee also reviewed the guidelines at various stages of their development and provided additional feedback before clearing their release for public review. The public review started from May, 13th 2016 and lasted until September, 15th, 2016. The review period was also announced to the public through an article published on the FAO website. The scientific community working on the accounting of greenhouse gas (GHG) emissions from livestock was alerted through the Livestock and Climate Change Mitigation in Agriculture Discussion group on the forum of the Mitigation of Climate Change in Agriculture (MICCA) Programme. Experts in life cycle assessment (LCA) were informed through an issue of the United Nations Environment Programme (UN Environment)/ Society for Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative newsletter and through announcements and reminders circulated via the mailing list on LCA held by PRé Consultants. The LEAP Secretariat also publicized the 2016 LEAP public review through oral speeches in international scientific conferences. The following have participated in the public review and contributed to improving the quality of this technical document: Michael Binder (Evonik, Germany), Eise Spijker (Joint Implementation Network – Climate & Sustainability, the Netherlands), Adrian Leip (European Commission, Joint Research Centre), Monique Eloit (OIE-World Organisation for Animal Health, France), and Michael Teillet (Manitoba Pork, Canada).

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Abbreviations and acronyms

AEZ	Agro-Ecological Zones
CF	Characterization Factor
CFP	Carbon footprint of a product
CHP	Combined heat and power
CO_2e	Carbon dioxide equivalent
dLUC	direct Land Use Change
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Reference Life Cycle Data System
iLUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
LAC	Latin America and the Caribbean
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
MMS	Manure management system
NENA	Near East & North Africa
NGGI	National Greenhouse Gas Inventory
NGO	Non-Governmental Organization
OECD	Organization for Economic Cooperation and Development
PAS	Publicly Available Specification
PCR	Product Category Rules
PEF	Product Environmental Footprint
PDF	Probability Density Functions
SAFA	Sustainable Assessment of Agriculture and Food systems
SETAC	Society for Environmental Toxicology and Chemistry
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa

TAG	Technical Advisory Group
TS	Technical Specification
UN	United Nations
UN Environment	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WRI	World Resource Institute
VS	Volatile solids
WTO	World Trade Organization
WWF	World Wide Fund for Nature

Glossary

Terms relating to feed and food supply chains

Annual forage	Forage established annually, usually with annual plants; generally involves soil disturbance, removal of existing vegetation, and other cultivation practices.
Animal by-product	A regulatory term in the EU for livestock production output classified in three categories mostly due to the risk associated to the bovine spongiform encephalopathy. This classification scheme is focused on public health, and is mentioned here to prevent confusion with the terms used in this guidance that relate to co-products, residuals, and waste.
Cold chain	Refers to a system for distributing products in which the goods are constantly maintained at low temperatures, for example in cold or frozen storage and transport, as they move from producer to consumer.
Combined heat and power (CHP)	Simultaneous generation in one process of useable thermal energy together with electrical and/or mechanical energy.
Compound feed/ concentrate	Mixtures of feed materials that may contain additives for use as animal feed in the form of complete or complementary feedstuffs.
Conserved forage	Conserved forage saved for future use. Forage can be conserved by stockpiling, or it can be harvested, preserved and stored as hay, silage, or haylage.
Cropping	Land on which the vegetation is dominated by large-scale production of crops for sale such as maize, wheat and soybeans.
Crop product	Product from a plant, fungus or algae cultivation system that can either be used directly as feed or as raw material in food or feed processing.
Crop residue	Materials left in an agricultural field after the crop has been harvested: straw and stover are examples.

Crop rotation	Growing of crops in a seasonal sequence to prevent diseases, maintain soil conditions and optimize yields.
Cultivation	Activities related to the propagation, growing and harvesting of plants and activities to create favourable conditions for growth.
Feed	Any single or multiple material, whether processed, semi-processed or raw, that is intended to be fed directly to food-producing animals. (FAO/WHO, *Codex Alimentarius* CAC/RC 54-2004, amended in 2008).
Feed additive (specialty feed ingredient)	Any intentionally added ingredient not normally consumed as feed by itself, whether it has nutritional value or not, that affects the characteristics of feed or animal products. Note: Micro-organisms, enzymes, acidity regulators, trace elements, vitamins and other products are covered by this definition, depending on the purpose of use and method of administration. (FAO/WHO, *Codex Alimentarius* CAC/RC 54-2004, amended in 2008).
Feed conversion ratio	Measure of the efficiency with which an animal converts feed into tissue, usually expressed in terms of kg of feed per kg of output, for example kg live weight or protein.
Feed digestibility	The proportion of ingested feed that is actually absorbed by an animal, and hence the availability of feed energy or nutrients for growth, reproduction, etc.
Feed ingredient	A component part or constituent of any combination or mixture making up a feed, whether or not it has nutritional value in the animals' diet; including specialty feed ingredients. Ingredients may be of plant, animal or aquatic origin, or may be other organic or inorganic substances. (FAO/WHO, *Codex Alimentarius* CAC/RC 54-2004, amended in 2008).
Fodder	Harvested forage fed intact to livestock; this can include fresh and dried forage.
Forage crop	Crops, annual or biennial, grown for grazing or harvested as a whole crop for feed.

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[1] See: http://www.codexalimentarius.org/codex-home/en/

Medicated feed	Any feed that contains veterinary drugs as defined in the *Codex Alimentarius* Commission Procedural Manual[1]. (FAO/WHO, *Codex Alimentarius* CAC/RC 54-2004, amended in 2008).
Natural or cross ventilation	Limited use of fans for cooling; frequently the sides of a building can be opened to allow air to circulate.
Natural pasture	Natural ecosystem dominated by indigenous or naturally occurring grasses and other herbaceous species, used mainly for grazing by livestock and wildlife.
Packing	Process of packing products in the production or distribution stages.
Primary packaging materials	Packaging in direct contact with the product. See also Retail packaging.
Raw material	Primary or secondary material used to produce a product.
Repackaging facility	A facility where products are repackaged into smaller units without additional processing in preparation for retail sale.
Retail packaging	Containers and packaging that reach consumers.
Secondary packaging materials	Additional packaging not in contact with the product that may be used to contain relatively large volumes of primary packaged products or to transport the product safely to its retail or consumer destination.
Silage	Forage harvested and preserved at high moisture contents generally >500 g kg^{-1} by organic acids produced during partial anaerobic fermentation.
Volatile solids (VS)	Volatile solids are the organic materials in livestock manure, consisting of biodegradable and non-biodegradable fractions; VS is measured as the fraction of sludge combusted at 550°C after 2 hours.

Terms relating to pig supply chains

Anaerobic lagoon	A manure management system in which the animals' urine and faeces fall through a slatted floor to a shallow collection area which is flushed every 5–10 days to an outside lagoon designed to treat the manure anaerobically.
Backyard system	Production that is mainly subsistence-driven or for local markets, displaying animal performance lower than in commercial systems and mostly relying on swill and locally-sourced materials to feed animals (less than 20 percent of purchased concentrate). Backyard production systems are the most basic traditional system of keeping pigs and the most common in developing countries, in both urban and rural areas. These systems are typically semi-intensive production.
Barrow	A castrated male pig intended for slaughter.
Boar	A sexually mature male pig used for breeding.
Breeding overhead	Animals dedicated to reproduction rather than production: that is, animals needed to maintain herd size and for control of population genetics.
Carcass weight (cold vs. hot)	Hot carcass weight refers to the weight after slaughter and before cold storage. During cold storage there may be some drip loss or evaporation of water from the carcass resulting in a small decrease in weight from the cold carcass weight.
Cooling cell	System in which ventilation air is passed over a wet mesh medium to evaporatively cool air entering a barn.
Cull sows	Sows that are euthanized before the end of the normal productive period; they may include sows that are diseased, injured, infertile or physically abnormal or those that do not conform to breed or production standards. These animals are disposed of after euthanasia and do not enter the human food supply. See also Spent sows.
Dead weight	Carcass weight including head and internal organs. See also Carcass weight.
Deep pit	A manure management system in which animals live on a slatted floor, and urine and faeces collect in a pit below. The pit is typically emptied directly to a crop or pasture. See also Anaerobic lagoon.

Dirt floor	Housing floor which is unimproved, generally associated with a simple shelter constructed to provide protection from the elements.
Dressed carcass	A slaughtered animal whose internal organs, hooves and head have been removed; surplus fat may also be removed from the carcass.
Dressed carcass fraction	The ratio of carcass weight to live weight, sometimes called carcass yield.
Dressing	Removal of parts not to be offered as edible products. Cutting up pigs into product parts.
Extensive system	Also known as a free-range system. Pigs are kept outdoors in paddocks or open pasture; some systems may include rooting areas, wallows and kennels or huts for shelter from environmental extremes and additional protection for young piglets.
Farrow	To give birth to piglets.
Farrow-to-finish	An operation that produces piglets and then raises them to market weight.
Feeder	An animal of typically 25 kg weight from a nursery that enters a growing/finishing barn.
Feed quality	This refers to the nutritional content of feed: specifically, the energy, amino acid, crude protein and phosphorus content.
Gilt	A female pig that has not farrowed and is intended for slaughter or breeding purposes.
Gutted pig	An animal whose viscera – excluding kidneys – cloaca, trachea and oesophagus have been removed.
Hoop barn	Barn without forced ventilation. Side walls may be lowered in cool or cold weather; the system typically uses deep bedding for manure management.
Intensive small-scale or medium-scale system	Pigs are kept in complete confinement; buildings are provided to separate feeders, boars, sows and sows with litters. The housing is much more than a simple shelter. Pigs are often feed on kitchen refuse and agricultural waste products and some concentrate feeds.
Litter	A group of piglets born at the same time from a single sow. Litter sizes are usually 8 to 12 piglets.

Nursery	A production phase in which weaners are raised from 7 kg to 25 kg. Animals leaving the nursery are commonly called feeders.
Pig space	The area available to house an individual animal. Barns are frequently described in terms of the number of pig spaces or capacity.
Pork	The meat that comes from pigs: it is processed into products such as chops, bacon, ham, sausage and roasting meat.
Pork meat processing	A general term for further processing after dressing such as cutting, selection and cooking.
Rendering	A process that converts animal tissue, bones and blood into stable, value-added materials.
Repackaging facility	A facility where products are repackaged into smaller units without additional processing in preparation for retail sale.
Retail cuts	Cuts of meat for retail sale such as ham and bacon.
Scavenging system	A traditional system of rearing in which pigs move freely round a homestead and its surroundings, scavenging for a large part of their feed. Often the food they collect is supplemented with kitchen refuse or agricultural waste products. Few or no arrangements are made to provide the pigs with shelter, and no money is invested in quality feed or veterinary services.
Semi-intensive system	A system in which pigs are kept in a *kraal* (enclosure) or tethered with rope during the night and allowed to move freely on pasture to feed during the day. Pigs are often given concentrate feeds as a supplement.
Sow	Female parent pig producing piglets for pig meat production. Pregnancy in pigs lasts for 112–115 days.
Spent sow	Adult female sow at the end of her productive life. These animals are sent to slaughter and enter the human food chain.
Stocking density	Area available to animals in housing, normally defined in m^2 per pig space. It should be specified whether overhead areas such as walkways are included in the reported value.
System, organic	In addition to providing free-range conditions, these systems adhere to local standards for organic production.

System, village	Village systems allowing free-range animals to scavenge for food; they may also be fed compound feed or concentrate rations.
Tunnel ventilation	Fans located at the ends of a building to provide airflow.
Weaner	A weaned animal aged 21–30 days and weighing 6–8 kg. These animals may be sent to either a nursery or a grow/finish operation.

Terms relating to environmental accounting and assessment

Acidification	Impact category that addresses impacts due to acidifying substances in the environment. Emissions of nitrogen oxides (NO_x), ammonia (NH_3) and sulphur oxides (SO_x) lead to releases of hydrogen ions (H+) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low. Acidification may result in the decline of forests and acidification of lakes. [Adapted from Product Environmental Footprint Guide, European Commission, 2013].
Activity data	Data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time [UNFCCC, 2014].
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	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/ Society for Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative, 2011].
Background system	Processes on which no or, at best, indirect influence may be exercised by the decision-maker for whom a life cycle assessment is carried out. Such processes are also called "background processes." [UNEP/SETAC Life Cycle Initiative, 2011].

Biogenic carbon	Carbon derived from biomass. [ISO/TS 14067:2013, 3.1.8.2].
Biomass	Material of biological origin, excluding material embedded in geological formations, material transformed to fossilized material and peat. [ISO/TS 14067:2013, 3.1.8.1].
Blue water	Fresh water flows originating from runoff or percolation, contributing to freshwater lakes, dams, rivers and aquifers. A special case exists with respect to water from flooding, where the moisture contributed to the soil is considered blue water.
Capital goods	Capital goods are final products that have an extended life and are used by a company to manufacture a product, provide a service or to sell, store and deliver merchandise. In financial accounting, capital goods are treated as fixed assets or as plant, property and equipment (PP&E). Examples of capital goods include equipment, machinery, buildings, facilities and vehicles. [GHG Protocol, Technical Guidance for Calculating Scope 3 Emissions, Chapter 2, 2013].
Carbon dioxide equivalent (CO_2e)	Unit for comparing the radiative forcing of a greenhouse gas (GHG) to that of carbon dioxide. [ISO/technical specification (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 CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change. [ISO/TS 14067:2013, 3.1.1.1].
Carbon storage	Carbon removed from the atmosphere and stored as carbon. [ISO 16759:2013, 3.1.4].
Characterization	Calculation of the magnitude of the contribution of each classified input or output to their impact categories, and aggregation of contributions within each category. This requires a linear multiplication of the inventory data with characterization factors for each substance and impact category of concern. With regard to the impact category "climate change", for example, CO_2 is chosen as the reference substance and kg CO_2 equivalents as the reference unit. [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].
Characterization factor	Factor derived from a characterization model that is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator. [ISO 14044:2006, 3.37].

Classification	Assigning the material or energy inputs and outputs tabulated in the life cycle inventory to impact categories according to the potential of each substance to contribute to each of the impact categories considered. [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].
Combined production	A multi-functional process in which production of various outputs can be independently varied. In a backyard system, for example, the number of poultry and pigs can be set independently.
Comparative assertion	Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function. [ISO 14044:2006, 3.6].
Comparison	A comparison of two or more products in terms of the results of their life cycle assessment according to these guidelines, and not including a comparative assertion.
Consequential data modelling	System modelling approach in which activities in a product system are linked so that activities are included in the 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].
Consumable	Ancillary input needed for a process to occur that does not form a tangible part of the product or co-products arising from the process. Note 1: Consumables differ from capital goods in that they have an expected life of one year or less, or a need to be replenished in one year or less: examples are lubricating oil, tools and other inputs to a process that wear rapidly. Note 2: Fuel and energy inputs into the life cycle of a product are not considered to be consumables. [PAS 2050:2011, 3.10].
Co-production	A generic term for multifunctional processes, either combined production 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 – the cradle – 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 governing life cycle assessments. [ISO 14044:2006, 3.45].
Critical review report	Documentation of the critical review process and findings, including detailed comments from the reviewer(s) or the critical review panel, and corresponding responses from the practitioner of the LCA study. [ISO 14044:2006, 3.7].
Cut-off criteria	Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study. [ISO 14044:2006, 3.18].
Data quality	Characteristics of data that relate to their ability to satisfy stated requirements. [ISO 14044:2006, 3.19].
Dataset – LCI dataset	A document or file with life cycle information for a specified product or other reference (e.g. site or process) which contains descriptive metadata and quantitative life cycle inventory data. [ILCD Handbook, 2010a].
Dataset –LCIA dataset	A document or file with life cycle information for a specified product or other reference (e.g. site or process) which contains descriptive metadata and quantitative life cycle impact assessment data. [ILCD Handbook, 2010a].
Delayed emissions	Emissions released over time for example through prolonged use or final disposal stages versus a single one-time emission. [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	Energy used on farms to support livestock production: lighting and heating are examples of such energy use.
Downstream	Occurring along a product supply chain after the point of referral. [Product Environmental Footprint Guide, European Commission, 2013].

Drainage basin	Area from which surface water runoff from precipitation drains by gravity into a stream or other water body. Note 1: The terms “watershed”, “drainage area”, “catchment”, “catchment area” and “river basin” are sometimes used to mean “drainage basin”. Note 2: “Groundwater drainage basin” does not necessarily correspond in area to surface drainage basin”. Note 3: The geographical resolution of a drainage basin should be determined at the goal and scope stage: it may regroup different sub drainage basins. [ISO 14046:2014, 3.1.8].
Economic value	Average market value of a product at the point of production, possibly over a 5-year time frame [Adapted from PAS 2050:2011, 3.17]. Note 1: if trade is by barter, the economic value of the commodity traded can be calculated on the basis of the market value and amount of the commodity exchanged.
Eco-toxicity	Environmental impact category that addresses the toxic impacts on an ecosystem that damage individual species and change the structure and function of the ecosystem. Eco-toxicity is a result of various toxicological mechanisms caused by the release of substances that have a direct effect on the health of the ecosystem. [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].
Elementary flow	Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation. [ISO 14044:2006, 3.12].
Emission factor	Amount of emissions emitted into the environment on the basis of one unit of activity. For example, the amount of greenhouse gases emitted expressed as carbon dioxide equivalent and relative to a unit of activity such as kg CO_2e per unit input. [Adapted from UNFCCC, 2014]. Note: Emission factor data is obtained from secondary data sources.
Emissions	Release of a substance to air and discharges to water and land.
Environmental impact	Any change to the environment whether adverse or beneficial that results wholly or in part from an organization’s activities, products or services. [ISO/TR 14062:2002, 3.6].

Eutrophication	Excess of nutrients (mainly nitrogen and phosphorus) in water or soil from sewage outfalls and fertilised farmland. In water, eutrophication accelerates the growth of algae and other vegetation. The degradation of organic material consumes oxygen, resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass. In soil, eutrophication favours nitrophilous plant species and modifies the composition of the plant communities. [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].
Extrapolated data	Refers to data from a process that is used to represent a similar process for which data is not available on the assumption that it is reasonably representative. [Product Environmental Footprint 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	Processes that are under the control of the decision-maker for which an LCA is carried out; also called "foreground processes". [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]. It is essential that the functional unit allows comparisons that are valid where the compared objects, or time series data on the same object for benchmarking, are comparable.
GHG removal	Mass of a 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 CO_2 over a given period of time. [ISO/TS 14067:2013, 3.1.3.4].
Greenhouse gases (GHGs)	Gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. [ISO 14064-1:2006, 2.1].
Green water	Precipitation that is transpired or evaporated at the place where it falls.

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, ingestion of food and water and penetration of 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, ingestion of food and water and penetration of the skin, insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionizing radiation. [Product Environmental Footprint Guide, European Commission, 2013].
Indirect land use change (iLUC)	Change in the use or management of land that is a consequence of direct land use change, but that occurs outside the product system being assessed. [ISO/TS 14067:2013, 3.1.8.5].
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	Quantifiable representation of an impact category. [ISO 14044:2006, 3.40].
Infrastructure	Synonym for capital good.
Input	Product, material or energy flow that enters a unit process. [ISO 14044:2006, 3.21].
Ionizing radiation, human health	Impact category that accounts for the adverse health effects on human health caused by radioactive releases. [Product Environmental Footprint Guide, European Commission, 2013].
Intermediate product	Output from a unit process that is input to other unit processes that require further transformation within the system. [ISO 14044:2006, 3.23].
Joint production	A multi-functional process that produces various outputs such as poultry meat and eggs in backyard systems. Production of the different goods cannot be independently varied, or only varied within a very narrow range.
Land occupation	Impact category related to use (occupation) of land area by activities such as agriculture, roads, housing and mining. [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].

Land use change	Change in the purpose for which land is used by humans (e.g. changing between crop land, grass land, forestland, wetland, or 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 (LCA)	Compilation and evaluation of the inputs and 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, within the specified product system boundaries. [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 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 make recommendations. [ISO 14044:2006, 3.5].
Material contribution	Contribution from any one source of GHG emissions of more than 1 percent of the anticipated total GHG emissions associated with the product being assessed. Note: A materiality threshold of 1 percent has been established to ensure that very minor sources of life cycle GHG emissions do not require the same treatment as more significant sources. [PAS 2050:2011, 3.31].
Multi-functionality	A process or facility that provides more than one function – that is, it delivers several goods and/or services known as "co-products" – is multi-functional. In these situations, all inputs and emissions linked to the process must be partitioned between the product of interest and the co-products in a principled manner. [Product Environmental Footprint Guide, European Commission, 2013].

Normalization	After characterization, normalization is an optional step in which the impact assessment results are multiplied by normalization factors that represent the overall inventory of a reference unit such as a whole country or an average citizen. Normalised impact assessment results express the relative shares of the impacts of the analysed system in terms of the total contributions to each impact category per reference unit. When displaying the normalised impact assessment results of the different impact topics next to each other, it becomes evident which impact categories are affected most and least by the analysed system. Normalised impact assessment results reflect only the contribution of the analysed system to the total impact potential, not the severity or relevance of the respective total impact. Normalised results are dimensionless, but not additive. [Product Environmental Footprint Guide, European Commission, 2013].
Offsetting	Mechanism for compensating for all or part of the CFP through the prevention of the release of, reduction in or removal of an amount of emitted GHG in a process outside the boundary of the product system. [ISO/TS 14067:2013, 3.1.1.4].
Output	Product, material or energy flow that leaves a unit process. [ISO 14044:2006, 3.25].
Ozone depletion	Impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances such as long-lived chlorine and bromine containing gases such as CFCs, HCFCs and halons. [Product Environmental Footprint Guide, European Commission, 2013].
Particulate matter	Impact category that accounts for the adverse effects on human health caused by emissions of particulate matter (PM) and its precursors NO_x, SO_x and NH_3. [Product Environmental Footprint Guide, European Commission, 2013].
Photochemical ozone formation	Impact category that accounts for the formation of ozone at ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and CO in the presence of NO_x and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and man-made materials through reaction with organic materials. [Product Environmental Footprint Guide, European Commission, 2013].

Primary data	Quantified value of a unit process or an activity obtained from a direct measurement or a calculation based on direct measurements at its original source. [ISO 14046:2014, 3.6.1].
Primary activity data	Quantitative measurement of activity from the life cycle of a product that, when multiplied by the appropriate emission factor, determines the emissions arising from a process. Examples of primary activity data include the amount of energy used, material produced, service provided or area of land affected. [PAS 2050:2011, 3.34].
Product (s)	Any good 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 rule (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 as a stand-in for the given activity. Proxy data can be extrapolated, scaled up or customized to represent the given activity. An example is using a Chinese unit process for electricity production in an LCA for a product produced in Viet Nam. [GHG Protocol, Product Life Cycle Accounting and Reporting Standard, 2011].
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, shareholders, the general public or stakeholder groups. [Adapted from: ENVIFOOD Protocol: 2013].

Residue or residual	Substance(s) that is/are not the intended end product(s) of a production process. [Communication from the European Commission 2010/C 160/02]. More specifically, a residue is any material without economic value that leaves the product system in the condition created in the process, but that has a subsequent use. There may be value-added steps beyond the system boundary, but these activities do not affect the product system calculations. Note 1: Materials with economic value are considered products. Note 2: Materials whose economic value is negligible relative to the annual turnover of the organization and is entirely determined by the production costs involved in not turning such materials into waste are to be considered, from an environmental accounting perspective, as residues. Note 3: Materials whose relative economic value volatility is high in the range of positive and negative value and whose average value is negative are residues from an environmental accounting perspective. The economic value volatility of a material may be calculated over a 5-year period at the regional level.
Resource depletion	Impact category that covers the use of renewable or non-renewable natural resources, biotic or abiotic. [Product Environmental Footprint Guide, European Commission, 2013].
Secondary data	Data obtained from sources other than direct measurement or calculation based on direct measurements at the original source [ISO 14046:2014, 3.6.2]. Secondary data are used when primary data are not available or it is impractical to obtain primary data. Some emissions such as methane from manure 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].
Sink	Physical unit or process that removes a GHG from the atmosphere. [ISO 14064-1:2006, 2.3].
Soil organic matter (SOM)	The measure of the content of organic material in soil. This derives from plants and animals and comprises all organic matter in the soil other than matter that has not decayed. [Product Environmental Footprint Guide, European Commission, 2013].

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.
Temporary carbon storage	When a product "reduces the GHGs in the atmosphere" or creates "negative emissions" by removing and storing carbon for a limited amount of time it is regarded as temporary carbon storage. [Product Environmental Footprint Guide, European Commission, 2013].
Tier-1 method	Simplest method that relies on single default emission factors such as kg of methane per animal.
Tier-2 method	A more complex approach that uses detailed country-specific data such as gross energy intake and methane conversion factors for specific livestock categories.
Tier-3 method	Method based on sophisticated mechanistic models that account for multiple factors such as diet composition, product concentration from rumen fermentation and seasonal variation in animal and feed parameters.
Uncertainty analysis	Systematic procedure to quantify the uncertainty introduced into the results of a life cycle inventory analysis resulting from 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 or services prior to entering the system boundary. [Product Environmental Footprint Guide, European Commission, 2013].
Waste	Substances or objects that the holder intends to or is required to dispose of. [ISO 14044:2006, 3.35]. Note 1: Deposition of manure on land where quantities and availability of soil nutrients such as nitrogen and phosphorus exceed plant nutrient requirements is considered a waste-management activity from an environmental accounting perspective. Derogation is only possible where evidence proves that soil is poor in terms of organic matter and there is no other way to build up organic matter. See also: Residual and economic value.

Water body	Water with definite hydrological, hydro-geomorphological, physical, chemical and biological characteristics in a given geographical area. Examples are lakes, rivers, groundwater, seas, icebergs, glaciers and reservoirs. Note 1: If possible, the geographical resolution of a body of water should be determined at the goal and scope stage; it may regroup different small water bodies. [ISO 14046:2014, 3.1.7].
Water consumption	The term “water consumption” is often used to describe water removed from, but not returned to, the same drainage basin. Water consumption can be because of evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea. Change in evaporation caused by land-use change is considered water consumption (e.g. reservoir) (ISO 14046:2014, 3.2.1).
Water use	Use of water by human activity (ISO 14046:2014, 3.2.1).
Water withdrawal	Anthropogenic removal of water from any water body or from any drainage basin, either permanently or temporarily (ISO 14046:2014, 3.2.2).
Weighting	Weighting is an additional but not mandatory step that may support the interpretation and communication of the results of an analysis. Impact assessment results are multiplied by a set of weighting factors that reflect the perceived relative importance of the impact categories considered. Weighted impact assessment results can be directly compared across impact categories, and also summed across impact categories to obtain a single-value overall impact indicator. Weighting requires making value judgements as to the respective importance of the impact categories considered. These judgements may be based on expert opinion, social science methods or cultural or political views, or on economic considerations. [Adapted from: Product Environmental Footprint Guide, European Commission, 2013].

Summary of Recommendations for the LEAP guidance

ENVIRONMENTAL PERFORMANCE OF PIG SUPPLY CHAINS: GUIDELINES FOR QUANTIFICATION

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

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

LEAP guidance uses a precise language to indicate which provisions of the guidelines are requirements, which are recommendations, and which are permissible or allowable options that intended user may choose to follow. The term "shall" is used in this guidance to indicate what is required. The term "should" is used to indicate a recommendation, but not a requirement. The term "may" is used to indicate an option that is permissible or allowable. In addition, as general rule, assessments and guidelines claiming to be aligned with the present LEAP guidelines should flag and justify with reasoning any deviations.

Topic	Summary recommendation	Section
DEFINITION OF THE PRODUCT GROUP		7
Product description	Pig products include: Meat products, with possible co-products of skin, blood, bone and inedible offal; For breeding operations, piglets and spent sows will be co-products; In some circumstances manure is a valuable (revenue generating) co-product; Wealth management is considered for some smallholder systems.	7.1
Life cycle stages: modularity.	The guideline support modularity to allow flexibility in modeling systems. The 3 main stages are feed production, animal production, and primary animal processing.	7.2
GOAL AND SCOPE DEFINITION		8
Goal of the LCA study	The goal shall define: the subject, purpose, intended use and audience, limitations, whether internal or external critical review is required, and the study commissioner.	8.1
Scope of the LCA	The scope shall define: the process and functions of the system, the functional unit and system boundaries, allocation principles and impact categories. The recommended scope is cradle to dressed carcass for meat products.	8.2
Functional unit and Reference flows	Both functional units and reference flows shall be clearly defined and measurable. The functional unit/reference flow, when the animal leaves the farm, shall be live-weight and at the stage of leaving the meat processing plant (or abattoir) shall be the weight of product (meat-product weight) destined for human consumption, including specification of product weight for meat products, with specified carcass or edible yield.	8.3
System boundary		8.4
General / Scoping analysis	The system boundary shall be defined following general supply chain logic including all phases from raw material extraction to the point at which the functional unit is produced. Scoping analysis may use input-output data and should cover impact categories specified by the study goal.	8.4.1
Criteria for system boundary	The recommended system boundaries start with feed production and extend through either the farm or processing gate.	8.4.2
Material boundaries	A material flow diagram should be produced and used to account for all of the material flows for the main transformation steps within the system boundary.	8.4.2
Spatial boundaries	Feed production and live animal rearing are explicitly included; details on feed production are provided in the LEAP feed guidelines.	8.4.2
Material contribution and threshold	Flows contributing less than 1% to impacts may be cut off, provided that 95% of each impact category is accounted, based on a scoping analysis.	8.4.3
Time boundary for data	A minimum period of 12 months should be used, to cover all life stages of the animal. The study should use an 'equilibrium population' which shall include all animal classes and ages present over the 12-month period required to produce the product. In case of significant inter-annual variability, the one-year time boundary should be determined using multiple-year average data to meet representativeness criteria.	8.4.4
Capital goods	May be excluded if the lifetime is greater than one year.	8.4.5
Ancillary activities	Veterinary medicines, accounting or legal services, etc. should be included if relevant, as determined by scoping analysis.	8.4.6
Delayed emissions	All emissions are assumed to occur within the time boundary for data. The feed guidelines address land-use and land use change related emissions.	8.4. 7
Carbon offsets	Shall not be included in the impact characterisation, but may be reported separately.	8.4. 8
Impact categories and characterisation methods	Climate change (IPCC - GWP100), fossil energy demand, eutrophication and acidification (ReCiPe), and water consumption are covered by these guidelines.	8.5

(Cont.)

Topic	Summary recommendation	Section
MULTI-FUNCTIONAL PROCESSES AND ALLOCATION		9
General principles	Follow ISO 14044 standard (section 4.3.4) – with restrictions on application of system expansion. The application of consequential modeling is not supported by these guidelines. System expansion may be used in the context of including expanded functionality. For example, calculating whole farm impacts of sow/piglet production without separately assigning impacts to sows and piglets as co-products.	9.1
Methodological choices	Guidance is given for separation of complicated multifunctional systems and application of bio-physical or economic allocation when process separation is not feasible. A decision tree is presented to facilitate division of processes into separate production units, and subsequently into individual products.	9.2
Meat production	The primary point for multi-functionality is in meat processing, where multiple edible and inedible products are generated. Causal reasoning is recommended to subdivide combined production, and to use economic allocation for joint production.	9.3.2
Allocation of manure	First the determination of whether the litter is classified as a co-product, residual or waste is made on the basis of revenue generation for the operation. Co-product: use biophysical reasoning (an example provided). Residual: the system is cut-off at the boundary and no burden is carried to downstream use of the litter. Waste: emissions from subsequent activities are assigned to the main co-products.	9.3.3
Multifunctional manufacturing facilities, primary processing	These guidelines do not support differentiation of edible products. Revenue based allocation is recommended for products which serve different markets (e.g., edible vs. rendering products).	9.3.4
COMPILING AND RECORDING INVENTORY DATA		10
General principles	Inventory should be aligned with the goal and scope, shall include all resource use and emissions within the defined system boundaries that are relevant to the chosen impact categories. Primary data are preferred, where possible. Data sources and quality shall be documented.	10.1
Collection of data	Primary and secondary data are described. A data management plan is recommended which should address: data collection procedures; data sources; calculation methodologies; data storage procedures; and quality control and review procedures.	10.2
Primary activity data	To the full extent possible, primary data are recommended for all foreground processes, those under control of the study commissioner.	10.2.1
Secondary and default data	Data from existing databases, peer-reviewed literature, may be used for background processes, or some foreground processes that are minor contributors to total emissions.	10.2.2
Addressing LCI data gaps	Proxy data may be used, with assessment of the interviews uncertainty. Environmentally extended input-output tables may also be used where available.	10.2.3
Data quality assessment	LCI data quality address representativeness, consistency, completeness, precision/uncertainty, and methodological appropriateness.	10.3
Uncertainty analysis	Uncertainty information should be collected along with a primary data. If possible, the standard deviation should be estimated, if not a reasonable range should be estimated.	10.4
LIFE CYCLE INVENTORY		11
Overview	Inventory should be aligned with the goal and scope, shall include all resource use and emissions within the defined system boundaries that are relevant to the chosen impact categories and shall support the attribution of emissions and resources use to a single production unit and co-products. Primary data are preferred, where possible. Data sources and quality shall be documented.	11.1
Cradle-to-farm gate	Data shall be collected for feed production (FEED guidelines), grandparent and parent hatchery, broiler and layer hen production, manure production and emissions.	11.2

(Cont.)

Topic	Summary recommendation	Section
Farm water	Background processes for purchased water may be used; guidance to estimate pumping energy for local groundwater consumption is provided.	11.2.1
Feed assessment	The type, quantity and characteristics of feed produced and consumed must be documented. Because ration characteristics and environmental conditions can affect feed conversion ratio primary data on feed consumption is critical.	11.2.2
Animal population and production	A full accounting of breeding pig replacement in each production cycle and spent sows is required, and must be linked to the reference flows of relevant products.	11.2.3
Manure production and management	Estimates of volatile solids and nitrogen excretion based on daily feed intake and properties of the feed are recommended. This will be further covered in the LEAP nutrient cycling guidelines. Procedures for calculating housing emissions of methane and direct and indirect nitrous oxide are provided.	11.2.4
Housing emissions	Guidance for estimation of methane and nitrous oxide emissions is provided.	11.2.5-6
Indirect nitrous oxide emissions	A summary for indirect nitrous oxide, including ammonia, estimation is provided.	11.2.7
Emissions from other farm-related inputs	The total use of fuel (diesel, petrol) and lubricants (oil) associated with all on-farm operations, including provision of water, shall be estimated.	11.2.8
By-products and waste	Mortality management as well as disposal of broken or damaged eggs, packaging or other solid waste shall be included in the inventory.	11.2.9
Water inventory	Guidance is provided on water consumption and losses to enable a water balance calculation.	11.3
Additional water use activity	Additional guidance on ancillary water use; including spillage, cooling water, and evaporation.	11.4
Water balance for manure	Guidance for evaluating effects of rainfall and background water system is provided.	11.5
Transportation	The load factor shall account for empty transport distance, maximum load (mass for volume limited), and use physical causality (mass or volume share) for simultaneous transport of multiple products.	11.6
Land use change	This topic is covered in the LEAP *Animal Feed Guidelines.*	11.7
Biogenic and soil carbon sequestration	This relates only to the feed production stage, the specific methods are covered in the LEAP *Animal Feed Guidelines*.	11.8
Primary processing stage	This stage includes slaughter, removal of blood, feathers, feet and head, evisceration, washing and cooling, cutting and packaging and production of byproducts such as in edible offal and bone meal in addition to the main meat products.	11.9
INTERPRETATION OF LCA RESULTS		12
Identification of key issues	The practitioner shall evaluate the completeness (with respect to the goal and scope); shall perform sensitivity checks (methodological choices); and consistency checks (methodological choices, data quality assessment and impact assessment steps).	12.1
Characterising uncertainty	Data uncertainty should be estimated and reported through formal quantitative analysis or by qualitative discussion, depending upon the goal and scope.	12.2
Conclusions, Recommendations and Limitations	Within the context of the goal and scope, the main results and recommendations should be presented and limitations which may impact robustness of results clearly articulated.	12.3
Use and comparability of results	These guidelines support cradle-to-gate LCA and do not include guidance for post-processing, distribution, consumption or end of life activities.	12.3.1
Report elements and structure	The following elements should be included: Executive summary summarizing the main results and limitations; identification of the practitioners and sponsor; goal and scope definition (boundaries, functional unit, materiality and allocation); lifecycle inventory modeling and life cycle impact assessment; results and interpretation, including limitations and trade-offs. A statement indicating third-party verification for reports to be released to the public.	12.5

PART 1

OVERVIEW AND GENERAL PRINCIPLES

1. INTENDED USERS AND OBJECTIVES

The methodology and guidance in this document can be used by stakeholders in all countries and across the entire range of pig production systems. The assumption was made when developing the guidelines that the primary users will be individuals or organizations with a sound working knowledge of life cycle assessment (LCA). The main purpose of the guidelines is to provide sufficient definition of calculation methods and data requirements to enable consistent application of LCA across different pig supply chains.

