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Environmental performance of feed additives in livestock supply chains

Guidelines for assessment

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Environmental performance of feed additives in livestock supply chains

Foreword

[LEAP Chairs to include]

Acknowledgments

These guidelines are a product of the Livestock Environmental Assessment and Performance (LEAP) Partnership. Three groups contributed to their development: The Technical Advisory Group (TAG) on feed additives conducted the background research and developed the core technical content. The feed additive TAG was composed of 26 experts: Ermias Kebreab (chair, University of California, Davis, USA), Aimable Uwizeye (Food and Agriculture Organization of the United Nations, FAO, Italy), Abdulrasak Ige Badina (University of Leeds, UK), Armin Towhidi (University of Tehran, Iran), Aurelie Wilfart (Institut National de la Recherche Agronomique, INRA, France), Camillo De Camillis (Food and Agriculture Organization of the United Nations, FAO, Italy), Chaouki Benchaar (Agriculture and Agri-food Canada, Canada), Clandio Favarini Ruviaro (Universidade Federal da Grande Dourados, Brazil), Colm Moran (Alltech, Ireland), Gunilla Eklund (Food and Agriculture Organization of the United Nations, FAO, Italy), Fafioulu, Adeboye Olusesan (Federal University of Agriculture, Abekuta, Nigeria), Heinz Stichnothe (Institute of Agricultural Technology, Thünen Institute, Germany), Herve Juin (Institut National de la Recherche Agronomique, INRA, France), Ildiko Edit Tikasz (Research Institute of Agricultural Economics, Hungary), Joop de Knecht (National Institute for Public Health and the Environment, The Netherlands), José Velazco (National Institute of Agricultural Research, Uruguay), Laurence Shalloo (Teagasc, Ireland); Michael Binder (Evonik Nutrition & Care GmbH, Germany), Mingjia Yan (University College Dublin, Ireland); Mojtaba Zaghari (University of Tehran, Iran); Nicolas Martin (Ajinomoto, France); Patrick van Beelen (National Institute for Public Health and the Environment, The Netherlands); Philippe Becquet (DSM Nutritional Products Ltd., Switzerland), Rob Kinley (CSIRO, Australia); Vyas,Diwakar (University of Florida, USA) and Yuan Yao (North Carolina State University, USA). The LEAP Secretariat coordinated and facilitated the work of the TAG, guided and contributed to the content development and ensured coherence between the various guidelines. The LEAP secretariat, hosted at FAO, was composed of: Camillo De Camillis (LEAP manager), Carolyn Opio (Technical officer and Coordinator), Félix Teillard (Technical officer), and Aimable Uwizeye (Technical officer). The LEAP Steering Committee provided overall guidance for the activities of the Partnership and facilitated review and clearance of the guidelines for public release.

Glossary

Acidification is an impact category that addresses impacts due to acidifying substances in the environment. Emissions of NOx, NH_3 and SOx lead to releases of hydrogen ions (H+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.

Additive Scenario refers to the scenario where the effect of the specific feed additive or mixture of additives under evaluation is considered in the emission modeling.

Allocation partitions 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.

Antimicrobial resistance (AMR) refers to microorganisms – bacteria, fungi, viruses, and parasites – becoming resistant to the antimicrobial substances that normally inhibit or kill them. AMR can occur naturally but the pace of AMR's spread is on the rise due to inappropriate and excessive use of antimicrobials.

Attributional refers to process-based modelling intended to provide a static representation of average conditions, excluding market-mediated effects.

Baseline Scenario refers to the livestock system used as reference for the comparison with the additive scenario.

Biogenic Carbon: Carbon derived from biomass (ISO/TS 14067:2013, 3.1.8.2)

Carbon dioxide equivalent (CO_2 eq.) is a unit used for comparing the radiative forcing of a Greenhouse Gas (GHG) to carbon dioxide (ISO14064-1:2006, 2.19) expressed in terms of the amount of carbon dioxide that would have an equivalent impact. The carbon dioxide equivalent value is calculated by multiplying the mass of a given GHG by its global warming potential (GWP) (see also definition of global warming potential).

Carbon footprint is the level of greenhouse gas emissions produced by a particular activity or entity or product.

Co-production is a multifunctional process with the production of the various products, which cannot be independently varied, or only varied within a very narrow range.

Co-product is the output from a production activity that generates more than one output. The term does not include services that may also be provided.

Cradle-to-gate covers the life-cycle stages from the extraction or acquisition of raw materials to the point at which the product leaves a defined output point or gate.

Critical review is the process intended to ensure consistency between a life cycle assessment and the principles and requirements of this guide.

Δ is the ratio between the data for the baseline scenario (bs) and for the additive scenario (as) ($data_{as}/data_{bs}$). It is then used to affect the parameter measured in the equations used for evaluating the impact of the feed additive. It is accompanied by a subscript, indicating the type of impact assessed.

Ecotoxicity is the environmental impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances that have a direct effect on the health of the ecosystem.

Emission Factor (EF) represents the amount of emissions to land, water or air, expressed as unit emission and relative to a unit of activity (e.g. kg CO_2 eq. per unit input). NOTE Emission factor data is obtained from secondary data sources.

Emission Model is the mathematical description, with parameters and emission factors that describe the relationship between the input and the emission to land, water or air.

Emission intensity is the level of emissions per unit of economic activity or product. Usually the term 'emission intensity' is used in relation to CO_2 emissions of a given country, measured at the national level as GDP (Baumert et al., 2005) or for specific economic outputs (kg of animal sourced product (milk, meat, egg and wool) produced). It serves as an indicator suitable to measure the 'de-coupling' of economic growth and GHG emissions. In analogy, emission intensity or more generally flow intensity is used here to describe the flow of reactive N (Nr) caused by the production of one unit of an economic activity. This can be physical unit (e.g. kg of meat or milk).

Emissions represent the release of substance(s) to air and discharges to water and land.

Environmental impact corresponds to any change to the environment, whether adverse or beneficial, that wholly or partially results from an organization's activities, products or services (EMAS regulation).

Enzyme is a compounds that is produced by living organisms and function as biochemical catalysts. Some enzymes are simple proteins while others consist of a protein linked to one or more non-protein groups.

Eutrophication is linked to the flow of nutrients (mainly nitrogen and phosphorus) from sewage outfalls and (fertilized) farmland that accelerates the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death.

Eutrophication Potential (EP) translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass.

Feed covers any single or multiple materials, whether processed, semi-processed or raw, which are intended to be fed directly to food-producing animals. (Good practices for the feed industry, FAO and IFIF, 2010). In these guidelines, feed does not include feed additives.

Feed additive covers any intentionally added ingredient not normally consumed as feed by itself, whether or not it has nutritional value, which affects the characteristics of feed, animal productivity or emissions. Note: Micro-organisms, enzymes, acidity regulators, trace elements, vitamins, phytogenic substances, functional ingredients and other products fall within the scope of this definition depending on the purpose of use and method of administration - Codex Alimentarius Code of Practice on Good Animal Feeding CAC/RCP 54 (FAO/WHO Codex Alimentarius Commission, 2008).

Global Warming Potential (GWP) is the capacity of a greenhouse gas to influence radiative forcing, expressed in terms of a reference substance (for example CO_2-equivalents units) and a specified time horizon (e.g. GWP 20, GWP 100, GWP 500 for 20, 100 and 500 years respectively). It is related to the capacity to influence changes in the global average surface-air temperature and subsequent changes in various climate parameters along with their effects, such as storm and intensity, rainfall intensity, frequency of flooding, etc.

Greenhouse gases (GHGs) are gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the earth's surface, the atmosphere, and clouds (PAS2050:2011, 3.24) GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluoro-carbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

Impact category is a class representing environmental issues of concern to which life cycle inventory analysis results may be assigned.

Impact category indicator is a quantifiable representation of the contribution of a product unit to the specific impact category.

Input is a product, material or energy flow that enters a unit process.

Ionophore is a class of compounds, generally cyclic, having the ability to carry ions across lipid barriers of the microbial cell due to the property of cation selectivity; examples are monensin sodium, lasalocid sodium, salinomycin and nonactin.

Land-Use Change (LUC) Corresponds to the changes in the purpose for which land is used by humans (e.g. from cropland to forest or grassland, from forest land to industrial land).

Life cycle represents the consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to end of life, inclusive of any recycling or recovery activity.

Life Cycle Assessment (LCA) is the compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle.

Life Cycle Impact Assessment (LCIA) is a phase of life cycle assessment that aims at understanding and evaluating the magnitude and significance of the potential environmental impacts for a system throughout the life cycle (International Organization for Standardization- ISO 14044:2006, 3.4). The LCIA methods used provide impact characterization factors for elementary flows to aggregate the impact to a limited number of midpoint and/or damage indicators.

Multi-functionality is the capacity of a process or facility to provide more than one function, i.e. it delivers several goods and/or services ("co-products"). The process or facility is then “multifunctional”. In these situations, all inputs and emissions linked to the process or facility must be partitioned between the product of interest and the co-products in a principled manner.

Non-Starch Polysaccaharides (NSP) are components of the plant-cell-wall polysaccharides (e.g. xylans and beta-glucans) and lignin in feed that are not broken down by the digestive enzymes of animals.

Output is a product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases.

Phytase: is an n enzyme occurring in plants, especially cereals, or produced by fermentation which catalyzes hydrolysis of phytic acid to inositol and phosphoric acid.

Phytogenic substances are substance derived from or produced by plants used as a feed additive. Similar substances might be produced by chemical synthesis or fermentation.

Prebiotic is an undigestible substance used to induce the growth or activity of beneficial microorganisms (e.g. bacteria and fungi) in the gastrointestinal tract. Prebiotics can alter the composition of organisms in the gut microbiome. It usually confers a health benefit on the host associated with modulation of the microbiota (FAO 2007).

Primary data are directly measured or collected data representative of specific activities within the product’s life cycle.

Product category is a group of products that can fulfil equivalent functions.

Product Category Rules (PCR) are a set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories.

Probiotic is a live microorganism administered to an animal as a feed additive. Probiotic may improve the feed digestibility by breaking down feed ingredients into nutrients and/or produce certain vitamins necessary for the host and/or alter the composition of organisms in the gut microbiome. Microorganisms regarded as probiotics used in animal nutrition are typically bacteria of the genera *Lactobacillus*; *Saccharomyces, Enterococcus, Bacillus* and *Bifidobacterium.*

Protease is an enzyme that digests proteins

Raw material is a primary or secondary material used to produce a product. Secondary material includes recycled material.