This guidance is relevant to a range of livestock stakeholders:

- livestock producers who wish to develop inventories of their on-farm resources and assess the performance of their production systems;
- supply-chain partners such as feed producers, farmers and processors wishing to improve their understanding of the environmental performance of products in their production processes; and
- policymakers interested in developing, accounting and reporting specifications for livestock supply chains.

The benefits of this approach include:

- use of recognized, robust and transparent methodology developed to take account of the nature of pig supply chains;
- identification of supply-chain hotspots and opportunities to improve and reduce environmental impacts;
- identification of opportunities to increase efficiency and productivity;
- ability to benchmark performance internally or against industry standards;
- support for reporting and communication; and
- raising awareness of and support for environmental sustainability.

2. SCOPE

2.1 ENVIRONMENTAL IMPACT CATEGORIES ADDRESSED IN THE GUIDELINES

Among the various impact categories common in LCA, these guidelines cover climate change in detail, introduce water consumption, and provide a general overview of additional categories (as noted in Table 2 and Figure 2); Biodiversity is noted as potentially relevant and covered by the Biodiversity TAG guidance rather than this document. This document does not support the assessment of comprehensive environmental performance or the social or economic aspects of pig supply chains. A full sustainability assessment should include these additional dimensions.

The *Animal Feed Guidelines* of the Livestock Environmental Assessment and Performance (LEAP) partnership cover additional categories: acidification, and land occupation, which may be reported for the life-cycle stages of pig products.

The intention is to update these guidelines to include additional impact categories provided that they are judged reliable and inventory data is available.

In the LEAP *Animal Feed Guidelines*, greenhouse gas (GHG) emissions from direct land-use change is analysed and recorded separately from GHG emissions from other sources. The two reasons for this are: i) time-frame – emissions attributed to land-use change may have occurred in the past or may be set to occur in the future; and ii) uncertainty – there is considerable debate about the best method for calculating direct land-use change.

Regarding land occupation, the LEAP *Animal Feed Guidelines* divide land areas into two categories: arable land and grassland. Appropriate indicators are included because they provide important information about the use of a finite resource – land – and reflect follow-on implications such as effects on soil degradation, biodiversity, carbon sequestration or loss, and ground water depletion. Users wishing to relate land use specifically to follow-on effects will nonetheless need to collect and analyse additional information on production practices and local conditions.

2.2 APPLICATION

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

A stricter methodological approach, including allocation and acceptable data sources, is required for product labelling or comparative performance claims. Users are referred to International Organization for Standardization (ISO) 14025 for information and guidance on comparative claims of environmental performance.

The LEAP Guidelines are based on the attributional approach to life-cycle accounting, which involves process-based modelling with a view to providing a static representation of average conditions.

In view of the limited number of environmental impact categories covered here, results should be presented in conjunction with other environmental metrics to understand the wider environmental implications, positive or negative. It is also relevant to note that either synergies or trade-offs between different impact categories may arise and acknowledging and reporting these is important. It should be noted that comparisons between final products should only be based on full life-cycle assessment. Users of these guidelines shall not utilize results to claim that some pig production systems and products are environmentally superior.

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

3. STRUCTURE AND CONVENTIONS

3.1 STRUCTURE

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

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

The Glossary provides a common vocabulary for practitioners; additional information is presented in the Appendices.

Users of this methodology should also refer to other guidelines as necessary or as indicated. The LEAP pig guidelines are not intended to stand alone, but should be used in conjunction with the LEAP *Animal Feed Guidelines*. Guidance developed under the LEAP partnership but published in other documents will be cross-referenced: specific guidance for calculating associated emissions for feed, for example, is to be found in the LEAP *Animal Feed Guidelines*[2].

3.2 PRESENTATIONAL CONVENTIONS

These guidelines indicate explicitly the requirements, recommendations, and permissible or allowable options ensuring conformity with the guidelines: i) the term "shall" is used to indicate a required action for an assessment to conform to these guidelines; ii) the term "should" is used to indicate a recommendation, not a requirement; iii) the term "may" is used to indicate an allowable option; and iv) commentary, explanations and general information such as notes are presented in footnotes; they do not constitute a normative element.

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

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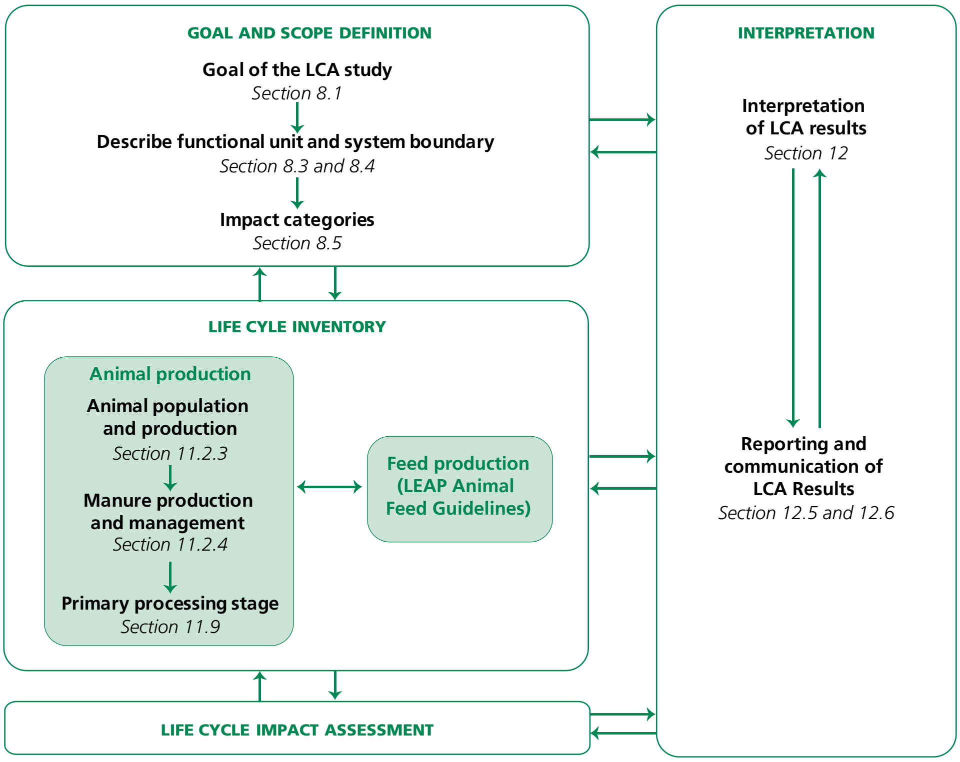
[2] See: http://www.fao.org/3/a-mj751e.pdf

Figure 1

Schematic of ISO 14044 stages of life cycle assessment with reference to the guideline series



4. ESSENTIAL BACKGROUND INFORMATION AND PRINCIPLES

4.1 A BRIEF INTRODUCTION TO LCA

The LCA framework is recognized as one of the most complete and widely used methodologies for assessing the environmental impact of products and processes, and it can be used as a decision-support tool as part of environmental management. ISO 14040:2006 defines LCA as a "… compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle." In other words LCA provides quantitative, confirmable and manageable process models to evaluate production processes, analyse options for innovation and improve understanding of complex systems. LCA can identify processes and areas where process changes stemming from research and development can contribute significantly to the reduction of environmental impacts. ISO 14040:2006 sets out the four phases of LCA (see Figure 1):

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

4.2 ENVIRONMENTAL IMPACT CATEGORIES

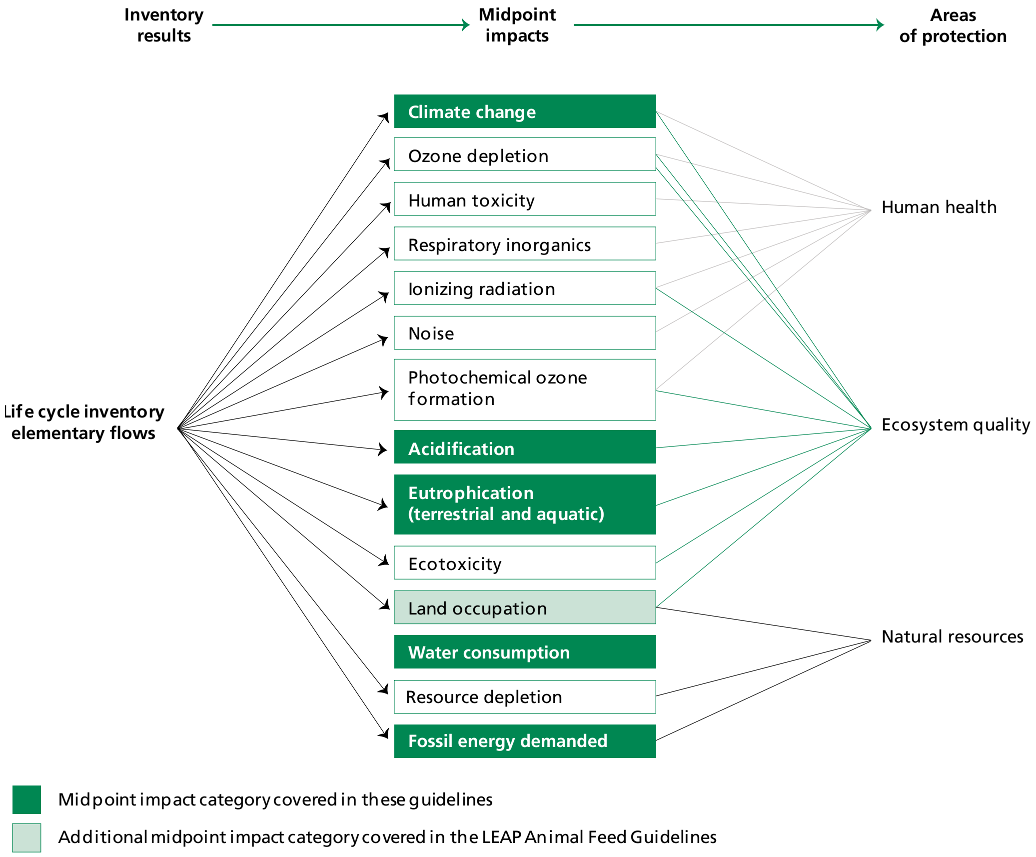
Life cycle impact assessment (LCIA) is used to understand and evaluate the magnitude and significance of potential environmental impacts for a product system throughout the life cycle of the product (ISO, 2006a). The selection of environmental impacts is a mandatory step, which shall be justified and consistent with the goal and scope of the study (ISO, 2006a). Impacts can be modelled at different levels in the environmental cause-and-effect chain linking elementary flows of the life cycle inventory to midpoint and endpoint impact categories (see Figure 2).

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

Climate change is an example of a midpoint impact category. The results of the LCI are the amounts of GHG emissions per functional unit. On the basis of a radiative forcing model, characterization factors known as global warming potentials specific to each GHG can be used to aggregate all emissions to the same mid-point impact category indicator reported in kg CO_2 equivalents per functional unit.

Figure 2

Environmental cause-and-effect chain and categories of impact.



Source: adapted from (Pant *et al.*, 2010).

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

4.3 NORMATIVE REFERENCES

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

- ISO 14040:2006 *Environmental Management – Life Cycle Assessment – Principles and Framework*

  These standards give guidelines on the principles and conduct of LCA studies and provide organizations with information on ways of reducing the overall environmental impacts of their products and services. ISO 14040:2006 defines the generic steps for conducting an LCA; this document follows the first four phases – goal and scope, inventory analysis and impact assessment and interpretation.
- ISO 14044:2006 *Environmental Management – Life Cycle Assessment – Requirements and Guidelines*

ISO 14044:2006 specifies the requirements and provides guidelines for LCAs – definition of the goal and scope, the LCI analysis phase, the LCIA phase, the interpretation phase, reporting and review of the LCA and any limitations, the relationship between the LCA phases, and conditions for use of value choices and optional elements.

4.4 NON-NORMATIVE REFERENCES

- ISO 14025:2006 E*nvironmental Labels and Declarations – Type III Environmental Declarations – Principles and Procedures*

  ISO 14025:2006 establishes the principles and specifies the procedures for developing type III environmental declaration programmes and type III environmental declarations. It specifically establishes the use of the ISO 14040:2006 in the development of type III environmental declaration programmes and type III environmental declarations.

  Type III environmental declarations are primarily intended for use in business-to-business communication, but their use in business-to-consumer communication is possible under certain conditions.
- ISO/TS 14067:2013 *Greenhouse Gases – Carbon Footprint of Products – Requirements and Guidelines for Quantification and Communication*

  This specifies the principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product (CFP) on the basis of ISO 14040 and ISO 14044 for quantification and on environmental labels and declarations, and ISO 14020, ISO 14024 and ISO 14025 for communication (ISO/TS 14067:2013, ISO, 2006b, 2010).
- World Resource Institute (WRI)/World Business Council for Sustainable Development (WBCSD) (2011) *Product Life Cycle Accounting and Reporting Standard*

  The GHG protocol from the World Resources Institute and World Business Council for Sustainable Development (WRI and WBCSD, 2011) provides a framework that helps users to estimate the total GHG emissions associated with a CFP. Its approach is similar to that of the ISO standards, but emphasizes analysis, the tracking of changes over time, reduction options and reporting. Like PAS2050 this standard excludes impacts arising from production of infrastructure, but whereas PAS2050 includes “operation of premises” such as retail lighting or office heating the GHG protocol does not.
- ENVIFOOD Protocol, 2013: *Environmental Assessment of Food and Drink*

  This protocol was developed by the European Food Sustainable Consumption Round Table to support environmental instruments for communication and the identification of environmental improvement options. It could be the baseline for developing communication methods, product category rules (PCRs), criteria, tools, datasets and assessments (Food SCP RT, 2013).
- International Reference Life Cycle Data System (ILCD), 2010a. *ILCD Handbook: General Guide for Life Cycle Assessment – Detailed Guidance*.

  The ILCD handbook was published in 2010 by the EC Joint Research Centre. It provides detailed guidance for LCA based on ISO 14040 and 14044 in a set of documents that includes a general guide for LCA and specific guidance for life cycle inventory and impact assessment (European Commission *et al.*, 2010).

- The Product Environmental Footprint Guide developed by the EC is a general method for measuring and communicating the potential life cycle environmental impact of a product. Its main aim is highlight the discrepancies in environmental performance information (Manfredi *et al.*, 2012).
- The BPX-30-323 General Environmental Footprinting Methodology developed by the Agence de l'Environnement et de la Maîtrise de l'Energie (French Agency for Environment and Energy Management) and the Association Française de Normalisation and its further specifications (Association Français de Normalisation, 2011) constitute a general method for measuring and communicating the potential life cycle environmental impact of a product. It was developed at the request of the Government of France to highlight the discrepancies environmental performance information. Guidelines specific to food production are also available, along with a range of product-specific rules on livestock products.
- British Standards Institution Publicly Available Specification (PAS) 2050:2011 *Specification for the Assessment of Life Cycle Greenhouse Gas Emissions of Goods and Services*.

  It is a Publicly Available Specification (i.e. not standard) sponsored by the United Kingdom Carbon Trust and the Department for the Environment, Food and Rural Affairs. PAS 2050, which was published by the British Standards Institution (BSI), uses BSI methods for agreeing a publicly available specification. It is targeted at applying LCA consistently to a range of products; it is for industry users and concerns only the carbon footprint indicator. PAS 2050 has many elements in common with the ISO 14000 series; there are differences, however, some of which limit choices for analysts – exclusion of capital goods and setting materiality thresholds for example.

4.5 GUIDING PRINCIPLES

Nine guiding principles support users in their application of this sector-specific methodology. They are consistent across the methodologies developed by the LEAP partnership, and apply to all steps from the definition of goal and scope, to data collection, LCI modelling and reporting. Adherence to these principles ensures that any assessment made in accordance with the methodology will be robust and transparent. The principles can also guide users making choices not specified in the guidelines.

The principles are adapted from: i) ISO 14040:2006 – the *Product Environmental Footprint* guide (Manfredi *et al.*, 2012); ii) the WBCSD-WRI *Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard*; iii) the BSI PAS 2050:2008; iv) the ILCD handbook; and v) ISO/TS 14067:2013. They are intended to guide the accounting and reporting of GHG emissions and fossil energy use.

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

Life cycle perspective

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

Relative approach and functional unit

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

Relevance

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

Completeness

Quantification of the product environmental performance shall include all environmentally relevant material, energy flows and other environmental interventions as required for adherence to the defined system boundaries, data requirements and the impact assessment methods employed (European Commission, 2013).

Consistency

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

Accuracy

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

Iterative approach

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

Transparency

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

Priority of scientific approach

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

5. LEAP AND THE PREPARATION PROCESS

LEAP is a multi-stakeholder initiative launched in July 2012 with a view to improving the environmental performance of livestock supply chains. It is hosted by the Food and Agriculture Organization of the United Nations (FAO) and brings together the private sector, governments, civil society and experts with an interest in the development of transparent and pragmatic science-based guidance for measuring and improving the environmental performance of livestock products.

Demand for livestock products is projected to grow by 1.3 percent per annum until 2050; this will be driven by global population growth and increasing wealth and urbanization (Alexandratos and Bruinsma, 2012). Against the background of climate change and increasing competition for natural resources, the projected growth places significant pressure on the livestock sector to perform in a more sustainable way. The identification and promotion of the contributions that the sector can make to more efficient use of resources and better environmental outcomes is also important.

Many different methods are in use to assess the environmental impacts and performance of livestock products. This causes confusion and makes it difficult to compare results and establish priorities for continual improvement. With increasing market demands for sustainable products there is a risk that debates about how sustainability is measured will distract from the task of driving real improvement in environmental performance. And there is the danger that labelling or private standards based on poorly developed metrics could lead to erroneous claims and comparisons.

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

The LEAP technical advisory group (TAG) was formed in early 2015 to develop guidelines for assessing the environmental performance of pig supply chains.

The work of LEAP is challenging, but vital to the livestock sector. The diversity and complexity of livestock farming systems, products, stakeholders and environmental impacts can only be matched by the willingness of practitioners to work together to improve performance. LEAP provides robust and pragmatic measurement methods to enable assessment, understanding and improvement (see also www.fao.org/partnerships/leap/en/)

5.1 DEVELOPMENT OF SECTOR-SPECIFIC GUIDELINES

Sector-specific guidelines for assessing the environmental performance of the livestock sector are a major element of the LEAP partnership work programme. They are developed by experts with extensive experience in LCA and livestock supply chains and take into account the nature of the livestock supply chain under investigation.

The benefit of a sector-specific approach is that it guides the application of LCA by users and provides a common basis from which to evaluate resource use and environmental impacts.

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

5.2 THE PIG TECHNICAL ADVISORY GROUP AND THE PREPARATION PROCESS

The pig TAG, which was formed at the start of 2015, consisted of 21 experts in pig supply chains, leading LCA researchers and industry practitioners. Their various backgrounds and experience of different products, systems and regions enabled them to understand and address different interest groups and hence ensure credible representation. The TAG was led by Dr Greg Thoma, with co-leaders Dr Yaosheng Chen and Dr Hongmin Dong.

Its role was to:

- review existing methods and guidelines for assessment of GHG emissions from livestock supply chains, and identify priorities for further work;
- develop methods and sector-specific guidelines for the LCA assessment of GHG emissions from pig supply chains; and
- provide guidance on future work to improve the guidelines and encourage greater uptake of the above methods and guidelines.

The first TAG workshop took place on 22–23 April 2015 in Rome, and its work was continued via email and teleconferences before the second workshop on 19–20 August 2015 in Bangkok. The experts in the TAG came from Australia, Brazil, China, Denmark, France, India, Ireland, Italy, Mexico, Kenya, Spain, the United Kingdom, the United States of America, and Uruguay. The members were Airton Kunz, Miguel Angel Aparicio Tovar, Balram Sahu, Ben Lukuyu, Gonzalo Becoña, Ilias Kyriazakis, Jean-Luc Farinet, Jeffery Escobar, John Hermansen, Mariscal Landin Gerardo, Paolo Masoni, Paula Gaspar, Peadar Lawlor, Sandrine Espagnol, Stephen Wiedemann, Valentina Fantin, T.C. Wang and Hui Zhang.

The first step was to review published studies and methods to determine whether they offered a suitable framework for a sector-specific approach. This approach prevented confusion and duplication resulting from the development of potentially competing standards or approaches. The review followed the procedures set by the international guidance sources listed in section 4.3.

The TAG identified 33 studies addressing aspects of pig supply chains for background review, selected on the basis of LCA studies in the pig sector, with a view to determining the methodological choices made to date. The studies included peer-reviewed articles, theses, dissertations and conference proceedings, which enabled evaluation of the methodological consistencies and differences in global systems (see Appendices 1 and 2). The review concluded that no existing approach or study set out comprehensive guidance for quantifying GHG emissions and fossil energy demand throughout a supply chain, and that further work was needed to reach consensus on detailed guidance.

5.3 PERIOD OF VALIDITY

It is intended that these guidelines will be periodically reviewed to ensure the validity of the information and methodologies on which it relies: users are invited to visit the LEAP website (www.fao.org/partnerships/leap) for the latest version.

6. Pig Production Systems

6.1 BACKGROUND

The world population of pigs in 2013 was 977 million head: i) Asian countries accounted for 60.4 percent; China alone had 482 million pigs; ii) Europe accounted for 18.8 percent; Germany had 27.7 million head, 16 percent of European pig numbers; iii) the Americas accounted for 16.6 percent: in South America, Brazil dominated with 36.7 million pigs; the USA had 64.8 million head; iv) Africa accounted for 3.7 percent; and Oceania accounted for 0.5 percent (FAOSTAT, 2015).

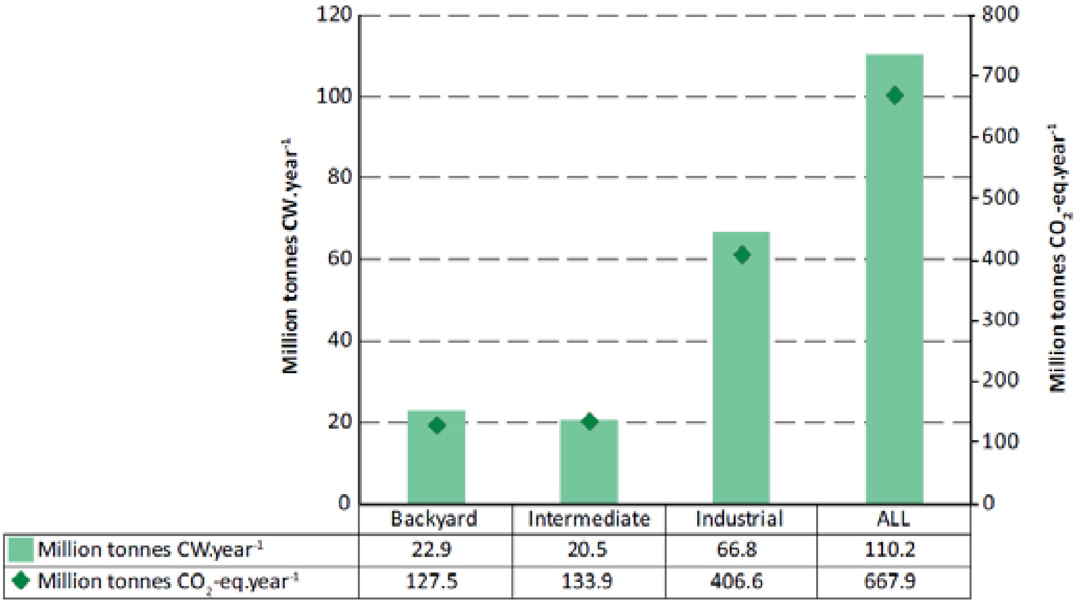
The world's pig population increased by 8 percent between 2005 and 2013. A significant number of animals are kept in backyard systems to provide pork for families and local markets. Good manure management is more difficult in small-scale backyard systems than in commercial pig farms. In South Asia and East Asia the number of pigs kept in semi-intensive farms is decreasing.

The main tangible product is meat: the pig sector is the largest contributor to global meat production, accounting for 37 percent of the 296 million tonnes carcass weight produced in 2010. Backyard production accounted for 19 percent, intermediate production for 20 percent and large-scale production for 61 percent of carcass weight production (see **Figure 3**) (MacLeod *et al.*, 2013).

Global production of pig meat was 113 million mt in 2013, of which 98 percent originated in Asia – 57 percent, Europe – 24 percent and the Americas – 17 percent.

Figure 3

Emissions and production distribution by type of pig production system



	Backyard	Intermediate	Industrial	ALL
🟩 Million tonnes CW.year^{-1}	22.9	20.5	66.8	110.2
◆ Million tonnes CO_2-eq.year^{-1}	127.5	133.9	406.6	667.9

Source: Macleod *et al.*, 2013.

CW = carcass weight

In 2015, China contributed 48 percent of global pig-meat production, followed by the USA with 10 percent (FAOSTAT, 2015).

Global production of pig-meat has doubled in the last three decades: in Asia production increased 3.5-fold, and in the Americas production increased by 1.7-fold. Pork production in Europe increased from 21.8 million tonnes in 2005 to 21.9 million tonnes in 2013 (EUROSTAT, 2015). China has led this growth, contributing 70 percent of increased production, followed by the USA with 6 percent (FAOSTAT, 2015).

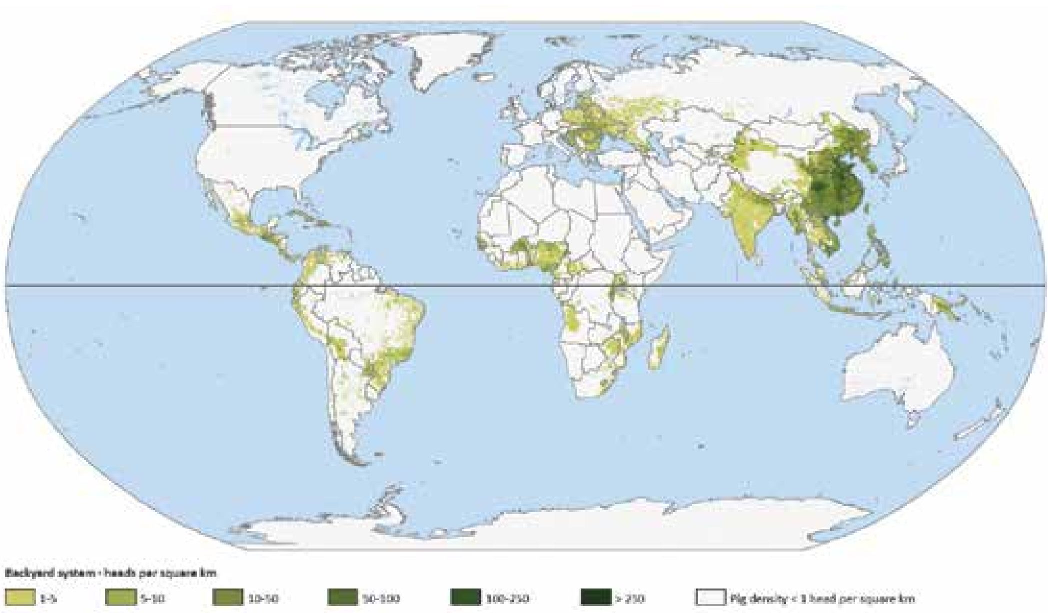
6.2 DIVERSITY OF PIG PRODUCTION SYSTEMS

Pig production systems vary greatly in response to factors such as socio-economic conditions, people's expectations, available inputs, markets and consumption patterns. Different pig production systems can be identified in most countries, from the simplest systems that require minimal investment to large-scale market-oriented enterprises (see Figures 4 - 6).

Backyard production is the basic traditional system of keeping pigs, and the most common in urban and rural areas in developing countries. Production is typically semi-intensive, with small-scale farms producing for home consumption, local markets or specialty restaurants or food chains. In recent decades, however, large-scale intensive production systems have emerged in many developing regions in response to growing demand for inexpensive livestock products (Steinfeld *et al*., 2006).

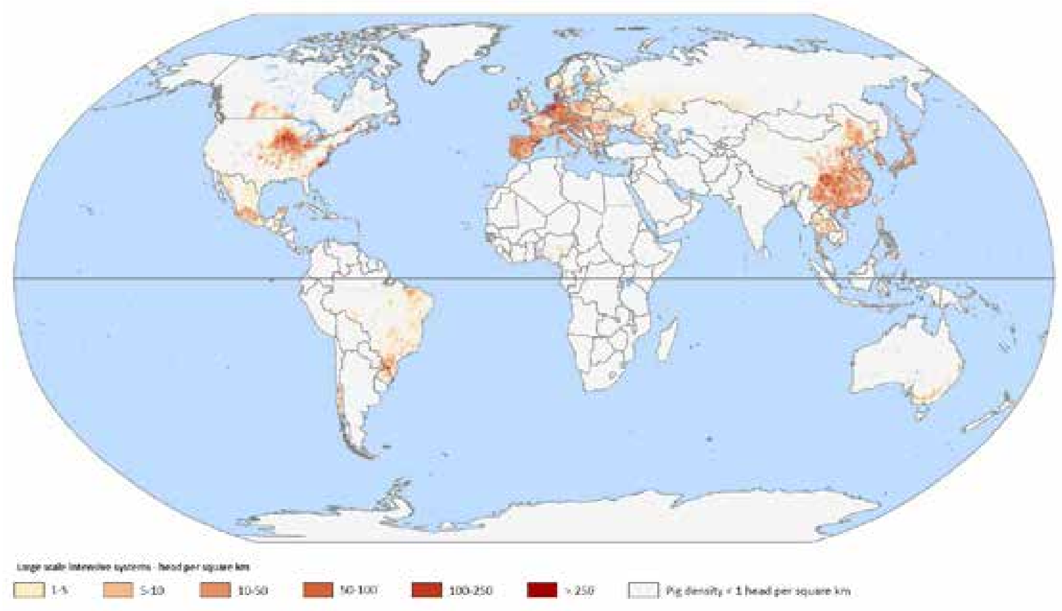
Pig production systems in the world can be classified on the basis of scale, market objectives, feed sources and production goals, husbandry and management.

Figure 4
Global distribution of backyard pig production systems



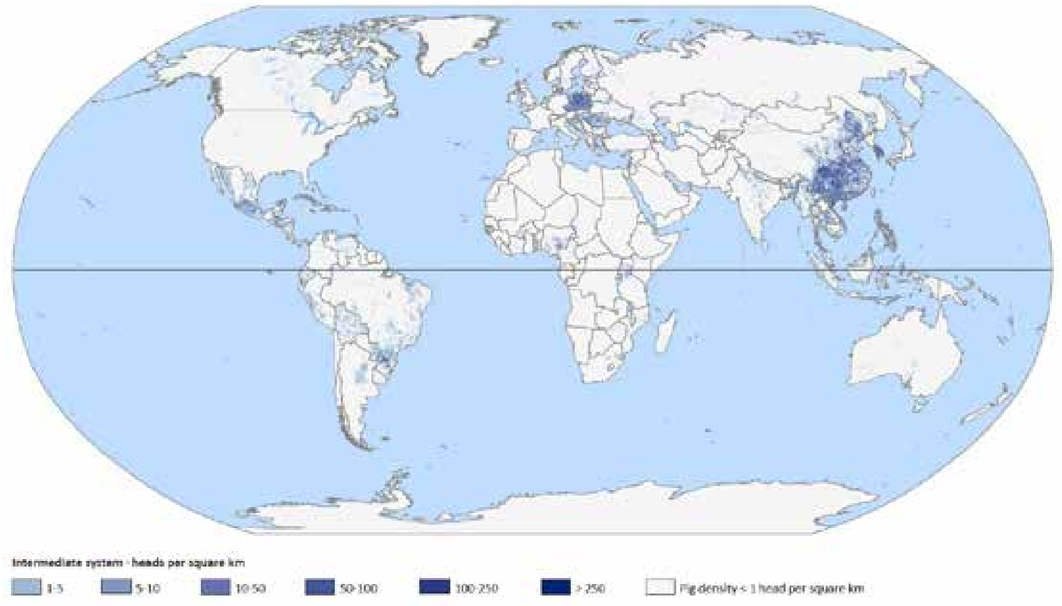
Source: Macleod *et al.*, 2013.

Figure 5
Global distribution of small-scale to medium-scale intensive pig production systems



Source: Macleod *et al.*, 2013.

Figure 6
Global distribution of large scale, intensive pig production operations



Source: Macleod *et al.*, 2013.

Based on these factors and the LCA goals, these systems are defined as scavenging, extensive systems, semi-intensive systems, intensive (small-medium scale) systems, or intensive (large scale) systems.

6.2.1 Scavenging production

The scavenging system is the traditional subsistence-level way of keeping pigs, and the one most commonly used in urban and rural areas of developing countries. In this free-range system pigs find feed themselves, but they may also receive supplementary feed such as kitchen waste or agricultural by-products. Depending on circumstances pigs may be free-range for most of the year, and only penned during rainy seasons. The systems is often characterized by high piglet mortality and a poor feed conversion rate.

6.2.2 Extensive systems

Extensive pig production is characterized by the utilization of local pig breeds and local feed resources, with limited dependence on external supplies. These systems are small-scale to medium-scale, and may utilize a combination of family and hired labour depending on farm size.

Among the local pig breeds reared in Europe is the Iberian pig in Spain, with 2.4 million animals[3] in various types of farm and production systems. The main producing region is Extremadura,[4] where regional legislation includes a farm classification based on zootechnical and productive capacity criteria: the key element is the availability of on-farm feed resources for all the animals. During the 70–90 day fattening phase, the pigs can eat as much grass and acorns as they want and increase in weight up to 160 kg. Stocking density is one pig to 1.5 ha to 2 ha depending on climatic conditions and the density of oak trees. Pigs are fed concentrate diets with grass during other production phases.

Housing varies according to the production phase. During the breeding phase, for example, it is common to use individual stalls for sows with piglets; this is known as "camping". Farms must be perimeter fenced to comply with strict biosafety legislation and to prevent contact with animals from other farms and with wild animals such as deer and boar.

The animals are used to produce premium priced hams and sausages such as acorn-fed Iberian ham – *Jamon Ibérico de bellota* – which has a high oleic acid content; it is well-known in the market. Acorn-fed ham from the Cinta Senese area in central Italy – *Prosciutto di ghianda* – has similar qualities, but production is relatively limited.

Extensive pig production is an alternative model in areas where suitable local breeds, high-quality feed resources and qualified labour are available. Extensive pig production can have positive environmental effects because it helps to maintain some ecosystems such as the *dehesa* system[5] and other Mediterranean landscapes.

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[3] Ministerio de Agricultura y Medio Ambiente. 2015. *Encuestas ganaderas, Noviembre 2014*. Madrid. Spain. Available at: http://www.magrama.gob.es/es/estadistica/temas/estadisticas-agrarias/ganaderia/encuestas-ganaderas/default.aspx#para4

[4] Junta de Extremadura. 1999. *Decreto 158/1999, de 14 de septiembre por el que se establece la regulación zootécnica-sanitaria de las explotaciones porcinas en la Comunidad autónoma de Extremadura*. Mérida.

[5] A multi-functional agro-sylvo-pastoral system and cultural landscape of southern and central Spain and southern Portugal, where it is known as montado. A dehesa may be private or communal property.

In these systems, the quantity of purchased feed used will have a substantial impact on energy consumption and GHG emissions. Nutrients are mostly deposited directly to land rather than being treated in a manure management system. The most important aspects influencing eutrophication will be the amount of nitrogen and phosphorus excreted, the degree to which manure is concentrated in the landscape (nutrient hotspots), and the amount of ground cover and nutrient movement. GHG emissions are influenced by the soil and climatic conditions that influence nitrous oxide emissions. These factors should be assessed in the LCI stage.

6.2.3 Semi-intensive systems: backyard production

These are typically production systems in which small-scale farms produce pork for home consumption, local markets or specialty restaurants or retail chains. They are found in rural and urban areas.

In such systems the pigs are confined in simple pens, with separate pens for feeders, boars, gestating sows and sows with litters. The floors of the pens are generally dirt, but they may be made of mud bricks, thatch or timber. Herd size may be anything from one to 100 animals reared per year, and activities focus largely on fattening. Technical performance in terms of feed conversion ratio and daily weight gain is generally lower than in intensive production systems.

The systems are located in areas where farmers have access to commercial feeds, usually close to peri-urban markets. The farms are family run and use family labour and the animals are kept primarily for commercial purposes. The level of inputs is relatively low: diets contain a maximum of 20 percent non-local purchased feed. Farmers provide meat or live animals for local or regional markets, which gives them an important source of income. In these systems, nutrients are mostly deposited directly to land rather than being treated in a manure management system. The most important aspects influencing GHG emissions and eutrophication will be the amount of nitrogen and phosphorus excreted, the degree to which manure is concentrated in the landscape (nutrient hotspots), the amount of ground cover, and the soil and climatic conditions that influence nitrous oxide emissions and nutrient movement. These factors should be assessed in the LCI stage.

6.2.4 Small-scale and medium-scale intensive systems

Small-scale systems raise pigs for subsistence or commerce, whereas in medium-scale production the animals are kept primarily to supply pork to local markets and urban markets. Medium-scale confined pig production is common everywhere: the animals are kept in shelters ranging from simple pens made from local materials to modern housing with concrete floors and steel roofs. In temperate regions with no severe cold seasons, pigs may be kept in outdoor fenced units, which requires less investment.

In these systems pigs are often housed in sheds, with separate pens for fatteners, boars, gestating sows and sows with litters. The farms are in areas where commercial feeds are available, particularly in peri-urban areas close to markets. Unlike backyard systems, intensive rearing calls for relatively high inputs for items such as housing materials, feed and labour.

The pigs depend for feed on the keepers, who may provide branches, leaves, crop residues, agricultural by-products or prepared feed, though the latter may be of poor quality. Locally-sourced feeds constitute 30 percent to 50 percent of the pigs' diet.

The quantity of purchased feed has a substantial impact on energy consumption and GHG emissions. Unlike extensive systems, the main effects of these systems are evident during finishing. Because the pigs are housed, a manure management system must be used, which must be assessed to determine emission levels. If manure is stored in an anaerobic liquid system, methane emissions may be high but if liquids flow into soil without storage, nitrous oxide emissions will be significant. If manure is deposited in a confined area, eutrophication effects may be important.

6.2.5 Large-scale intensive systems

Large-scale confined pig production farms vary in size, but are generally significantly larger than farms in the categories described above. The objective is to maximize production through efficient use of resources such as feed, thereby reducing the cost of production. Farmers seek commercial profits, and production is fully market-oriented. The pigs are normally housed indoors in special facilities that will vary in terms of location and of structure, location, floor type, ventilation and manure storage. There are intensive outdoor production systems in some EU countries – the United Kingdom is an example – where precipitation is relatively low and land drains freely.

The main cost savings associated with large-scale confined production are achieved through economies of scale, efficiency associated with specialized farm activities, improved feed-conversion rates with the use of purchased or home-produced feeds that match nutritional requirements, and increased purchasing and selling power. Large pig farms may be family-owned, affiliated to companies or corporately owned. Labour is predominantly hired.

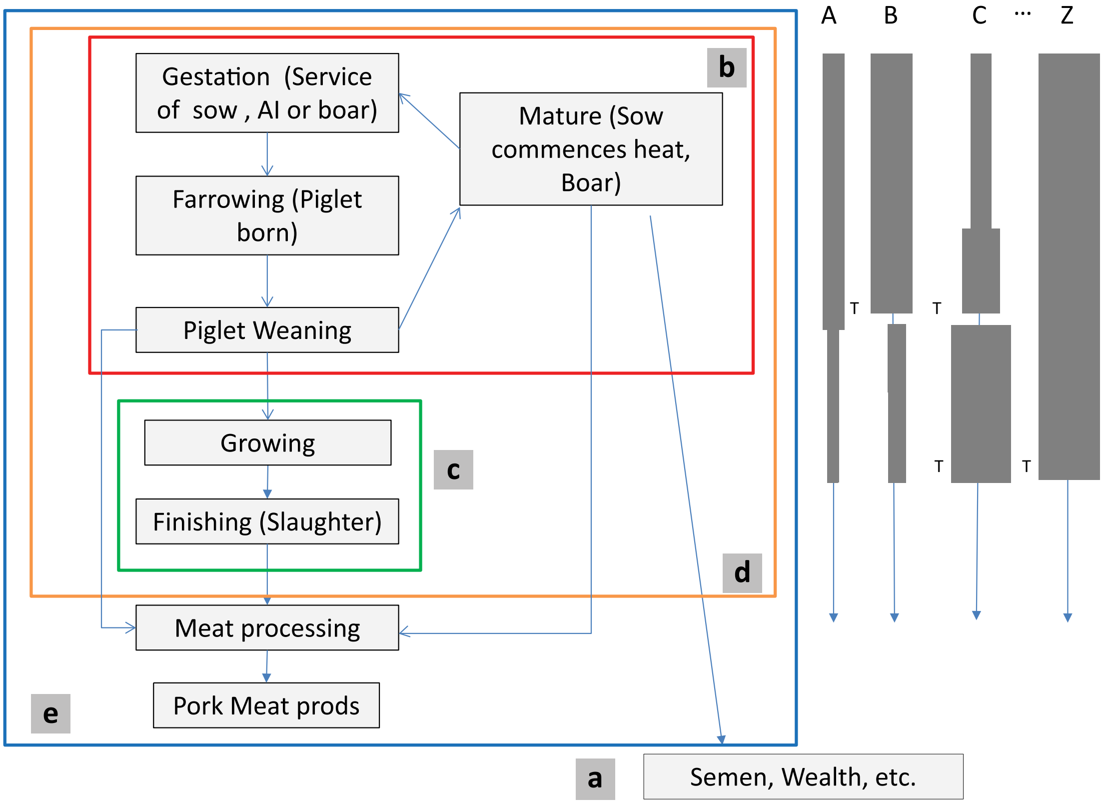
Intensive systems may utilize various housing types. The type of housing determines the amount of energy used, the performance of the pigs and the type of manure management system used. In temperate zones the buildings are closed and often fan-ventilated. In tropical zones the sides are open to provide natural ventilation and trees are often planted alongside the buildings to provide shade and cooler temperatures.

The most common intensive housing systems are: i) deep bedding, where pigs are housed on materials such as straw, sawdust or peat; and ii) liquid manure management systems, where manure drops into pits or channels underneath the pens and may be stored in under-floor tanks or channels until it is removed or fed into to outside storage lagoons or tanks for later use. In deep bedding manure systems, LCI data must account for inputs of the bedding material and factors influencing nitrous oxide emissions such as nitrogen excretion and bedding conditions. In liquid manure management systems, particular attention must be given to inputs of volatile solids such as significant flows from wasted or spilled feed. Emissions from nitrous oxide tend to be less significant, but ammonia emissions may be high. Spent bedding and outflows of liquid manure to land are important factors in understanding GHG emissions and eutrophication.

6.3 THE DIVERSITY OF PIG VALUE CHAINS

Given the variety of pig production systems, it is impossible to describe all of them here. Figure 7 shows the important points to be considered when determining the scope of assessment and system boundaries of a pig production system. On the basis of biophysical criteria and production stages, pig production managed as discrete but connected sub-systems under the control of one or more operational entities includes:

Figure 7
Conceptual model of pig production systems showing life stages and relationships between the systems and outputs. (See text for explanation of grey rectangles.)



- breeding (orange box b in Figure 7) – produces piglets weighing 7-15 kg between 21 days to days of age;
- weaner (red box c) – pigs, from (b), weighing 7–15 kg raised to 25–35 kg at age 56–84 days;
- growing to finishing (green box d) – feeder pigs, from (c) weighing 25–35 kg grown to market weight;
- farrowing to finishing (light orange box e) – piglets born, weaned and fed to market weight on the same farm; and
- fully integrated systems (blue box f) – piglets born, weaned and fed to market weight on the same farm, with feed manufactured by the operation; a totally integrated system will also have its own abattoir.

The coloured solid line boxes in Figure 7 show the different stages in the production system; the dashed boxes denote the raw and processed products, the main product being pork. Other possible outputs from mature animals are shown by the dashed arrow (e.g. semen sales, wealth management).

In production stage b in Figure 7, gestation refers to the development of the pig foetus during pregnancy. Farrowing to piglet weaning is the period from birth until the piglet is weaned from its mother's milk; the duration of this stage will vary according to the production system. Replacement female animals – known as gilts – are grown to mature body weight and introduced into the herd for breeding.

This is followed by the nursery or first-stage and second-stage weaner box c, which focuses on growing weaned pigs from 7–15 kg/3–8 weeks to 25–35 kg, depending on the country.

Growing to finishing – box d – is the stage at which animals gain weight from 25–35 kg to finishing weight, which may be 60 kg to 125 kg or more depending on market requirements and whether male piglets are castrated or left intact; the slaughter age depends on the growth rate of the pigs, which is largely determined by genotype, feed quantity and quality, and the health status of the farm.

Farrow to finish systems (box e) include all production phases from breeding through finishing when animals have reached slaughter weight. The feed may be self-produced in an integrated unit or purchased, but it will be centrally managed.

Fully integrated production systems – box f –produce pigs from birth to slaughter, with feed manufactured by the producer. These are usually large-scale production systems in which dressed carcasses may be sold to secondary processors before reaching retail outlets; in a few cases the producer may be involved in secondary processing of the pork, which may even be sold in company-owned shops.

To evaluate production systems it is essential to collect inventory data at each production stage of the full system. On the right side of Figure 7, some examples of full production systems are shown with grey rectangles representing operations of a single entity with connecting arrows indicating transfer of pigs. These examples are intended as a guide to point out the range of activities that need to be considered when evaluating a production system. The widths of the rectangles denote the average nutritional quality of feed at the designated stage in terms of energy, amino acid, crude protein and phosphorus content. This and the feed intake per pig at the different stages are crucial in determining GHG and other emissions from the production system. A gap between life stages indicates that the animals are moved to a different enterprise, in which case transport between enterprises is denoted by the "T". If the rectangle is continuous, there is no change of enterprise between life stages: the piglets are sold to another enterprise after weaning – denoted by the gap – and finished by the new owners, who sell them to a meat processing plant. System C shows a complex production system in which the animals are fed diets of different quantities and nutritional quality during breeding; the width of the rectangle at the last stage shows finishing with high-quality rations. System Z shows a farrow-to-finish system in which the animals receive high-quality feed during all production stages and are finally sold to a meat processor.

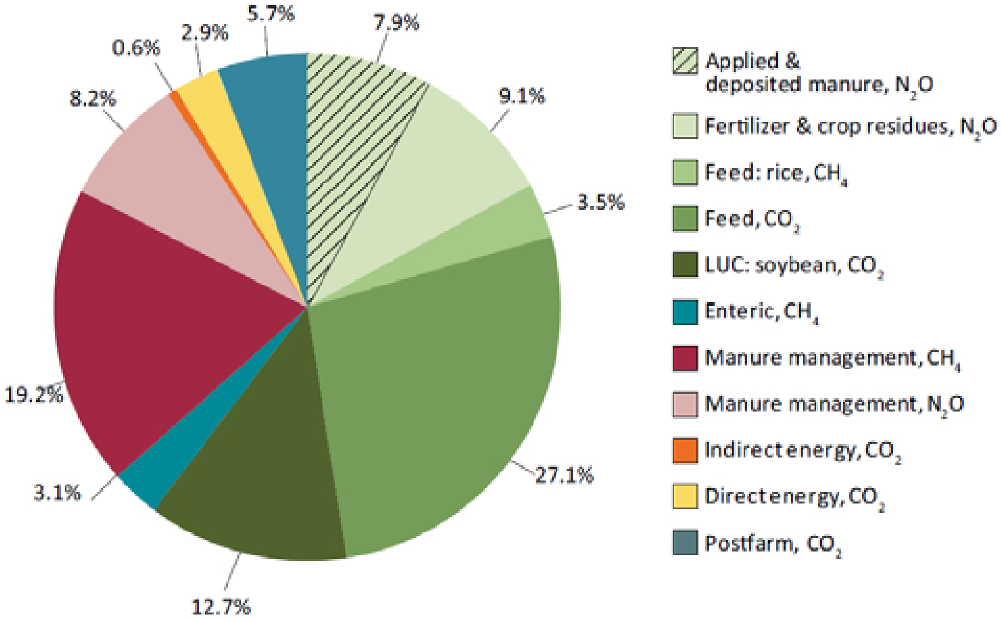
Case study examples of various regional pig production systems and value chains are illustrated in Appendix 3.

6.4 OVERVIEW OF GHG EMISSIONS FROM PIGS

GHG emissions from the livestock supply chain are estimated at 7.1 billion mt CO_2e per annum, accounting for 14.5 percent of all human-induced GHG emissions. Pig supply chains are estimated to produce 0.7 billion mt CO_2e per annum, accounting for 9 percent of the emissions from the global livestock sector. Although these emissions are in fact comparatively low, the scale of the sector and its rate of growth mean that reductions in emission intensity should be targeted (Macleod *et al.*, 2013). The pig sector accounted for 37 percent of global meat production in 2010, with demand for pig meat projected to rise by 32 percent by 2030 (Macleod *et al.*, 2013)

Figure 8

Breakdown of GHG emission sources in the global pig supply chain



Source: Macleod *et al.*, 2013.

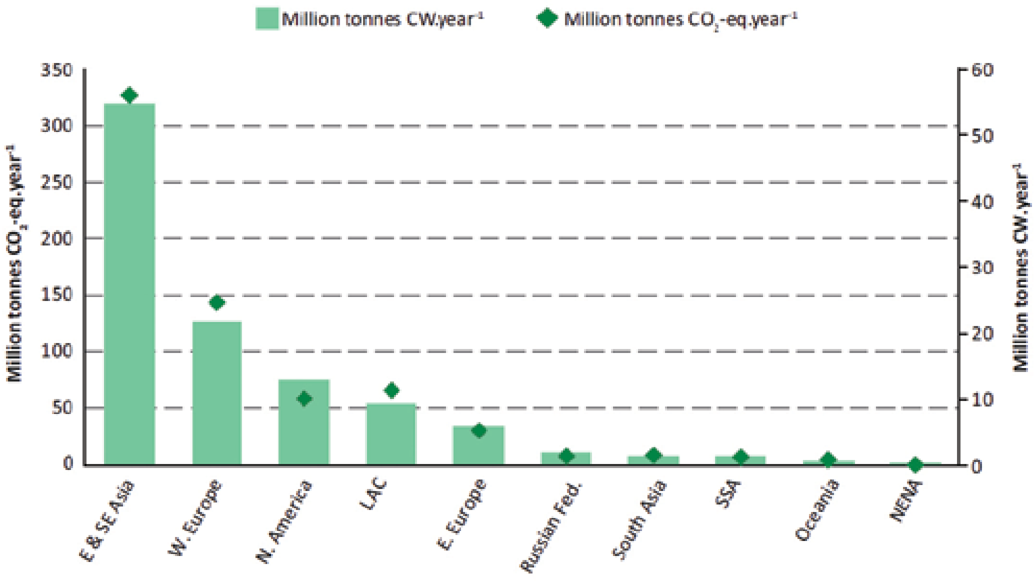
Although there is tremendous variation in sources of emissions as a function of any production system, it has been reported that global feed production contributes 60 percent of GHG emissions (Figure 8). Within the feed production category, 13 percent of the total emissions arises from in use change associated with the expansion of soybean crops to supply the protein component of feed, and 17 percent arises from N_2O emissions from the use of synthetic fertilisers and manure on land used to grow crops for animal feed. The remaining contributions to the emissions from feed production include field operations, transport, processing and embedded energy from fertiliser production.

Manure storage and processing are the second largest source of GHG emissions, accounting for 27.4 percent, of which 19.2 percent are in the form of CH_4 predominantly from anaerobic storage systems in warm climates; the other 8.2 percent are in the form of N_2O.

Of the 13 percent remaining, post-farm emissions from processing and transport account for 5.7 percent of total GHG output. On-farm energy consumption accounts for only 3.5 percent of emissions, but when other indirect and direct energy uses in post-farm activities and feed production are added, overall emissions from energy use amount to 33 percent (Figure 8).

The average intensity of GHG emissions from pig production is 6.1 kg CO_2e per kilogram of meat (Figure 9). On a global scale the difference in emission intensities among the various production systems is not substantial; large-scale intensive systems account for most of total production and emissions (Macleod *et al.*, 2013).

Figure 9
Global emissions and pig production



Source: Macleod *et al.*, 2013.

Backyard systems have relatively high manure emissions caused by larger amounts of volatile solids (VS) and N excretion per kg of meat produced. This is the result of poor conversion of low-quality feed into carcass weight. Higher manure emissions in backyard systems are, however, offset by low emissions from the provision of feed.

Emission intensity in intermediate systems is generally higher than in intensive systems as a result of poorer feed-conversion efficiency and a higher share of rice products in animal feed. A large share of intermediate production is located in rice-growing areas in eastern and south-eastern Asia, and rice by-products are used as feed: the production of paddy rice emits CH_4 and has higher emission intensities than the production of other cereals. High emission intensities are also linked to the storage of manure in anaerobic storage systems, leading to higher CH_4 emissions. (Macleod *et al.*, 2013).

6.5 THE MULTI-FUNCTIONALITY OF PIG SUPPLY CHAINS

Farmers keep pigs with various objectives in mind. Pigs are important in farmers' food security and livelihoods because they provide meat for consumption and income from sales of animals. At the global level, pig production may occur in less favoured regions and poor remote areas where alternative sources of income may be limited: this means that in many cases the future of rural areas is at least partially dependent on the viability of the local pig sector, which may also provide the function a wealth management service for local economies.

Smallholder production systems are multi-functional. The first objective is to produce meat, but they also deliver valuable commodities such as manure, a natural fertiliser. Pigs may also be used for wealth management, which should be included as a functional output of the system. In cases where breeding is a separate process, spent sows and piglets are distinct functional products and the multi-functionality of the system must be appropriately accounted.

In post-farm-gate production co-products may also be generated, which should be properly accounted. Chapter 8 provides guidance regarding system boundaries and describes potential co-products at various stages in the supply chain. Chapter 9 discusses methods for accounting for the multi-functionality of these production systems.

In some areas, pig production uses by-products from the human food, distilling and brewing industries as part of pig diets: these constitute waste that might otherwise be disposed of through landfill or land application. Proper accounting of the impacts of these materials is covered in the LEAP *Animal Feed Guideline*s.

PART 2

METHODOLOGY FOR QUANTIFICATION OF ENVIRONMENTAL IMPACTS FROM PIG PRODUCTS

7. Definition of products and production systems

These guidelines cover the supply chain from cradle to primary processing gate. The main products may comprise: meat products, with possible co-products of hides, blood, bone and inedible offal.

7.1 PRODUCTS DESCRIPTION

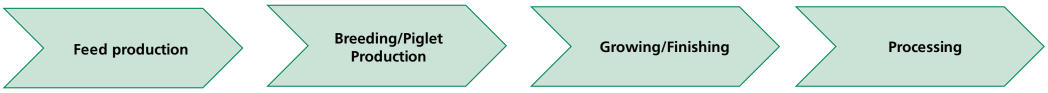
These guidelines cover the entire supply chain from cradle to primary processing ate and the main products involved are:

- meat products, with possible co-products of skin, blood, bone and inedible offal;
- breeding operations, piglets and spent sows as co-products;
- manure as a revenue-generating co-product; and
- wealth management.

7.2 LIFE CYCLE STAGES: MODULARITY

An LCA of primary products can be conducted by dividing the production system into three modules relating to the life-cycle stages: i) feed production, including processing, milling and storage; ii) animal production, including breeding; and iii) primary processing as outlined in **Figure 10**. The feed-production module covers the cradle-to-animal's mouth stages and includes a range of feeds as processed concentrates, grains, forage crops, pastures, shrubs and trees (refer to the LEAP *Animal Feed Guidelines*. The animal production stage covers the cradle-to-farm gate stages, of which the main products include live animals by live weight and wealth-management services.

Figure 10
Modular scheme of pig production chains



8. Goal and scope Definition

8.1 GOAL

The first step in initiating an LCA study is to define the goal or make a statement of purpose giving the goal to be pursued and the intended use of results. There are various reasons for carrying out an LCA: the method can be used, for example, for GHG emission management by determining the carbon footprint of products and determining GHG emission hotspots to prioritize emissions reduction along supply chains. Full LCAs cover environmental impact categories such as eutrophication and provide detailed information about a product's environmental performance; they can also serve to track performance and set progress and improvement targets (ISO, 2006b) and to provide a basis for reporting on the environmental impacts of products.

It is essential that the LCA goal and scope are accurately defined to ensure that the aims, methods and results are aligned. Fully quantitative studies, for example, will be required for benchmarking or reporting, whereas a lower standard of rigour may serve for analysis of hotspots.

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

Seven aspects shall be addressed and documented when goals are defined (European Commission, 2010):

i. the subject of the analysis and major properties of the assessed system – organization, location(s), dimensions, products, sector and position in the value chain;
ii. the purpose of the LCA study and the context in which decisions will be made;
iii. the intended use of the results: internal use for decision-making or sharing with third parties;
iv. limitations associated with the method, assumptions and choice of impact categories, particularly limitations affecting conclusions associated with the exclusion of impact categories;
v. the target audience of the results;
vi. comparative studies to be disclosed to the public and requiring critical review; and
vii. the identities of the commissioner of the LCA study and relevant stakeholders.

8.2 SCOPE

The scope, which is defined in the first phase of an LCA along with the goal, shall identify the product system or process to be studied, the functions of the system, the functional unit, the system boundaries, the allocation principles and the impact categories; it must be defined in such a way that the breadth, depth and detail of the study are compatible and sufficient to achieve the stated goal. In an LCA of livestock products the scope of the study may need to be modified as information is collected to reflect data availability and techniques or tools for filling data gaps; specific guidance is provided in the sections below. The definition of scope will affect data collection for the LCI, as discussed in Section 10.1.

These guidelines refer to a limited set of environmental impact categories and hence should not be used to provide an indicator of overall environmental effects of a production system. Caution is needed in reporting the results of assessments based on these guidelines to avoid misinterpretation of the scope and application of the results.

8.3 FUNCTIONAL UNITS AND REFERENCE FLOWS

The concepts of the functional unit and the reference flow refer to input and output exchanges in the system under study. A functional unit describes the quantified performance of the function(s) delivered by a system, whereas a reference flow refers to intermediate exchanges of data that have been scaled mathematically to ensure precise delivery of the functional unit. Functional units and reference flows shall be clearly defined and measurable (ISO 14044, 2006).

Livestock products are among those characterized by a variety of uses (see Envifood Protocol, 2013), and the functions delivered change accordingly. Many livestock products might be intermediate products and final products: for example, farmers can distribute meat directly to consumers or supply it for processing. For these reasons and to ensure consistency in assessments conducted at the sector level, livestock products are not classified in final and intermediate products in these guidelines and so no differentiation is made between functional units and reference flows.

Recommended functional units and reference flows for various main product types are given in Table 1. Where meat is the product, the functional unit or reference flow at the stage where the animal leaves the farm shall be live-weight; when the meat leaves the meat processing plant or abattoir it shall be the weight of the product destined for human consumption – the meat-product weight or carcass-weight. In many developed countries with commercial processing plants the product-weight is usually identified as carcass-weight when the product leaves the meat processing plant. Carcass-weight, also referred to as dead-weight, generally refers to the weight of a carcass after removal of the skin, head, feet and internal organs including the digestive tract and sometimes some surplus fat. Such internal organs are in general edible. Red offal such as liver, kidney and heart and green offal such as stomach and intestines are increasingly harvested and should be included in the edible yield when they are destined for human consumption.

The product-weight may include a proportion of bone and cartilage retained in the parts for human consumption, which are disposed of at the consumption stage; in this case the product is the final reference flow necessary to deliver the functional unit of edible meat. The edible yield shall therefore be specified in the functional unit or reference flow. A reference flow or functional unit of meat products could be, for example, 1,053 kg of meat product with 95 percent edible yield equivalent to 1,000 kg edible content, with specified moisture, fat and protein content packaged for secondary processing. In this guidance the preferred functional unit or reference flow is a specified quantity of product ready for shipping or sale at the processing

Table 1: Recommendations for choice of functional units/reference flows.

	Weight of product	System boundary	Qualifying characteristics
Meat	Live-weight	Farm gate	Specified carcass yield
	Carcass-weight	Processor loading dock or equivalent	Specified edible yield
Piglets	Live-weight	Farm gate – breeding system	
Spent sows	Live-weight	Farm gate – breeding system	Specified carcass yield

facility, or farm gate in the case of backyard systems. The qualifying characteristics shown in Table 1 shall be defined in the study to ensure that sufficient information is available for future harmonization of studies.

The bone content of the total meat product should be defined on the basis of assumptions relevant to the country being investigated. For small-scale production where a farmer may sell live animals or eviscerated carcasses directly to consumers, an appropriate functional unit would be 1 kg live-weight or carcass-weight with a specified edible yield. Some pig parts such bone, feet or blood may also sold in local markets for consumption: in such cases the functional unit should include any bone or skin that may be consumed. Because the purpose of these guidelines is to support benchmarking and system improvement, analysts choosing different but locally relevant functional units will find that their ability to benchmark the progress of the system of interest will not be compromised. Where specific data for product-weight is not available, the cold carcass-weight (see Glossary) shall be used: this can be estimated from the live-weight using default values based on international data. An example of the relative contribution by weight of different cuts of meat and co-products is given in Section 9.

No distinction is made between different cuts of meat, meat products or other edible parts, and it is recommended that they be treated as equivalent with no specific allocation method used for different cuts. This recommendation holds for other parts considered edible in some cultures such as pigs' feet or neck, as mentioned above.

There are situations in which additional functions of pig systems may be of interest, especially for smallholder systems in developing countries; in particular, pig may be held for wealth management. When functions without physical flows fall within the defined goal and scope, the multi-functional character must be accounted following the procedures in Section 9.

It is important that there is agreement between the functional unit and the system boundary. Some studies have applied a functional unit of "dressed carcass" at the farm gate, but because farm-gate assessments do not include the burdens of post-farm-gate processing the published results should be accompanied by discussion of possible allocations of total emissions to co-products. For information purposes the dressed carcass fractions should be specified as live-weight to carcass-weight and carcass-weight to edible-weight; but it is not appropriate to report farm-gate burdens on, for example, a carcass-weight or edible-weight basis without knowledge of post-farm processing burdens and co-product allocation. The appropriate functional unit at the farm gate is "animal live weight": this is because the use of carcass weight at the farm gate is doubly mistaken: i) none of the burdens of post-farm gate processing are included in the analysis; and ii) no allocation of farm and pre-farm burdens are attributed to the co-products of the processing. If the available data do not support the farm-gate boundary, the iterative nature of the LCA should lead to a revision of the boundary to match the available data, and the cut-off criteria applied and justified if the data at the processor's premises are not available for the allocation.

8.4 SYSTEM BOUNDARY

This guidance on the pig sector specifically includes breeding and commercial production in a range of production systems. The following sections provide guidance on the steps of an LCA as given in Section 4. It should be noted that because the systems are so diverse, the descriptions in Section 6 should be seen as a guide rather than definitive descriptions. Practitioners shall accordingly describe the system under study accurately and fully when defining the system boundary.

The system boundary shall be defined according to general supply-chain logic covering all phases from the extraction of raw material to the point at which the functional unit is produced. The system covered by these guidelines includes the cradle-to-primary-processing stages of the life cycle of the main products from pigs (see Figure 11). The modular approach outlined in Section 7.2 illustrates the three main stages of the cradle-to-primary-processing-gate. The feed stage is covered in LEAP *Animal Feed Guidelines* (FAO, 2016), detailing feed production from the cradle-to-animal's-mouth – raw materials, inputs, production, harvesting, storage and feeding. A full LCA would include processing, distribution, consumption and final end-of-life management of the product, but this guide does not cover post-processing stages in the supply chain.

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

The primary processing stage shall be limited to the pig processing factory and animal slaughter facility (backyard, village slaughter centre or abattoir. All transport in and between the cradle-to-primary-processing-gate shall be included.

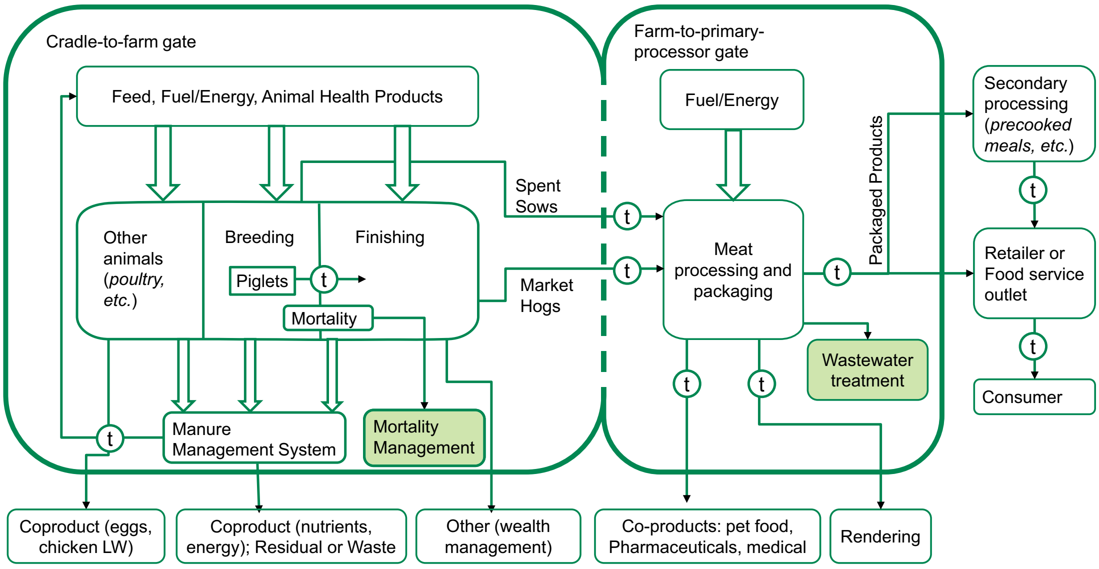
8.4.1 General/scoping analysis

The recommended system boundaries shown in Figure 11 start with the parent generation and end with dressed carcass ready for transport to customers or storage. An alternative system boundary of the farm gate is also supported, provided the functional unit is the live-weight of animals produced.

The choice of dressed carcass as a typical sector output is intended to provide a point in the supply chain that has an analogue across the range of possible systems, geographies and goals that may be encountered in practice. Because the dressed carcass is a necessary stage in small-scale village systems with direct sales and post-farm processing, practitioners whose system boundary extends to prepared meals, for example, or a full cradle-to-grave assessment can use this guide up to the point of dressed carcass and supplement the later stages on the basis of the references given in Appendix 2.

Guidance is also provided for the post-processing supply chain in the EPD® *Rule for Meat of Mammals* (Boeri *et al.*, 2012). Figure 11 illustrates a range of co-products from the farm through primary processing that may be produced within the system boundary and that are covered by these guidelines. Value-added processing steps oc-

Figure 11
Schematic of pig production system



curring beyond the system boundary, however, are not included. In cases where the raw materials for subsequent processing steps have value at the point where they cross the system boundary, they are treated as co-products subject to allocation of upstream burdens. There are no PCRs relating specifically to these co-products, but there are some relevant LCA publications for leather – Joseph and Nithya (2009); Mila i Canals *et al.* (1998 and 2002) – for biofuel from tallow – Thamsiriroj and Murphy (2011) – for thermoplastic from blood meal – Bier *et al.* (2012) – and for products from rendering animal processing by-products – Ramirez *et al.* (2011).

Scoping analysis

A scoping analysis based on a rapid assessment of the system can frequently provide valuable insight into areas that may require additional resources to establish accurate information for the assessment. Scoping analyses can use secondary data to provide an overall estimate of the effects of the system, and it is clear from the literature reviews in the pig sector (see Appendix 1) that it is important that the following factors are assessed with high accuracy: i) rations; ii) feed conversion efficiency; iii) daily weight gain; iv) reproductive efficiency; and v) manure production and management. Additional effects may be observed according to the operation under study. In the post-farm supply chain, energy efficiency at the processing and manufacturing stages and accurate assessment of modes of transport and distances are important.

8.4.2 Criteria for system boundary

Material system boundary

A flow diagram of all assessed processes should be drawn indicating where processes were cut off. For the main transformation steps within the system boundary it is recommended that a material flow diagram be produced and used to account for all material flows: for example within the processing stage the live-weight shall be defined and shall be equal to the sum of the mass of the products.

Spatial system boundary

The cradle-to-farm-gate stage includes feed and animal components. The LCA of feeds is covered in the LEAP *Animal Feed Guidelines*, detailing the cradle-to-animal-mouth stage for all feed sources – raw materials, inputs, production, harvesting, storage, losses and feeding. The LEAP *Animal Feed Guidelines* cover all emissions associated with land use and land-use change.

The animal components cover all inputs and emissions in the pig supply chain not covered by the LEAP *Animal Feed Guidelines*, including emissions associated with pig production and management. The latter includes accounting for the use or disposal of excreta, but it is important to avoid double counting if excreta are captured as manure and used as a direct input for feed production. The estimation of emissions from transport and application of manure is included in the LEAP *Animal Feed Guidelines*. Animal production may involve more than one farm if animals are traded between farms prior to processing: piglets born on one farm or grown through the nursery phase on one farm and sold on to another farm for finishing are an example. Such multiple components shall be accounted for in the calculations.

The primary processing stage is limited to animal slaughter for meat processing to produce the functional unit. For primary processing in developing countries, village slaughter centres are common and can include direct processing and sale of live animals to consumers for home-processing or re-sale to abattoirs. Emissions directly related to inputs and activities in the cradle-to-primary-processing chain stages are included, irrespective of location; transport in and between these stages are included along with any packaging materials associated with products sold from the slaughtering facility.

8.4.3 Material contribution and thresholds

Managing the large amounts of data and information required is an important aspect of carrying out LCAs, which are likely to have limited resources for data collection. In principle, LCA practitioners attempt to include all relevant exchanges in the inventory: some are clearly more important in terms of their contribution to the relevant impact categories, and significant work is required to reduce the uncertainty associated with them. Cut-off criteria may be adopted to help to determine whether project resources should be expended to reduce the uncertainty of small flows (see Section 8.4.1). Data for exchanges that contribute less than 1 percent of mass or energy flow may be cut off from further work on reducing uncertainty, but should not be excluded from the inventory. Large thresholds shall be explicitly documented and justified by the definition of the project goal and scope. A minimum of 95 percent of the impact for each category shall be accounted for. Inputs to the system that contribute less than 1 percent of the environmental significance for a specific unit process or activity in the system can be included with an estimate from a scoping analysis (see Section 8.4.1), which can also provide an estimate of the total environmental impact to evaluate against the 95 percent minimum.

In the case of exchanges that have small mass or energy contributions there may still be significant impact in one of the environmental categories. In these cases, additional effort should be undertaken to reducing the uncertainty associated with them. Lack of knowledge about the existence of exchanges relevant for a particular system is not considered a cut-off issue but as a modelling error. The application of cut-off criteria in an LCA is not intended to support the exclusion of known exchanges: it is intended to guide the expenditure of resources for the reduction of uncertainty associated with the exchanges that matter most in the system.