Secondary data is an information obtained from sources other than direct measurement of the inputs/outputs (or purchases and emissions) deriving from processes included in the life cycle of the product (PAS 2050:2011, 3.41). NOTE: Secondary data are used when primary data are not available or when it is impractical to obtain primary data. Some emissions, such as methane from litter management, are calculated from a model, and are therefore considered secondary data.

Sensitivity analysis is a systematic procedure for estimating the effects of the choices made regarding methods and data on the results of an LCA study.

System boundary is a set of criteria specifying which unit processes are part of a product life cycle.

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

Livestock Environmental Assessment and Performance (LEAP) Partnership and the preparation process

The LEAP Partnership is a multi-stakeholder initiative launched in July 2012 with the goal of improving the environmental performance of livestock supply chains. Hosted by the Food and Agriculture Organization of the United Nations (FAO), LEAP brings together the private sector, governments, academia, civil society representatives and leading experts who have a direct interest in the development of science-based, transparent and pragmatic guidance to measure and improve the environmental performance of livestock products. The first phase of the LEAP Partnership (2013-2015) focused mainly on the development of guidelines to quantify the greenhouse gas (GHG) emissions, energy use and land occupation from feed and animal supply chains as well as on the principles for biodiversity assessment. The second phase (2016-2018), known as LEAP+, broadened the scope and is focusing on water footprinting, nutrient flows and impact assessment, soil carbon stock changes, quantification of the impact of livestock on biodiversity, impact of feed additives, etc. In the context of environmental challenges such as climate change and increasing competition for natural resources, the projected growth of the livestock sector in the coming decades places significant pressure on livestock stakeholders to adopt sustainable development practices. In addition, the identification and promotion of the contributions that the sector can make towards a more efficient use of resources and better environmental outcomes is also of great significance. Currently, many different methods are used to assess feed additives and their associated environmental impacts as well as the performance of livestock products when feed additives are used. This may raise confusion and makes it difficult to compare results and set priorities for continuing improvement. With increasing demands in the marketplace for more sustainable products, there is also the risk that debates about how sustainability is measured will distract people from the task of making real improvement in environmental performance. There is the added danger that either 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 develop clear guidelines for environmental performance assessment based on international best practices. The scope of LEAP is not to propose new standards but to produce detailed guidelines that are specifically relevant to the livestock sector and to refine guidance concerning existing standards. The three groups that form the LEAP Partnership, have an equal say in deciding work plans and approving outputs from LEAP, thus ensuring that the guidelines produced are relevant to all stakeholders, widely accepted and supported by scientific evidence. The work of LEAP is challenging yet vitally important to the livestock sector. The diversity and complexity of livestock farming systems, products, stakeholders and environmental impacts can only be matched by the willingness of the sector's practitioners to work together to improve performance. LEAP provides the essential backbone of robust measurement methods to enable assessment, understanding and improvement in practice. More background information on the LEAP Partnership can be found at: www.fao.org/partnerships/leap/en/

The Feed additive Technical Advisory Group (TAG) and the preparation process

The feed additive TAG of the LEAP Partnership was formed in November 2017. The core group included 29 experts in animal sciences, crop sciences, soil sciences, life cycle assessment, environmental science, and livestock production systems. Their backgrounds, complementary between systems and regions, allowed them to understand and address different perspectives. The TAG was led by Ermias Kebreab (University of California, Davis, USA) and Chaouki Benchaar (Agriculture and Agri-Food Canada, Canada), who were assisted by Aimable Uwizeye (FAO, Rome, Italy), Technical Secretary of the TAG and Camillo de Camillis (FAO, Rome, Italy), LEAP manager. The role of the TAG was to develop a technical guidline for the accounting of:

1. Environmental impacts associated with the production of feed additives and
2. The effect of the use of feed additives on the environmental impacts of livestock systems

The TAG met in two workshops. The first one was held from 26 to 28 February 2018 at FAO, in Rome, Italy, and the second one was held from 4 to 6 July 2018 at FAO, in Rome, Italy. Between the workshops, the TAG worked via online communications and teleconferences.

Period of validity

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

Structure of the document

This document adopts the main structure of ISO 14040:2006 and the four main phases of the Life Cycle Assessment (LCA) – goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and interpretation. Part 2 of this methodology covers quantification of environmental impacts from production of feed additives:

- Section 1 describes the goal and scope definition of feed additives production.
- Section 2 describes the life cycle inventory.

Part 3 of this methodology describes the quantification of the effect of feed additives on the environmental impacts of livestock systems including goal and scope of the study, and life cycle inventory. Part 4 of this methodology provides guidance on the interpretation and summarizes the various requirements and best practice for reporting, including the uncertainty analysis.
A glossary providing a common vocabulary for practitioners has been included. Additional information is presented in the appendices.

Presentational conventions

These guidelines are explicit in indicating which requirements, recommendations, and permissible or allowable options users may choose to follow. The term “shall” is used to indicate what is required for an assessment to conform to these guidelines. The term “should” is used to indicate a recommendation, but not a requirement. The term “may” is used to indicate an option that is permissible or allowable. Commentary, explanations and general informative material (e.g. notes) are presented in footnotes and do not constitute a normative element

PART 1: OVERVIEW AND GENERAL PRINCIPLES

1. OBJECTIVES AND INTENDED USERS

The methodology and guidance developed here can be used by stakeholders in all countries and across the entire range of livestock production systems. In developing the guidelines, it was assumed that the primary users will be individuals or organizations with a good working knowledge of LCA. The main purpose of the guideline is to provide a sufficient definition of calculation methods and data requirements on quality and transparency to enable consistent application of LCA across differing livestock supply chains. The guideline allows for comparison of scenarios with and without specific feed additives and combinations thereof, supporting the evaluation of their effect in the given situation. This guideline further supports the applicant in communicating the final aggregated results of the LCA.

This guideline is relevant to a wide range of livestock stakeholders including:

- livestock producers, advisors, or civil associations, extension agents who wish to develop inventories of on-farm resources and assess the performance of their production systems with or without specific feed additives or combinations thereof;
- supply chain partners, such as feed additive manufacturers, feed producers and farmers, seeking a better understanding of the environmental performance of products in their production processes;
- policy makers interested in developing accounting and reporting specifications for livestock supply chains; and
- researchers and scientists interested in understanding the potential environmental impact of new feed additives or relevant technologies under development.

The benefits of this approach include:

- the use of a recognized, robust and transparent methodology developed to take account of feed additive function and the nature of livestock supply chains;
- the identification of supply chain hotspots and opportunities to improve and reduce environmental impact;
- the estimation of efficiency and productivity changes;
- the provision of support for reporting and communication requirements; and
- awareness raising and supporting action on environmental sustainability.

The objective of these guidelines is twofold

1. Provide detailed guidance on how to measure the environmental performance of the production of feed additives. Feed additives are feed ingredients and recommendations and principles defined in the LEAP guidelines on feed supply chains therefore also apply to feed additives. However, The LEAP guidelines on feed supply chains do not provide detailed recommendations on how to address the specificity of the production of feed additives, which differ significantly from other feed ingredients such as agricultural products. One of the objectives of these guidelines is to close this gap.
2. Provide detailed guidance on how to measure the effects of feed additives on the environmental performance of livestock products. Likewise, the effect of feed additives on the environmental performance of animal products is not included in the different LEAP guidelines on animal supply chains published so far and these guidelines also aim to close this gap.

These two objectives can be seen as modules when performing an LCA of animal products, with the possibility that different stakeholders take care of the different modules. In a study assessing the effect of feed additives on the environmental impact of livestock systems, the impact of the production of the feed additives shall be included.

2. SCOPE

2.1. Environmental impact

The production and the use of feed additives influences the environmental impact of livestock production. The use of feed additives significantly acts on feed efficiency, and thus animal and environmental performance (nitrogen and phosphorus flows). Following the Guidelines for Feed Supply Chains and the Guidelines for environmental quantification of nutrient flows, the most relevant impact categories are the global warming potential (GWP), eutrophication potential (EP), acidification potential (AP), land occupation (LO) and fossil energy use (FEU). Therefore, the feed additive guidelines cover the following environmental impact categories: climate change, fossil energy use, acidification, and eutrophication.

These guidelines should be used with other guidance developed in the LEAP Partnership such as biodiversity. Other impact categories such as ecotoxicity may be applicable. In such cases, users will need to collect and analyse additional information on feed additive production and use. This document does not provide support for the assessment of comprehensive environmental performance nor the social or economic aspects of feed additive supply chain. It is intended that in future these guidelines will be updated to include multiple categories, if enough reliable data become available to justify the changes.

Antimicrobials use is beyond the scope of this guideline. They will not be addressed here since the current state of knowledge does not permit quantification of development of antimicrobial resistance (AMR), caused by the use of antimicrobials.. Antibiotic resistance is a subset of the broader concept of AMR. AMR can occur naturally but development and spread of AMR is exacerbated by inappropriate use of antimicrobials. There is growing concern and evidence that some commonly used additives, such as copper, may co-select for antibiotic resistance in bacteria exposed to them (Medardus et al. 2014; Fang et al 2016) . On the other hand, it is recognized that adequate nutrition, including the use of feed additives, provide solutions to reduce the use of antimicrobials in livestock production systems.

2.2. Application

These guidelines can be applied to various livestock production systems including large and small ruminants, poultry and pig production systems. These guidelines should be used with other LEAP Partnership guidelines for specific livestock production system. Veterinary medicines intended to be used for therapeutic purposes are beyond the scope of these guidelines and will not be addressed here, as these guidelines focus on the effect of the use of feed additives on the environmental impacts of livestock production systems..

This guideline shall be read in conjunction with the species-specific guidelines and with the feed guidelines as described in Figure 1.

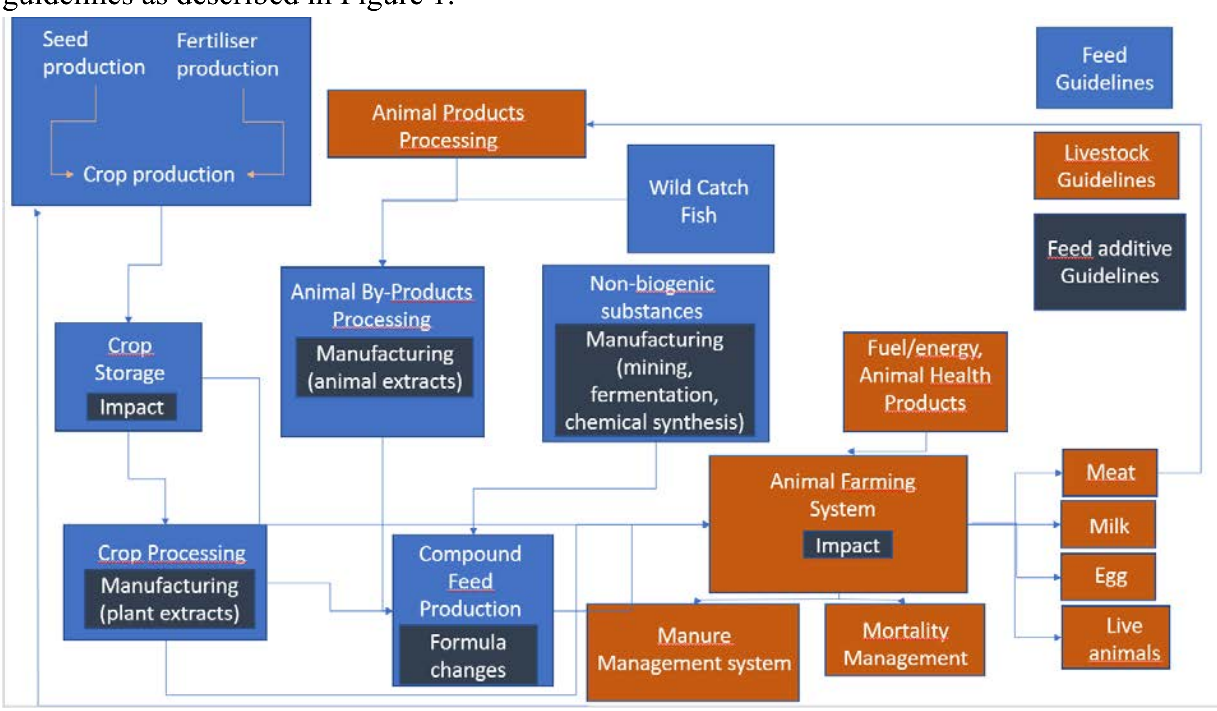

Figure 1. The relationship between the current guidelines and other LEAP guidelines

Some flexibility in methodology is desirable to accommodate the range of possible goals and special conditions arising in different sectors. This document strives for a pragmatic balance between flexibility and rigorous consistency across the scales, geographic locations and project goals. These guidelines can be used as building block for more sophisticated methodologies for environmental footprinting and environmental claims. Users are referred to ISO 14025 for more information and guidance on comparative claims of environmental performance.

These LEAP guidelines are based on the attributional approach to life cycle accounting. The approach refers to process-based modelling, intended to provide a static representation of average conditions. Due to the limited number of environmental impact categories covered here, results should be presented in conjunction with other environmental metrics to understand the wider environmental implications, either positive or negative. It should be noted that comparisons between final products should only be based on a full LCA of animal products. Users of these guidelines shall not employ results to claim overall environmental superiority or to communicate overall environmental superiority of feed additives. 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. BACKGROUND INFORMATION AND PRINCIPLES

3.1. A brief introduction to LCA

Life cycle assessment (LCA) is an established methodology used to quantify the environmental performance of products, processes or services, and is increasingly being used as a basis for information to purchasers along the supply chain, including the final consumers (Fava et al. 2011). LCA addresses the environmental aspects and potential environmental impacts such as the use of resources and the environmental consequences of releases throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal. There are four phases in an LCA study: (1) The scope, including the system boundary and level of detail of an LCA, depends on the subject and the intended use of the study; (2) The life cycle inventory (LCI) analysis phase. It is an inventory of input/output data with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study; (3) The life cycle impact assessment phase (LCIA). The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance; and (4) Life cycle interpretation, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a sound basis for conclusions, recommendations and a decision-making process in accordance with the goal and scope definition (DIN EN ISO 14040:2009-11). A detailed explanation on the structure and conduction of a LCA is given in detail in Chapter 5 of the FAO Guidelines for environmental quantification of nutrient flows and impact assessment in livestock supply chains.

3.2. Environmental impact categories

Life cycle impact assessment aims at understanding and evaluating the magnitude and significance of potential environmental impacts for a product system throughout the life cycle of the product (ISO-14040; ISO, 2006a). The selection of environmental impacts is a mandatory step of LCIA and this selection shall be justified and consistent with the goal and scope of the study (ISO, 2006a)

A distinction must be made between midpoint impacts, which characterize impacts in the middle of the environmental cause-effect chain, and endpoint impacts, which characterize impacts at the end of the environmental cause-effect chain. Endpoint methods provide indicators at, or close to, an area of protection. The aggregation at endpoint level and at the areas of protection level is an optional phase of the assessment according to ISO-14044 (ISO, 2006b). Climate change is an example of a midpoint impact category. The results of the LCI are the amounts of GHG emissions per functional unit. Based on a radiative forcing model, characterization factors, known as global warming potentials, specific to each GHG, can be used to aggregate all of the emissions to the same midpoint impact category indicator, e.g.. kilograms of CO_2 equivalents per functional unit. (IPCC 2014, ARC 2014)

Following the guidelines for feed supply chains and the guidelines for environmental quantification of nutrient flows, the most relevant impact categories are the global warming potential (GWP), eutrophication potential (EP), acidification potential (AP), land occupation (LO) and fossil energy use (FEU). Since the use of feed additives significantly acts on feed efficiency and thus influencing animal and environmental performance (nitrogen and phosphorus flows), these already indicated impact categories EP and AP are of almost importance within these guidelines.

This guideline provides detailed information on the most relevant environmental impact categories for livestock systems. However, the collection of full inventory data allows using various LCIA-methods and extend the selection of environmental impact categories. The users of the report are encouraged to conduct the environmental assessment as comprehensively as possible within the limits of data and resource availability.

3.3. Normative references

The following referenced documents provide critical framework for the application of this methodology and guidance.

- *ISO 14040:2006 Environmental management - Life cycle assessment – Principles and framework (ISO, 2006b)*

These standards give guidelines on the principles and conduct of LCA studies, providing organizations with information on how to reduce the overall environmental impact of their products and services. ISO 14040:2006 define the generic steps that are usually taken when conducting an LCA, and this document follows the first three of the four main phases in developing an LCA (goal and scope, inventory analysis, impact assessment and interpretation).

• *ISO14044:2006 Environmental management - Life cycle assessment – Requirements and guidelines (ISO, 2006c)*

ISO 14044:2006 specifies requirements and provides guidelines for LCA including: definition of the goal and scope of the LCA, the LCI, the LCIA, the life cycle interpretation, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.

3.4. Non-normative references

• *ISO 14025:2006 Environmental labels and declarations - Type III environmental declarations - Principles and procedures (ISO, 2006a).*

ISO 14025:2006 establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations. It specifically establishes the use of the ISO 14040 series of standards in the development of Type III environmental declaration programs and Type III environmental declarations. Type III environmental declarations are primarily intended for use in business-to-business communication, but their use in business-to-consumer communication is not precluded under certain conditions.

• *ISO 14046:2014 Environmental Management – Water Footprint -- Principles, Requirements and Guidelines (ISO, 2014).*

ISO 14046:2014 establishes the principles and specifies the procedures for developing water footprints for products, processes and organizations. It provides guidance on water footprint assessment as a stand-alone assessment or as part of a larger assessment. Only air and soil emissions affecting water quality are included, but not all air and soil emissions are covered.

• *ISO/TS 14067:2013 Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication (ISO, 2013a).*

ISO/TS 14067:2013 specifies the principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product. It is based on ISO 14040:2006 and ISO 14044:2006 for quantification, and ISO 14020:2000 (ISO, 2000), ISO 14024:1999 (ISO, 1999) and ISO 14025:2006, which deal with environmental labels and declarations for communication.

• *Product Life Cycle Accounting and Reporting Standard (WRI and WBCSD, 2011a).*

This standard from the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) provides a framework to assist users in estimating the total GHG emissions associated with the life cycle of a product. It is broadly similar in its approach to the ISO standards, although it puts more emphasis on analysis, tracking changes over time, reduction options and reporting. Like PAS 2050:2011 (see below), this standard excludes impacts from the production of infrastructure, but whereas PAS 2050:2011 includes 'operation of premises', such as retail lighting or office heating, the *Product Life Cycle Accounting and Reporting Standard* does not.

• *ENVIFOOD Protocol, Environmental Assessment of Food and Drink Protocol (Food SCP RT, 2013).*

The European Food Sustainable Consumption Round Table developed this Protocol to support a number of environmental instruments for use in communication and to support the identification of environmental improvement options. The Protocol might be the baseline for developing: communication methods, product category rules (PCRs), criteria, tools, datasets and assessments.

• *International Reference Life Cycle Data System (ILCD) Handbook: - General guide for Life Cycle Assessment - Detailed guidance (European Commission, 2010b).*

The *ILCD Handbook* was published in 2010 by the European Commission Joint Research Centre and provides detailed guidance for LCA based on ISO 14040:2006 and ISO 14044:2006. It consists of a set of documents, including a general guide for LCA and specific guides for LCI and LCIA

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

This Guide is a general method to measure and communicate the potential life cycle environmental impact of a product developed by the European Commission to highlight the discrepancies in environmental performance information.

• *Feed Product Environmental Category Rules (European Commission, 2018)*

The Feed PEFCR provides feed-specific guidance on how to implement the requirements of the PEF developed by the European Commission. It has been approved and published in April 2018 by the European Commission as an outcome of the Environmental Footprint pilot phase which included several rounds of public consultation.

• *BPX-30-323-0 General principles for an environmental communication on mass market products - Part 0: General principles and methodological framework (AFNOR, 2011)*

This is a general method developed by the ADEME-AFNOR stakeholder platform to measure and communicate the potential life cycle environmental impact of a product. It was developed under request of the Government of France again with the purpose of highlighting the discrepancies in environmental performance information. Food production specific guidelines are also available, along with a large set of product specific rules on livestock products.

• *PAS 2050:2011 Specification for the assessment of life cycle greenhouse gas emissions of goods and services (BSI, 2011)*

PAS 2050:2011 is a Publicly Available Specification (PAS), i.e. a not standard specification. An initiative of the United Kingdom and sponsored by the Carbon Trust and the Department for Environment, Food and Rural Affairs, PAS 2050:2011 was published through the British Standards Institution (BSI) and uses BSI methods for agreeing on a PAS. It is designed for applying LCA over a wide range of products in a consistent manner for industry users, focusing solely on the carbon footprint indicator. PAS 2050:2011 has many elements in common with the ISO 14000 series methods but also a number of differences, some of which limit choices for analysts (e.g. exclusion of capital goods and setting materiality thresholds).