8.4.4 Time boundary for data

For products from the pig sector a minimum period of 12 months should be used, provided it covers all life stages of the animal through to the end point of the analysis. The study must therefore use an "equilibrium population" that shall include all animal classes and ages present over the 12-month period required to produce the given mass of product.

Documentation for temporal system boundaries shall describe how the assessment deviates from the 12-month timeframe. The time boundary for data shall be representative of the period associated with the average environmental impacts for the products.

In extensive production systems important parameters often vary from year to year: reproductive rates or growth rates, for example, may change according to seasonal conditions. In cases where there may be considerable variability in inputs, production and emissions over time, the 12-month boundary must be determined on the basis of data averaged over three years to meet the criteria for representativeness. An averaging period of three to five years is commonly used to smooth the effects of seasonal and market variability on agricultural products.

It must be noted that in this section the time boundary for data is described, not the time boundary of a specific management system. When a specific management system or additional system function such as wealth management influences the life cycle of the animal, the case must be clearly stated even though it would not normally influence the 12-month time boundary for the data.

8.4.5 Capital goods

The production of capital goods – buildings and machinery – with a lifetime greater than 12 months may be excluded from the LCI. If capital goods are included in the accounting, their use should be amortized over their useful lifetimes. All consumables and at least those capital goods with a life span of less than 12 months should be included for assessment, unless they fall below the 1 percent cut-off threshold noted in section 8.4.1

8.4.6 Ancillary activities

Emissions from ancillary inputs such as veterinary medicines, servicing, employee's travel to work, air travel or accounting or legal services may be included where relevant. An input-output analysis can be used as part of a scoping analysis to determine their relevance.

8.4.7 Delayed emissions

Emissions associated with products up to the primary processing stage are assumed to occur within the time boundary for data, which is usually 12 months (see Section 8.4.4). Delayed emissions from soil and vegetation are considered in the LEAP *Animal Feed Guidelines*. PAS 2050:2011 provides additional guidance with regard to the calculation of delayed emissions (BSI PAS 2050, 2011.

8.4.8 Carbon Offsets

Offsets shall not be included in the carbon footprint, but they may be reported separately as "additional information", in which case details of the methods and assumptions must be documented.

8.5 IMPACT CATEGORIES

All impact categories qualified as relevant and operational should be covered in an LCA (see Section 2.1): these include climate change, acidification, eutrophication, land occupation, biodiversity change, water use and fossil energy use. For climate change and climate change associated with change of land use, land occupation and fossil energy use the recommended method should be applied. For the other impact categories, **Table 2** provides examples of methods frequently applied to model them, but it does not cover all available methods or models. Other methods and models may be applied if i) they have particular local relevance; (ii) they are science-based, as proven in peer reviewed publications; and c) they are publicly available.

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

8.5.1 Eutrophication

Nutrients in manure – mainly nitrogen and phosphorus – or in chemical fertilisers used to produce feed may flow into surface water, either directly or after application. This process can provide limiting nutrients for algae and aquatic vegetation, leading to a proliferation of aquatic biomass. Decomposition of this biomass consumes oxygen, thereby creating conditions of oxygen deficiency that kill fish and other aquatic organisms. Many countries have strict regulations for containing (e.g., catchment basins) or preventing (e.g., soil phosphorus directive) the direct flow of manure or fertiliser nutrients into surface or ground water, but in others such regulations are lacking and adverse climatic events can lead to the uncontrolled release of nutrients into water bodies. Eutrophication is one of several impact categories that could be considered in an LCA; documenting it would require an impact assessment and a description of the emissions influenced (see **Table 3**). Direct quantification of eutrophication from pigs in grazing systems with access to streams or water bodies is difficult and hence likely to be imprecise because such areas are often shared with wildlife. Approaches to developing a score for eutrophication associated with manure from pigs or arising from chemical fertilisers used in crop production are covered in the LEAP *Animal Feed Guidelines*.

8.5.2 Acidification

Nutrients in manure or chemical fertilisers used to produce feed can emit NO_x, NH_3 and SO_x, leading to a release of hydrogen ions (H+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where buffering capacity is low, resulting in acidification of soils and bodies of water. Stone *et al.* (2012) estimate the potential terrestrial acidification effects of grow-to-finish pig production systems in the United States at 25.5 g SO_2 eq per kg live weight. The main contributors to this were manure emissions and handling – 11.4 g SO_2 eq – followed by contributions from feed production

– 10.9 g SO_2 eq – and enteric emissions – 2.7 g SO_2 eq. These values were lower than those reported in systems in France – 43.5 g SO_2 eq per kg live weight (Basset-mens and van der Werf, 2005). Ammonia emitted from manure can also be a major contributor to soil acidification. Quantifying NH_3 emitted from pig production systems must account for factors such as manure management, ambient temperature, wind speed, manure composition and pH. Current approaches include micro-meteorological methods, mass balance accounting and chamber methods. Arogo *et al.* (2004) indicate that data on NH_3 emissions from pig production systems are highly variable, with pig farms in North America emitting from 3 g to 226 g NH_3 / AU/day. Many countries have strict regulations for preventing soil acidification as a result of the direct flow of excessive manure or fertiliser nutrients into the environment – the EU Thematic Strategy for Soil Protection is an example – but others lack them. Acidification is one of several impact categories that can be considered in LCAs, and its documentation requires the use of an impact assessment method and a description of the relevant emissions influenced. Approaches to developing an acidification score associated with manure arising from pigs or chemical fertilisers used in crop production are covered in the LEAP *Animal Feed Guidelines*.

8.5.3 Biodiversity

Five main drivers of biodiversity loss are recognized by the *Millennium Ecosystem Assessment* (2005) and described in the LEAP *Biodiversity Principles*: habitat change, pollution, climate change, over-population and invasive species. For most of them, livestock can have positive or negative effects on biodiversity, and in some cases there are continuous gradients between negative and positive effects, for example where different management practices leading to degradation or restoration in the same region. Pressure indicators must reflect both these attributes. A primary example of habitat change putting pressure on biodiversity is the clearing of large areas of the Amazonian rainforest to produce pasture and arable crops for livestock feed. Such processes simplify the landscape, restrict species composition and fragment ecosystems. Intensification and overgrazing can also lead to desertification, soil degradation and preferential selection for invasive species.

Quantifying the impact of livestock systems on biodiversity is crucial because options for mitigating environmental impacts may have various effects on biodiversity. If biodiversity and ecosystem services were considered along with environmental impacts to develop a sustainability assessment, extensive systems could result in higher levels of sustainability even though they typically have higher levels of GHG emission per kg of meat. Trade-offs exist between the environmental performance and biodiversity environmental criteria, so it is essential to assess both sets of criteria to reveal the mitigation options that will enhance the sustainability of pig production. Approaches to considering biodiversity in LCAs are under development and are discussed in the LEAP *Biodiversity Principles*.

Table 2: Examples of impact categories and impact assessment methods

Impact category	Impact category indicator	Characterization model	Sources and remarks
Climate change	Kg CO_2 equivalent	Bern model: global warming potentials (GWP) over a 100-year period	IPCC, 2006c
Climate change from direct land-use change to be reported separately	Kg CO_2 equivalent	Bern model: GWP over a 100-year period Inventory data for area associated with land-use change per land occupation type and related GHG emission based on two methods: 1. 20 years depreciation of historical land use change (PAS2050-1:2012) 2. global marginal annual land-use change (Vellinga, 2012)	BSI, 2012 PAS2050-1:2012 Vellinga, 2013
Fossil energy use	MJ (lower heating value)	Based on inventory data concerning energy use Primary energy for electricity production required No impact assessment method involved	In several impact assessment methods such as (Goedkoop *et al.*, 2008; Guinee *et al.*, 2002) fossil energy use is either a separate impact category or part of a larger category such as abiotic depletion
Water consumption	Depends on the impact assessment method	Inventory data Water availability and degradation	ReCiPe (Goedkoop *et al.*, 2008); ISO 14046 (International Organization for Standardization, 2014)
Land occupation	m^2 year per land occupation category – arable land and grassland and location	Inventory data No further impact assessment method involved	
Acidification	Depends on the impact assessment method	Depends on the impact assessment method	ReCiPe (Goedkoop *et al.*, 2008), ILCD or a region-specific impact assessment method For the United States and Japan: Hauschild *et al.* (2013)
Eutrophication	Depends on the impact assessment method	Depends on the impact assessment method	ReCiPe (Goedkoop *et al.*, 2008), ILCD or a region-specific impact assessment method

9. Multi-functional processes and allocation

One of the challenges in LCA is associated with correct allocation of shared inputs and emissions to the several products of multi-functional processes. The choice of method for handling co-production often has a significant impact on the final distribution of impacts across co-products. In any case, the procedure adopted shall be documented and explained: this must include a sensitivity analysis of the chosen procedure on the results. Multi-functional procedures should as far as possible be applied consistently within and among datasets. In these guidelines "consistent use" refers to choosing the highest method from the ISO hierarchy that can be applied for all multifunctional processes at a given stage of the supply chain. If economic allocation is used for soymeal/oil, for example, then all meal/oil combinations should also use economic allocation. These guidelines require the adoption of: i) system separation – for example separate inventories for pigs, chickens and goats in multi-species systems; and ii) system expansion to include several products as the functional unit. This must be done in the order stated and in alignment with the goal and scope of the LCA. Consequential use of system expansion using an avoided burden calculated through substitution is not compliant with these guidelines.

For purposes of these guidelines the allocation to wealth management or other value-added functions shall be based on an assessment of importance in consultation with the stakeholders involved in the study to determine their perceptions of the relative contribution of each function delivered (Weiler *et al.*, 2014). If stakeholders perceive that the wealth management function is 20 percent of the value of the system, for example, then 20 percent of the whole system emissions are allocated to wealth management before any other allocations among other system functions.

9.1 GENERAL PRINCIPLES

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

Step 1: Allocation should be avoided wherever possible by: i) 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 ii) expanding the product system to include the additional functions related to the co-products.

Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them: they should, in other words, reflect the way in which the inputs and outputs are affected by quantitative changes in the products or functions delivered by the system. ISO 14044 states: "The inventory is based on material balances between input and output. Allocation procedures should therefore approximate as much as possible such fundamental input/output relationships and characteristics."

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[6] See: http://www.fao.org/ag/againfo/themes/en/pigs/production.html

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

Where allocation of inputs is required – for example the allocation of process energy between meat products and other products not intended for human consumption – the allocation procedures should follow the ISO 14044 allocation hierarchy. When allocation choices significantly affect the results, a sensitivity analysis shall be performed to ensure that conclusions are robust.

Common procedures for addressing multi-functional processes in attributional studies are: i) bio-physical causality arising from underlying biological or physical relationships between the co-products, such as material or energy balances; ii) physical properties such as mass or protein or energy content; and iii) economic value in terms of revenue share based on market prices of products. A decision-tree diagram to help decide the appropriate method for dealing with co-products is given in Figure 12.

9.2 A DECISION TREE TO GUIDE METHODOLOGY CHOICES

Application of the decision tree involves a three-stage approach: the principles involved in working through it are set out below.

Stage 1

Avoid allocation by subdividing the processing system. A production unit is defined here as a group of activities and the necessary inputs, machinery and equipment in a processing facility or a farm that are needed to produce one or more co-products. Examples are the crop fields on a farm, the different animal herds such as fattening pigs, sows and piglets, or the individual processing lines in a manufacturing facility.

In the first stage (ISO step (1a) subdivision), all processes and activities of a farm or at processing facilities are subdivided on the basis of the following characteristics:

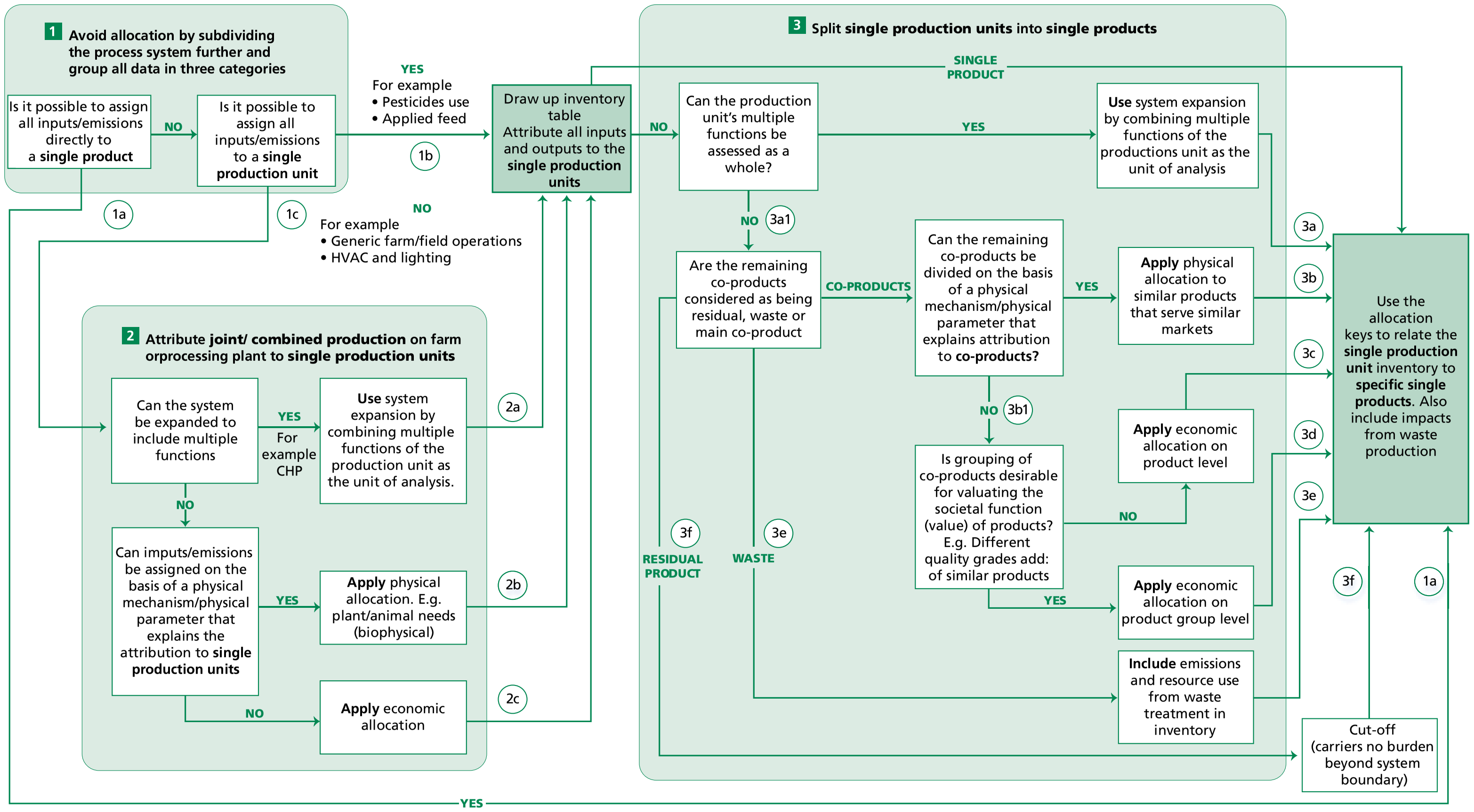
Flow 1a: Inputs and activities that can be directly assigned to a single co-product should be assigned to that co-product: packaging and post-processing storage for meat products, for example, or rendering energy requirements in the post-exsanguination phase at the processing plant.

Flow 1b: Inputs and activities that can be assigned to single production units that may provide several co-products should be assigned to the specific production unit: inputs of pesticides for corn are assigned to the “corn production unit” of a farm with several crops, for example, or energy inputs for a specific barn operation or manufacturing facility, or feed for a specific animal that may yield multiple products in a farm operation with several species.

Flow 1c: Inputs and activities of a non-specific nature in a farm or processing facility such as heating, ventilation, climate control and internal transport in a manufacturing facility or farm that cannot be directly attributed to specific production units: energy used to pump drinking water for different animal species in a small-scale, multi-species operation, for example, would be categorized as non-specific. It may be possible for these inputs to be assigned to each production unit in proportion to the causal relationship that determines increased need for each input, such as weight, volume or area (e.g., for transport, roads, buildings) or revenue (e.g., for offices and accounting).

Figure 12

Multi-functional output decision tree



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

Stage 2

Attribute combined production to production units. In theory, all combined production systems are separable where sufficiently detailed data exist, and they should normally follow path (1a). Nevertheless, situations exist where this is impractical, and in stage 2 in Figure 12) the non-specific processes should be attributed to production units on the basis of ISO steps (1b), (2) and (3). These steps and the conditions applied in selecting the allocation method will be discussed: in backyard systems, for example, it may be that poultry, cattle, sheep and pigs are all raised in a single production unit; in this situation farm overhead operations that cannot be explicitly assigned to an individual species should be handled using the criteria in Box 2/Step 2. For most large-scale production systems, the (1b) path to Box 3 will be followed, because the inputs and outputs in single-species systems are clearly assigned to the single production unit and its activities and operations and several products.

System expansion: ISO step (1b)

As part of the harmonization effort behind these guidelines, the range of allocation options in applying LCAs to pig systems is narrowed: it excludes the application of system expansion by means of substitution, and restricts its use to situations in which "expanding the product system to include the additional functions related to the co-products" is acceptable in the goal and scope of the study (ISO, 2006 b). In the case of dedicated sow operations, for example, this means that GHG emissions can only be attributed to the combined outputs of spent sows as meat and of piglets, and that neither product receives a separately identified impact. For benchmarking operations this is entirely appropriate in that the overall reduction of impacts for the multi-functional system can be easily monitored and managed.

The alternative – consequential use of system expansion using an avoided burden calculated through substitution – is not compliant with these guidelines.

Allocation: ISO step (2)

When it is not possible to apply system expansion to include additional functions in the scope of the analysis, the second question is whether a physical allocation is possible. The condition imposed by these guidelines is that the products have similar physical properties and serve similar goals or markets: for example human food or pet food markets for products of meat processing as opposed to pharmaceuticals (Marti et al., 2011). Alternatively, known processing or biophysical relationships can be used to assign inputs and outputs of a single production unit to each product of that production unit (ISO 14044, 4.3.4.2, Step2). If, for example, feed is provided for several animal species, animal growth requirements may be used to apportion the shared feed between the species. The result of this stage will be the splitting of some inventory flows between the production units, and if any of the resulting production units is still multi-functional these inventory flows will be allocated to single co-products in the next stage of the procedure (Box 3 in Figure 12): for example in a backyard system where sows and poultry feed from the same pasture the separation of the production unit of the sow operation from production unit of the poultry still leaves a multi-functional production unit of the sow operation with the two products: spent sows and piglets. In the pig sector it is unlikely that a multi-functional production unit will remains after this step.

If inputs in a multiple production system benefit all products and cannot be specifically assigned to production units, the allocation should preferably be based on a mechanistic algorithm or physical property, as in Flow (2b) in Figure 12).

Allocation: ISO step (3)

When physical allocation is computationally impossible, the last option is economic allocation. As with physical allocation the result of this step will be a splitting of some inventory flows between the production units. If the resulting unit process is still multi-functional, these inventory flows will be allocated to single co-products in the next stage of the procedure – Box 3 in the diagram.

Stage 3

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

Outputs of a production process are considered as residual flows under the following conditions (flow 3f):

- They are exported in the condition in which they are created in the process and do not contribute revenue to the company.
- There may be value-added steps beyond the boundary of the pig system under study that do not affect the pig-system calculations in these guidelines.
- Residual products will not receive any allocated emissions nor contribute emissions to the main co-products of the production unit; it is useful, however, to track residual flows for the purpose of understanding the mass balance for the production unit.
- An output of a production process shall be considered as waste if the production unit incurs a cost for treatment or removal. Waste has to be treated and/or disposed of, and the associated emissions shall be included in the inventory and allocated among the co-products. It is a requirement that all activities associated with waste treatment comply with legal or regulatory requirements. For the pig sector, the most common process in this category is wastewater treatment at manufacturing facilities; manure is discussed in Section 9.2.3.
- Co-products that are not residual or waste are subject to allocation where some fraction of the entire production unit's emissions are assigned to each co-product, leading to flows (3b), (3c) and (3d) in Figure 12. Assignment to these flows depends on whether biophysical or mechanistic allocation or allocation based on physical characteristics is possible or allowed under these guidelines (3b), or whether an economic allocation at a single product (3c) or product group level (3d) is applied.
- Following the ISO standard, the preferred approach is to identify a straightforward mechanistic algorithm such as when energy inputs in the process are

directly correlated with mass flow, or a biophysical causal relationship that can be used to assign inputs and emissions to each co-product. The condition for determining whether allocation on the basis of physical characteristic such as energy or protein content is appropriate is that the products should have similar physical properties and serve similar functions or markets. When physical allocation is not feasible, for example if interactions are too complex to accurately define a mechanistic relationship or are not allowed because of dissimilar properties or markets, the remaining option is economic allocation.

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

9.3 APPLICATION OF GENERAL PRINCIPLES FOR PIG SYSTEMS AND PROCESSES

To make these general ISO requirements operational for allocation in the pig production life cycle, the ISO steps are applied to combined and joint production processes such as farms and food processing plants that have multiple products and for manure. Table 3 summarizes the allocation procedures supported by this guidance.

Allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration. If, for example, allocation is made to usable products such as intermediate or discarded products leaving the system, the allocation procedure shall be similar to the allocation procedure used for such products entering the system. The decision tree in Figure 12 can be applied to determine the assignment of individual flows from a production unit dataset to multiple products that may be produced. In a small-scale system where other animal species are also present, for example, the unit process created will probably have an output product identified for each animal species, and it is necessary to assign the inputs and emissions of this combined production system separately to each product of the farm. The decision tree guides the choice of approach for assigning inputs and emissions of the overall unit process to individual products: where the allocation can affect results more than one method shall be used to illustrate the effects of the choice of allocation method. The principal reason for this requirement is to provide an evaluation of the robustness of the conclusions of the study: where the choice of allocation significantly alters the study result the conclusions cannot be considered robust.

9.3.1 Cradle-to-farm-gate

A number of allocation decisions associated with feed lie within the cradle-to-farm-gate boundary. Among these, the multi-functionality of feeds is handled in the LEAP *Animal Feed Guidelines*. This may be a system boundary issue, but it could be an allocation issue according to the way in which the material is classified at the processor gate. There are two main areas where co-products need to be accounted for in the animal production stage: i) where different animal species consume the same feed and/or share non-feed related inputs, as in path 1c in the decision tree; and ii) where there are several live-animal products such as cull sows, piglets or replacement gilts, and wealth management.

In pig livestock systems, the main determinants of GHG emissions are feed production, methane from manure and, in some cases, N_2O emissions in systems using the bedding or dry-stack handling for manure. The drivers of these are the intake and characteristics of feed and technical performance of the animals, expressed as the feed conversion ratio. If the activities, inputs or emissions cannot be separated, the preferred method for accounting for multi-functional processes and co-products shall be a biophysical approach based on feed intake associated with the animal species or co-products concerned.

In practice, accounting for several animal species – step 1c in Figure 12 because the subject is not a single production unit – is based on separation of activities between species and determination of feed intake for each species – step 2b in Figure 12). Any other shared inputs such as energy use for providing water are allocated according to relative feed intake by different species.

At the farm level the equivalent output from this approach would be the determination of all emissions related to feed and animals and use of the allocation factors for pigs based on relative feed intake to determine the allocation of emissions to the pig-production unit.

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

In the many instances where several species (e.g., sheep, cattle or poultry along with pigs) are farmed together, the activities should be separated, where possible, into activities supporting each of the different animal species where specific uses can be defined: the use of nitrogen fertiliser for pasture grown to feed sheep is an example. For the other environmental effects in the cradle-to-farm gate stage where there is common grazing or feeding, the actual amount of feed consumed by the pigs under study shall be calculated as outlined in Section 11.2.2, along with the intake of other animal species. Emissions associated with other non-feed shared activities such as fuel used for transporting animals, cleaning drains, cutting hedges and maintaining fences shall be allocated to animal species on the basis of a biophysical allocation key based on calculation of the total feed intake for each species, with allocation based on the relative feed intake per species. The reason for choosing feed intake as the basis for determining allocation among species is that it is connected to upstream feed production and downstream manure emissions, which are major inputs into the production system.

9.3.2 Meat production

For pigs there are two points of separation into different products: i) the breeding stage, where spent sows are sent for processing for human consumption or cull sows for the pet food sector; and ii) piglets grown to hogs for market. The primary point of separation is the processing stage at which edible meat products, bone and blood meal and tallow, skins and rendering products are generated.

Breeding stage

In situations where assessment focuses on a breeding stage at which spent sows are sent to slaughter and piglets are sold to finishing operations, allocation to spent sows and piglets sold is needed. Such farms generally have replacement gilts purchased from another facility, in which case the burden of production of the replacement guilt shall be accounted as an input to the breeding stage. In farrow-to-finish operations where an integrated self-replacing herd is modelled, replacement breeding animals are retained from a proportion of the finished sows: these represent an internal flow with no allocation required. There is no need for allocation between sows and piglets because the piglets also represent an internal flow, unless some are sold to other finishing operations. Because these guidelines assume the equivalence of meat produced for human consumption, there is no allocation between spent sows and market-ready pigs: the total live-weight of market pigs and spent sows is hence the functional unit of production for the operation.

Nursery stage

In this intermediate stage weaned piglets are grown to 20 kg to 25 kg and transferred to a finishing operation. There should be no allocation from this stage because animals leaving it on a live-weight basis are considered equivalent. In the case of dedicated nurseries, purchased piglets shall be considered an input and a burden assigned accordingly.

Finishing stage

Animals leaving this stage for slaughter are considered in these guidelines as equivalent on a live-weight basis. Equivalence refers to the functionality of the animals sent to slaughter: this is to restrict the application of allocation among types of animals that share an inventory and to maintain the perspective of the abattoir, where all cuts of meat are considered equivalent. In a situation where the production units can be separated, however – for example groups of animals fed different rations – the guidelines support this approach. In a split-sex farm with barrows (castrated boars) and gilts in different barns with different feed regimes, for example, these guidelines support differentiation of production units through system separation. In the case of dedicated growing-finishing operations, purchased piglets or feeders shall be considered an input and the burden accounted accordingly. In farrow-to-finish systems that include the breeding and nursery stages, spent sows and finished hogs shall be considered the aggregate production from the system; allocation is hence not required. If the breeding stage is considered as a background system for which secondary data are used, the first multifunctional issue – spent sows and piglets – will have been accounted for in the secondary data and a burden assigned to piglets or feeders entering the stage.

9.3.3 Allocation of manure and bedding exported off-farm

This discussion follows the decision tree presented above. The first determination to be made is the classification of manure as a co-product, waste or residue. This guidance recommends the consideration of manure as a residual material, provided it is used subsequently as a source of fertiliser or biomass energy. This leads to system separation in which post-farm emissions from use of the manure are assigned to that use. On-farm management is assigned to the main products of the farm, and the previous allocation procedures apply.

Co-product

When manure is a valuable farm output and the system of manure production cannot be separated from the system of animal production, emissions in the supply chain to the farm gate shall be shared by all co-products. In line with Table 3, the first method for allocation is to apply a biophysical approach based on the energy expended for digestion that enables an animal to utilize nutrients and create manure. This is calculated as the heat increment for feeding the diet – the energy expended by the animal on feeding and digestion and subsequent production of manure; it is distinct from maintenance energy requirements (Emmans, 1994; Kaseloo and Lovvorn, 2003). This may occur in any livestock system. There may be several co-products such as spent sows, piglets, cull sows and manure: the allocation fraction assigned to each co-product shall be calculated as the ratio of consumed feed required for each of the functions to the total feed consumed for all functions (see Appendix 3). If the energy content of the diet is unknown, the next step in the decision tree is economic allocation: this is because allocation based on physical characteristics is not appropriate given the different markets of the products – e.g. meat for human consumption and manure used as fertilizer. It should be noted that in this situation a methodological inconsistency arises if biophysical allocation is used for part of the system and economic allocation is used for another part.

Residual

When manure has no value at the system boundary and has a subsequent beneficial use, the next section on waste treatment should be consulted. This amounts to system separation by cut-off in that activities associated with conversion of the residual to a useful product such as energy or fertilizer occur outside the system boundary. In this recommended approach emissions associated with manure management up to the point of field application are assigned to the animal system, and emissions from the field are assigned to the crop production system.

Waste

Manure is generally classified as waste when it is disposed of by landfill, incineration without energy recovery, or treatment at a facility, and when it is applied in excess of crop nutrient requirements. In the first case, on-farm and off-farm emissions shall be assigned to the animal production system according to standard LCA practice for waste management. In the second case, the fraction of manure applied to meet crop nutrient requirements shall be considered as a residual as described above – on-farm manure-management emissions, whether residual or waste fractions, are assigned to the animal production system. Excess manure application shall be treated as a waste, and emissions from this fraction shall also be assigned to the animal production system. Emissions associated with the final disposal of manure as a waste lie within the system boundary and must be assigned to the animal products. A more detailed discussion of crop nutrient requirements is presented in the forthcoming LEAP Guidelines on Nutrients Modelling currently under review.

9.3.4 Multi-functional manufacturing facilities

In commercial processing of pig products, as a single production unit (see Box 3 in Figure 12), the edible products and the remaining non-edible co-products have different functions and markets. Allocation based on physical attributes such as mass or the protein or fat content of edible and non-edible co-products – as in path 3b in Figure 12 is not appropriate and shall not be employed. Mechanistic process-based models of abattoir operation developed in future may, however, provide a mechanism for following path 3b. For edible products such as pig feet and cuts of pig meat that serve a food market, the decision tree follows path 3d: this is because all edible products are grouped together in these guidelines in a simple revenue allocation of similar products grouped into an average product. Secondary rendering products such as blood and bones that serve as a source of protein shall be combined and treated as a single commodity, and the revenue accruing to the operation from them is used to allocate the abattoir burdens to the co-products. Differentiation among products within the average commodity may be desirable in some situations, but such additional differentiation is not permitted in these guidelines. Box 1 presents an example of allocation factors for meat processing in China based on mass and revenue

9.4 RECOMMENDATIONS FOR ALLOCATION

Table 3 summarizes the allocation methods arising from the decision tree for pig production and processing.

Table 3: Recommended methods multi-functional processes and allocation between co-products for the cradle-to-primary processing gate stages of the life cycle of pig product

Source/stage of co-products	Recommended method*	Basis
Animal species: in- farm multi-species production systems	System separation Biophysical causality	Separate activities specific to each animal species. For remaining non-feed inputs such as common costs for providing water, or heating a barn with several species, use biophysical allocation based on the proportion of the total feed energy requirement for each species.
Spent sows/piglets: breeding stage	Biophysical causality	Use biophysical allocation based on the proportion of total energy requirements for growth and piglet production. Culled sows do not enter the human food supply: if they are disposed of they should be treated as a waste; if they enter another supply chain such as pet food, use biophysical allocation and consider them as a co-product.
Live animals, wealth management: on-farm	System separation Biophysical causality	If wealth management is a function of the system, allocate the fraction of total system emissions to be assigned to wealth management first, then separate activities specific to products such as electricity for heat lamps. Then use biophysical allocation according to energy requirements for growth, reproduction, activity and maintenance as required.
Manure: breeding and production stages	Biophysical causality	Use heat increment of digestion – the energy used to digest feed – as the biophysical basis for creating manure; create allocation factors on the basis of the fraction of feed energy calculated for digestion, growth and piglet production.
Meat processing to edible and non-edible products	System separation Economic	Separate the activities specific to individual products where possible. Then use economic allocation after combining meat cuts into a product group, possibly based on a five years of recent average prices.

* Where choice of allocation can have a significant effect on results more than one method should be used to illustrate the effects of the method. In particular, biophysical causality and economic allocation should be used in sensitivity assessment, and market price fluctuations should be included as a tested parameter in all economic allocation (European Food Sustainable Consumption and Production, 2013).

Box 1. Example calculation for on-farm energy generation

Advanced options for manure management are continually being developed. Anaerobic digestion is one such technology which holds high promise in some areas and is well developed".

This example, which considers manure management calculations according to the attribution approach required by these guidelines, involves a sow operation of 3,000 head using a covered lagoon as an anaerobic digester. The animals are housed in a barn with a subfloor that is regularly flushed to remove manure for transfer to the digester. The biogas produced is used to produce electricity in a 130 kW generator for on-site consumption; excess electricity is sold to the local grid. In this operation each gestating animal produces 5 litres of manure per day and each lactating animal produces 12 litres per day, amounting to 10 percent of total solids.

Given a lactation period of 21 days and an average of 2.3 litters per year, there will be an average of 3,000 lactating animals at any time. Assuming that: i) 5 percent of feed is wasted (80% digestibility and 5% ash); ii) gestating sows receive 2 kg of dry feed per day; iii) lactating sows receive 5 kg of dry feed per day; and iv) methane is produced at 0.35m^3 CH_4/kg VS, then 1,035 m^3 of biogas is produced each day – 59.1 percent methane, 39.2 percent carbon dioxide and trace amounts of other gases such as ammonia and hydrogen sulfide.

This results in the production of 1,220 kWh per day, equivalent to 1.176 kWh per m^3 of biogas.

Emissions associated with the period in which the manure lies in the barn are attributed to the animal system; feedstock going to the anaerobic digester is considered as a residual and carries no burden into the digester process. On the basis of unit processes from the eco-invent database – V2. 2: biogas, agriculture covered, in cogen with ignition biogas engine – for electricity and heat cogeneration from manure slurry, and assuming a 1 percent leak rate of methane and 1.4E-3 kg N_2O per m^3 biogas processed from the anaerobic digester, the carbon footprint for this electricity is 556 kg CO_{2e} per day.

This analysis accounts for the energy required to operate the anaerobic digester, which is primarily derived from the digester itself as excess heat from the generation of electricity is used to maintain the operating temperature. The excess heat is hence not allocated any burden of digester operation.

The digester produces 3 m^3 of solid material per day, which can be composted to remove pathogens and sold for US$ 17 per m^3. The liquid effluent, which contains most of the remaining nutrients from the manure, is stored on-site and used as fertilizer. The liquid is treated as a residual, and emissions associated with its application are assigned to the subsequent crop. Electricity is valued at US$ 0.08 per kWh and allocated among the co-products of compost and electricity generation in the ratio of 1,220x0.08 = US$ 97.60 and 97.60+3x17= US$ 148.6 = 0.657. Thus the carbon footprint for electricity produced from the anaerobic digester system is 0.657x556/1,220 = 0.3 kg CO_{2e}/kWh. The electricity used for pig operation supplied by the anaerobic digestion process is treated as electricity purchased from the grid, except that it has a carbon footprint of 0.3 kg CO_{2e}/kWh.

Box 2. Effect on allocation calculations of mass and economic value of different components of an average market hog leaving an abattoir

The data in Table 9-2 are based on a summary of the average weight of different meat cuts and co-products from pig leaving an average abattoir in China. The mass and average economic value of the components is given and used to calculate the allocation among co-products.

Table 4. Economic and mass allocation calculation at an abattoir

	Average mass of component (kg)	Component as % of total mass	Component as % of total economic value
Meat			
Live-weight	97	28	24
Streaky belly	21		
Meat with bone – ribs, shank	11	15	22
Pork – loin/shoulder/belly/leg	23	31	20
Co-product			
Head, feet, tail	5	7	12
Organs/viscera	5	6	10
Fat	7	9	8
Blood	3	4	4
Total		100	100

Thus the economic allocation percentage (EA) for meat relative to the total returns was calculated using:
$EA\ (\%) = 100 \times \Sigma\ (\text{meat product revenue contribution}) / [\text{total revenue}]$

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

$MA\ (\%) = 100 \times \Sigma\ (\text{weight of meat components}) / [\Sigma\ (\text{weight of meat components} + \Sigma\ (\text{weight of co-products})]$

These calculations resulted to a percentage allocated to meat equal to 74 percent using mass allocation (MA) vs. 66 percent using economic allocation (EA).