3.5. Guiding principles

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

The principles are adapted from ISO 14040:2006, the *Product Environmental Footprint (PEF) Guide*, *the Product Life Cycle Accounting and Reporting Standard*, PAS 2050:2011, the *ILCD Handbook* and ISO/TS 14067:2013, and are intended to guide the accounting and reporting of GHG emissions and fossil energy use. Accounting and reporting of environmental impacts of the production and use of feed additives in livestock production shall accordingly be based on the following principles:

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

Relative approach and functional unit: LCA is a relative approach, which is structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit (ISO 14040:2006, 4.1.4). In this guideline, the functional unit will vary depending on the livestock supply chain, on which the feed additives have an impact.

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

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

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

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

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

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

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

4. BACKGROUND INFORMATION ON FEED ADDITIVES

Feed additives are manufactured and used in animal nutrition to achieve a particular purpose or function along the feed chain. Feed additives are usually not used on farm as such and the feed additive chain is composed of multiple actors, as described in Figure 2.

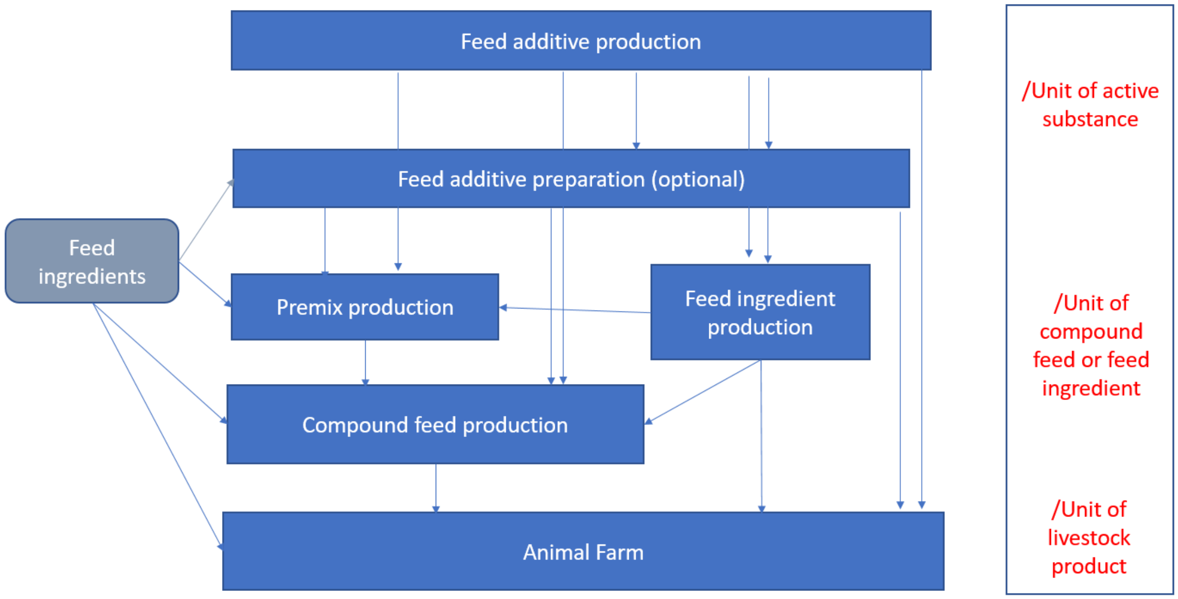

Figure 2. The manufacturing and use of feed additives along the livestock production chain.

4.1. Manufacturing (production) of feed additives

4.1.1. Product description

Feed additive is defined as a component, part or constituent of any combination or mixture making up a feed, whether or not it has a nutritional value in the animal's diet. Ingredients are of plant, animal or aquatic origin, or other organic or inorganic substances. (FAO/WHO, Codex Alimentarius CAC/RC 54-2004, amended in 2008). In some feed production chains, feed additive production can make a significant contribution to environmental impacts of feed rations, but feed additives can also contribute to significant mitigation potentials through their application in livestock production. Therefore, feed additives need to be taken into account along with the feed to food value chain assessment. Feed additives as well as the overall compound feeds are intermediate products in the life cycle of livestock supply chains. Feed additives can play an essential role in improving animal performance and animal wellbeing. The production of feed additives differs from general feed production as many additives are derived from fossil and mineral materials or manufactured industrially.

The LCA practitioner shall, where available, first source primary data. As an option, secondary data from internationally accepted databases may also be used. A number of commonly used feed additives such as salt, chalk and other minerals can be found in the databases presented in Table 1, which is not an exhaustive list. In the absence of information on feed additives in these databases (which is likely the case for the organic compounds such as amino-acids, enzymes, etc.), the LCA practitioner should look for reviewed and/or validated publications, including papers published in scientific journals, reports from consultants or research institutes, or reports from industry. Additional to the environmental impact of the feed additives, the effect of the additive on animal performance and feed conversion ratio shall be considered to calculate the impact of applying additives along the chain as a whole.

Table 1. Databases that can be used in LCA analysis for collecting secondary data (updated from Table 4 in the LEAP Environmental performance of animal feeds supply chains v1)

Name	Database / software	Countries/Regions represented	Salient features and access points
AgriBalyse	Database	France	http://www.ademe.fr (Free)
Agri-footprint LCI data (includes most Feedprint data)	Database	Global	LCI database that includes full inventory data expansion of Feedprint data http://www.agri-footprint.com http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm
European Reference Life Cycle Database (ELCD)	Database	European Commission	Data for transport and energy production and some chemicals and materials (Free)
AusLCI	Database	Australia	National and public LCA database for Australia http://www.auslci.com.au/ (Free)
ecoinvent	Database as such and implemented in LCA software	Global	Most used database in LCA, limited amount of feed raw material data http://www.ecoinvent.ch/
Japan Environmental Management Association for Industry	Database (web-based)	Japan, with limited coverage for other Asian countries	Database originated by the Japanese government and since April 2012, managed by JEMAI, which has taken over the responsibility to maintain the Japanese CFP scheme http://www.cfp-japan.jp/english/ (Free) (English site has limited information)

(JEMAI) CFP Program			http://www.cfp-japan.jp/calculate/verify/data.html
GaBi	Software (graphical user interface-based) with database	Global	Thinkstep in partnership with Department of Life Cycle Engineering at University of Stuttgart developed GaBi LCA software. Subscription required http://www.gabi-software.com
GFLI	Database	Global	LCI and LCA tools. LEAP and PEF methodology compliant (Free) http://globalfeedlca.org/
PEF for agricultural and food	Database	EU feed supply chains (includes non-EU datasets)	Based on Agri-footprint, World Food LCA Database, ecoinvent and Agribalyse. (Free) To be included in LCA software and available from http://eplca.jrc.ec.europa.eu/EF-node/
United States Department of Agriculture (USDA) LCA Commons	Database (web-based)	U.S.	US agricultural data (Free) http://www.lcacommons.gov
U.S. Life-Cycle Inventory (LCI) Database	Database (web-based)	U.S.	Database providing individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the US (Free) http://www.nrel.gov/lci/

4.1.2. Description of the production processes

Feed additives can be manufactured through different processes. We have divided the various manufacturing processes in 4 main categories for modelling and assessment. As described in chapter 2.3 on the functional unit for the manufacturing process, in some cases the environmental impact of the manufacturing process of the active substance has to be extended, when feed additives are placed on the market in the form of a commercial product (i.e. the active substance sprayed on a carrier or a pre-mixture of different active substances).

Primary data shall be used for robust results of the feed additives production, although feed additives might be a small contributor to the overall environmental impacts of livestock products. Hence, the practitioner may use default data for feed additives production, if primary data are not available.

The collection of primary data should be based on the flow chart of the manufacturing process as shown in Figures 3 to 7 (subchapters 4.1.2.1 to 4.1.2.6). The data and modelling results can be presented at different levels:

- Level 1: fully aggregated data of all unit processes
- Level 2: fully or partly disaggregated data. Minimum requirement is the disaggregation of processes used for separation as shown in Figure 8. A more detailed description of the consequences of data aggregation can be found in the chapter 4.1.3. (modularity).

Manufacturing of the preparation (e.g. coated, mixing): In some instances, the active substance might not be usable as such in compound feed production systems, for example due to their limited stability during feed processes or storage or to their poor flowability. For this reason, feed additive manufacturer are manufacturing preparations of feed additive, consisting of the active substance and other ingredients (e.: flowability agent, antioxidants, carriers). The preparation manufacturing processes are very diverse, e.g: coating, mixing, granulated…
When a feed additive is used within the feed chain and/or within the livestock production system in the form of a preparation, the environmental impact of the feed additive manufacturing shall encompass the environmental impact of the preparation manufacturing processes.

4.1.2.1. Mining

The system boundaries of the mining process depends on the details of the specifically given process. The following process steps shall be covered for modelling (see also Figure 3): Mining and processing (e.g. purification, further extraction) and packaging, if appropriate.

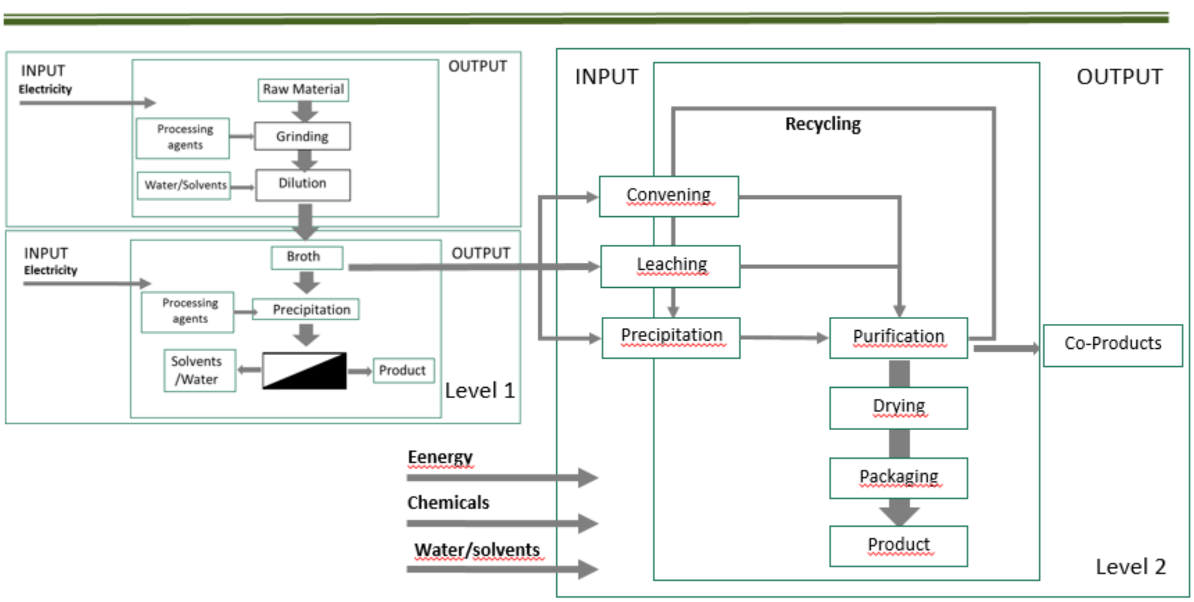

Figure 3 - General description of a representative mining process to get access to minerals as feed additives. Level 1 shows the minimum requirements for the modelling and the aggregation of the results. Level 2 explains the detailed requirements for best case modelling with primary data.

4.1.2.2. Biomass extraction

Figures 4 and 5 define generalized requirements for production of most types of plant and algae based feed additives and variable production systems will have variable input requirements and waste management. Feed additives derived from terrestrial plants may be sourced from traditional soil based cultivation or greenhouse operations including hydroponics, and additives derived from aquatic plants and algae (micro or macro algae) may be sourced from natural or manmade water systems cultivation or land based tank and bioreactor operations. There may also be wild-harvest of plants and algae which removes the cultivation aspect of the LCA but inputs and outputs of harvesting still apply.

The outputs from these systems prior to harvest are generally due to losses of water, nutrients, and chemicals in the form of runoff including drainage and greenhouse gases. Nutrients in fertiliser is determined by the fertility state of the growth media (soil or water) relative to requirements of the growing organisms and may be chemical or organic in nature, or waste nutrients from other processes.

Most of the differences in production of the feed additive between plants and algae reside in the cultivation aspect. Post-harvest the differences are minor and generally relate to handling and storage. Cleaning of the biomass may be required to remove undesired entities such as fouling organisms, salt, pesticides, detritus, as examples. In some cases, plant and/or algae-based feed additives might be further processed for example through conversion of biomass components into another chemical form such as trans-esterification or pyrolysis. Thus, next to the basic cultivation stage described here, the chemical synthesis processes shall be included accordingly.

The system boundaries of the process on the extraction of feed additives out of any type of biomass depend on the details of the specifically given process. The following process steps shall be covered for modelling (see also Figure 4): biomass production, extraction, purification and further chemical modifications, and packaging.

4.1.2.2.1. Plant based biomass

The process include extraction (e.g. energy linked to extraction), purification, packaging (if appropriate) and solvent recycling (if appropriate).

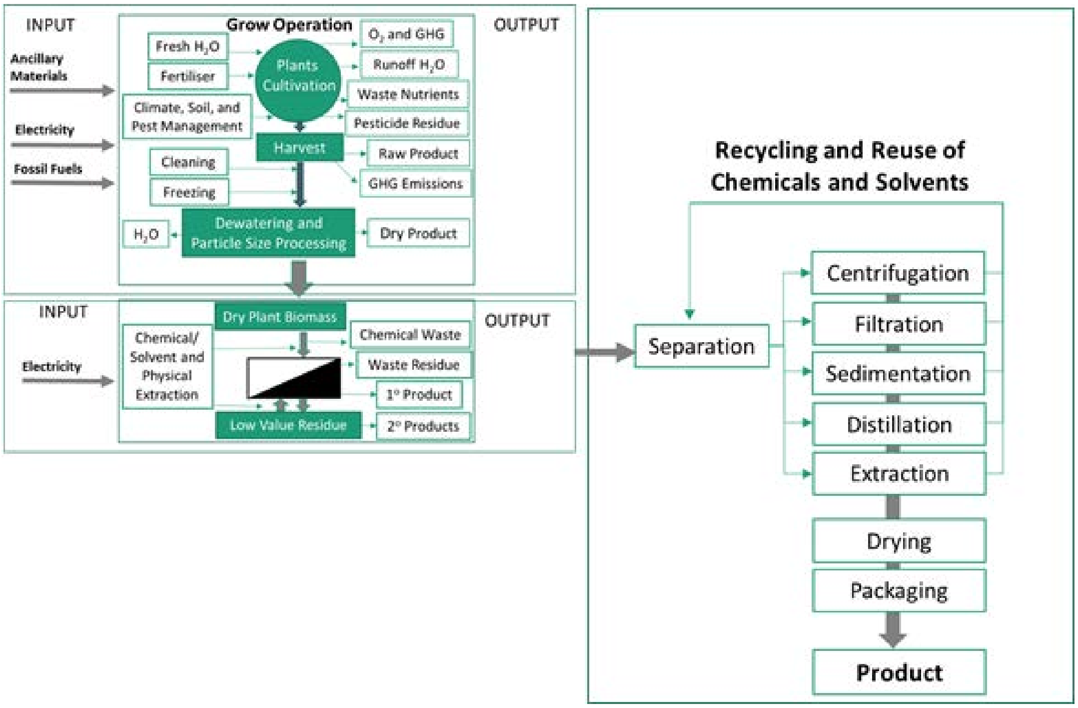

Figure 4. General description of a representative process to extract feed additives out of plant based biomass. Level 1 shows the minimum requirements for the modelling and the aggregation of the results. Level 2 explains the detailed requirements for best case modelling with primary data.

4.1.2.2.2. Algae based biomass

The process that need to be considered include:

- Algae production
- Extraction process (e.g. energy linked to extraction)
- Purification process
- Packaging, if appropriate
- Solvent recycling, if appropriate

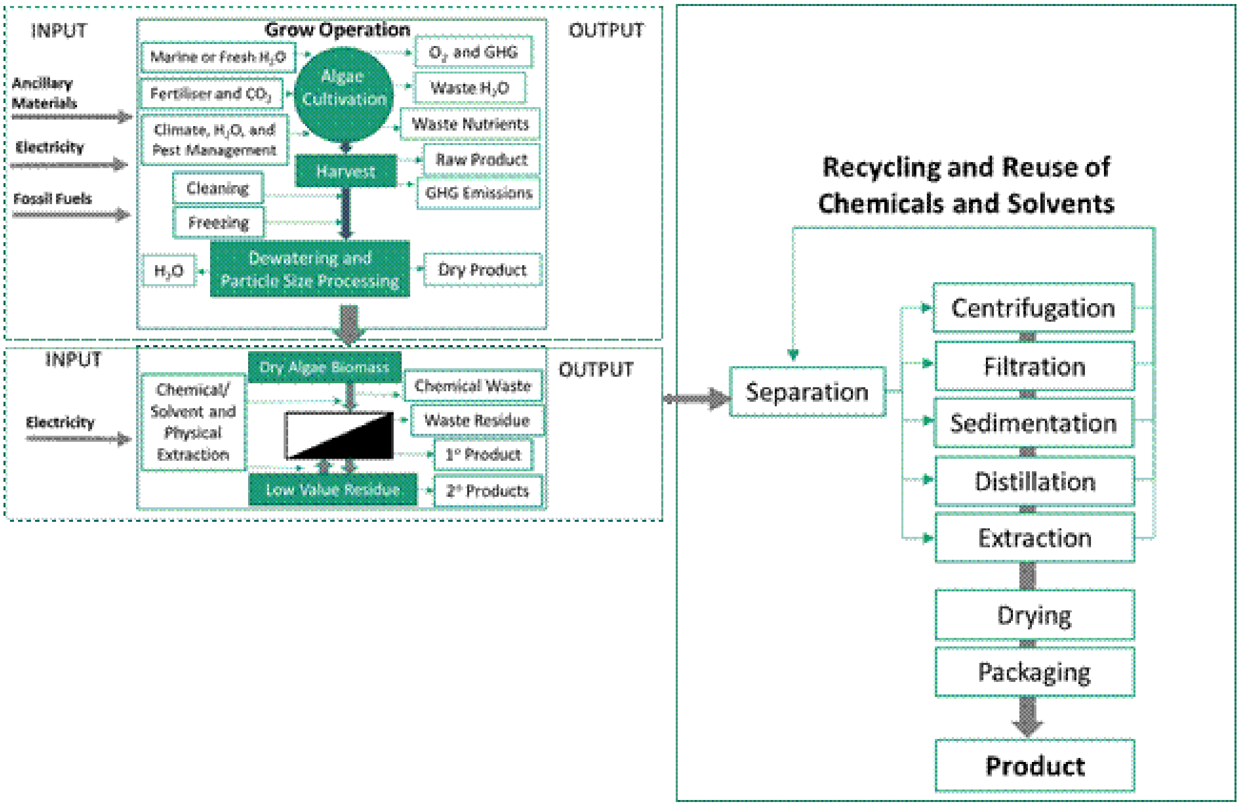

Figure 5. General description of the representative process for the extraction of algae based biomass. Level 1 shows the minimum requirements for the modelling and the aggregation of the results. Level 2 explains the detailed requirements for best case modelling with primary data.

4.1.2.3. Chemical process

Starting from mostly petrochemical derived raw materials a complex multistep chemical process transforms these small molecules into specific feed additives. These processes are performed in large scale facilities under optimally controlled reaction conditions, ensuring a highly efficient process. These products can be in dry or liquid form and can be further reacted or coated to produce additional products. Depending on the dedicated use of the resulting products, different types of downstream steps for isolation, drying or further processing can be applied.