10. COMPILING AND RECORDING INVENTORY DATA

10.1 GENERAL PRINCIPLES

The compilation of inventory data should be aligned with the goal and scope of the LCA. The LEAP guidelines provide LCA practitioners with advice on various potential study objectives because studies may assess pig supply chains at levels from the individual farm to integrated production systems to the region, country or sector. Evaluation of a project's data-collection requirements must consider the influence of its scope. In general, these guidelines recommend collection of primary activity data (see Section 10) for foreground processes, which are generally considered as under the control or direct influence of the commissioner of the study. For projects with a larger scope, however, such as sector-level or national-level analyses, the collection of primary data for all foreground processes may be impractical. In such situations or when an LCA is conducted for policy analysis, foreground systems may be modelled using data obtained from secondary sources such as national statistical databases, peer-reviewed literature or other reputable sources.

An inventory shall be compiled of materials, energy inputs, and outputs such as products, co-products and emissions for the product supply chain under study. The data recorded for the inventory shall include all processes and emissions occurring within the system boundary of that product.

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

There are two main differences between agricultural systems and industrial systems: i) production may not be static from year to year; and ii) some inputs and outputs are difficult to measure. Consequently, the inventory stage of an agricultural LCA is more complex than most industrial processes and may require extensive modelling to define the inputs and outputs of the system: hence agricultural studies often rely on a smaller sample size and are often presented as "case studies" rather than "industry averages". For agricultural systems, many foreground processes must be modelled or estimated rather than measured. Assumptions made during development of the inventory are critical to the results of the study and must be fully explained in the study methodology. To clarify the nature of the inventory data it is useful to differentiate between "measured" and "modelled" foreground system LCI data. For a finishing operation, measured foreground system data may include fuel use and pig numbers; modelled foreground system data may include manure quantity and characteristics.

The LCA practitioner shall demonstrate that the following aspects in data collection have been considered in the assessment based on ISO 14044:

- representativeness: qualitative assessment of the degree to which the dataset reflects the true population of interest. Representativeness covers the following three dimensions:
  a. temporal – age of data and the length of time over which data was collected;
  b. geographical – the area from which data for unit processes were collected to satisfy the goal of the study; and
  c. technology – specific technology or mix of technologies;
- precision: measure of the variability of the data values for each data expressed (e.g. standard deviation);
- completeness: percentage of flow that is measured or estimated;
- consistency: qualitative assessment of whether the study method is applied uniformly to the various components of the analysis;
- reproducibility: qualitative assessment of the extent to which information about the method and data values would allow an independent practitioner to reproduce the results reported in the study;
- sources of data; and
- uncertainty of the information in terms of data, models and assumptions.

For significant processes, the LCA practitioner shall document data sources, data quality and work done to improve data quality.

10.2 REQUIREMENTS AND GUIDANCE FOR THE COLLECTION OF DATA

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

- primary data, defined as directly measured or collected data representative of processes at a specific facility or for specific processes within the product supply chain; and
- secondary data, defined as information obtained from sources other than direct measurement of the inputs, outputs, purchases or emissions from processes included in the life cycle of the product (BSI PAS 2050:2008, 3.41). Secondary data are used when primary data of higher quality are not available or cannot in practice be obtained. Some emissions such as methane from manure management are calculated from a model and hence considered as secondary data.

For projects where significant primary data are to be collected, a data-management plan should be created to facilitate the management of data and to track the process of creating an LCI dataset, including the documentation of metadata. The data management plan should include:[7]

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

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[7] Bhatia *et al.*, 2011.

The recommended hierarchy of criteria for acceptance of data is:

- i. primary data collected as part of the project that have a documented quality assessment (see Section 11.3);
- ii. data from previous projects that have a documented quality assessment;
- iii. data published in peer-reviewed journals or from accepted LCA databases such as those described by the database registry project of the United Nations Environment Programme (UNEP)/SETAC Life Cycle Initiative;[8]
- iv. data presented at conferences or otherwise publicly available, for example on the internet; and
- v. data from industrial studies or reports.

10.2.1 Requirements and guidance for the collection of primary data

Primary data shall in general and as far as possible be collected for all foreground processes – those under the direct control of or significantly influenced by the study commissioner – and for the main contributing sources to GHG emissions. It is impractical to measure some foreground processes for an LCA: methane emission from deep bedding is an example. In such cases when a model is used to estimate emissions, the input data used for the model shall be measured: in practice, for farm-level studies the ration and its characteristics and the observed feed- conversion ratio are required to estimate the volatile solids and nitrogen content of the manure, which in turn can be used to estimate the methane and nitrous oxide emissions from manure management.

For most large-scale systems production of the ration may be considered a background process, whereas for many small-scale systems it can be integrated into the production system. The breeding system may be considered as a background operation in some large-scale production systems. For analyses of the breeding system itself these operations would clearly be considered in the foreground, and primary data shall accordingly be obtained.

The practicality of obtaining measured data for all foreground processes is also related to the scale of the project. If a national-scale evaluation of the pig sector is planned, for example, it is impractical to collect farm-level data from all pig producers: aggregated data from national statistical databases or other sources such as trade organizations may accordingly be used for foreground processes. In every case, clear documentation of the data-collection process and data quality documentation to ensure compatibility with the goal and scope of the study shall be incorporated into the report. Local conditions relevant to manure management emissions shall be considered. Workbooks with a template for primary data collection are available as spreadsheets.

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

Secondary data refers to life cycle inventory datasets available from third-party databases, government or industry association reports, peer-reviewed literature and other sources. It is normally used for background system processes such as electricity or diesel fuel that may be consumed by foreground system processes. When using secondary data it is necessary to select datasets that will be incorporated into the analysis: an LCI for goods and services consumed by the foreground system

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[8] https://nexus.openlca.org/dataproviders

should be geographically and technically relevant. The quality of datasets (see Section 10.2.3) for use in specific applications should be assessed and included in the documentation of the analysis of data quality.

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

In view of the importance of the contribution of the ration to the environmental impacts of pig production, secondary data used for the ration must always be relevant to the supply chain under study. In evaluating a pig production system in China, for example, the use of proxy LCI for maize produced in the United States would only be suitable as secondary data if it were known that the operation being studied imported its maize from the United States.

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

- They shall be as current as possible and collected within the past 5–7 years; if only older data is available, documentation of the data quality is necessary and determination of the sensitivity of the study results to these data must be investigated and reported.
- They should be used only for processes in the background system. When available, sector-specific data shall be used instead of proxy LCI data.
- They shall fulfill the data-quality requirements specified in Section 3.4 of these guidelines.
- They should be obtained from the data sources provided in these guidelines, for example Section 11.2.3 for animal assessment and the Appendix 1.
- They may only be used for foreground processes if specific data are unavailable or the process is not environmentally significant. However, if the quality of specific data is considerably lower and the proxy or average data sufficiently represents the process, then proxy data shall be used.

An assessment of the quality of these datasets for use in the specific application should be made and included in the documentation of the analysis of data quality.

10.2.3 Approaches for addressing data gaps in LCIs

Data gaps exist when there is no primary or secondary data available that is sufficiently representative of a given process in the life cycle of a product. LCI data gaps can result in inaccurate and erroneous results (Reap *et al.*, 2008). When missing LCI data is set to zero the result is biased towards lower environmental impacts (Huijbregts *et al.*, 2001; Finnveden *et al.*, 2009).

Several approaches have been used to bridge data gaps, but none are considered standard LCA methodology (Finnveden *et al.*, 2009): the LCA practitioner shall therefore try to fill gaps by collecting the missing data. Data collection is time-consuming and expensive, however, and is often not feasible. The following sections provide additional guidance on filling data gaps with proxy and estimated data. The discussion of proxy data is intended primarily for LCA practitioners: proxy data are never recommended for use in foreground systems, as discussed elsewhere in this guidance.

The use of proxy datasets – LCI datasets that are the most similar process or product for which data is available – is common. The technique relies on the practitioner's judgment and is hence likely to be arbitrary (Huijbregts *et al.*, 2001). It has been suggested that use of the average of several proxy datasets may reduce uncertainty more effectively than use of a single dataset.

Mila i Canals *et al.*, (2011) suggest the use of extrapolation from one dataset to bridge a gap in another: data from pig production in one area or system, for example, could be extrapolated to production in another area on the basis of expert knowledge of differences in feed requirements, feed conversion ratios and excreta characteristics. They showed that the use of proxy datasets is the simplest solution, but that the approach has the highest uncertainty. Extrapolation methods require expert knowledge and are difficult to apply, but they provide more accurate results.

In countries that can provide environmentally extended economic input-output tables, a hybrid approach can also be used to bridge data gaps. In this approach the monetary value of the missing input is analysed through the input-output tables, and then used as a proxy LCI dataset. It is of course subject to uncertainty, and has been criticized (Finnveden *et al.*, 2009).

Any data gaps shall be filled by using the best available secondary or extrapolated data. The contribution of such data and any gaps in secondary data shall not account for more than 20 percent of the overall contribution to each emission factor impact category considered. The use of such proxy data shall be reported and justified. Independent expert peer review of proxy datasets should be sought where possible, especially when the datasets approach the 20 percent cut-off point of overall contribution to each emission factor: this is because errors in extrapolation at this point can be significant. The experts should have the skills to cover the breadth of LCI data being developed from proxy datasets.

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

10.3 ASSESSMENT OF DATA QUALITY

LCA practitioners shall assess data quality by using appropriate indicators with a view to indicating the quality of the data and the extent to which they are representative. This is important for: i) optimizing the data content of the LCI; ii) communicating and interpreting results; and iii) informing users of the possible uses of the data. Data quality refers to characteristics of data that enable them to satisfy stated requirements (IOS, 2006a). Data quality covers technological, geographical and time-related representativeness and completeness and accuracy. This sub-section explains how the quality of data shall be assessed.

10.3.1 Data quality rules

Criteria for assessing LCI data quality can be categorized in terms of: i) technological, geographical and time-related representativeness; ii) completeness as to coverage of impact categories; iii) the accuracy or uncertainty of collected or modelled inventory data; and iv) methodological appropriateness and consistency. Representativeness quantifies the extent to which the collected inventory data represents the "true" inventory of the process for which they are collected in terms of technology, geography and time. With regard to data quality, the representativeness of the LCI data is significant, and primary data gathered shall adhere to the criteria for data quality in terms of technological, geographical and temporal representativeness. Table 5 summarizes selected data-quality requirements. Any deviations from the requirements shall be documented. Data quality requirements shall apply to primary and secondary data. With regard to LCA studies using actual farm data and addressing farmers' behaviour, it is more important to ensure that the farms surveyed are representative and that the data collected is accurate and well managed than to provide a detailed assessment of uncertainty.

10.3.2 Data quality indicators

Data quality indicators, which define the standard of the data to be collected, relate to issues such as representativeness, age and system boundaries. During the data-collection process, the quality of data on the activity, emission factors and direct emissions shall be assessed on the basis of the indicators.

The validity of data collected from primary sources should be established by ensuring that the units for reporting and conversion and material balances are consistent so that, for example, all incoming materials are accounted for in products leaving a processing facility.

Secondary data for background processes can be obtained from sources such as the EcoInvent database. In such cases the data-quality information provided by the database manager should be evaluated to determine whether it requires modification for the study being carried out: an example is whether use of European electricity grid processes in other areas will increase the uncertainty of those unit processes.

Table 5: Overview of selected requirements for data quality

Indicator	Requirements/data-quality rules
Technological representativeness	The data gathered shall represent the processes under consideration
Geographical representativeness	If multiple units are under consideration for the collection of primary data, the data gathered shall represent at least a region such as EU-27 Data-collection should respect geographic relevance to the goal and scope of the analysis.
Temporal representativeness	Primary data gathered shall be representative of the preceding three years; secondary data shall be representative of the preceding five to seven years The period on which data is based shall be documented.
Biophysical causality	Use heat increment of digestion – the energy used to digest feed – as the biophysical basis for creating manure; create allocation factors on the basis of the fraction of feed energy calculated for digestion, growth and piglet production.
System separation Economic	Separate the activities specific to individual products where possible. Then use economic allocation after combining meat cuts into a product group, possibly based on a five years of recent average prices.

10.4 UNCERTAINTY ANALYSIS AND RELATED DATA COLLECTION

Data with high uncertainty can have negative effects on the overall quality of an LCI. It is crucial to collect data for the assessment of uncertainty and hence accurate interpretation of results (see Section 12) and reporting (see Section 12.5). The World Resources Institute World Business Council for Sustainable Development has published additional guidance on quantitative uncertainty assessment and a spreadsheet to assist in the calculations (WRI/WBCSD, 2011).

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

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

10.4.1 Secondary activity data

For guidance with regard to secondary activity data, consult Section 10.2.2 and Appendix 1.

10.4.2 Default/proxy data

For guidance with regard to default and proxy data, consult Section 10.2.2 and Appendix 1.

10.4.3 Inter-annual and intra-annual variability in emissions

Agricultural processes are highly susceptible to annual variations in weather patterns, which particularly affect crop yields and may affect feed-conversion ratios when environmental conditions are severe enough to affect an animal's performance. Depending on the goal and scope of the study, additional information may be warranted to capture and identify seasonal or annual variability in the efficiency of the product system.

11. LIFE CYCLE INVENTORY

11.1 OVERVIEW

The LCI analysis phase involves the collection and quantification of inputs and outputs throughout the life cycle stages covered by the system boundary of the study. This typically involves an iterative process as described in ISO 14044 (2006), the first steps of which involve collecting data on the basis of the principles outlined in the previous section. The subsequent steps involve: i) recording and validating the data; ii) relating the data to each unit process and functional unit, including allocation for different co-products; iii) aggregating the data; and iv) ensuring that all significant processes, inputs and outputs are included in the system boundary. The system boundary (see Figure 8) has pre-farm gate and post-farm gate stages.

11.2 CRADLE-TO-FARM GATE

To assist the user in calculating carbon footprint as an example impact category of products for the cradle-to-farm gate stage, a flow diagram is presented in Figure 13.

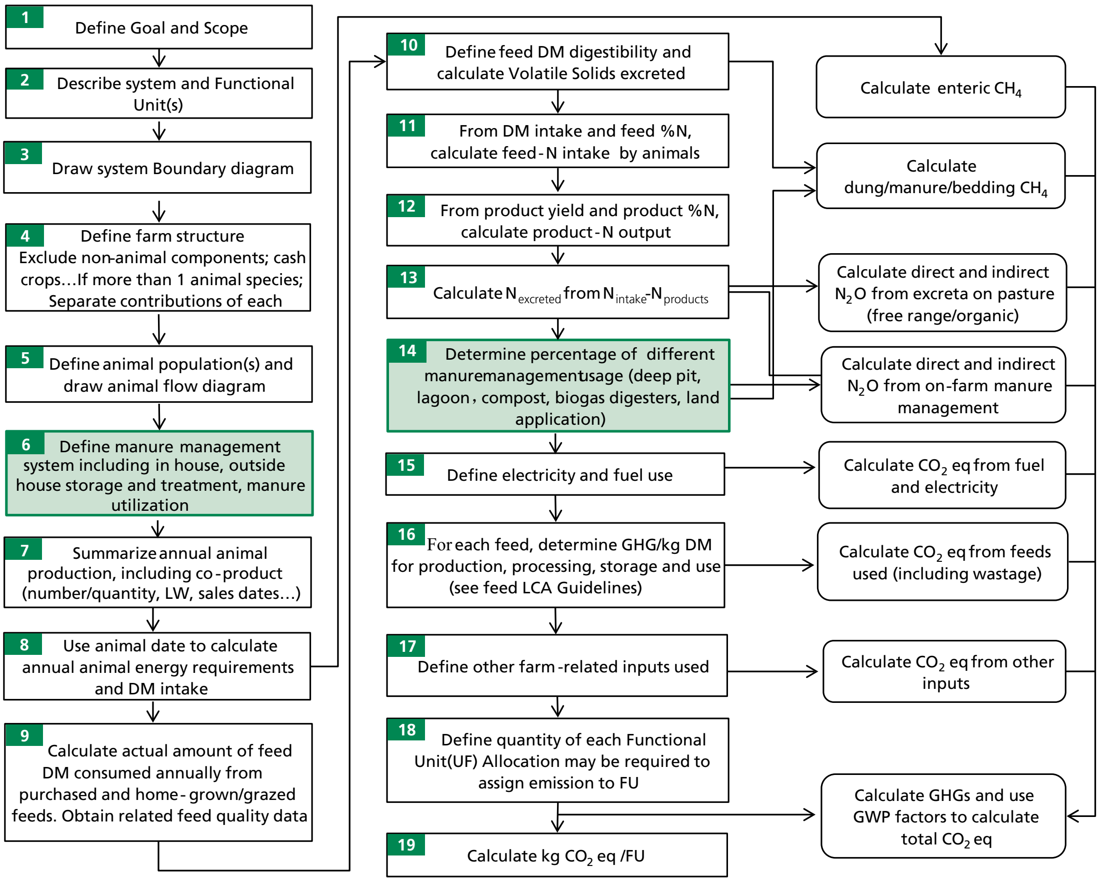
Previous research has shown that at the cradle-to-farm gate stage, the largest source of GHG emissions is feed production (Cederberg and Flysjö, 2004; Wiedemann *et al*., 2010). Manure management also contributes to emissions and is directly related to feed quality and quantity consumed. An important first step is hence to define the amount of each feed type used and nutritional quality in terms of energy, amino acid, crude protein and phosphorus content.

Box 3. Data requirements for specific processes in an LCI of a pig supply chain

- *Data on feed production – on-farm or purchased – including minerals and other supplements, upstream fertilizer manufacture, delivery and application, diesel fuel used in cultivation and N_2O emissions from soil. The LEAP* Animal Feed Guidelines *(FAO, 2016) provide detailed information for calculating the contribution of feed to the environmental footprint.*
- *Data on the parent farm – sows producing piglets – to calculate the upstream impacts of pig production. When this is a foreground system the quantity and type ration, energy use and manure management shall be fully accounted. For situations in which this stage is a background system, a default LCI is provided in Appendix 3.*
- *Primary data on pig production shall include an accurate description of the production system and its targets –growth rate, for example, final weight, actual performance for example as influenced by climate, feed properties and specialty feed ingredients, and product and market specifications. The systems may be different in different countries or regions. Primary data on heating, ventilation, lighting and other energy uses associated with feed and water management shall be collected.*
- *Estimation of manure production and emissions associated with on-farm manure management. See section 11.2.3 for guidance on this topic.*
- *Post-farm transport and resource consumption at processing facilities, including types and quantities of co-products such as blood, meat or meat and bone meal.*

Figure 13

Flow diagram for determining the carbon footprint of pig products for the cradle-to-farm gate stage



Note: Content in the shaded boxes relates to allocation decisions; rounded boxes are GHG calculation steps

The cradle-to-farm gate stage can be separated into the processes of acquiring raw materials, producing water and feed and using all these for animal production. The acquisition of most raw materials is associated with the production of feed. These guidelines provide limited information about pig feed, which is covered in the LEAP *Animal Feed Guidelines* (FAO, 2016). The information on pig feed in this document is largely for context; it also reflects the strong linkage between feed and animal production. When animal feed is derived from annual and perennial plants the inputs of fertiliser, manure and lime are often significant sources of GHG emissions. When annual crops are used to produce feed, the fuel used for tillage, harvest and transport; crop residues that produce N_2O emissions and land-use change also contribute to GHG emissions. In the case of highly processed feed such as compound feeds or concentrates there may also be significant energy use and emissions during processing and storage. Estimation of GHG emissions during the feed-production-to-consumption is covered in the LEAP *Animal Feed Guidelines* (FAO, 2016).

11.2.1 Farm water

Energy inputs such as pumping, circulation and transport are often required to supply water for animals. Background processes from existing databases can be used when water is purchased from a municipal source. If well water is used the pumping power required can be estimated with the following equation:

$$P_h = q\rho gh/(3.6e6) \quad (1)$$

where P_h = fluid power (kW), q = pumping rate (m^3/h), ρ = fluid density (1,000 kg/m^3 for water), g = gravity ($9.8 m/s^2$) and h = differential head (m), which is approximately the depth of the well plus the additional elevation necessary to deliver the water. The power required for the motor is the fluid power divided by the motor efficiency, η, typically 60-70 percent:

$$P = P_h/\eta \quad (2)$$

For electric pumps, the total energy consumption is estimated as *P*pumping hours.*

There is also a small contribution to resource use and GHG emissions from the production and provision of animal health inputs such as treatment for infectious diseases, parasites and mineral deficiencies. These materials are likely to be below the material cut-off and can be estimated from secondary or proxy data from existing databases; they can be omitted if there is no reasonable proxy, and the omission shall be justified.

11.2.2 Feed assessment

This section covers the downstream impacts of manure management. The identification of the type, quantity and characteristics of feed in terms of upstream impacts is covered in the LEAP *Animal Feed Guidelines* (FAO, 2016). Some commercial operations consider the composition of the ration to be confidential business information, but it is nonetheless important to obtain primary data on the ration; this may require assistance from industry partners. In many regions much of the ration may be imported. There is considerable diversity among pig supply chains: reproductive systems involve feed for boars, sows and their litters; growing-finishing production may include post-weaning piglets; feed may include meal, mash and pelleted diets; and, particularly in Northern Europe, entire cereal grain may be used in pig diets.

Because of the diversity of feeds and because the production of feed contributes to environmental impacts, it shall be important to evaluate the feed consumed and represent it accurately in LCA of pig supply chains. Different production systems result in different environmental conditions (e.g., temperature) that can affect maintenance energy needs and hence feed-conversion ratios: this shows the need for primary data on feed consumption that accounts for inputs at the farm level. Feed ccharacteristics that shall be included are energy content, crude protein or amino acid content, and ash: these are used with physiology models to predict the quantity and characteristics of excreted manure when measurements are unavailable.

The LEAP *Animal Feed Guidelines* (FAO, 2016) should be referred to when assessing feed. In practice there is wastage of feed at various stages between harvest and feeding, which shall be accounted for. To determine animal performance in terms of feed conversion ratio, the effects of climate, management techniques, feed and special ingredients and other inputs at the farm level shall be fully accounted. If, for example, there is 10 percent wastage between harvesting maize and its consumption by animals, the emissions from crop inputs should be based on the crop harvested and not the final amount eaten. At the farm level, a significant component of wastage occurs during feeding: such waste may enter the manure management system, so its contribution to subsequent methane and N_2O emissions should be accounted for and included with the manure emissions estimation.

Feed milling

An important area in pig production systems is the formulation of feed at a mill using least-cost algorithms to select the raw inputs. Least-cost formulations can change weekly or monthly and hence and annual average ration is needed to account accurately for the environmental footprint.

Pig nutritionists require information about the nutrient content of feed. Milling processes can change the characteristics of feeds in terms of digestibility and crude protein content, so it is important to determine that a ration specified in an LCA matches pigs' nutrition requirements and that the milling process model (see LEAP *Animal Feed Guidelines* (FAO, 2016)) provides the required characteristics. Reference to the LEAP *Animal Feed Guideline*s (FAO, 2016) will ensure that appropriate feed burdens are captured for the system under study: a more expensive formulation may result in lower excretion and GHG emissions, for example, and the cost of environmental management will fall accordingly.

Computing emissions

Emissions from feed ration should be calculated on the basis of the LEAP *Animal Feed Guidelines* (FAO, 2016). In large-scale operations rations account for a significant fraction of the environmental footprint, and it is hence critical that the emissions accurately reflect actual production practices. The source of the feed, whether local, regional or imported must be representative of the feeds provided. If feeds are imported, the protocol in the LEAP *Animal Feed Guidelines* (FAO, 2016) should be used to calculate the environmental burden of production and delivery to the exporting country port and to estimate international transport distances. The related emissions can be combined directly with production and post-farm emissions to calculate the totals for the supply chain. In practice most diet decisions are based on least-cost considerations, but an LCA could illustrate the effects of emissions related to changes of feed. It may be more cost-effective, for example, to have a slightly less efficient feed conversion.

11.2.3 Animal population and production

Most models used to calculate feed requirements derive feed intake from the energy requirements for growth, reproduction and maintenance; this requires data on animal numbers and productivity. Information about mortality losses and numbers of live piglets and marketed animals produced over a year is necessary for baseline evaluations. The age or weight of animals that die should be noted if possible, because the later in the cycle a death occurs the larger the quantity of feed consumed, which constitutes an additional burden assigned to the live-weight sold from the production cycle. Information requirements will depend on the type of the facility under analysis –sow/nursery/finish production and the type of production – large-scale, small-scale or backyard.

To assess a 12-month time unit, data should be collected for the operation over a whole year. The animal population associated with the products shall be defined; because there will be a non-integer number of generations in the time frame, the rolling herd average and annual live-weight production can be used to calculate total inputs and emissions. This requires accounting for sows, piglets, sow replacements for each production cycle and spent sows sold for meat.

Animal enteric methane emissions

Three approaches for estimating enteric methane have been suggested; the choice will depend on the goal and scope of the LCA. Enteric methane emissions can be modeled after Rigolot *et al.* (2010) to account for differences in feed use.

For sows:

$$CH_4\frac{kg}{yr} = \frac{ResD * \frac{1340J}{kg\ ResD}}{5.665e7\frac{J}{kg\ CH_4}} \qquad (3)$$

For weaners, growers and finishers:

$$CH_4\frac{kg}{yr} = \frac{ResD * \frac{670J}{kg\ ResD}}{5.665e7\frac{J}{kg\ CH_4}} \qquad (4)$$

where ResD = annual digested fiber ingested, estimated as the difference between digested organic matter and digested sugar, starch, fat and protein (Rigolot *et al.*, 2010).

The second approach primarily for national-level assessments using Intergovernmental Panel on Climate Change (IPCC) default emission factors may be adopted. According to IPCC (2006), Table 10.10 enteric emissions from pigs in developed countries are estimated at 1.5 kg CH4/head/year; in developing countries they are estimated at 1.0 kg CH4/head/year (Dong *et al.*, 2006).

A third approach primarily for national-level assessments using Intergovernmental Panel on Climate Change (IPCC) default emission factors may be adopted. According to IPCC (2006), Table 10.10 enteric emissions from pigs in developed countries are estimated at 1.5 kg CH_4/head/year; in developing countries they are estimated at 1.0 kg CH_4/head/year (Dong *et al.*, 2006).

11.2.4 Manure production and management

Biological principles

From an animal physiology perspective, the characteristics of manure are defined by the characteristics of the feed ingested and the efficiency with which it is converted into the product of interest – meat or piglets. The digestibility and ash content, which characterize the fraction of the ration that is not available to support metabolic needs, are particularly relevant. The content, digestibility, balance and utilization of amino acids relative to the protein deposition rate define the nitrogen content of the manure. In deep bedding systems such as hoop barns pig manure may have additional material such as straw added, with additional carbon, phosphorus and nitrogen, which affects the emissions from the subsequent management system.

Manure production

The first step in estimating manure GHG emissions is to estimate manure excretion and the mass of volatile solids (VS) and nitrogen (N) and phosphorus (P) excreted in manure. Excretion of VS, N and P in manure may be estimated from information collected from pig producers such as daily feed intake and feed properties and from the relationships given by the American Society of Agricultural Engineers (ASAE) or IPCC (Dong *et al.*, 2006).

N and P excretion is calculated by:

$$\begin{aligned} N_{E-T} &= N_{I-T} - N_{R-T} \equiv {}^{g\,N}/_{phase} \\ P_{E-T} &= P_{I-T} - P_{R-T} \equiv {}^{g\,P}/_{phase} \end{aligned} \quad (5)$$

where $N/P_{E\text{-}T}$ = total nitrogen/phosphorus excretion per phase or animal group; $N/P_{I\text{-}T}$ = total nitrogen/phosphorus intake in feed per phase or animal group; $N/P_{R\text{-}T}$ = total nitrogen retention per phase or animal group. Equation 5 shall be summed overall growth phases in a single year of operation.

Annual excretion shall be estimated from the animal population, excretion per pig per phase and 365 days per year. The ASAE gives equations for the calculation of N and P in the ration and for animal retention. The use of a constant factor of feed N as an estimate of retention is not recommended.

VS excretion in kg may be predicted from feed intake, digestibility of the diet and ash content in the manure using the following formula:

$$VS = FI_{PH}(1 - DMD)(1 - A) + VS_{WF} \equiv {}^{kg\,VS}/_{phase} \quad (6)$$

where FI_{PH} = feed intake per pig-phase (kg, as fed); DMD = diet digestibility expressed as a fraction (range: 0.6 - 0.8); A = ash content of manure (range: 0.1 - 0.2); VS_{WF} = VS contribution from wasted feed entering the manure management system. VS shall be summed across all production phases during a year of operation and shall be adjusted to account for spilled or wasted feed that enters the manure management system. The VS content of wasted feed can be estimated by:

$$VS_{WF} = FI_{PH}(1 - A)WF \equiv {}^{kg\,VS}/_{phase} \quad (7)$$

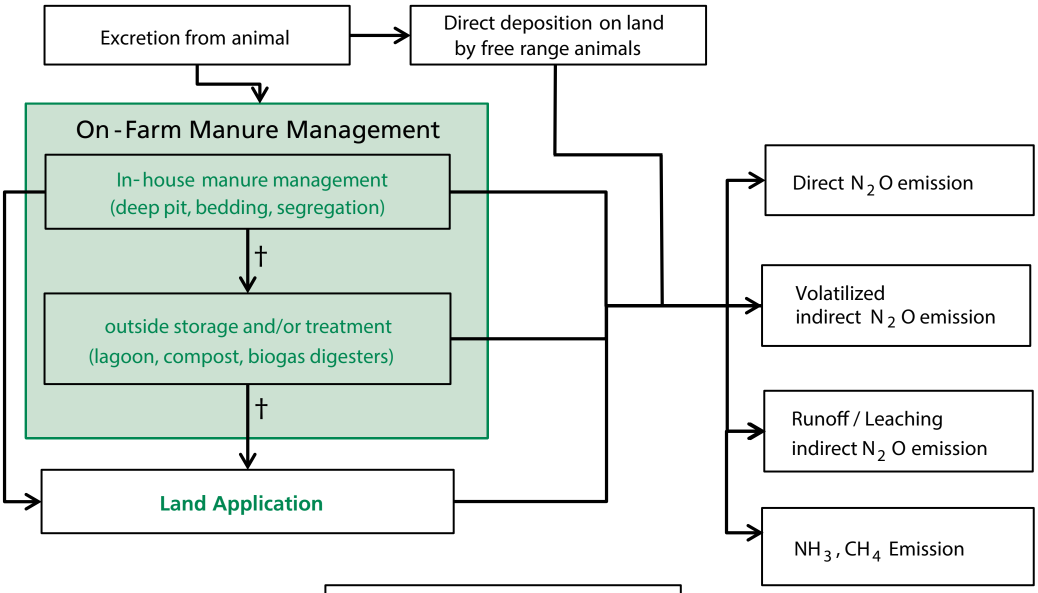
where WF is the fraction of feed that is not consumed.

Manure management systems

Manure emissions shall be estimated at each point in the manure management system using a mass balance approach. Emission sources are shown in Figure 11 for pig production utilizing housing systems. Emissions shall be fully accounted at each stage of the management system on the basis of the mass of manure managed at that stage, including emissions from field application resulting from differences in susceptibility to leaching and runoff. Chapter 9 discusses the assignment of field emissions according to whether manure is considered as a co-product, residue or waste. If several management systems are used, or if the VS and nitrogen excretion

Figure 14

Nitrogen mass flows from pig manure



On farm manure management includes manure management occurring both in-house and outside.

† N transferred must account for N lost by volatilization/transformation in previous MMS stage

varies significantly throughout the year, these factors must be accounted for in the analysis. A flow chart for determining the type of manure management system following IPCC nomenclature (Dong *et al*., 2006) is given in Figure 14.

11.2.5 Housing emissions – methane

Manure methane emissions may be estimated with the following formula:

$$CH_4 = VS_e(B_O)(MCF)(\rho)\left[\prod_{n=1}(1-R_{VS,n})\right]\sum_j(MS\%_j MCF_j) \equiv {}^{kg\ CH_4}/_{day} \quad (8)$$

where VS = VS excretion (kg/day); B_o = maximum emissions potential - m^3 CH_4/ kg VS as in IPCC (Dong *et al*., 2006) or other country-specific or herd-specific factors; MCF = integrated methane conversion factor; ρ = density of methane (0.662 kg CH_4/m^3); = fraction of manure handled in the manure management system; MCFj = the emission factor for the relevant manure management system j; $R_{vs,n}$= % of VS degraded in the manure management system of stage n.

11.2.6 Housing emissions – Nitrous Oxide

Direct nitrous oxide emissions from manure management in the shed can be calculated by:

$$N_2O = N_E\left[\prod_{n=1}(1-R_{N,n})\right]\sum_j(MS\%_j EF_{MMSj})\left(\frac{44}{28}\right) \equiv {}^{kg\ N_2O}/_{day} \quad (9)$$

where: N_2O = nitrous oxide emissions from manure management (kg/day); NE = nitrogen excretion (kg/day if nitrogen excretion is based on equation (5), when the N_2O emissions will be per phase rather than per day); the factor 44/28 is used to convert mass of N_2O-N to mass of N_2O. = the fraction of manure handled in system j as a %; = the emission factor for the relevant manure management system j. KgN_2O-N/kgN; Rvs,n = fraction of nitrogen degraded in an animal manure management system of n stage as %; if nitrogen excretion is based on equation (5) the N_2O emissions will be per phase rather than per day; EFMMS = the emission factor for the relevant manure management system; the factor 44/28 is used to convert mass of N_2O-N to mass of N_2O. If several management systems are used or if the nitrogen excretion varies significantly during the year, these factors must be accounted in the analysis. This formula is sensitive to the estimated nitrogen excretion and the emission factor applied.

In free-range pig systems, which use a different manure management system and hence require different emission factors, a proportion of manure is deposited indoors – which may vary according to season and climate zone – and the remainder is deposited outdoors.

11.2.7 Indirect Nitrous Oxide Emissions

Indirect N_2O emissions from ammonia loss and N leaching from manure deposited directly to land during grazing shall be calculated as shown in Figure 15. Country-specific factors that are integrated into most national GHG inventories shall be used; if they are not available the IPCC (2006) default factors shall be used instead. Calculations first require an estimate of the amounts of ammonia loss and N leaching from manure deposited on land. The default IPCC (2006) loss factor for FRAC$_{\text{GASM}}$ is 20 percent of N manure and for FRAC$_{\text{LEACH}}$ is 30 percent for soils with net drainage; otherwise it is 0 percent of N excreted. These are multiplied by the corresponding IPCC (2006) emission factors of 0.01 kg N_2O-N/kg N lost as ammonia and 0.0075 kg N_2O-N/kg N leached. The total N_2O emissions from manure are calculated by summing the direct and indirect N_2O emissions after adjustment for the N_2O/N_2O-N ratio of 44/28.

Ammonia volatilization

Indirect emissions of N_2O occur as the result of ammonia volatilization from the production system and from manure application. Ammonia emissions are deposited on to land and contribute to a pool of soil nitrogen, some of which is re-emitted as N_2O. The emissions are therefore attributed to the facility responsible for the ammonia emissions. Values may be derived from IPCC (Dong *et al*., 2006), published literature, research or national inventories. Of the nitrogen lost as ammonia (NH_3-N), the IPCC recommends an emission factor of 0.01 – or 1 percent – to calculate indirect N_2O emissions.