The system boundaries of the process on the chemical synthesis of feed additives depend on the details of the specifically given process. The following process steps shall be covered for modelling (see also Figure 6):

- Sourcing of raw materials
- Chemical process (e.g. energy, water use)
- Separation and Purification process
- Packaging, if appropriate
- Solvent recycling, if appropriate

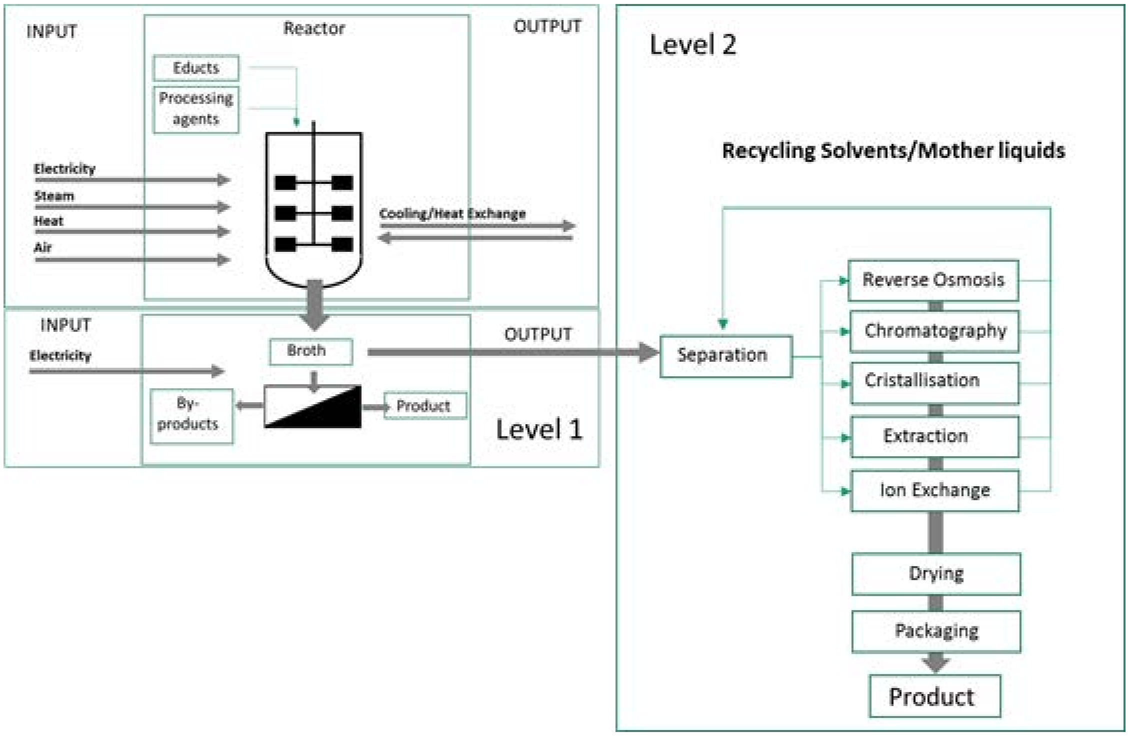

Figure 6 - General description of a representative process for the chemical synthesis of feed additives. Level 1 shows the minimum requirements for the modelling and the aggregation of the results. Level 2 explains the detailed requirements for best case modelling with primary data.

4.1.2.4. Fermentation

The generalised flow diagram for the production of feed additives by fermentation is shown below (Figure 7). As a representative example the description is based on different documentations of the biotechnological production. Advanced modern biotechnology has allowed rapid progress to be made in the selection of specialised microorganisms that transform carbohydrates such as starch and sugar, through fermentation to feed additives in a highly efficient and sustainable manner. Sufficient quantities of nitrogen and a range of micro nutrients must also be supplied during the process. Hygiene and control of the conditions with the fermenter are critical; they are continuously monitored to ensure optimal production and product quality.

For substances, after fermentation, the microorganisms are inactivated and further processing steps take place to produce the various end products. Depending on the dedicated use of the resulting products different types of downstream steps for isolation, drying or further processing can be applied.

For probiotics, the microorganism is removed from the majority of the substrates and lyophilized for further packaging.

The system boundaries of the biotechnological process such as fermentation to get access to feed additives depend on the details of the specifically given process. The following process steps shall be covered for modelling (see also Figure 7):

- Sourcing of raw materials and of production organism

- Fermentation process (e.g. energy, water use)
- Separation
- Purification process, if appropriate
- Packaging, if appropriate
- Solvent recycling, if appropriate

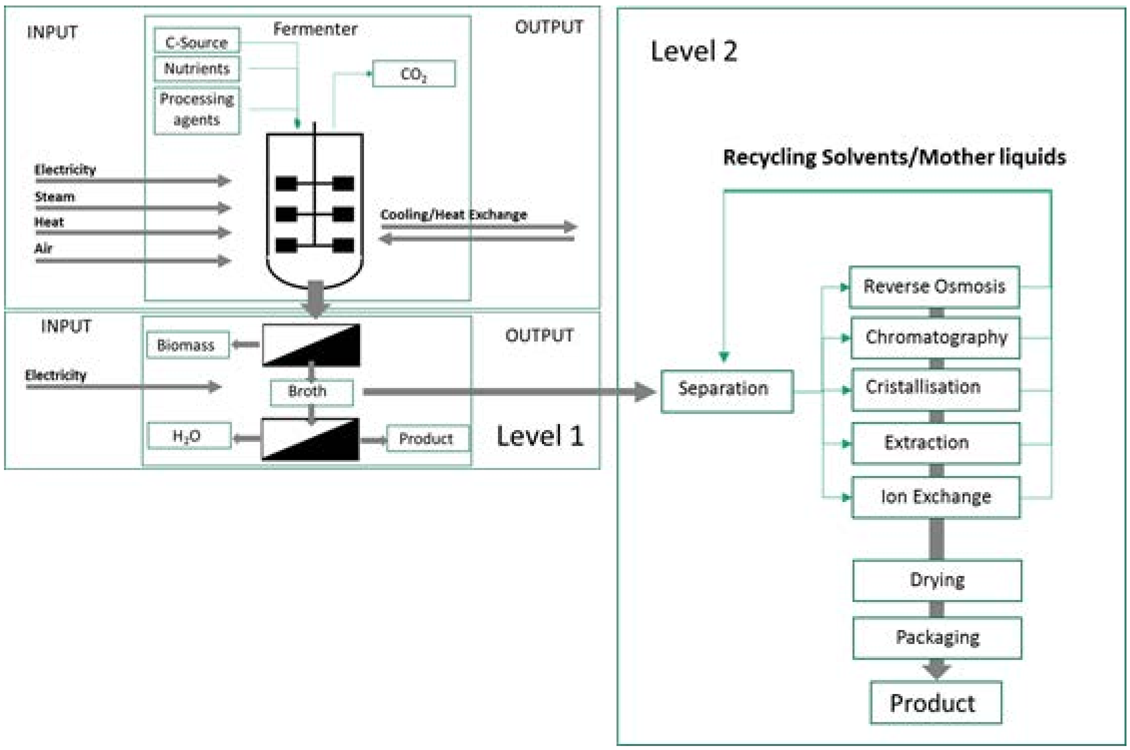

Figure 7. General description of a representative process for the biotechnological synthesis of feed additives. Level 1 shows the minimum requirements for the modelling and the aggregation of the results. Level 2 explains the detailed requirements for best case modelling with primary data.

4.1.3. Modularity

This guidance covers the feed additive chain from the extraction/production of raw materials to the time when feed formulations are digested by the farm animals. There is a wide range of feed additives, produced by different technologies as described above. To deal with the variety of feed additive supply chains and to preserve maximum flexibility, this guidance and methodology is based on a modular approach. This will allow users to utilize only those modules that are relevant to the feed additive production, under evaluation. An example of an entire system is shown in Figure 8.

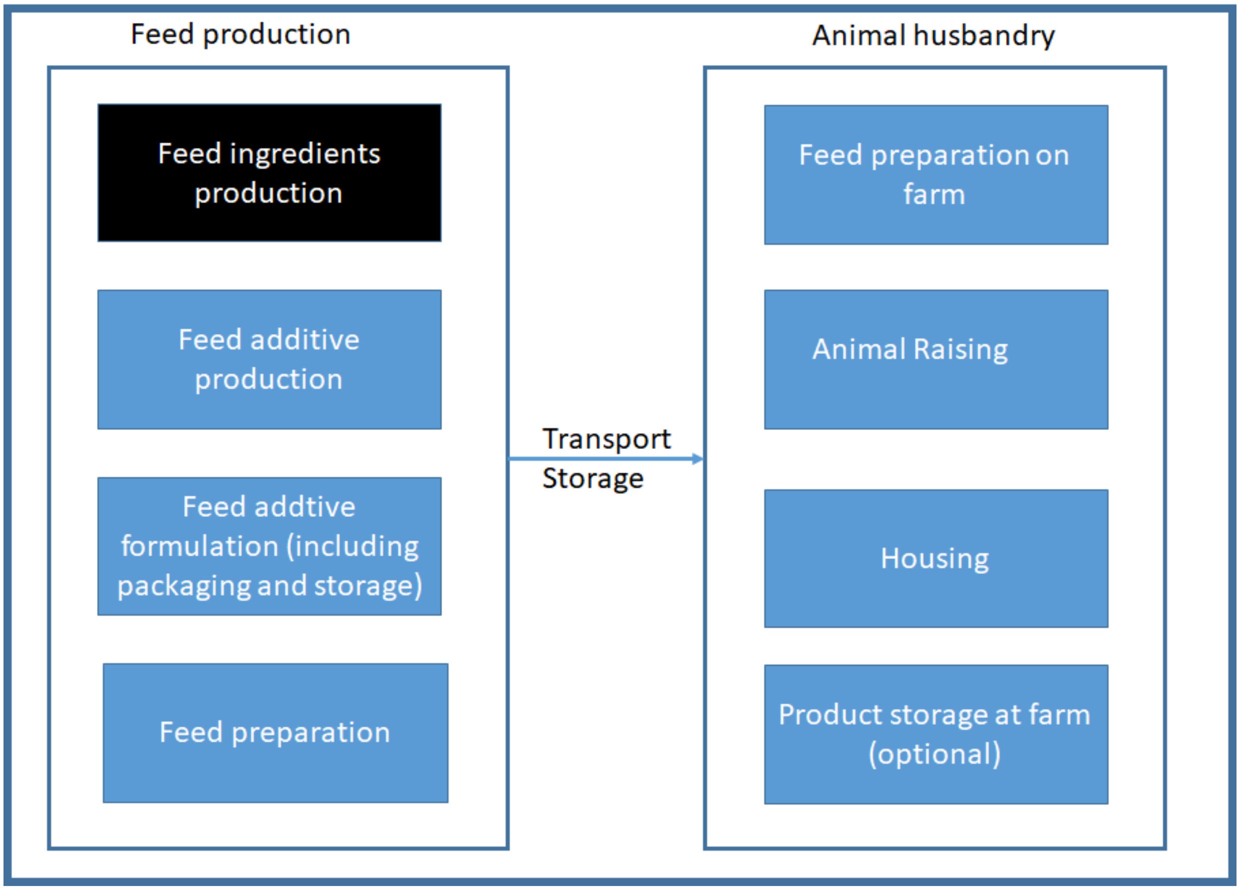

Figure 8. Generalised system diagram showing the life cycle stages covered in these guidelines

Feed additives belong to the feed production module. The feed additive production can be subdivided in several modules as shown in Figure 8. Feed additives can be either used directly after manufacturing, but can also undergo further treatment slike coating or formulation depending on the type and fate of the active substance or microorganism produced.
Feed additives are then transported to users and may be stored at various points along the supply chain. Transport and the related storage are intermediate steps within the feed production stages. In some situations, traders also play an important role. The upstream and downstream system boundaries depend on the respective stages. For further information the reader is referred to section 8.4.6 of the LEAP guideline on Environmental Performance of Animal Feeds Supply Chains.
If the feed additive is stored and transported before including to the feed, there can be losses due to several factors. In such cases, the amount of feed additive required shall be corrected for losses.

Feed additives production consists of an assembly of unit processes. Data collection can be conducted either at a unit process level or at certain aggregation levels, which usually consist of several aggregated unit processes. A generic unit process and the associated input and output flows are shown in Figure 9.

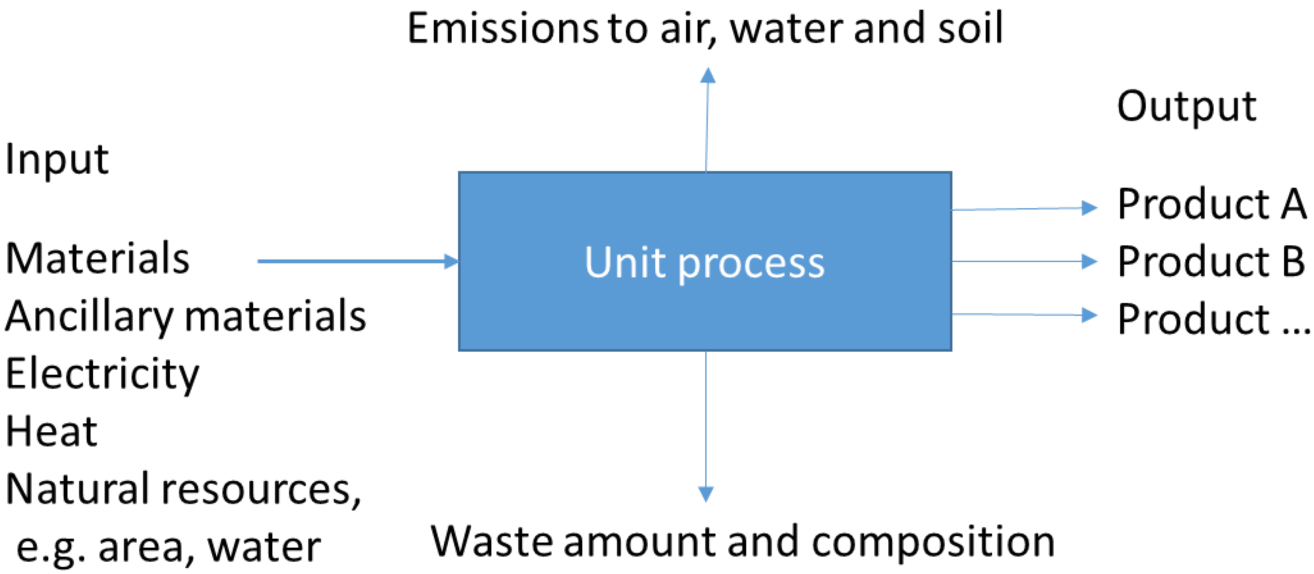

Figure 9. Generic unit process within the life cycle inventory

In general, the input flows into the processes consist of materials (e.g. acrolein, potassium carbonate, etc.), ancillary materials (e.g., lubricant for pumps), energy (e.g., heat and electricity) and in some cases also natural resources (e.g., water, land, etc.). Whenever possible, primary inventory data shall be collected for all resources used and emissions associated with the processes under investigation.

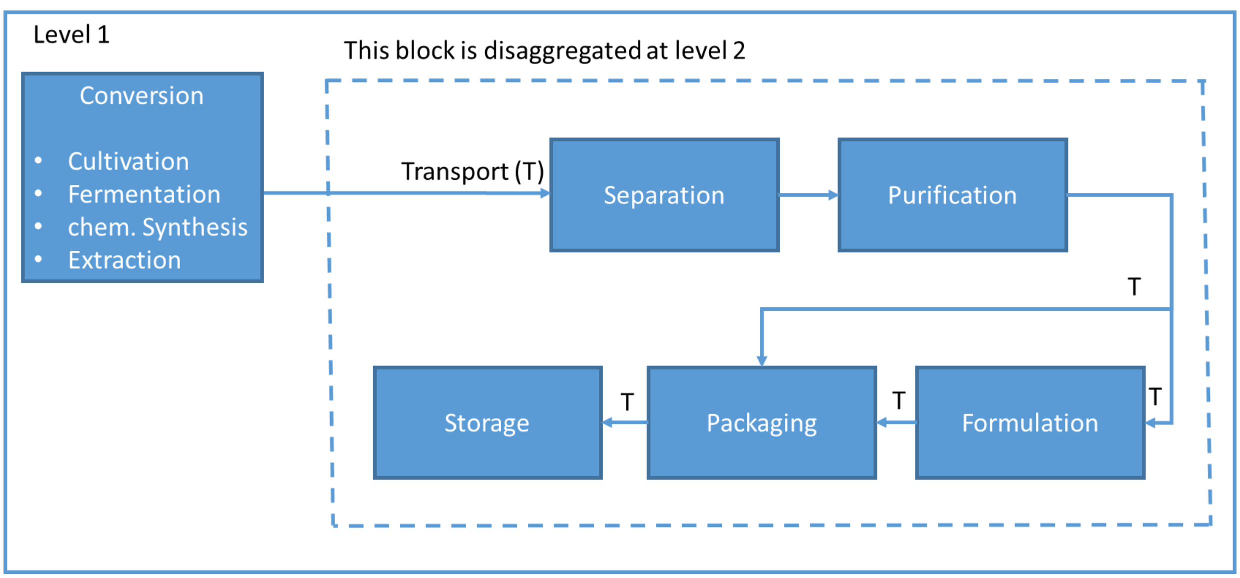

Figure 10. Typical modules for the production of feed additives

Each of the life cycle modules can consist of several unit processes (see "Description of the production processes"). However, it has to be recognized that the allocation approach for multi-output systems requires that the maximum level of aggregation is defined by the occurrence of by-products at the unit process level. If the aggregation level is higher, allocation may not be possible, which is illustrated with a virtual example in Figure 11.

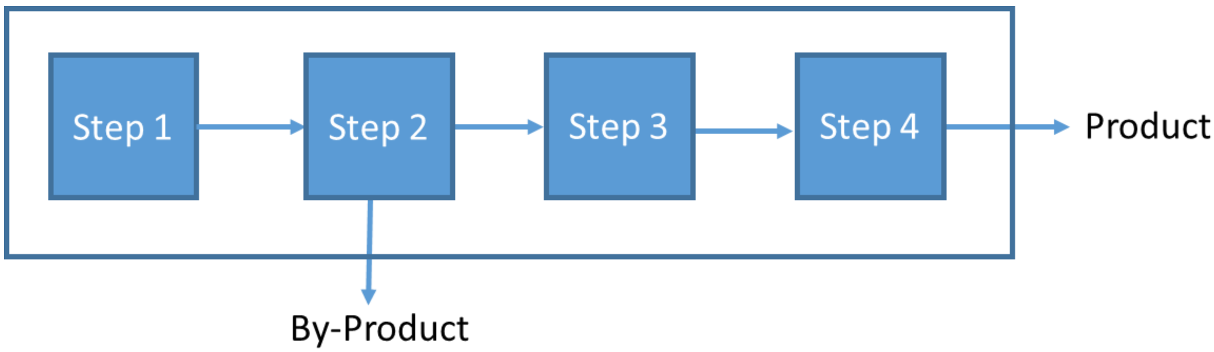

Figure 11. Virtual example for aggregated systems

In Figure 11 input and output flows of 4 process steps are aggregated (e.g. due to confidentiality issues) and a by-product occur at process step 2, then allocation is not a suitable approach because emissions of process steps 3 and 4 would be allocated to the by-product.
In these cases two options shall be considered:

- avoid aggregation of the process steps by subdivision;
- use substitution. However, substitution/crediting can have a substantial impact on the final results. As recommended in the LEAP Guidelines on animal feed supply chains, substitution shall only be used in situations where there is clearly no ambiguity about the avoided external production. In addition, it is recommended to conduct a sensitivity analysis to show the consequences of the modelling choice for substitution.

More information on product modularity can be found in section 7.2 of the LEAP Guidelines on animal feed supply chains.

4.2. Use of feed additives

Feed additives are usually incorporated in feeds and may have an influence on the:

- Feed composition
- Feed efficiency, either through modification of the feed consumption and/or animal performances (milk, meat, egg, wool)
- Reduction of feed losses, e.g. through improved preservation during handling and storage
- Mitigation of environmental emissions through changes of the excreta composition and/or directly through emission modification

4.2.1. Feed composition

Feeds are composed of a combination of different feed ingredients with the aim to meet nutrient requirements (protein, energy, vitamins, and minerals) of the animal for maintenance, growth, reproduction and production (i.e., milk, meat, egg). Depending on the livestock production systems, the feed composition is limited by the availability of feed ingredients on the farm and cannot be modified easily or is purchased outside of the farm.

In the most developed systems, feed composition is defined through IT-based formulation programs that consider, on one hand the nutritional quality of the different available feed ingredients and on the other hand, the nutritional quality of the feed, fitting to the animals' requirements. The nutritional constraint on the feed, e.g. level of crude protein, total phosphorus, are defined based on animal performance objectives, while each feed ingredient is characterized by nutrient concentration to achieve the nutritional constraints of the feed. The formulation program then investigates, analyses, and indicates how best the available feed ingredients can be combined effectively and efficiently to achieve the nutritional constraints (El-Deseit, 2009). In addition, the program aims to produce a feed composition at least cost (least cost formulation).

Feed additives may be used for improving the nutritional value of feed ingredients, by increasing their digestibility, by making nutrients present in these feed ingredients more available for the animals, particularly for monogastric animals (pigs and poultry). By increasing the availability of nutrients from specific feed ingredients, the nutritional value of those ingredients is modified compared to the others. Hence, their potential incorporation rate in feeds might be modified, using least cost formulation. As a consequence, the composition of the feed (i.e. the different feed ingredients used and their incorporation rate) might be modified; while the nutritional characteristic remains unchanged.

Alternatively, some feed additives might be used to improve the digestibility of specific nutrients, particularly proteins, starch and non-starch polysaccharides, and phosphorus, enabling a modification of the nutritional constraints of the feed (e.g. reducing the crude protein content in feed). This modification usually leads to a modification of the relative value of feed ingredients used for the formulation and hence a modification of the feed composition.

Such modification of feed composition can have an impact on the environmental footprint of animal sourced products, considering that more than 50% of the animal production footprint is related to feed ingredients (Wideman et al., 2012). Examples of modification of feed composition are provided in the Annex of this guidance document for further reference.