Leaching and runoff

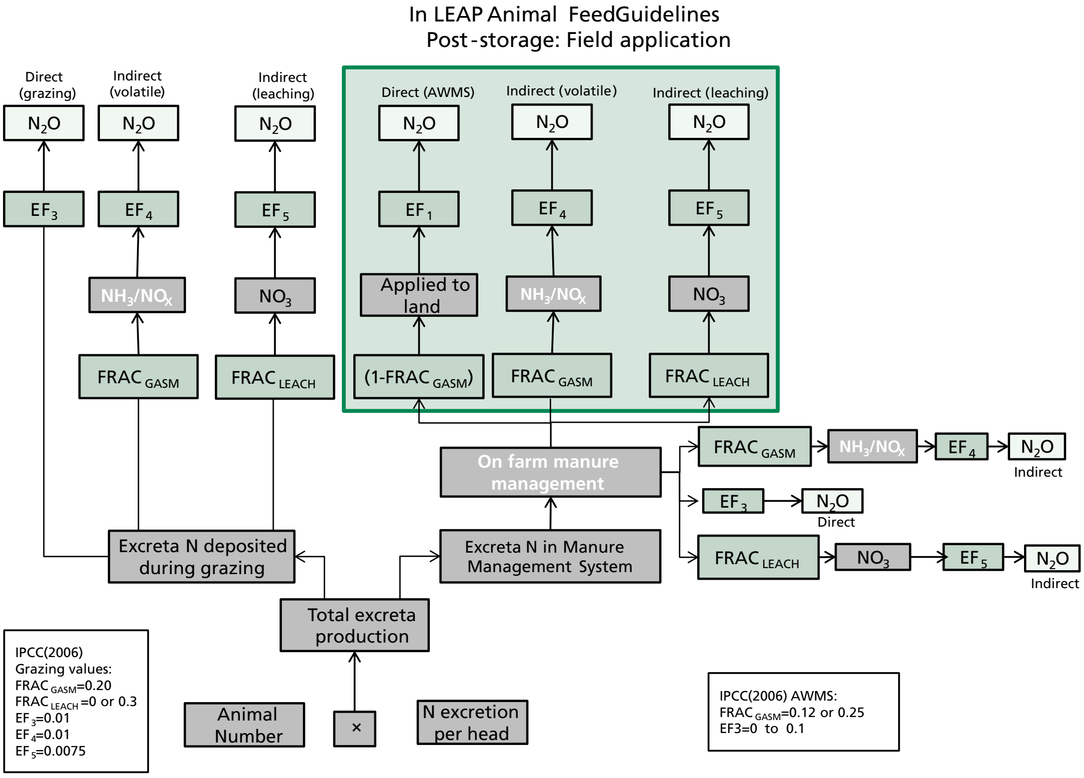
Indirect N_2O emissions from N leached or lost from runoff after manure application may be predicted with the following formulas:

$$N_L = N_A(Frac_{wet})(Frac_{leach}) \equiv {}^{kg\,N}/_{day} \quad (10)$$

where: N_L = N content of manure in kg lost through leaching and runoff; N_A = N content of manure in kg stored in a system potentially subject to leaching and

Figure 15

Summary of approach for calculating N_2O emissions from pig excreta and waste management systems using IPCC (2006) activity factors – FRAC refers to fraction of N source contributing – and emission factors – EF in kg N_2O-N/kg N



Note: Summary of approach for calculating N_2O emissions from animal manure and the waste management system using IPCC (2006) activity factors (FRAC refers to fraction of N source contributing) and emission factors (EF in kg N_2ON/kg N). GASM = gaseous loss as ammonia; FRACgasm and EF1 vary with type of animal waste management system. For manure, only manure storage losses are included in these guidelines; losses from land application are covered in the LEAP *Animal Feed Guidelines*.

runoff; $Frac_{wet}$ = fraction of N available for leaching and runoff; $Frac_{leach}$ = 0.3 – the IPCC default fraction of N lost through leaching and runoff; the default N_2O emission factor from manure N lost through leaching and runoff is 0.0125 according to the IPCC (Dong *et al.*, 2006):

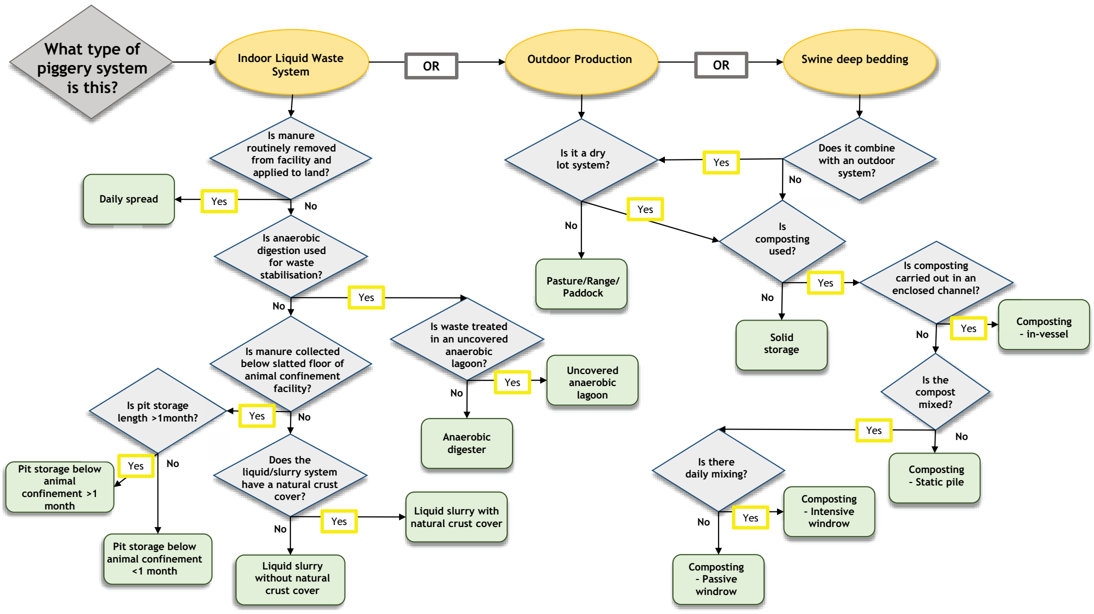
$$N2O_L = 0.0125\, N_L \left(\frac{44}{28}\right) \equiv {}^{kg\ N2O}/_{day} \quad (11)$$

11.2.8 Emissions from other farm-related inputs

There may be substantial variations in energy requirements between different types of production, but in intensive systems there are generally requirements for lighting, ventilation and heating according to the climate. Extensive systems may not have significant inputs, but fuel for transport shall be accounted. Where there is a significant use of consumables in farm operations, the GHG emissions associated with their production and use should be accounted: in practice these will often be a

Figure 16

Decision guide for selection of manure management system for use with IPCC models



minor contribution and data relating to them may be difficult to find. Section 8.4.3 gives cut-off criteria for treatment of minor contributors.

The total use of diesel or petrol fuel and oil lubricants for on-farm operations shall be estimated on the basis of actual use, and shall include those used by contractors involved in on-farm operations. Where actual fuel-use data is unavailable, fuel use should be calculated from the operating time in hours for each activity and fuel consumption per hour. The data on fuel consumption per ha can be derived from published data or databases such as Ecoinvent. Operations associated with the production, storage and transport of pig feed should be carefully accounted for to avoid double counting. If values for the associated emissions are derived from a database. The inventory shall, however, include fuel used for transport from the source of feed storage to the farm, where the point of storage is not on-farm if it has not been accounted in the feed calculations, for example, compound feed or concentrates purchased from a feed merchant. Some of the main processes that use fuel are transporting water and using vehicles to move animals and feed to the farm and other specific farm activities.

The total use of a particular fuel is then multiplied by the relevant country-specific GHG emission factor, which accounts for production and use of fuel; third-party databases or geographically specific datasets may be used for secondary inventories. The process for calculating fuel-related emissions also applies to electricity. Electricity use associated with farm activities – excluding feed production and storage where they are included in the emission factor for feeds – shall be estimated: this includes electricity for water circulation, ventilation and lighting. Country-specific emission factors for electricity production and use shall be applied according to the source of the electricity concerned. These emission factors are typically the national or regional averages, which would account for the mix of renewable and non-renewable energy sources used for the electricity grid mix. Various third-party databases contain country-specific datasets for electricity grid mixes.

The final on-farm results are calculated on the basis of the cumulative inventory of inputs and emissions converted to the appropriate impact category according to characterization factors: for climate change resulting from electricity use, for example, the total annual kilowatt hours consumed is multiplied by the national emission factor in kg – CO_2e/kWh. Once each inventory has been converted to the appropriate impact category metric they are summed and divided by total annual production to be reported on a per-functional-unit basis.

11.2.9 Residues and waste

The management of wastes other than manure shall also be accounted. In particular, the management of animals that die and are disposed of by burial, rendering, composting or other method shall be included in the inventory. Solid waste materials such as discarded packaging shall also be accounted for.

11.3 WATER USE INVENTORY METHODS

Water inventories should be developed using water balances for each component of the system – water supply, housing and manure management. Freshwater consumption – direct water use affecting the availability of fresh water for ecosystems (Milà i Canals *et al.*, 2009) is an appropriate indicator of water use. Other indicators associated with nutrient load in water may also be included in accordance with ISO 14046 (2014).

Major components of the foreground and background system are listed below.

Foreground system:

- piggery water supply system if water is supplied from on-site sources (see water balance 1);
- water use for piggery housing (see water balance 2); and
- piggery manure management (see water balance 3).

Background system:

- piggery water supply system if drawn from a major water supply;
- water used to supply feed grain – irrigated feed; and
- water use associated with other inputs such as energy.

Methods and assumptions used to determine water use in each stage are provided in the following sections.

11.3.1 Water Supply and Water Balance

Water supplies may be drawn from different sources: groundwater through bores and wells and surface water such as rivers and creeks, or it may be captured from rainfall in on-site tanks. Not all farms have records of direct water use for activities such as drinking or cleaning. Records of water use will not include water losses between the point of collection and the piggery – but it is essential to establish and include these losses. If, for example, a farm pumps from a bore to an open water storage dam and then to the piggery, losses may occur via evaporation and seepage during storage. If the water meter is located after the storage stage, metered water use will not take these losses into account.

Pan evaporation is one way of estimating evaporation related to temperature, humidity and rainfall. The method involves direct measurement of natural evaporation from a water surface in a shallow pan. Evaporation pans are simple, but they require daily measurement and maintenance and there may be significant variation between the evaporation from a small pan and a large body of water (Watts, 2005).

Brutsaert (1982) describes pan evaporation results as "...of uncertain and often dubious applicability." Watts and Hancock (1985) attribute the inconsistencies in pan evaporation estimates to the differences between radiation and the aerodynamic characteristics of the pan and the conditions prevailing for crops and large bodies of water, adding that "... all evaporation pan data should be regarded as untrustworthy."

The calculation of open-water evaporation is achieved by applying a "pan factor" to the measured evaporation. The equation for this conversion is:

$$E = K_p \times E_{pan}$$

where E = open-water evaporation in mm/day; K_p = pan factor, a constant determined by the pan siting, relative humidity and wind speed; and E_{pan} = pan evaporation in mm/day, based on local data.

The value of K_p can vary widely. Ham (1999) determines a value of 0.81 for a farm lagoon containing animal waste; Ham (2007) shows the ratio between lagoon and pan evaporation as variable but typically between 0.7 and 0.8. As an intermediate, a K_p value of 0.75 may be suitable, but this should be assessed on-site.

Water may also be lost during storage through seepage, which is the loss of water through the bed and banks of a water storage. Seepage is often considered a marginal contribution to total storage losses as compared to evaporative losses and has not been extensively researched. In the context of LCA, it is difficult to determine whether seepage is actually a loss, because the water may enter underground aquifers or flow to nearby streams via subsurface lateral flow. It should be determined whether seepage of clean water is likely to return to usable groundwater, or whether it is lost. A decision can then be made as to classification of this water flow.

Seepage rates are variable and depend on the characteristics of soil, hydraulic flows and the water itself. Watts (2005) states that seepage should theoretically increase with increased amounts of water, an approach used by Duesterhaus *et al.* (2008).

11.3.2 Water use for piggery housing

In conventional housed piggeries water is primarily used for drinking, cleaning and cooling. In some systems, clean water may also be used for flushing, and significant amounts of water may be spilled from drinkers. Because it is difficult to disaggregate these uses of water at commercial piggeries, various assumptions may be required to establish a water balance and quantify uses and outputs.

The first assumptions relate to drinking water and the fate of drinking water from pigs. For the pig herd, drinking water and the fate of this water may be estimated using an animal water balance, for example using data from Mroz *et al.* (1995) and the National Research Council (1998).

Table 6: Range of values for pig water intake (litres/head/day) in published literature and PIGBAL

Pig type	Range from the literature	PIGBAL estimates
Suckers	0.0 – 0.4	0.5
Weaners	0.49 – 3.1	3.6
Growers-finishers	1.9 – 10.5	4.0 – 8.0
Gestating sows	5.0 – 25.0	13.0
Lactating sows	1.0 – 49.0	30.0
Boars	10.0 – 5.0	13.0

Drinking water intake

The factors determining pigs' intake of drinking water include feed intake, ambient temperature and water temperature, class of pig and live-weight (National Research Council, 1998). Reviews of water intake require careful scrutiny of the data to determine whether spillage was included or excluded and hence whether the study determined a true measure of intake. Spillage from drinkers can be considerable and must be determined separately in the housing water balance because it is subject to a different water-flow pathway.

Water use can vary in response to climate, which makes prediction difficult. As a proportion of feed intake, predicted drinking water may be as follows: i) for grower and finisher pigs, the ratio of water intake to feed may be 2.5 (Braude *et al.*, 1957 cited in National Research Council, 1998; and ii) for dry sows the ratio of water intake to feed may be 2.8 (Van der Peet-Schwering *et al.* 1997, cited in Froese and Small, 2001). Mroz *et al.* (1995) suggest that water consumption for lactating sows is at least 40 percent higher than that of non-lactating sows

The resulting formula for drinking water in growing pigs, gestating sows and lactating sows is:

$$WI = FI \times W_f$$

where WI = water intake; FI = feed intake; W_f = water intake factor – growing pigs = 2.5, gestating/lactating sows = 2.8.

Table 6 compares drinking water predicted using the above equation with the standard values used in the Australian PIGBAL waste estimation programme (Skerman *et al.*, 2015).

11.3.3 Water intake with feed

In addition to drinking water, pigs ingest water with feed equivalent to the moisture content of the feed – generally 11 percent to 12 percent – and generate additional water from the breakdown of carbohydrates, fat and protein during digestion. This is known as metabolic water and is excreted as urine and faeces. Metabolic water may be determined from the simple relationship reported in the National Research Council (1998), which suggested that 0.38-0.48 litres of water is produced per kilogram of feed.

The water ingested with feed can be determined from analysis of diets in piggeries multiplied by the feed intake of each class of pig. Water inputs may also arise from water constituting part of the body weight of purchased pigs. Water content in pigs is 60 percent of body weight (National Research Council, 1998).

11.3.4 Water loss pathways from pigs

Water losses or outputs from a pig herd consist of water uptake in live-weight gain, losses through respiration and perspiration, and excreted losses in urine and faeces.

Water contained in the live-weight of sale pigs may be determined using the 60 percent moisture content mentioned above, also called unfasted body weight, which is similar to the values reported in National Research Council (1998) after being adjusted for the inclusion of feed content in the gastro-intestinal tract.

Perspiration losses may be determined by using a loss rate of 13.2 ml m^2 skin area per hour, as published by Mroz *et al.* (1995).

Respiration losses may be determined by using an average loss rate of 0.58 litres per pig per day, as reported by the National Research Council (1998). This loss rate was for a 60 kg pig, and may be adjusted on the basis of body weight for different classes of pig.

Water excreted in urine and faeces for manure may be determined by difference: this may result in a manure moisture content of 93 percent, though it may be lower where drinking water intake is also lower as in countries with a cool climate.

11.4 ADDITIONAL WATER USE ACTIVITIES

11.4.1 Spillage, cleaning and flushing

Pigs waste large amounts of water. Li *et al.* (2005) reported wastage rates of 15 percent to 42 percent of total drinking water supplied, which matches observations from Australian piggeries. An appropriate wastage rate should be included in the assessment.

The use of cleaning water should be included according to housing type on the basis of local estimates.

11.4.2 Cooling water

Cooling by evaporation can be a major water use, and shall be included in the assessment.

11.4.3 Shed evaporation

The small amount of water that may evaporate from housing floors or effluent channels should be estimated and included as a loss in the water balance.

11.5 PIGGERY MANURE MANAGEMENT WATER BALANCE

In conventional piggeries with effluent flushing systems, effluent from the piggery – a mixture of excreted faeces and urine, spilled water, cleaning water, clean and recycled water and spilled feed – may be flushed into open lagoons or tanks for storage.

Rainfall that may be collected in open storage ponds constitutes an input to the water balance. Outputs from lagoons or tanks include evaporation, irrigation or regulated releases, and possibly seepage. Evaporation may be determined by using the same approach as for clean water storage (see Equation 3).

11.5.1 Background water use

The major source of water use in the background system arises from irrigation in the production of feed grain. Even small proportions of grain from irrigated land can contribute significantly to water use, and must be accurately assessed. Water balances for the irrigation water system are required so that all losses back to the first point of extraction from the environment are included.

Other background processes such as energy use may include water as an input. A review of inventory datasets is often required to determine and classify water use.

11.6 TRANSPORT

Estimating the environmental impacts of transport entails two allocation issues: allocation of empty transport distance of the means of transport, and allocation of the load fraction of the means of transport.

Empty transport distance is often allocated in the background models used for deriving the secondary LCI data for transport, but if primary data for transport are used the practitioner should estimate the empty transport distance. It is good practice to provide a best estimate with a corresponding uncertainty, in accordance with the requirement in Section 10.4 of these guidelines.

Kilometres of empty return of transport shall be allocated on the basis of the average load factor of the transport under study. If no supporting information is collected, 100 percent empty return should be assumed.

If products are transported on a vehicle, resource use and emissions for that vehicle shall be allocated to the transported products. A means of transport has a maximum load expressed as tonnage, but the maximum weight can only be achieved if goods are loaded at maximum density.

Transport emissions shall be allocated to transported products on the basis of mass share, unless the density of the transported product is significantly lower than average such that the volume restricts the maximum load, in which case a volume share shall be used.

Fuel consumed by transport can be estimated using: i) the fuel cost method; ii) the fuel consumption method; or iii) the ton-per-kilometre method. Transport distances may be estimated from routes and maps or obtained from navigation software.

11.6.1 Calculation method for fuel consumption during transport

Fuel consumption method

Data must be collected on “fuel consumption [L]” for each mode of transport. GHG emissions in kg-CO_2e are calculated by multiplying fuel consumption [L] by “life cycle GHG emissions related to supply and use of fuel” in kg-CO_2e/L for each type of fuel.

Fuel cost method

Data must be collected on “fuel expense” in US$/year and “average fuel price” in US$/litre for each mode of transport. GHG emissions are calculated in kg-CO_2e by multiplying fuel consumption – fuel expense/average fuel price – by “life-cycle GHG emissions related to supply and use of fuel” in kg-CO_2e/litre for each type of fuel.

Ton-per-kilometre method

Data must be collected on loading ratios as percentage and transport load in terms of tonnes per kilometre [t-km] for each mode of transport. Life cycle GHG emissions are calculated in kg-CO_2e by multiplying the transport load – [t-km] – by the "life cycle GHG emissions related to fuel consumption per transport ton-kilometre" – kg-CO_2e/t-km – for different loads for each mode of transport.

11.7 INCLUSION AND TREATMENT OF LAND-USE CHANGE EFFECTS

The LEAP *Animal Feed Guidelines* provide additional detail. GHG emissions associated with changes in land use should be accounted separately and reported. PAS 2050 provides additional guidance.

11.8 BIOGENIC AND SOIL CARBON SEQUESTRATION

This relates only to the feed production stage of pig production, and the methods are covered in the LEAP *Animal Feed Guidelines*. As noted in these guidelines, biogenic and soil carbon sequestration shall be included in the final GHG emissions value. Where no data relating to soil carbon sequestration are available, the LEAP *Animal Feed Guidelines* provide default values for temperate climates. The last option is to assume zero change in soil carbon.

11.9 PRIMARY PROCESSING STAGE

This stage of the pig value chain includes slaughter, removal of blood, hair, hooves and head, evisceration, washing and cooling, cutting and packaging, and production and management of by-products such as blood and meat and bone or bone-meal in addition to the main meat products. In operations that include rendering, the energy requirements can be significant. Other inputs that shall be included at this phase are electricity for refrigeration and water and chemicals for cleaning equipment. The following processes shall be evaluated:

- transport of live animals to the processing site from the farm gate;
- production, delivery and consumption of materials used in processing such as cleaning chemicals and packaging materials;
- other purchased inputs or ingredients;
- usage of fresh water and treatment of waste water treatment in terms of quantity, chemicals and energy;
- releases from background processes, including production of chemicals, ingredients and refrigerants and losses and other sources of emissions;
- energy consumption – electricity, natural gas and energy produced on-site; and
- management of waste with environmental impacts such as disposal in landfill and treatment of waste water.

11.9.1 Calculating GHG emissions from meat processing

Calculation of these GHG emissions shall account for resource use, waste-water processing and the associated GHG emission factors. The use of electricity and other energy shall account for total embodied emissions relevant to the country where primary processing occurs. Data on waste-water quantity and composition are used with the GHG emission factors used in the method of waste-water processing (IPCC, 2006) to calculate GHG emissions. An example is given in Box 4. Total GHG emissions shall be allocated among the various co-products, as outlined in Section 9.3.4.

Box 4. Example of emissions calculation for an average abattoir in the United States

This facility processes 75,000 head per week with an average weight of 125 kg. Data are given for the entire facility on an annual basis

		Emission factor*
Water use (m^3)	1 041 000	0.435 kg CO_2e/m^3
Waste-water treatment (m^3)	1 041 000	3.99 kg CO_2e/m^3
Electricity (MWh)	87 165	770 kg CO_2e/MWh
Natural gas (m^3)	14 152	2.5 kg CO_2e/m^3
Propane (L)	32 867	4.3 kg CO_2e/litre
Fuel oil #2 (L)	112 059	3.3 kg CO_2e/litre
Fuel oil #5 #6 (L)	848 682	3.2 kg CO_2e/litre
Diesel (L)	1 150 677	3.2 kg CO_2e/litre
Gasoline (L)	59 667	3.0 kg CO_2e/litre
Meat products (kg)	274 220 000	
Inedible co-products (kg)	213 828 000	

* *Calculated from Ecoinvent processes using SimaPro 7.3®*

The unallocated gate-to-gate GHG emissions for the facility are calculated as the sum of the products of the inputs and emission factors: 78,845 mt CO_2e. The calculation of the estimated impact of the meat products is achieved through an economic or mass allocation, as shown in a subsequent example.

11.9.2 Calculating GHG emissions from pig processing

Calculation of these GHG emissions shall account for resource use, waste-water processing and management of inedible offal and bones, using appropriate emission factors. The use of electricity and other energy shall account for total embodied emissions relevant to the country where primary processing occurs.

12. INTERPRETATION OF LCA RESULTS

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

1. At all steps of the LCA the calculation approaches and data shall match the goals and quality requirements of the study: in this sense interpretation of results may inform an iterative improvement of the assessment until all goals and requirements are met; and
2. Conclusions and recommendations shall be developed, for example in support of environmental performance improvements. Interpretation entails three elements, as detailed below.

12.1 IDENTIFICATION OF MAJOR ISSUES

The identification of important issues involves the identification of the main impact categories and life cycle stages and assessment of the sensitivity of results to methodological choices.

The first step is to determine the life cycle stage processes and elementary flows that contribute most to the LCIA results, and the most relevant impact categories.

The second step is to assess the extent to which methodological choices such as system boundaries, cut-off criteria, data sources and allocation choices affect the outcome of the study; this applies especially to the life cycle stages with the most important contributions. Any explicit exclusion of supply-chain activities, including those excluded by cut-off criteria, shall be documented in the report. Checks to be used to assess the robustness of the footprint model include the following (ILCD, 2010):

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

Table 7: Guide for decision robustness from analysis of sensitivity and uncertainty.

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

12.2 CHARACTERIZING UNCERTAINTY

This section is related to Section 10.3. Several sources of uncertainty are present in LCAs: lack of precise knowledge regarding the quantity of an input or emissions from a process contributes to the uncertainty of the result. The inherent variability of complex systems are also inherently variable, which also introduces imprecision in the final result. Imprecision arising from lack of knowledge can be reduced by collecting more data. It may be possible to reduce the influence of fundamental process variability on the results by disaggregating complex systems into smaller parts, but inherent variability cannot be eliminated completely. The LCIA characterization factors used to combine the many inventory emissions into impacts introduce uncertainty into the estimation of impacts. And bias is introduced if the LCI model is missing processes or otherwise does not represent the modelled system accurately.

Variations and uncertainty in data should be estimated and reported, because results based on average data – the mean of several measurements from a given process at single or many facilities – or on LCIA characterization factors with known variance do not reveal the uncertainty in the reported mean value of the impact. Uncertainty may be estimated and communicated quantitatively through a sensitivity and uncertainty analysis and qualitatively in discussion. Understanding the sources and magnitude of uncertainty in the results is critical for assessing the robustness of decisions made on the basis of the results of a study. When mitigation action is proposed, knowledge of the sensitivity to and uncertainty associated with the changes proposed provides information about the robustness of decisions, as shown in Table 7.

Accurate characterization of stochastic uncertainty and its effect on the robustness of decisions should focus at least on the supply chain stages or emissions identified as significant in the impact assessment and interpretation. Such an uncertainty analysis shall be conducted and described in reports to third parties.

12.2.1 Monte Carlo analysis

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

12.2.2 Sensitivity analysis

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

The relative sensitivity of specific activities measures the percentage change in impact arising from a known change in input parameter (Hong *et al*., 2010).

12.2.3 Normalization

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

12.3 CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

The final part of interpretation is to draw conclusions from the results, provide answers to questions raised in the goal and scope definition stage and recommend actions to the intended audience. This must be done within the context of the goal and scope and must account explicitly for limitations in robustness, uncertainty and applicability.

Conclusions derived from the study should identify supply chain "hotspots" derived from the contribution analysis and the improvement potential associated with possible management interventions. Conclusions should be given in the context of the goal and scope of the study; any limitation of the goal and scope can be discussed subsequently in the conclusions.

If a study is intended to support comparative assertions – that is claims asserting difference in the merits of products based the study results – consideration must be given to whether differences in method or data quality in the model of the compared products impairs the comparison, as required under ISO 14044:2006. Any inconsistencies in functional units, system boundaries, allocation, and data quality or impact assessment shall be evaluated and communicated.

Recommendations are based on the final conclusion of the LCA study: they shall be logical, reasonable and plausible and must relate strictly to the goal of the study. Recommendations shall be given with any relevant limitations to prevent misinterpretation beyond the scope of the study.

12.4 USE AND COMPARABILITY OF RESULTS

These guidelines refer only to a partial LCA. If results are required for products through the entire life cycle, the analysis must be linked with relevant methods for secondary processing through to consumption and waste stages, as recommended in EPD (2012) and PAS 2395 (2013; draft). Results from the application of these guidelines cannot be used to represent the whole life cycle of pig products, but they can be used to identify hotspots in the cradle-to-primary processing stages – which are major contributors to emissions in the whole life cycle – and to assess potential GHG reduction strategies. The recommended functional units are intermediate points in the supply chains for virtually all pig-sector products and hence will not be suitable for a full LCA. They can, however, provide valuable guidance for practitioners to the point of divergence from the system into different types of products.

12.5 GOOD PRACTICE IN REPORTING LCA RESULTS

The LCA results and interpretation shall be fully and accurately reported, without bias and in accordance 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; language and terminology should be readily understood by the intended user to minimize the risk of misinterpretation.

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

The report should include extensive discussion of limitations related to accounting for a non-comprehensive number of impact categories and outputs, addressing: i) possible positive or negative impacts on non-GHG environmental criteria; ii) possible positive or negative environmental effects, for example on biodiversity, landscape or carbon sequestration; and iii) multi-functional outputs other than production, such as economic, social and nutrition outputs.

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

12.6 REPORT ELEMENTS AND STRUCTURE

The following elements should be included in an LCA report:

- an executive summary targeting a non-technical audience such as decision-makers that includes the main elements of goal and scope of the system studied and the main results and recommendations along with an indication of assumptions and limitations;
- the LCA name, date, responsible organization or researchers, objectives and intended users;
- the goal of the study – intended applications and targeted audience, methodology and consistency with these guidelines;
- functional unit and reference flows, including overview of species, geographical location and regional relevance of the study;
- system boundary and unit stages such as from farm gate to the primary processing gate;
- materiality criteria and cut-off thresholds;

- allocation methods, with justification if different from the recommendations in these guidelines;
- a description of inventory data – representativeness and averaging periods and assessment of data quality;
- a description of assumptions or value choices made for the production and processing systems, with justification;
- feed intake and application of the LEAP *Animal Feed Guidelines*, including descriptions of emissions and removals if estimated for land-use change;
- LCI modelling and calculation of LCI results;
- results and interpretation of the study and conclusions, including recommendations for impact mitigation if relevant;
- a description of the limitations and any trade-offs; and
- an account of independent third-party verification if the study is intended for the public domain.

12.7 CRITICAL REVIEW

Any LCA must be subject to internal reviews and iterative improvements, and if the results are intended for publication third-party verification or external critical review must be carried out – and should be undertaken for internal studies – to ensure that:

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

Any critical review shall be undertaken by a panel of suitably qualified reviewers from the agriculture industry, or government or non-government officers with experience in the assessed supply chains and LCA. Independent reviewers are preferable. The panel's report and the critical review statement and recommendations shall be included in the study report if it is to be published.

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APPENDICES

Appendix 1

Literature review of available life cycle assessment studies focused on pig supply chains

GHG emissions from livestock systems have been identified as a significant contributor to total global emissions (e.g. Steinfeld et al., 2006). There have been many published environmental assessments of livestock systems globally. However, the methodologies used for estimating the environmental impacts have varied widely. Various authors have highlighted the difficulties in making comparisons across published studies because of the large differences in methodologies used (e.g. Roma *et al.* 2015). Consequently, there has been interest in trying to agree on a common methodology for estimating the environmental impacts both between and within sectors. Estimates of environmental impacts are now often been based on use of LCA. The purpose of this brief review is to highlight differences in methodological approaches and results of published LCAs of pig farming systems.

A1.1 NGUYEN *et al.*, 2011

Nguyen *et al.* 2011 presents an environmental profile of Danish pork through a life cycle assessment (LCA). Such assessments often use two different approaches – attributional and consequential. The former describes the resources used and the related emissions in producing the product – in this case 1 kg of pork – and the latter accounts for the resources used and the related emissions in producing a further 1 kg of pork.

This choice of method affects the results in that the attributional approach uses information about impacts related to factors such as specific feed production, whereas the consequential approach relies on data on issues such as the environmental cost of producing the feed necessary to produce a further 1 kg of pork. Both methods are in use.

A previous LCA of Danish pork used the consequential method. The publicly available specification (PAS 2050) for documenting the global warming potential or carbon footprint of a product, however, requires the attributional approach. In the Nguyen report, therefore, the assessment uses both methods. The PAS 2050 has the option of including the effects of changes in land use on the global warming potential following the production of feed, but because this aspect is not sufficiently developed, it is not included here for any of the methods. If it had been included, the global warming impact would have been higher.

The environmental assessment uses data representing typical Danish pork production in 2010, and data from the 25 percent of Danish pig herds with the highest technical efficiency in terms of piglets per sow and feed use per kg of pork produced. On the basis of historical development, these herds will in a few years be representative of Danish pig production. The assessment treats pig production as a landless business where all feeds are imported and all manure exported. The method

Table A1.1: Environmental impact per 1 kg Danish pork from slaughterhouse (carcass weight).

	Typical 2010 production		25% of herds with higher efficiency	
	Attributional PAS 2050	Consequential	Attributional PAS 2050	Consequential
Global warming potential (GWP): kg CO_2e	3.1	3.4	2.8	3.1
Acidification: g O_2e	56.0	61.0	51.0	55.0
Eutrophication: g NO_3e	243.0	321.0	220.0	292.0
Non-renewable energy: MJ primary	21.0	22.0	20.0	21.0
Land occupation: m^2 year	5.8	8.5	5.3	7.9

used ensures that the results do not differ from a situation where a farmer produces part of the feed and uses some of the manure for production on his farm.

The environmental impact is expressed in terms of “1 kg Danish pork carcass-weight delivered from the slaughterhouse”. Five impact categories are considered: global warming potential, acidification, eutrophication, non-renewable energy use and land occupation.

Table A1.1 shows the environmental performance with respect to the five impact categories expressed in equivalents (e) of each category. Estimated environmental impact is higher under the consequential approach than PAS 2050, largely because feed cereals produced in Danish conditions are estimated to have less environmental impact than the estimated marginal production of cereals on world markets: this is partly because of the higher yields per ha and partly because of the strict environmental regulations in Denmark, which minimize the effects of eutrophication, global warming and land-use requirements.

Unlike earlier results for Danish pork based on 2006 data and the consequential approach, this work is based on updated emission coefficients and housing conditions, which makes comparison difficult. The global warming impact is nonetheless slightly lower in Nguyen *et al.* at 0.2 kg CO_2e per 1 kg pork, which probably reflects the improvements in cereal production and pig rearing in the period concerned.

The environmental burden of the pork is primarily related to the farming stage, and less so to the slaughter stage product. Less than 0.2 kg CO_2e per 1 kg pork – 6 percent – is related to the slaughter stage, so increased efficiency in the primary stage must affect the total environmental impact of the pork. This is also shown in Table A1.1, which shows that pork from the 25 percent of pig herds with the highest technical efficiency have an environmental effect that is 8 percent to 10 percent lower than the average.

Table A1.2 shows the contribution of different elements to the environmental impact categories at the farming stage, expressed as 1 kg live weight of pig leaving the farm, whose total impact is estimated at 2.2 kg CO_2e for the typical Danish product under the PAS 2050 model. The contribution of ”feed use” is 60 percent of the total and ”on-farm emissions” account for 30 percent, whereas ”transport of feed” and ”on-farm energy use” are minor contributors. The main contributor to feed use impact is cereal, which reflects the importance of environmentally efficient cereal production. The main contribution to ”on-farm emissions” is from methane emissions from the manure and, to a lesser extent, N_2O emissions: these could be reduced by manure management procedures, which offers potential for improvement. With regard to acidification, one third of the total impact is related to on-farm emissions of NH_3, which shows the importance reducing them.

Table A1.2: Breakdown of contributing factors to different impact categories using PAS 2050 methodology for typical 2010 production, per live-weight of pig leaving farms.

Item	Global warming: g CO_2e	Acidification: g SO_2e	Eutrophication: g NO_3e	Non-renewable: MJ
Feed use	1 281	15.3	109.7	11.5
Transport of feed	130	1.8	1.7	1.9
On-farm energy use	148	0.2	0.3	2.0
On-farm emissions	662	15.0	28.4	
Manure utilization for fertilizer	261	16.4	55.5	0.5
Total	**2 482**	**48.7**	**195.6**	**15.9**

The manure produced results in on-farm emissions, but it has a value as a substitute for synthetic fertilizer. Danish regulations stipulate that 75 percent of fertilizer N must be derived from manure. Even though transport costs related to manure handling are high and field emissions are higher for manure because the substitution rate is not 100 percent, the net effect is a saving as a result of saved CO_2e emissions related to fertilizer production. In the typical case, the net effect is a saving of 0.03 kg CO_2e per 1 kg of pork produced.

A recent literature review arrived at a reference value of the climate impact associated with the primary production of 1 kg pork of 3.3 kg CO_2e per kg carcass weight leaving the farm. In the case of typical Danish pork the value arrived at is between 2.9 kg to 3.3 kg CO_2e per kg carcass weight leaving the farm; the lower figure is reached with the attributional approach, which is the most widely used, and is hence well below the reference value in the literature.

A1.2 DALGAARD *et al.*, 2007

This report uses the LCA approach to present data on the environmental profile of pork and identify the most polluting parts of the product chain of Danish pork. The functional unit was ”1 kg of Danish pork (carcass weight) delivered at the port of Harwich”; the environmental impact categories considered were global warming, eutrophication, acidification and photochemical smog. The global warming potential was 3.6 kg CO_2e per functional unit, which corresponds to the emissions from a 10 km drive in a car. The report found that the environmental ”hot spots” in the production chain occur in the stages before the pigs arrive at the slaughterhouse. The highest contributions to global warming, eutrophication and acidification arise from production of feed and handling of manure in the pig housing and under storage; the manure and slurry applied to fields contributed significantly to potential eutrophication. Transport of the pork to the port of Harwich did not constititue an environmental hot spot in that it contributed less than 1 percent of the greenhouse gases (GHGs) emitted during production. This result indicates that ”food miles” are a misleading environmental indicator.

The environmental profile of pork established in the report was based on data from 2005. The environmental impact in terms of global warming, eutrophication and acidification potentials were found to be lower than the values for 1995. These environmental improvements were mainly obtained as a result of lower consumption of feed and protein and improved handling of manure and slurry. There was also potential for improving the environmental profile further, particularly in reducing GHG emissions per 1 kg pork and digesting manure anaerobically and using biogas to produce heat and power.

Comparison of the environmental impact of Danish pork and British and Dutch pork showed that the global warming potentials were equal, whereas eutrophication and acidification potential was highest for British pork. Dutch pork had slightly lower eutrophication and acidification potential than Danish pork.

A1.3 BASSET-MENS AND VAN DER WERF, 2005

Intensive pig production is often associated with environmental burdens, but few studies deal with the environmental performance of current and alternative systems. This study uses LCAs to evaluate the environmental impacts and environmental hot spots of three contrasting pig production systems – conventional good agricultural practice according to French production rules, a French scenario called ”red label” and a French scenario called ”organic agriculture”. A “favourable” and an “unfavourable” variant was defined for each and used as indicators of uncertainty with respect to major parameters for technical performance and emission of pollutants. The environmental categories assessed were eutrophication, climate change, acidification, terrestrial toxicity, energy use, land occupation and pesticide use. Two functional units were used to express impacts: 1 kg of pig produced, and 1 ha of land used. The scenarios were examined with emphasis on their contribution to eutrophication and acidification.

Given this perspective, the red label scenario is an interesting alternative to good agricultural practice provided that its GHG emissions can be reduced. The results for organic agriculture depended largely on the choice of functional unit. For each 1 kg of pig produced, eutrophication and acidification were similar in organic agriculture and good agricultural practice, though the former agriculture led to less eutrophication and acidification than the latter when expressed per hectare. Environmental hot spots and important margins of improvement were identified in all three scenarios. The uncertainty analysis indicated that more reliable field-based estimations of emission factors for NO_3, NH_3 and N_2O were needed.

A1.4 RONGOOR *et al.*, 2015

Three pork production systems in the Netherlands are compared in an LCA using five environmental impact categories – global warming potential, fossil energy use, eutrophication potential, land occupation and water consumption. The pork production system uses locally cultivated and residual food products as feed, and bioenergy produced on-farm has the lowest environmental impacts in all categories. Cultivation and transport of feed products, and to a lesser extent manure management, are in all cases the process steps with the largest environmental impacts.

A1.5 RECKMANN *et al.*, 2013

With population growth resulting in increased demand for food, production systems, especially for meat, are under pressure to tackle climate change. With pork accounting for two thirds of German meat production, there is a need to assess the associated environmental impacts. This study uses an LCA to provide data for an environmental profile of pork production in Germany in 2010 and 2011. The system boundaries encompassed the production of feed, the housing of pigs, slaughter and pork production. The pig housing stage was modelled on the basis of separate data for different housing stages for farrowing, weaning and finishing. Results for the impact categories of global warming potential, eutrophication and acidification are expressed per 1 kg pork as slaughter-weight. The global warming potential was estimated at 3.22 kg CO_2-e per 1 kg of pork. Eutrophication was 23.3 g PO_4-e, whereas acidification was 57.1 g SO_2-e per 1 kg of pork. A sensitivity analysis was carried out for four input parameters to estimate their influence: these were related to water and energy use for feed production, the fattening stage, pig housing, slaughter and water use because the values given in the literature differ significantly. Three characterization methods were used for each – CML 2 Baseline 2000, EDIP 2003 and IMPACT 2002+. The only input parameter tested that affected the results was energy use in the fattening stage.

A1.6 CEDERBERG AND FLYSJÖ, 2004

This reports describes an environmental system analysis of three scenarios for future pig farming systems in Sweden: A – animal welfare, B – environment and C – product quality at low prices. The aim was to investigate the environmental benefits and disadvantages of pig meat production systems.

The LCA is the principal method. The functional unit is 1 kg of meat free of bone and fat. The systems include all phases in the life cycle of fertilizers, feed products, seed, diesel and pesticides; transport is also taken into account, but buildings, machinery and medicines are not included. Allocation is done on an economic basis, and alternative allocation methods are tested in a sensitivity analysis. Data were collected for future pig farming systems on the basis of expert opinion, yield trend data and application of future techniques in the production systems.

The chosen impact categories were: i) use of energy, non-renewable resources and land; ii) toxicity from pesticide use; iii) climate change; iv) acidification, v)eutrophication and vi)photo-oxidant formation.

The use of energy was 16.1 MJ/functional unit (FU) in scenario A, 14.7 MJ/FU in B and 18.4 MJ/FU in C. The lower energy requirement in A and B resulted largely from the differences in feeding strategy: in these scenarios 90 percent of protein feed was cultivated locally, whereas in scenario C all protein feed was imported. The higher energy use in A in comparison with B resulted from lower piglet production per sow and higher feed consumption in A, and extra requirements for the field work associated with the sows´ outdoor grazing period.

Much of the use of resource phosphorous in scenarios A and C was explained by the consumption of mineral feed. Introduction of the enzyme phytase in scenario B kept the consumption of new phosphorous at a low level: the positive effect of adding phytase to the feed was evident in the evaluation of farm-gate balances in the three scenarios; no P-surplus was found in scenario B.

Total annual land occupation varied between 11.3 and 13.5 m^2 per functional unit. Scenario A required the largest grass area because the sows had a period of grazing; scenario B had the lowest land occupation.

In scenario B (environment), there was a very conscious strategy to reduce pesticide use by measures such as a diversified crop rotation (due to altered protein feeding in comparison with C) and the practice of mechanical weed regulation. The use of pesticides per ha was halved on the pig farms in scenario B in comparison with C. in the whole life cycle of pig meat, the use of pesticides was only 40% in B in comparison with C.

Total GHG emissions varied between 3.6 and 4.4 kg CO_2-e/functional unit; scenario B had the lowest input. Nitrous oxide is the dominant GHG emitted in pig production. The positive outcome for scenario B was mainly an effect of lower fossil fuel requirements.

Total potential acidification associated with pig meat production is highly correlated with ammonia emissions. The use of modern ventilation in the pig houses and an efficient technique for manure spreading led to significantly lower acidification potential in scenario B.

Nitrate leaching from arable land is the most significant nutrifying emission. Leaching per hectare was calculated to be low in the three scenarios; leaching per functional unit was lowest in scenario B as a result of a combination of high yields and high feeding efficiency.

Improving pig meat production from an environmental perspective is largely a question of improving feed production. The cultivation of protein feed crops along with grain crops enables diversified crop rotation, which is an important measure for keeping pesticide use at a low level. The use of locally and regionally produced protein feeds reduces fossil fuel use and hence emissions of CO_2, NO_X and SO_2. New techniques for handling pig manure, which involve detailed planning and strictly controlled application during crop rotation, can significantly reduce emissions of reactive nitrogen. A mixed-livestock farming system with a practical balance between animals and fodder crops is likely to minimize nutrient losses and resource use while maintaining high yields and good production quality.

A1.7 WILLIAMS *et al.*, 2006

As agreed with the United Kingdom Department of Environment, Food and Rural Affairs (Defra), this research addresses questions relating to the development of sustainable production and consumption systems based on domestically produced foods. It quantifies resource use and environmental burdens arising from the production of ten food types – bread wheat, potatoes, oilseed rape, tomatoes, beef, pig meat, sheep meat, poultry meat, milk and eggs – and delivers accessible models that enable detailed examination of resource use and emissions arising from various production options in England and Wales.

The specific objectives were to identify and define major production systems and the related process flows, to establish the relevant data such as mass and energy flows and their uncertainties, to code the LCA models in a package such as Microsoft Excel, and to use the LCA to analyse the production systems and demonstrate that the model can compare production systems and identify-high risk elements.

Inputs for each food were traced back to primary resources such as coal and crude oil. All activities supporting farm production such as feed production and processing, manufacture of machinery and fertilizer, and fertility building and cover crops were included. The system included soil to a nominal depth of 3 mm. With regard to tomatoes and potatoes, the products were defined as ”national baskets of products” – tomato types such as loose and on-the-vine, for example – each included as a proportion of national production. Abiotic resources used were consolidated into a single scale based on relative scarcity. Individual emissions such as carbon dioxide and nitrous oxide were quantified and aggregated into impacts for global warming, eutrophication and acidification. Organic production systems were analysed for each food type, as were variations of non-organic or contemporary conventional production.

Table A1.3: The main burdens and resources used in the production of field and protected crops in the current national proportions of production systems; current organic share shown in parentheses.

Impacts and resources used per t	Bread wheat (0.7%)	Oilseed rape (0%)	Potatoes (1%)	Tomatoes (3.6%)
Primary energy used, GJ	2.5	5.4	1.4	130.0
GWP_{100}, t CO_2 (1)	0.80	1.7	0.24	9.4
Eutrophication potential, kg PO_4^{-3}	3.1	8.4	1.3	1.5
Acidification potential, kg SO_2	3.2	9.2	2.2	12.0
Pesticides used, dose-ha	2.0	4.5	0.6	0.5
Abiotic ressource used, kg antimony	1.5	2.9	0.9	100.0
Land occupation (grade 3a), ha	0.15	0.33	0.030	0.0030
Irrigation water, m^3			21	39

Table A1.4: The main burdens and resources used in animal production in the current national proportions of production systems; current organic share shown in parantheses.

Impacts and resources used per mt of carcass, per 20 000 eggs or per $10m^3$ milk	Beef (0.8%)	Pig meat (0.6%)	Poultry meat (0.5%)	Sheep meat (1%)	Eggs (1%)	Milk (1%)
Primary energy used, GJ	28.0	17.0	12.0	23.0	14.0	25.0
GWP_{100}, t CO_2	16.0	6.4	4.6	17.0	5.5	10.6
Eutrophication potential, kg PO_4^{-3}	158	100.0	49.0	200.0	77.0	64.0
Acidification potential, kg SO_2	471.0	394.0	173.0	380.0	306.0	163.0
Pesticides used, dose ha	7.1	8.8	7.7	3.0	7.7	3.5
Abiotic resorce use, kg antimony	36.0	35.0	30.0	27.0	38.0	28.0
Land occupation						
Grade 2, ha	0.04			0.06		0.22
Grade 3a, ha	0.79	0.74	0.64	0.49	0.67	0.98
Grade 3b, ha	0.83			0.48		
Grade 4, ha	0.67			0.38		

Interactions between inputs, outputs and emissions are represented by functional relationships derived from process models wherever possible, so that as systems are modified they respond holistically to specific changes: examples include crop yields and nitrogen supply, dairy cow diet formulation and milk yield, grass productivity, emissions, animal grazing and fertilizer applications. Process simulation models were also used to derive the long-term outcomes of nitrate leaching, soil, crop type and nitrogen supply.

In the analysis of results care is needed in comparing food types because they have different nutritional properties and different roles for consumers. The results for plant foods are shown in Table A1.3, those for food derived from animals in Table A1.4.

The relationship between energy use and GHG emissions in agriculture contrasts with most other industries. Nitrous oxide from the nitrogen cycle dominates GWP from field crops, contributing about 80 percent in organic and non-organic wheat production. Methane from livestock production, particularly beef, sheep meat and milk, is a GHG emission not related to energy use. About 97 percent of the energy used in tomato production is for heating and lighting to extend the growing season. Because energy use is almost identical for all tomato production systems per unit area, the highest yielding tomatoes – non-organic, loose, classic or beefsteak – incur lower burdens than other types of tomato.

On the livestock side, poultry meat production appears to be the most environmentally efficient, followed by pig meat and sheep meat – primarily lamb – with beef the least efficient. This results from factors such as: i) the low overheads of poultry breeding stock, which involves about 250 progeny per hen per year as opposed to one calf per cow; ii) very efficient feed conversion; iii) high daily weight gain of poultry, made possible by genetic selection and improved diets.

Poultry and pigs consume high-value feeds and live on arable land because their nutritional needs are largely met by arable crops produced in the United Kingdom and overseas. Ruminants can digest cellulose and hence make good use of upland and lowand grass. Much of the land in the United Kingdom is unsuitable for arable crops but highly suited to grass. One environmental disadvantage, however, is that ruminants emit more enteric methane, which contributes to the ratios of GWP produced to primary energy consumed; it is 50 percent higher for ruminant than pig or poultry meats. Unlike most of industry and domestic activity, the GWP from agriculture is dominated by nitrogen oxide, not by carbon dioxide from fuel use. Nitrogen oxide contributes about 80 percent of GWP in wheat production, but its contribution falls to 50 percent for potatoes because a large amount of fossil energy is used in cold storage. Because the underlying driver is the nitrogen cycle, the GWP of crop production is similar for different production systems, including organic. In contrast, carbon dioxide from the use of natural gas and electricity in tomato production is the dominant contribution to GWP.

The balance of GHG emissions and fossil fuel consumption is hence different from most industries. In agriculture nitrogen oxide dominates, with substantial contributions from methane. Consequently, the term "carbon-nitrogen footprint" is a more accurate term than carbon footprint in describing agriculture. Indeed, the nitrogen fluxes in agriculture and other types of land use also contribute to eutrophication and acidification. The majority of environmental burdens arising from the organic and non-organic production of agricultural foods arise directly or indirectly from the nitrogen cycle and its modification.

With regard to analysis of organic and non-organic production, 27 percent less energy was used for organic wheat production than for non-organic, but there was little difference for potatoes. The large reduction in energy used achieved by by avoiding synthetic nitrogen production was offset by lower organic yields and higher inputs into field work. GWP was only 2 percent to 7 percent less for organic than non-organic field crops, reflecting the need for nitrogen supply to equal nitrogen take-off and the consequent emissions to the environment as nitrous oxide to air and nitrate to water.

Most organic animal production reduced primary energy use by 15 percent to 40 percent, but organic poultry meat production increased energy use by 30 percent and egg production by 15 percent. The benefits of the lower energy needs of organic feed was over-ridden by lower performance per bird. Other environmental burdens were larger in organic production, but abiotic resource use was mostly lower – the exceptions were poultry meat and eggs – and most pig meat burdens were lower. GWP from organic production ranged from 42 percent less for sheep meat to 45 percent more for poultry meat. Land occupation was higher in organic systems, with lower yields and overheads for fertility building and cover crops, ranging from 65 percent more for milk and meat to 160 percent more for potatoes and 200 percent more for bread wheat, though the latter was a special case in that only part of a crop meets the specified bread-making protein concentration. Organic tomato yields were 75 percent of non-organic output. The lowest yielding organic tomatoes were the on-the-vine product; specialist tomatoes incurred six times the burden of non-organic loose classic tomatoes.

Other analyses showed that:

i. breeding a new variety of wheat that increases yield by 20 percent could reduce energy use by 9 percent;
ii. the choice of indoor or outdoor sow housing has a negligible effect on pig meat burdens;
iii. non-organic free-range poultry production increases energy use for meat by 20 percent and for eggs by 15 percent compared with housed production;
iv. beef production based 100 percent on beef cows wouold increase energy use by 50 percent; and
v. tomato burdens can be reduced by 70 percent if the proportion of combined heat and power used is increased nationally from the current 25 percent to 100 percent.

The use of Microsoft Excel spreadsheets enables users to change variables such as: i) the balance of organic and non-organic production at the national scale; ii) nitrogen supply to crops; iii) the balance of housing types in animal production; and iv) the use of combined heat and power systems in greenhouses so that alternative systems can be examined in detail. Default values representing the current balance of production methods in England and Wales for all food types are included: national proportions of main production systems and sub-systems and fertiliser application rates are examples.

Development of the modelling continues under project IS0222. The main activities include: i) development of versions suitable for analysis at the farm and regional levels; ii) inclusion of new foods such as sugar beet; and iii) analysis of the national basket of foods, which implies accounting for interactions between production systems such as crop rotations and land availability. The current model is an LCI of production; it will be developed to produce an LCA that will show the relative importance of the burdens of food production processes.

The conclusions of the research were:

i. Nitrous oxide is the single largest contributor to global warming potential for all foods except tomatoes, exceeding 80 percent in some cases.
ii. Organic field crops and animal products generally consume less primary energy than non-organic counterparts as a result of the use of legumes to fix nitrogen rather than fuel to make synthetic fertilizers; poultry meat and eggs are exceptions as a result of the high efficiency of feed conversion in the non-organic sector.
iii. The relative burdens of global warming potential, acidification potential and eutrophication potential between organic and non-organic field-based products are more complex than energy, and organic production often incurs greater burdens.
iv. Between 65 percent and 200 percent more land is required for organic production.
v. Arable crops incur smaller burdens per mt than meats, but all products have different nutritional properties and energy requirements beyond the farm, so care must be taken in comparisons.

vi. Meat from ruminants incurs more burdens than that from pigs or poultry, but ruminants can derive nutrition from land that is unsuitable for the arable crops that pigs and poultry must eat.
vii. Heating and lighting dominate the burdens of tomato production, but maximizing national use of combined heat and power could reduce primary energy consumption by about 70 percent.
viii. Non-organic loose classic tomatoes incur the smallest burdens, which increase progressively and definably towards organic on-the-vine specialist types.
ix. The model has been used to inform other research projects; it can be used to analyse variations in existing production systems and can be developed for new systems or products.

A1.8 NIELSEN *et al.*, 2008

Feed production is a major source of environmental impacts in animal production. Many feed ingredients are not fully digested by livestock, but the addition of enzymes to improve digestibility can increase absorption of energy and protein and thereby enhance the nutrient value of the feed. The study assess and compares the environmental burdens of the supplements and compares them with the savings made when enzymes are used in animal production. The study takes as its starting point the enzyme product Ronozyme WX CT, which is a xylanase that depolymerises xylans – a group of dietary fibres found in cereal cell walls – into smaller units. The product is widely used to improving the energy value and the protein digestibility of pig and poultry feed. The study relates to pig fattening in Denmark.

The LCA models Ronozyme WX CT production and reductions in feed consumption using SimaPro 7.0.2. data on Ronozyme WX CT production are derived from the Novozyme production facilities in Denmark. Other data are derived from the literature and public databases. Changes in feed consumption are determined by modelling in AgroSoft® feed optimization software. Guidelines published by IPCCC are used to estimate reductions in GHG emissions resulting from reduced manure generation and changed manure composition.

The study shows that the use of Ronozyme WX CT to increase the nutritional value of pig feed is justified in terms of reduced potential contribution to global warming, acidification, photochemical ozone formation and reduced energy use, and in most cases also nutrient enrichment and use of agricultural land. Ronozyme WX CT is often used with Ronozyme P5000 CT – a phytase – which together contribute considerably to reducing a range of environmental impacts from pig production.

Reduced contribution to acidification and nutrient enrichment is partly driven by reduced feed consumption and partly by reduced nitrogen emissions from manure resulting from reduced protein content in the feed. Sensitivity analyses of various parameters show that the observed advantages are generally robust, though the magnitude of the environmental advantages is uncertain. Changes in feed prices, for example, may turn contributions to nutrient enrichment and use of agricultural land into trade-offs.

Improvement of the energy and protein value of pig feed by application of Ronozyme xylanase and subsequent feed savings reduces the environmental impact per unit of pig meat produced; the enzyme product hence contributes to a sustainable development the Danish pork meat industry.

Enzymes that improve digestibility are a promising means of reducing the environmental impact of pig production. The potential of Ronozyme WX CT to reduce GHG emissions in Danish pig production is estimated at 5 percent – of the order of 4 million tons of CO_2e if the results are extended to the whole of Europe. Use of Ronozyme WX CT is driven by cost savings in animal production, so it is recommended that the use of digestibility-improving enzymes be explored as a cost-efficient means of reducing GHG emissions.

A1.9 PEREZ, 2009

Perez investigated the environmental impact of the pig production chain by modelling contrasting scenarios using LCA and scenario analysis methods to identify opportunities for improving sustainability. Pig production systems were modelled in the United Kingdom and Mexico, each with a standard production system and an alternative to give four scenarios that were different in the degree of integration between pig and crop production and that were then specified in detail to allow for comparison of environmental impact.

For analysis, the study used: i) a pre-assessment to establish the system boundary and clarify the processes and foods to be included in the LCI; and ii) a hybrid LCA method combining environmental burdens, or e-burdens, from the main sources and a compilation of e-burdens from indirect sources such as an economic-input-output LCA. The pre-assessment explored new techniques for constructing the system boundary and exploring the supply chains in detail with a view to establishing the importance of the supply chains of different feeds used in pig farms. The importance of previously reported products and processes that contribute to the environmental impact such as feed consumption and manure fermentation was confirmed. Novel findings included the importance of the environmental impacts of goods and services such as machinery, equipment, disinfectants and medicines, that are negligible with regard to the impact of the usual environmental indicators – global warming, acidification and eutrophication. The inclusion of new indicators such as ozone depression and ecotoxicity transferred to water and soil demonstrated the importance of including in the LCA the products and indicators excluded from many previous studies on the sustainability of pig production. Subsequently, the hybrid-LCA method made it possible to expand the system boundary of the LCA in a detailed evaluation of each scenario.

Results showed the United Kingdom scenarios to be superior in terms of management of nutrient flows, manure management and good agricultural practices. Opportunities to capture methane and recycle nutrients for crop production in the Mexican scenarios were highlighted, whereas reduction in machinery and equipment use and fuel consumption were the main opportunities in the United Kingdom scenarios. Opportunities to reduce the environmental impact of different pig supply chain sectors were identified in each scenario. The economic-input-output LCA method enables an extension of the traditional system boundary of the LCA to encompass e-impacts not included in previous studies. Comparison of the different scenarios revealed opportunities to reduce the environmental impact of pig production by highlighting the main challenges, avoiding the controversial issue of denoting a set of specific e-impacts that then favour one production system over another.

A1.10 STEPHEN, 2011

An LCA was developed to evaluate the environmental impacts of producing 1 kg of pig live-weight that compared dietary protein sources such as imported soybean meal with sources of protein in the United Kingdom – peas, beans and lupins. The LCA used several sub-models to include all processes within the system boundaries for pigs grown from 12 kg to 106 kg. Two sites were modelled – East Anglia and Yorkshire – each with individual site conditions; a comparison of the two sites used a soil type present at both. A Brazilian corn-soya rotation was simulated for the production of soybean meal.

Soil and climate conditions were defined at each site in the United Kingdo, and synthetic fertilizer and slurry scenarios were modelled. The environmental impacts assessed were GWP, eutrophication and acidification. There were differences between diets and sites and between the fertilizer scenarios.

It was concluded that GWP per 1 kg of pig in the slurry fertilizer scenario were consistently higher. The bean-based diets resulted in the lowest GWP100, with a range between 1.85 to 2.67 kg CO_2e; the soya-based diets had the highest GWP100 per 1 kg of pig, ranging from 2.52 to 3.08kg CO_2e. Diet production contributed the most to GWP per 1 kg of pig 63.9 to 78.5 percent. Transport contributed 1 percent to GWP in the home-grown diet scenarios, but in the soya-based diets the average figure was 3 percent. Eutrophication potentials were higher in the synthetic fertilizer scenario. The lupin-based diets consistently had the highest eutrophication potential at 0.056 to 0.133 kg PO_4e in the fertilizer scenarios, whereas the pea-based diets were consistently associated with the lowest eutrophication potential at 0.049 to 0.103 kg PO_4e. The soya-based diets were associated with the highest acidification potential at 0.054 to 0.129 kg SO_2e in the fertilizer scenarios. The results were weighted from the lowest to highest results for each impact category for each diet scenario at each site.

The conclusion was that the bean-based diets had the lowest environmental impact per pig and the soya-based diets had the highest. The pea-based and lupin-based diets were seen to have equal environmental impacts per 1 kg of pig.

A1.11 JONES AND CHERRUAULT, 2011

Given the consensus that global warming is partly a result of human activity, particularly from the release of GHGs from fossil fuels, the Government of the United Kingdom has a target to reduce GHG emissions by 80 percent by 2050.

Midland Pig Producers was accordingly developing a new farm in the United Kingdom at Foston, Derbyshire that would be self-sustaining and would minimize GHG emissions from food production by increasing production efficiency and improving resilience to uncertain weather, yields and food prices while respecting animal welfare. The company commissioned a comparative study of the environmental impacts at Foston and a typical outdoor breeding farm where sows and weaners lived outdoors and breeding, fattening and finishing took place indoors. The Foston farm was to have an indoor breeding system in large-scale sustainable enterprise using locally grown and purchased feeds, anaerobic and bio-gas digesters and water-efficiency measures; most material would be recycled and nitrate neutrality would be maintaind.

The study used the LCA ISO 14040 approach covering the supply chain from the extraction of raw materials to final disposal of the product; this approach helped to prevent decisions that could shift the environmental burden up or down the supply chain. The LCA used a systems perspective and quantified several environmental categories.

Table A1.5: Environmental impacts expressed per kg of pork produced

Parameter	Foston Farm	Comparison Farm
GWP – kg CO_2e	2.2	4.7
Eutrophication potential – kg PO_4e	0.0215	0.0265
Acidification potential – kg SO_2e	0.0349	0.0523

The comparative model captured GHG emissions over the life-cycle phases of pork production for the two farms and identified the main environmental impacts in terms of GWP – GHG emissions and contribution to climate change, eutrophication – damage to lakes and rivers, and acidification – reduction of soil quality. The results are given in Table A 1.5.

The lower GWP emissions and acidification potential at Foston were primarily a result of the slurry manure management system, which minimized nitrous oxide emissions, and the anaerobic digestion plant, which captured most methane emissions. GWP emissions at Foston could be further reduced by generating electricity and heat from a combined heat and power system, thereby obviating the need for national grid electricity and natural gas.

Per tonne of feed, the GWP and acidification potential of the Foston farm feed mixture was lower, largely as a result of greater use of by-products from other industries. The eutrophication potential of the Foston feed mixture was slightly higher than the comparison farm per tonne of feed. Per 1 kg of pork produced, all environmental impacts were lower at Foston, primarily because of the smaller amount of food required compared with the outdoor farm.

At both farms the main contributors to GWP potential were feed production – 50 percent – and manure management – 40 percent. The main contributors to eutrophication potential were feed production – 75 percent – and manure management – 20 percent. The main contributors to acidification potential were manure management – 70 percent – and feed production – 25 percent. The contributions from energy, transport and slaughter were much lower.

A1.12 STERN *et al.*, 2005

This study used a step-by-step method to create three future scenarios for pig production based on different sustainability goals. The first focused on animal welfare and the natural behaviour of the animals, the on low environmental impacts and efficient use of natural resources, and the third on product quality and safety. Each scenario dealt with different aspects of sustainability, but there were conflicts because no scenario fulfilled all sustainability goals. The scenarios were then parameterized. Environmental impact was calculated through LCA methods, and economic costs were calculated from the same dataset. The cost per 1 kg of pork was highest in the animal welfare scenario, and similar in the other two scenarios. The environmental scenario had the lowest environmental impact, and the product quality scenario the highest. The results are discussed on the basis of different future priorities.

A1.13 CEDERBERG *et al.*, 2005

Two scenarios for future pig meat production were constructed: i) a ”business as usual” scenario in which the pig feed was based on domestic grain and imported soy-meal with no attempt to reduce pesticide use; and ii) a scenario with an environmental focus inwhich peas and rapeseed were grown at pig farms to produce protein feed, with measures such as diverse crop rotation and mechanical weed control used to reduce pesticide use. The two scenarios were environmentally assessed by an LCA and a pesticide risk indicator model called PRI-Farm.

The results showed environmentally sound possibilities of reducing dependency on pesticides and identified risks associated with altered plant protection strategies in pig feed production. Organizing on-farm feed production so that protein feed crops are integrated with grain crops contributes to diverse crop rotation.

A1.14 ZHU *et al.*, 2004

The production and consumption chains of pork and novel protein foods and their environmental pressures were compared in an LCA in terms of environmental pressure indicators. Two types of environmental pressure indicator were defined: emission indicators and resource use indicators. Five emission indicators were considered: carbon dioxide equivalents for global warming, ammonia equivalents for acidification, nitrogen equivalents for eutrophication, use of pesticide and fertilizer for toxicity, water consumption and land occupation.

The LCA showed that the pork chain contributed 61 times more to acidification than to global warming, and 6 times more to to eutrophication than the novel protein foods chain. It also need 3.3 times more fertilizers, 1.6 times more pesticides, 3.3 times more water and 2.8 times more land than the novel protein foods chain. According to these environmental indicators the novel protein foods chain is more environmentally friendly than the pork chain. Replacing animal protein by plant protein is promising in terms of reducing environmental pressures, particularly acidification.

A1.15 KOOL *et al.*, 2009

This study investigated the contribution of GHGs from the animal production chain by focusing on conventional and organic pork from Denmark, England, Germany and the Netherlands with a view to i) understanding the contribution of typical production systems to GHGs and the contribution of each process and activity; ii) making an inventory of possible reduction options for Dutch conventional and organic production chains; and iii) providing a starting point for developing methods and protocols for assessing the carbon footprint of animal products. It reviewed methods such as descriptions of functional units in the pork production chain, allocation of upstream emissions to co-products and analysis of statistical uncertainty. It described several scenarios for improved carbon footprints.

The carbon footprint of conventional pork was estimated at between 3.5 and 3.7 kg CO_2e per 1 kg pork as fresh meat at slaughter. None of the differences between the farming systems studied was within the statistical certainty range of 90 percent. The carbon footprint of organic pork was estimated at between 4.0 CO_2e per 1 kg pork in Denmark and 5.0 CO_2e per 1 kg pork in Germany. The difference between conventional and organic was within the 90 percent certainty range in both countries. The GHGs from land use and land use change were calculated separately from other emissions attributed to pork because of methodological uncertainty. Emissions related to land use and land use change, however, were 50 percent of the carbon footprints: hence in addition to competition for land use and pressure on biodiversity, the use of land for pork production has a major effect on GHG emissions. Production of feed contributed between 50 percent and 60 percent the carbon footprints of conventional and organic pork. For most systems the second most important source was the 12 percent to 17 percent from methane emissions from manure storage. Danish and English organic systems with a substantial share of grazing were the second most important source of emissions.

The most obvious GHG reduction options were: i) digestion of manure to reduce methane emissions from storage and prevent GHG emissions from fossil fuels by generating energy; ii) reducing feed conversion rates to minimize the amount of feed and nitrogen intake per pork product and hence the emissions from feed production and manure management; iii) use of wet co-products in pig rations; and iv) improving slaughter efficiency and upgrading pork co-products to reduce the carbon footprint of pork, but with increases in the carbon footprint of the co-products. Alternative activities were considered with a smaller effect on the carbon footprint of pork, but that could ensure GHG reductions for example by covering liquid manure silos, pumping liquid manure from pig housing to silos, closing the cycle of raw material production, maximizing the use of feed and manure management, and adding value to manure exported from the pig farm. Setting limits on the carbon footprint when optimizing feed composition might help to reduce the use of a particular feed, but it is uncertain whether it would achieve reductions at the global scale.

To compare the results of different studies of carbon footprints of pork and to stimulate international discussion of methods and exchanges of data, guidelines are needed for the assessment of pork and other animal product carbon footprints. There were also recommendations for: i) more detailed analysis of the determinants of the ratio between pork and co-products at slaughter; ii) gathering representative data; and iii) assessing the carbon footprints of pork from actual pork production. More insight is needed into feed composition, origin and production of feedstuffs and pig production at the farm level, given their large effect on carbon footprint. Assessment of the sustainability of pork production should take into account the carbon footprints of pork and other aspects of sustainable pork production such as animal welfare and socio-economic factors.

A1.16 MATLOCK *et al.*, 2014

This study analysed water use in the United States pork industry through an LCA at two scales: a cradle-to-grave scan-level analysis and a cradle-to-farm gate detailed analysis. The environmental impact category used to evaluate processes throughout the pork supply chain was cumulative water use. The pig production environmental footprint calculator was enhanced with water consumption algorithms and used to estimate the LCI of water use.

The literature review gathered water-use information for the United States pork industry from field-to-farm gate. The findings from the literature review and discussions with industry experts were used to create the LCI, establish the input data for the production system models and provide the information used to create water use algorithms for the PPEFC.

The review showed that 70 percent of the water footprint could be attributed to crop irrigation when low-resolution global datasets were used. The provenance of the feed crops can affect the associated blue water footprint of the crops significantly, but spatially explicit feed-crop water use is rare in the United States literature.

The scan-level LCA was a cradle-to-grave water footprint analysis of the production, distribution and consumption of pork in ten United States Department of Agriculture production regions (see Figure ES.1). The functional unit was a four-ounce serving of undefined boneless pork prepared for consumption in the United States.

The water footprint was estimated at 8.2 gal (0.03 m^2) per 4 oz (113.4 g) serving of boneless pork, and hence total water use in the pork industry of 525 billion gal (1.9 million m^3) per year on the basis of a weighted ration based on nationally weighted crop production. In the sensitivity analysis, the ten regions were analysed in three scenarios: i) with the imported ingredients of swine feed rations; ii) with regionally sourced rations; and iii) using a weighted ration calculated on the basis of estimated mixtures of feed and regional feed consumption by region.

The feed ration footprint accounted for 83 percent to 93 percent of the footprint of the pork supply chain, depending on the feed source. The main contributor was water used to irrigate crops, whose footprint can vary by 100 percent from one region to another. The second largest contributor was on-farm activities at 5 percent to 13 percent; post-farm-gate activities contributed between 2 percent and 4 percent. There are opportunities for post-farm-gate water savings through more efficient dish-washing, which accounts for 90 percent of consumers' water footprint and 1 percent of the cradle-to-farm gate footprint. Sourcing rain-fed rather than irrigated feed crops would significantly reduce the pork industry's water footprint.

The detailed LCA considered the water footprint at higher resolution. The functional unit was 1 pound (0.45 kg) of swine live-weight at the farm gate. This LCA showed that water use ranged from 18.4 to 18.9 gal/lb live-weight (0.153 to 0.158 m^3/kg live-weight) in all production strategies and regions. Barn types were identified by the assumed cooling systems used. Tunnel-ventilated barns were assumed to use the most water-based cooling systems, whereas hoop barns were assumed to have no water-based cooling systems. Although the hoop barn used less water in warm regions, animal performance was likely to suffer during hot weather without cooling systems.

The largest water footprint was found in warm southern regions resulting from increased use of water-based cooling systems. When considering the total water use per production phase, the grow/finish phase accounted for 75 percent more of the footprint, including feed production, than the sow and nursery phases. Larger facilities had marginally smaller water footprints because the number of piglets per litter was greater, which distributes a sow's footprint across more pigs, and better climate-control efficiencies.

The results show that rations accounted for 90 percent of the farrow-to-slaughter water footprint. Cooling water and washing water were also contributors, but they were small and unlikely to offer opportunities for improved efficiency. Drinking water was the second most significant contributor at 9 percent of the farrow-to-slaughter water footprint and 87 percent of the on-farm water footprint. Improved on-farm water efficiency would improve the total water footprint, especially reductions of water wasted in drinking systems: replacing nipple drinkers with cup-style drinkers could reduce water use by 20 percent to 31 percent and hence reduce the overall water footprint by 1.8 percent to 2.7 percent.

A 1.17 CO-PRODUCT ALLOCATION IN LCAS OF PIG FARMING SYSTEMS

The aim was to establish the frequency with which different methods for co-product allocation have been adopted in LCAs of pig farming systems. The 23 LCAs identified were those cited in Table 22 of (Macleod *et al.*, 2013)), which compared the results of several pig LCA models; other studies were only included if selected by the search terms "Life Cycle Assessment Pork" or "Life Cycle Assessment Pig" for 2004 to 2014 in the Scopus and Web of Science databases. Of the 23 studies, 19 are shown in Table A 1.6. Studies were excluded if the allocation method adopted in some or all parts of the LCI was not clear – (Devers *et al.*, 2012; Eshel *et al.*, 2014; Lesschen *et al.*, 2011; Vergé *et al.*, 2009).

Co-product allocation in the studies is shown in Table A1.6. LCA studies can be categorized as attributional or consequential in the modelling approach (Finnveden *et al.*, 2009). In consequential LCA models, co-product allocation is avoided through system expansion (Nguyen *et al.*, 2011; Weidema and Schmidt, 2010). Studies were classed as consequential in Table A 1.6 only when allocation was avoided throughout the LCI by using system expansion. Attributional LCAs of pig farming systems contain multi-output processes that require co-product allocation in three areas of their inventories: i) the feed supply chain; ii) farm outputs as live-weight pigs for slaughter, and manure; and iii) the slaughterhouse if it is within the system boundary (Kool *et al.*, 2009). The co-product allocation method or the approach used to avoid allocation for these areas of the LCI were identified for all studies.

Of the 19 studies analysed, five were consequential models that avoided co-product allocation throughout the LCI, leaving 14 attributional studies that adopted co-product allocation of which 11 used economic allocation in the feed supply chain. The three attributional studies that adopted biophysical allocation based allocation in the feed supply chain on different physical properties – gross energy content, nitrogen content and mass the problems associated with avoiding allocation through system expansion or adopting a suitable biophysical methodology in animal feed supply chains are documented in FAO (2016).

Twelve of the 14 attributional studies avoided co-product allocation between pigs' live-weight gain and manure through system separation or system expansion. Of these, six adopted a system-expansion approach whereby the application of manure to land replaced some demand for the production and application of inorganic fertilizer. Three studies assigned the impact of manure application to specific crops in the animal feed supply chain, thereby reducing the inorganic fertilizer input to the LCI of those crops. The two approaches are only subtly different and produce similar outcomes. Allocation is more easily avoided at this stage of the LCI because there is much more certainty that manure is used by farmers to reduce the input of inorganic fertilizer to crop production. Three studies avoided allocation by assigning all emissions from manure application to live-weight gain in the pigs. (Ogino *et al.*, 2013) used economic allocation to partition the inputs to the animal production between live-weight pigs and manure, with 99.4 percent of burdens allocated to live-weight gain in the pigs. (Kool *et al.*, 2009) used co-product allocation to partition the emissions from manure application between live-weight pigs and crops in the feed supply chain on the basis of "active nitrogen content" in the manure.

Of the 14 attributional LCA studies, five had functional units of live-weight and hence did not require any consideration of the slaughterhouse. The nine remaining attributional LCAs accounted for carcass yield at slaughter; of these six avoided co-product allocation by assigning all upstream burdens in the LCI to the edible carcass. Kool *et al.* (2009) and Thoma *et al.* (2011) adopted economic allocation, which resulted in 12 percent of upstream burdens being allocated to by-products other than fresh meat. Cherubini *et al.* (2015) used mass allocation between output streams at the slaughterhouse with 13.1 percent of upstream environmental impacts assigned to edible offal and other by products; this was the only study to adopt a biophysical allocation method at the slaughterhouse.

Table A1.6: Summary of the allocation approaches adopted in LCAs of pig farming systems.

Study	Functional unit	Consequential or attributional	Allocation system - feed supply chain	Allocation system -manure application	Allocation system - slaughter by-products
(Cederberg and Flysjö, 2004)	1kg meat, fat + bone free	Attributional	Economic^{1}	System separation (to crops)	System separation (to edible carcass)
(Basset-mens and van der Werf, 2005)	1 kg live-weight	Attributional	Economic	System separation (to crops)	N/A
(Eriksson *et al.*, 2005)	1 kg live-weight	Attributional	Economic	System separation (to crops)	N/A
(Williams, A.G. Audsley, E. Sandars, 2006)	1 mt carcass-weight	Attributional^{2}	Economic	System expansion (credits for reducing fertilizer application)	System separation (to edible carcass)
(Dalgaard *et al.*, 2007)	1 kg carcass-weight	Consequential	System expansion	System expansion	System expansion
(Cederberg *et al.*, 2009)	1 kg carcass-weight	Attributional	Economic	System separation (to animal production)	System separation (to edible carcass
(Kool *et al.*, 2009)	1 kg carcass-weight	Attributional	Economic	Biophysical allocation (based on active N content)	Economic
(Olea *et al.*, 2009)	1 mt live-weight	Consequential	System expansion^{3}	System expansion	N/A
(Halberg *et al.*, 2010)	1 kg live-weight	Consequential	System expansion	System expansion	N/A
(Pelletier *et al.*, 2010)	1 kg live-weight	Attributional	Biophysical (gross energy)	System separation (to animal production)	N/A
(Stone *et al.*, 2010)	89 kg live-weight	Attributional^{2}	Biophysical (mass)	System expansion (credits for reducing fertilizer application)	N/A
(Wiedemann *et al.*, 2010)	1 mt carcass-weight	Consequential	System expansion^{1,4}	System expansion	System expansion
(Nguyen *et al.*, 2011)	1 kg carcass-weight	Consequential	System expansion^{4}	System expansion	System expansion
(Thoma *et al.*, 2011)	4 oz boneless pork^{5}	Attributional	Economic	System separation (to animal production)	Economic
(Weiss and Leip, 2012)	1 kg carcass-weight	Attributional^{2}	Biophysical (N content)	System expansion	System separation (to edible carcass)
(Ogino *et al.*, 2013)	115 kg live-weight	Attributional	Economic	Economic	N/A
(Reckmann *et al.*, 2013)	1 kg carcass-weight	Attributional^{2}	Economic	System expansion	System separation (to edible carcass)
(Cherubini *et al.*, 2015)	1 mt carcass-weight	Attributional	Economic	System expansion	Biophysical (mass)
(Mackenzie *et al.*, 2015)	1 kg carcass-weight	Attributional^{2}	Economic	System expansion	System separation (to edible carcass)

Note: Studies were classed as consequential or attributional in their modelling approach. The allocation method adopted for the three stages of an LCI where allocation is usually required in LCA of pig farming systems – feed supply chain, manure application and slaughter by product – is shown in each case.

1. Comparison with an attributional approach-based mass allocation included.
2. System expansion used within an attributional LCA framework for manure application.
3. Some instances of mass allocation included within the consequential framework in the feed supply chain.
4. A comparison with an attributional approach based on economic allocation included.
5. The results from farrow to farm gate for the function unit 1 kg live-weightW also included

CONCLUSIONS

- Economic allocation is the dominant strategy for co-product allocation in LCAs of pig systems in the animal feed supply chain.
- Most attributional LCAs of pig systems avoid co-product allocation between manure and live-weight gain during pig production. Adopting the system expansion approach to account for a reduction in demand for inorganic fertilizers as a result of manure application was the most common method used.
- Only three of the LCAs reviewed adopted a method for co-product allocation to account for the multiple outputs from the slaughterhouse. Many attributional LCAs of pig production allocated all upstream burdens in the LCI to the edible carcass after accounting for a dress carcass percentage. Two of these studies that did use co-product allocation in the slaughterhouse adopted economic allocation.
- Five of the 14 attributional LCAs assessed used biophysical allocation at any point in the LCI; three adopted biophysical allocation in the feed supply chain, one between manure and live-weight gain in pigs and one at the slaughterhouse.

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Appendix 2

Summary of available standards and specifications of LCA methodologies for pig production supply chain analysis

A2.1 INTRODUCTION

This document was prepared by the LEAP technical advisory group on pigs with a view to providing an overview of standards and specifications guiding LCA. It is a synopsis of an evaluation by the European Commission Joint Research Centre Institute for Environment and Sustainability (Chomkhamsri and Pelletier, 2011), which considered seven product-specific methods and seven organization-specific methods. This synopsis focuses on the relevant product-specific methodologies:

- Environmental management LCA requirements and guidelines (ISO 14044:2006, 2006);
- Carbon footprint of product (International Organization for Standardization, 2010);
- International Reference Life Cycle Data System (European Commission *et al.*, 2010);
- Product and Supply Chain Standards Greenhouse Gas Protocol (WRI/WBCSD) (Bhatia *et al.*, 2011);
- French Environmental Footprint (BPX 30-323) (AFNOR, 2011); and
- United Kingdom product carbon footprint (PAS 2050) (DEFRA, 2009).

This document evaluates several methodological issues including applications of LCAs, target audience, functional unit, system boundary, cut-off criteria, impact categories, data modelling and quality, primary and secondary data, allocation, biogenic carbon emissions, direct and indirect land-use change, carbon sequestration, renewable energy, land occupation, offsets, review and reporting, interpretation and uncertainty.

The ISO 14044 standard is the basis for the other standards, which are hence largely in agreement – certainly on all major points. The few points of divergence will be summarized at the end of the document.

A2.2 GOAL AND SCOPE

All methodological guidelines employ the life cycle approach in product evaluation. The goal and scope of LCAs range from hotspot identification to product analysis to benchmarking for understanding and opportunities for improvement. All the methodologies and standards support the identification and benchmarking of improvements to track performance. Only the WRI/WBCSD guidance does not support comparative assertion as defined in the ISO 14044 standard. It is important to allow sufficient flexibility to encompass this range of potential reasons for conducting an LCA of swine systems.

A2.3 TARGET AUDIENCE

The target audience is individuals or organizations identified by the authors of the study who rely on the study for decision-making. All the standards except for PAS 2050, which does not specify requirements for communication, refer to B2B and B2C communications; the BPX 30-323 standard only refers to B2C communications. In general the target audience should be explicit in the LCA report.

A2.4 FUNCTIONAL UNIT

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

A2.5 SYSTEM BOUNDARY DEFINITION

Determination of the processes to be included in the LCA must be based on the goal and scope of the study and defined iteratively to identify the most relevant processes. The extant protocols define the system as beginning with raw material acquisition and concluding with end-of-life and disposal. The WRI/WBCSD, PAS 2050 and ISO 14067 allow for both cradle-to-grave and cradle-to-farm gate studies; the other protocols require a full cradle-to-grave analysis.

A2.6 MATERIALITY

The question of materiality is related to the cut-off criteria chosen for the study, particularly specification of material or energy flows that are insignificant enough to be excluded from the system. This is important in the context of balancing the representativeness of the model and data collection by the practitioner. All the standards provide guidance with regard to LCI or emissions, which should not be neglected. The ISO 14044 standard and ILCD guidance do not specify cut-off percentages, but do require a full description of the criteria used for cut-off flows (ISO 14044:2006, 2006). The cut-off criteria are typically reported in terms of an estimated percentage of materials or emissions that have been excluded. The PAS 2050 and French standard require that all material contributions be included, and that 95 percent of GHG emissions and impacts must be accounted (British Standards Institution, 2011). The WRI WBCSD does not specify cut-off, but does require justification for exclusion of attributable processes and reporting of the insignificance threshold to justify exclusion.

A2.6.1 Infrastructure

There is a range of approaches for accounting for capital infrastructure. It is a requirement of the French standard that infrastructure associated with transport be included. Infrastructure is considered a non-attributable process in WRI/WBCSD and is not mandatory, but if it is included it shall be disclosed. PAS 2050 excludes capital goods unless supplementary requirements have been established, in which case those requirements should be adopted. The PAS 2050 allows for inclusion of capital goods when a materiality assessment shows a significant contribution.

A2.6.2 Ancillary activities

The PAS 2050 explicitly excludes capital goods, human energy inputs, transport by animals, transport of the consumer to and from retail and employee commuting. The French standard excludes carbon offsets, research and development, employee commuting, associated services such as advertising or marketing and consumer travel to and from retail.

A2.7 IMPACT CATEGORIES

These are potential effects on the environment or human health or natural resource depletion that result from activities of the system under study. The PAS 2050 and WRI/WBCSD protocols focus only on climate change, including the effects of land-use change on GHG emissions which are reported separately. The other protocols recommend a wider range of impact categories: BPX 30-323 follows the JRC recommendations, with impact categories fixed by the product category. The LCD handbook (Joint Research Centre, 2010) provides recommendations for the following impact categories which constitute a superset of the ISO 14044 categories: climate change, acidification, eutrophication, ozone depletion, summer smog, human toxicity – respiratory inorganics, carcinogens and non-carcinogens – land use including biodiversity and land productivity, and material and energy resource depletion.

A2.8 BIOGENIC CARBON AND METHANE

ISO 14044 does not provide guidance on biogenic carbon emissions. The other standards agree that fossil and biogenic carbon emissions should be included in the analysis and should be reported separately. With regard to the effects of climate change, all the guidelines refer to the IPCC for characterization factors. In the most recent publication, biogenic methane has a different global warming potential from fossil methane (Myhre *et al.*, 2013).

A2.9 CARBON SEQUESTRATION AND DELAYED EMISSIONS

This refers to fossil or biogenic carbon removed from the atmosphere and sequestered – that is not re-released to the atmosphere during production or end-of-life disposal; it may, however, be slowly released over longer time periods. Chomkhamsri & Pelletier (2011) suggested that ISO 14044 considers carbon storage and delayed emissions to be outside the usual scope of study, as is explicitly stated in the ILCD handbook; if it is considered as part of the study goal, operational guidance is provided. The handbook also differentiates temporary from permanent storage if guaranteed for more than 10,000 years. The ISO-14067, PAS 2050 and WRI/WBCSD standards all require separate reporting of temporary carbon storage. The WRI/WBCSD, PAS 2050 and French standards allow for waiting factors in the calculation of delayed emissions, which are to be reported separately.

A2.10 LAND USE: DIRECT AND INDIRECT LAND-USE CHANGE

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

The French standard and ISO 14067 indicate that effects induced by indirect land-use change shall be considered once there is an internationally accepted methodology. The ILCD handbook considers indirect land-use change for consequential LCAs, but, in agreement with PAS 2050, excludes indirect land-use change from attributional product level LCAs. The WRI/WBCSD protocol does not require indirect land-use change, but if it is shown to be significant it should be reported separately.

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

A2.11 EMISSION OFF-SETTING

In general this refers to third-party GHG mitigation, which involves particular reductions used to compensate for emissions elsewhere. ISO 14044 does not provide guidance on this topic; the other methodologies do not allow the inclusion of emission offsets in the calculations.

A2.12 RENEWABLE ENERGY

In the standards that address renewable energy, the principal concern is the potential for double counting. ISO 14067 requires exclusion of renewable energy sources if they have been claimed elsewhere. PAS 2050 provides guidance on avoiding double counting associated with renewable electricity generation, and the French standard allows different energy models provided the renewable electricity is not connected to the main grid.

A2.13 MULTI-FUNCTIONALITY AND ALLOCATION

When a unit process in the system provides more than one function, the inputs, emissions and their impacts need to be partitioned among all of the provided functions. All the standards follow ISO 14044 in recommending that allocation be avoided by system separation if possible. The ILCD, WRI/WBCSD and ISO 14067 adopt the ISO 14044 hierarchy, which provides more refined guidance as to the preferred order of system separation followed by system expansion and then physical relationships with economic value as the final option. The PAS 2050 standard allows for supplementary requirements such as Product category rules (PCR) to be used if up appropriately specified before economic value is allocated. The French standard switches the process of allocation based on physical relationships such as mass and energy with system expansion, and leaves economic value allocation as the lowest priority choice.

A2.14 DATA QUALITY ASSESSMENT

Data quality refers to the suitability of the data with regard to achieving the goal and scope of the study. This must be evaluated to ascertain the robustness of decisions that may be made on the basis of the study results. The characteristics of data quality are identified in part one of this document and in the standards. The data quality requirements given by ISO 14044 include:

i. time-related coverage: age of data and the minimum length of time over which data should be collected;
ii. geographical coverage: the geographical area from which data for unit processes should be collected to satisfy the goal of the study;

iii. technology coverage: specific technology or a mix of technologies;
iv. precision: measure of the variability of the data values for all data expressed such as variance;
v. completeness: percentage of flow that is measured or estimated;
vi. representativeness: qualitative assessment of the degree to which the dataset reflects the true population of interest, for example geographical coverage, time period and technology coverage;
vii. consistency: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
viii. reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;
ix. sources of the data; and
x. uncertainty of information in, for example, datasets, models and assumptions.

ISO 14067 and PAS 2050 adopt the ISO 14044 data quality assessment guidance. The ILC D and WRI/WBCSD make small modifications with regard to temporal, technological and geographical representativeness and to combining other categories into completeness and precision. The French standard has a governance committee that advises on these issues and provides clarity, recognition, transparency, format and updates.

A2.15 PRIMARY/SECONDARY DATA

Primary data consist of information collected as part of an ongoing study; secondary data consist of information that may be available in LCI databases or that may be found in the literature. The standards agree that foreground processes – those owned or operated by the study commissioner – should be populated with primary data. The ILCD recommends primary data for the main background processes as well. Secondary data are acceptable for background processes, but are subject to the same data-quality assessment requirements as primary data. All the standards acknowledge the usefulness of a data-collection template for any project, but none provide examples except the LEAP guidance for the poultry sector, which includes a data-collection template in an Annex.

A2.16 UNCERTAINTY ANALYSIS

To determine whether apparent differences between the compared alternatives are statistically significant it is necessary to assess the uncertainties accompanying the results. Three major sources of uncertainty may be addressed (European Commission *et al.*, 2010): stochastic uncertainty, choice uncertainty and lack of knowledge about the studied system. Detailed guidance is lacking in all of the guidelines, however: the WRI/WBCSD and PAS 2050 provide guidance in separate supplementary documents and the French standard shifts the focus to sector-specific working groups and refers to ISO 14044.

In practice, Monte Carlo analysis is generally the method used to determine the propagation of input uncertainties to the environmental impacts reported; there may, however, be alternative methods appropriate to a particular study.

A2.17: Review of PCR and other protocols for LCA of pig products

Organization and method	INRA, ADEME, AGRIBALYSE
Date of publication	2013
Developed by	INRA
Products	Co-products: all products generated by a process in addition to the main product such as spent sows, piglets and finished animals. Depending on system boundaries may also include edible meat and non-edible products from manufacturing
Objectives	To contribute to environmental labelling of food products, provide reference methods for the agriculture sector for LCA assessment and guide mitigation strategies
Review panel	Yes
Public review/open consultation	No
Co-products	Pigmeat, piglets from breeding-only operations and edible offal and products for rendering
Functional unit	1 kg of live-weight
System boundaries	Cradle to gate; off-farm activities excluded; co-products from crop processing excluded
Handling multi-functional processes (allocation)	Bio-physical allocation based on physiological functions; spent sows and piglets;
Impact categories	GHG emissions/climate change, resource depletion, demand for fossil fuel energy, eutrophication, eco-toxicity, acidification, human toxicity, land use and land use change
Additional information	Koch P. and Salou T., 2013. AGRIBALYSE ®: *Rapport méthodologique – version 1.1., mars 2014*. Angers, France, ADEME.

Organization and method	FAO: GHG emission in pig and chicken supply chains: A global LCA
Date of publication	2010
Developed by	FAO
Products	Meat
Objectives	Present the first comprehensive and disaggregated global assessment of emissions to enhance understanding of emission pathways and hotspots; quantify the main sources of GHG emissions from the pig and chicken sectors; assess the relative contribution of different production systems and products to total emissions.
Review panel	Yes
Public review/open consultation	No
Co-products	None: no allocation of slaughter by-products
Functional unit	1 kg of meat
System boundaries	Cradle to retail
Handling multi-functional processes (allocation)	Biophysical allocation; economic allocation
Impact categories	GHG emissions/climate change
Additional information	

Organization and method	Earth sure Meat Environmental Product Declarations
Date of publication	2006
Developed by	Earth sure Meat, IERE
Products	Meat
Objectives	Support the EPD; learn more about environmental impacts of the product; improve environmental performance
Review panel	Yes
Public review/open consultation	Yes
Co-products	Meat
Functional unit	1 lb (0.45 kg) of meat at the processing plant exit gate
System boundaries	Cradle to plate
Handling multi-functional processes – allocation	All impacts allocated to meat
Impact categories	Climate change, stratospheric ozone depletion, acidification, eutrophication, photochemical smog, aquatic toxicity, fossil fuel depletion, mineral resource depletion, water use, antibiotic use, soil losses, hormone used, genetically modified organisms
Additional information	

Organization and method	Development of carbon calculator to promote low carbon farming practices
Date of publication	2013
Developed by	EC, JRC, SOLAGRO
Products	Livestock products
Objectives	Assess GHG emissions from farming and suggest climate change mitigation and sequestration actions at the farm level
Review panel	Yes
Public review/open consultation	No
Co-products	Meat
Functional unit	1 mt of meat
System boundaries	Cradle to farm gate
Handling multi-functional processes – allocation	Economic allocation; mass allocation; allocation according to the production cycle; protein or energy allocation for meat and milk
Impact categories	Climate change
Additional information	

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

Organization and method	World Food LCA Database
Date of publication	2014
Developed by	World Food LCA Database
Products	Agricultural products
Objectives	Environmental product declaration
Review panel	Yes
Public review/open consultation	No
Co-products	Meat and other non-animal products; slaughterhouse – high-quality meat, low-quality meat, fat, non-edible skin, non-edible bones
Functional unit	1 kg animal, live-weight at farm exit gate
System boundaries	Cradle to farm gate
Handling multi-functional processes – allocation	At slaughterhouse: Allocation based on dry matter for co-products (Agribalyse, Gac *et al.*, 2012)
Impact categories	Climate change, acidification, eutrophication, land use and change in land use; eco toxicity
Additional information	Ecological footprint, water footprint

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Appendix 3

Description of regional pig production systems

This appendix provides descriptions of small-scale, medium-scale and large-scale pig production systems.

A3.1 HIGHLY EFFICIENT MODERN INTENSIVE PIG PRODUCTION

This case study describes highly efficient modern intensive pig production using key performance indicators from the top 10 percent of herds for sow productivity and feed efficiency from the *Teagasc e-Profit Monitor* for 2014 (see Table A3.1).

Replacement sows are normally first crosses of dam line Large White and Landrace, but crosses with other dam lines of breeds such as Duroc may also be used. Terminal or meat/sire line sires such as Large White, Landrace, Duroc, Pietrain, Hampshire and composite breed are used to breed pigs for slaughter. Sow weights range between 200 kg and over 250 kg. Specialist genetic companies have nucleus units where pure-bred dam line and sire line pigs are produced. Multiplier units controlled by the genetics company are then used to produce boars and gilts for sale to commercial producers. For biosecurity reasons, however, only semen for artificial insemination (AI) is usually sold from these units to commercial producers.

Artificial insemination is used in up to 90 percent of services at commercial units, and for this reason as few as one boar per 150 sows is now quite normal. Sows farrow on a weekly basis with 2.4 litters per sow per year; 4.6 percent of the sow herd farrows every week. At some small units, batch farrowing is operated: in such cases sows farrow once every three, four or five weeks, depending on the system. Pigs are normally weaned at between 21 and 28 days of age, with 28 days becoming more common. Where sows are weaned at 28 days of lactation 18.5 percent of the sow

Table A3.1: Key performance indicators for sow productivity, mortality, growth and feed efficiency in top performing herds (Teagasc, 2015)

Sow productivity and mortality		Pig growth and feed efficiency from weaning to sale	
No. of pigs produced per sow per year	28.7	Average weaning weight (kg)	7.0
Litters per sow per year	2.41	Average live weight at sale (kg)	107.5
Average weaning age in days	28	Average dead weight at sale (kg)	82.0
Empty days per litter	7	Kill out (%)	76.3
No. born alive per litter	13.44	Average daily feed intake (g)	1549
No. born dead per litter	0.77	Average daily gain (g)	683
Piglet mortality (%)	9.0	Feed conversion ratio (g/g)	2.27
Weaner mortality (%)	1.23	Feed per pig weaning to sale (kg)	228.7
Finisher mortality (%)	1.48		
Sow culling rate (%)	47.5		
Sow mortality (%)	3.7		
Feed per sow per year (mt)	1.33		

herd will be lactating at any one time; the remainder will be pregnant or empty. At an annual culling rate of 47.5 percent, a fifth of each week's farrowings will be made up of replacement gilts. These are home produced using purchased dam line AI, or purchased as maiden gilts from a specialist breeding company; the latter course is less frequent for biosecurity reasons. Once born, piglets remain with their mothers for 21 to 28 days, at which time they are weaned abruptly. At this point they may be: i) reared on the farm to the target slaughter weight; ii) sold as piglets at 7–8 kg live-weight to a specialist producer for finishing; iii) reared on the farm to 20–35 kg live-weight before being sold to a specialist producer for finishing.

Carcass weight at slaughter can vary greatly depending on market requirements – 67 kg in Portugal, for example, and 121.5 kg in Italy – and whether male pigs are castrated or left entire. The number of pigs produced/slaughtered per sow per year in a high-performing unit is 28–30. In this example it is 28.7 pigs, which can be calculated as the (number born alive per litter x litters per sow per year) x (1– mortality %). A highly efficient unit will use 2.27 kg of feed for every 1 kg live-weight gained between weaning and slaughter, a feed conversion ratio of 2.27. In this example a pig consumes 228.7 kg feed between weaning and slaughter, but this depends on factors such as target slaughter weight, nutrient density of the diet and the health status of the herd. Mortality per unit can vary greatly according to health status and management level, but in this example annual sow mortality is 3.7 percent, piglet pre-weaning mortality is 9 percent and post-weaning mortality up to target slaughter weight is 2.71 percent. The number of piglets born dead per litter can also vary according to litter size, health status of the unit and the level of unit management; in this example it is 0.77 pigs per litter.

Most pig herds are housed indoors year-round in climate-controlled facilities. Gestating sows are loose-housed and use electronic feed systems, free access stalls or other types of loose housing. During lactation sows are generally housed in individual pens and confined in farrowing crates over a slatted floor. Loose-farrowing systems are being used more and more in some EU countries. After weaning groups of 10–100 pigs are in most cases housed on slatted floors until slaughter, but in cases where straw is available bedded floors may be used for gestating sows and in some cases for weaner and finisher pigs. Most pigs are housed on slatted floors, and liquid manure – a mixture of faeces, urine and wash water – is collected under the floor and flushed to outside storage or lagoons each week, or collected in a deep pit beneath the animal housing which is emptied several times per year.

In some regions of countries such as the United Kingdom where precipitation is not excessive and soils are free draining, intensive outdoor pig production systems are common. In such systems the sows are maintained in groups in paddocks; they farrow in small structures called "arcs" that are normally straw-bedded. In most cases the piglets remain with the sows for four weeks, after which they are weaned and moved into a conventional indoor facility where they are grown to slaughter weight. Because the outdoor sow system is considered "high-welfare", a substantial proportion of weaners end up in straw yards – solid-floor straw-bedded units. Sows are free to graze on grass in the paddock, but this is soon exhausted and paddocks are left without vegetation: in view of the risk of soil degradation, the paddocks are rotated. The sows are fed diets of balanced concentrates to meet requirements, as is the case in conventional indoor production systems. Sow manure is deposited directly on the paddocks and hence, depending on rainfall, soil texture and slope, leaching and run-off of nutrients can be a feature of these systems.

A single sow and her progeny produce 20.7 m^3 of liquid pig manure between farrowing and slaughter that contains 87 kg of nitrogen, 17 kg of phosphorus and 39 kg potassium. Manure dry matter is extremely variable: faeces and urine are collected in tanks under slats, mixed with wash water and spilled feed and stored until removal for spreading on the land or moved to underground or surface storage tanks. Manure storage time is typically 30 weeks. In systems where straw is used for bedding, the manure is high in solids; it is collected in dung heaps and left to rot down.

Manure is typically spread on the land as fertilizer for grass and crops. If there is not enough land available for this purpose, the manure may be transported considerable distances for spreading; in cases where the distances involved make it economically viable to separate pig manure into its liquid and solid fractions, with the liquid used locally as a nitrogen-rich fertilizer and the solid fraction transported for spreading to exploit its high phosphorus content, as in some areas in the Netherlands. In some cases liquid pig manure is anaerobically digested, usually in combination with an energy source such as maize, belly grass or grass silage to produce biogas; this is only economical when a premium is paid for renewable energy.

A breeding sow uses on average 1.33 mt of feed per year; a pig consumes 228.7 kg of feed between weaning and slaughter-weight. In this example a sow and her progeny use 7.89 mt of feed per year and, taking the cull sow into account, produce 2.42 mt of saleable carcass. The feed provided is entirely concentrate and either mixed on-farm or purchased. In some instances, particularly where liquid feeding systems are used – in the Netherlands and Ireland for example – liquid dairy by-products such as liquid whey or brewing and distilling products such as beer or pot ale syrup may be mixed with a balancer prior to feeding to pigs. Bakery and confectionery surpluses and other by-products and co-products may also be used in a similar fashion to reduce feed costs. For some pig units maize, soybeans and/or cereals may be produced on-farm for incorporation into pig diets, as in Denmark, the United Kingdom and the United States. In many countries, however, pig units have no land or a very limited area of land – Ireland is an example – and so all diet ingredients must be purchased from outside. Except for special diets used for short periods to feed newly weaned pigs, all pig diets are formulated on a least-cost basis.

A3.2 SEMI-INTENSIVE PIG SYSTEMS

Semi-intensive pig production systems vary among countries in terms of scale and level of specialization. Most herds consist of a variety of breeds such as Landrace, Yorkshire, Duroc, Jersey, Hampshire, Large White and Pietrain, local breeds suited to particular environmental conditions, and commercial trihybrids and tetrahybrids. Adult weight for sows is between 180 kg and 200 kg live-weight.

The number of litters per sow per year is determined by scale, market objectives, feed sources and production goals: it varies from one, when piglets are brought to market-weight for slaughter as piglets, to 2.5 a year in intensive systems. The number of piglets weaned per litter is between seven and nine, with a mortality rate of between 10 percent and 18 percent, mainly in the 30 days after birth. Young gilts are produced to replace culled sows, typically at a replacement rate of 20 percent to 25 percent per year. There are systems, however, with replacement rates as high as 100 percent each year. The weight of gilts at first mating ranges from 95 kg to 135 kg live-weight in genetically improved breeds. Natural breeding with a boar is usually used in backyard production systems, typically with one boar for every ten sows. Artificial insemination is used in advanced intensive systems.

Age at weaning varies among farms: it is usually 21 days at 7 kg live-weight, 45 days at 12 kg live-weight or 56 days at 18 kg live-weight; the age largely dictates the number of litters produced per sow per year. The feed for breeding sows is mainly pasture, which accounts for 40 percent to 50 percent of nutrition requirements with the remainder supplied from crops, animal by-products, supplements and milk by-products. The level of production performance and technical efficiency depends largely on the quantity and quality of the feed supplied.

Some farmers finish weaned piglets for sale as meat at an average weight between 25 kg and 28 kg live-weight. Farmers who keep weaned piglets feed them with high-quality concentrate to optimize feed conversion up to 30 kg live-weight. Mortality during this period is between 2 percent and 3 percent.

The period between 25–30 kg live-weight and slaughter is called the growing-and-finishing phase. The market dictates the amount of carcass fat and hence the slaughter weight, which averages between 100 kg to 120 kg live-weight, with 70 percent to 80 percent dressing out. Pig age at slaughter is determined by the quantity and quality of the feed used. In some cases it is possible to obtain 1 kg average daily gain, but in semi-intensive systems the average figure is 0.6 kg average daily gain. Mortality during this period is between 1 percent and 2 percent.

Daily manure production depends on the swine production phase and the weight of the animal. On a per-head-per-day basis, pigs between 25 kg and 120 kg produce whole liquid waste of 7 litres, gestating sows produce 16 litres, lactating sows and piglets produce 27 litres, breeding boars produce 9 litres and piglets from weaning to 25–30 kg live-weight produce 1.5 litres. When it is accounted, a sow and her progeny produce 20m^3 of liquid manure between farrow and slaughter. The bulk of manure is deposited directly by grazing animals on to pasture and cropland; manure produced indoors is spread on pasture and cropland as fertilizer. In some cases, however, manure is disposed of in an inappropriate manner with negative consequences, particularly where inappropriate disposal is in the vicinity of waterways.

A3.3 EXTENSIVE PIG PRODUCTION SYSTEMS

Extensive pig production systems are based on the use of local genetic resources, feed and techniques. The meat produced is frequently destined for local markets or industries. Sometimes local products are of very high quality and can become delicatessen items with a reputation at the national and international levels; Iberian pig products are an example.

Local breeds include Cinta Senese, Nero Siciliano and Sardo in Italy, Alentejano or Bísaro in Portugal, Iberian pig in Spain, Creole in Cuba and Venezuela and Pampa Rocha in Uruguay. In Argentina hybrid pigs from different breeds are raised, mainly Duroc, Landrace and Yorkshire.

Farm characteristics vary among countries and according to environmental and geographic conditions. In Argentina, for example, 85 percent of farms with pigs are extensive and have fewer than 50 sows. In Italy, farms with Cinta Senese frequently have fewer than 10 sows. In Portugal farms have an average of 60 sows of the Alentejana breed. In Spain the average number of sows in farms with Iberia pigs is 46.

Productivity indicators are low, corresponding to the characteristics and rusticity of the breeds used. With the Iberian pig, the number of sows per boar is ten, with natural mating: there are normally two litters per sow per year, farrowed in spring and autumn to minimize mortality caused by extreme temperatures at other times of the year. First breeding is at 8–12 months. Young gilts are produced on-farm, and boars are frequently replaced with animals from other farms to diversify the genetic pool. The sow culling rate is 36 percent, but some farms use different criteria: in general the more traditional the operation the lower the replacement rate.

The average weaning age varies from 28 days to 42 days. The number of piglets born per litter is between seven and ten; the average of still births per litter is 0.7. During lactation, piglet mortality is 19.5 percent and varies according to the season – higher in summer and lower in autumn. The number of pigs produced per sow per year is 12.4. Piglet live-weight at 28 days averages 7.03 kg, at 42 days it averages 12.35 kg and at 56 days it averages 17.28 kg. Piglets weaned at 28 days typically consume 1.7 kg of feed per day; those weaned at 42 days consume 6.35 kg of feed per day.

During rearing, the animals will be raised from 10 kg to 69 kg. Depending on their weight and time of birth, piglets will be designated for fattening or reproduction. The diet consists of grass, stubble, the remains of acorns and supplement concentrate feed at 1 kg to 1.5 kg per day. Feeding on pasture accounts for up to 60 percent of pigs' food needs during this phase.

Outdoor feeding of Iberian pigs in Spain has two phases: *premontanera*, or previous outdoor feeding, and *montanera*, the final phase or fattening in the *dehesa*.[10] The *premontanera* starts in July and lasts into early November, with slow growth to between 60 kg and 100 kg. To achieve this the pigs are kept in an enclosure of about 35 ha where they receive 1 kg to 2 kg of feed per pig per day. The goal is for the animals begin the *montanera* with a weight not exceeding 105 kg because, according to the regulations, heavier animals would be excluded and could not be marketed as conforming with the criteria for the Iberian production system.

In the *montanera* feeding phase the pigs eat only grass and other resources such as acorns in the *dehesa*, especially autumn grass. The pigs prefer the acorns of holm oaks (Quercus rotundifolia Lam.) because they are sweeter than those of cork oaks (Quercus suber Lam.). Acorn production is variable, averaging 10 kg per tree per year, so before the *montanera* the scale of acorn production is estimated and the stocking density of the pigs is determined accordingly.

Pigs only eat acorn pulp, not the shell. The average composition of acorn pulp is 6 percent protein, 9 percent fat and 50 percent starchy substances. A pig will eat up to 10 kg per day. Grass is an essential protein-and-vitamin in pig feed, and pigs will eat an estimated 3 kg per day. Average daily weight gain is 0.85 kg to 1 kg per day. The feed conversion ratio for acorns to live-weight is 10:1.

The *montanera* begins in late October or early November depending on weather conditions and lasts for three months, when the pigs reach a weight of between 150 kg and 170 kg. The quality standard for Iberian ham, regulated by Royal Decree 1083/2001 and modified by Royal Decree 4/2014, requires that the average starting weight of the pigs must be between 92 kg and 115 kg. During the *montanara* pigs gain about 60 kg. In accordance with the required feed conversion rate the pigs need to eat 600 kg of acorns, so there must be at least 60 holm oaks in the *dehesa* producing 10 kg each at a density of 30 to 40 trees per hectare; the land area per pig is accordingly 2 hectares.

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[10] A multi-functional agro-sylvo-pastoral system and cultural landscape of southern and central Spain and southern Portugal, where it is known as *montado*. A *dehesa* may be private or communal property.

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