4.2.2. Feed Efficiency

Feed efficiency is calculated as the ratio between the quantity of the feed consumed by the animals and the quantity of animal sourced products from these animals. Feed efficiency depends on following factors:

- The consumption of feed by the individual animals
- The performance of the animal (kg of functional unit)
- Animal health and welfare, including mortality or morbidity in the flock, particularly for meat and wool production
- The quality, i.e. the marketability, of the animal sourced product

In this context, the quality of the animal sourced product is linked to its compliance with food safety requirements (e.g. low somatic cell count), food quality standards (e.g. proper pigmentation of eggs) and/or percentage of condemnation of carcass (e.g. carcass conformation and composition). This affects primarily the quantity of products sold, hence the overall emission intensity of the animal production.

Different types of feed additives may have an influence on feed efficiency, either by reducing feed consumption, increasing performance, improving animal sourced products quality, or reducing mortality/morbidity. Feed additives might be classified based on their effect on:

- Feed digestibility, through nutrient availability or stabilized gut microflora
- Animal sourced products quality
- Reproduction and hatchability
- Animal health and welfare maintenance

Feed digestibility. The digestibility of feed is an important contributor to feed efficiency and also to the environmental impact of feed production on livestock production. With the exception of ruminants, which are able to digest a large variety of feeds and particularly diets with a high percentage of fibers, monogastric animals (pigs and poultry) are not able to digest fibers to a large extent. For this reason, high energy diet for monogastric animals is mainly composed of feed ingredients with a high digestibility (e.g. cereals and pulses). Feed additives can be used to improve the digestibility of feed ingredients containing a higher level of undigestible nutrients (e.g. fibers), thereby increasing either their energy, amino acids and/or mineral values.

By increasing feed digestibility, the availability of nutrients (carbohydrates, fatty acids, amino acids and minerals) present in the animal diet is increased. The consequences are that either animals need less feed to achieve their physiological requirements (maintenance, production) or they can produce more (e.g. by increasing their growth rate or milk/egg production).

Increased feed digestibility can be achieved either by acting on the nutrient availability from the diet or by improving the gastrointestinal tract function (e.g. influencing the microbiome). As an example, a description of the mode of action of enzymes is provided in the annex of this document for further reference.

Animal sourced product quality. The marketing of animal sourced product (either nationally or globally) is linked with adhesion to standards for food quality (e.g. on the acceptable concentration of somatic cell count in milk or organoleptic quality of the animal sourced product (e.g. pigmentation)). Feed additives might be incorporated into feed with the objective to improve the standardization of products, hence facilitating and securing their compliance with food quality standards. As a consequence, the quantity of animal sourced food that is marketed increased leading to less waste and decreased environmental impact intensity of the product. Examples of such effects are described in the annex of this document for further reference.

Reproduction and hatchability. Feed additives which can increase the rate of fertility and hatchability have a potential for e.g. decreasing unhatched eggs and hatchery waste or increasing the life span of reproductive animals. Any efforts to reduce waste and untreated hatchery disposal directly reduces greenhouse gas emissions and groundwater contamination.

Animal health and welfare maintenance. Diseases provoke disruption of physiological balance and can influence nutrient utilization. For example, *Eimeria* are unicellular parasites causing coccidiosis in cattle, poultry, sheep and goats. Coccidiostats are used as a prophylactic to prevent coccidiosis in poultry and other animals.

4.2.3. Reduction of feed losses

Feed production is one of the most impacting aspects of animal production. Hence, it is important to ensure that the large majority of the feed ingredients and feeds produced are delivered to the animal's mouth. For this purpose, the use of feed additives such as antioxidants, preservatives, and silage additives provides tools to reduce feed losses along the chain.

Antioxidants. Some feed ingredients, particularly oils and fats are particularly sensitive to oxidation. Oxidation leads to the degradation of the quality of lipids contained in these products. Therefore, they may be rendered unsuitable to feed the products to animals. In animal production free radical generation and lipid peroxidation are responsible for the development of various diseases as well as decrease in animal productivity. Antioxidants are used to prevent the oxidative degradation of feed ingredients, thereby, maintaining their suitability for feed production and reducing the quantity of feed being discarded from animal nutrition.

Preservatives. When stored after harvest, feed ingredients are sensitive to the development of moulds and microorganisms that affect feed quality. Example, the development of mycotoxins during feed storage may exert a negative impact on feed intake and feed efficiency.

Silage additives. Silage is one of the technologies used for the preservation of roughages and other feed ingredients containing a high level of humidity. It enables the provision of feed during period of the year when the animals are not able to graze outside.

The silage technology is based on the rapid fermentation of the stored roughage, leading to depletion of oxygen and the production of lactic acid and propionic acid, which limits the potential for growth of non-desirable microorganisms and moulds that could deteriorate the feed. In certain cases, the silage technology necessitates the use of feed additives to facilitate or even allow the rapid decrease of pH in the feed ingredients, guaranteeing its stability during storage. Moulds development leads to feed ingredients being discarded from the animal nutrition, but also leads to the presence of mycotoxins having a negative impact on feed efficiency.

Adding silage additives/inoculants to freshly harvested forage can greatly increase the likelihood of achieving good quality silage. Silage inoculants containing homolactic bacteria, such as *Lactobacillus plantarum* accelerate the decline in silage pH by preventing the growth of bacteria that increase dry matter losses. In addition, such bacteria conserve sugars in silage by reducing heterofermentation. Whereas, heterolactic silage inoculants such as *Lactobacillus buchneri* are more effective at improving aerobic stability by degrading lactic acid into acetic acid, which inhibits growth of yeasts and molds, and improves silage stability at feed-out (Reich and Kung, 2010). A recent meta-analysis has shown the feeding silage inoculated with homlolactic and facultative heterofermentative bacteria results in improved performance of the dairy cows (Oliveira et al., 2017).

4.2.4. Modification of environmental emissions

There are three main sources of emissions from animal production:

- Enteric methane emissions
- Gaseous emissions from manure storage (ammonia and nitrous oxide)
- Nutrients, minerals, feed additive metabolites concentrations in the manure

4.2.4.1. Enteric methane emissions

Livestock systems, particularly ruminants, contribute to greenhouse gas emissions, and particularly in the form of enteric methane (NASEM, 2018). A review of mitigation options for enteric methane from ruminants showed that some of the effective strategies include increasing forage digestibility, replacing grass silage with corn silage, feeding legumes, adding dietary lipids and concentrates (Hristov et al., 2013). Although effective, these types of system management options may not offer the scale of reduction required to dramatically change the agriculture contribution to the global GHG inventory and subsequent negative effects on climate change. However, the results of the present study and others suggest that feed additives may provide potent emissions reduction methodology. Feed additives have been tested to reduce methane emissions. For example, Appuhamy et al. (2013) showed about a 10% reduction using ionophores, specifically monensin in dairy and beef diets. Nitrates have also shown a potential to reduce emissions by 16% (van Zijderveld et al., 2011). Dijkstra et al. (2018) conducted a meta-analysis on the effect of 3-nitrooxypropanol to reduce methane emissions and reported that it is effective in reducing enteric methane by 39% in dairy and 22% in beef. Seaweed is reported to have antimethanogenic effect that reduces methane yield during in vitro fermentation (Kinley et al., 2016), which was confirmed in in vivo using sheep (Li et al., 2018) and dairy cattle (Roque et al., 2018).

4.2.4.2. Gaseous emissions from manure

Manure management, including storage, handling, and field application can be a source of emission of nitrous oxide and ammonia. The rate of emissions varies with the nitrogen quantity in the manure and its physico-chemical characteristics (e.g. pH in liquid manure). Manure management practices adopted by farmers can influence the magnitude of GHG emissions. Nitrous oxide is produced by the process of nitrification and de-nitrification in soil following manure addition (Chadwick et al., 2011) and the magnitude of these emissions are affected by climate, soil type, strategy of application, and composition of manure (Sommer et al., 2009; Chadwick et al., 2011). Manure from livestock production contributes to 30-50% of the global N_2O from agriculture (Oenema et al., 2005). While major source of methane emissions in agriculture is enteric fermentation and rice paddies, anaerobic decomposition of organic matter in manure also results in formation of CH_4 (Hellmann et al., 1997). Methane emissions from manure accounts for 12-41% of total agricultural CH_4 emissions for most countries (Chadwick et al., 2011) and emissions depend on the storage duration, temperature and manure composition (Monteny et al., 2006). Solid manure have been shown as the sources of CH_4 emissions with losses of 0.4 – 9.7% of C from heaps of cattle farmyard manure observed earlier (Chadwick, 2005; Szanto et al., 2007). Total emissions from solid manure are function of heat anaerobicity and temperature (Chadwick et al., 2011). The modification of the physico-chemical characteristics of the manure through feed additives enables in particular the reduction of ammonia and N_2O emissions.

4.2.4.3. **Nutrient, minerals and feed additive metabolites concentrations in the manure**

Nutrient cycling is an important element of the environmental impact of animal production. In more intensive systems, when the production of manure exceeds its capacity to serve as fertilizers, the reduction of the phosphorus and nitrogen excretion by the animals may represent an effective means to reduce the risk of leaching and eutrophication. In addition, feed efficiency is also a way to reduce nutrient concentration in the manure and is considered within the part on feed efficiency.

PART 2: METHODOLOGY FOR QUANTIFICATION OF ENVIRONMENTAL IMPACTS FROM MANUFACTURING/PRODUCTION OF FEED ADDITIVES

This section provides recommendation on how to assess the environmental impacts arising from the manufacturing of feed additives, in order to complete the recommendations provided in the LEAP guidelines on feed supply chains. Specifically it provides guidance for:

- A cradle to farm gate LCA of feed additives, which can be performed independently and whose results can be communicated as such or as input for a full LCA of feed or animal products
- The life cycle stage ‘production of feed additives’ of an LCA of feed production or of animal products

5. GOAL AND SCOPE DEFINITION

5.1. Goal

The first step in initiating an LCA study is to clearly define the goal or make a statement of purpose. This latter describes the goal to be pursued and the intended use of results. Reasons for carrying out an LCA are numerous: 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. Nevertheless, LCAs can go beyond a simple carbon footprint and include other environmental impacts categories. Indeed, full LCAs cover environmental impact categories such as eutrophication or acidification and provide detailed information about a product’s environmental performance. They can also serve to set progress and improvement targets (ISO, 2006b) and to provide a basis for reporting on the environmental impacts of products. However, these guidelines are not intended for the comparison of products or environmental performance labelling.

It is essential that the LCA’s goal and scope is 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 rigor 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. 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):

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

5.2. 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 feed additives 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. Caution is needed in reporting the results of assessments based on these guidelines to avoid misinterpretation of the scope and application of the results.

5.3. Functional unit and system boundary of feed additive production stage

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).

In these guidelines, the reference flow for feed additives production is 1 kilogram of the final product leaving the manufacturing plant, packaged for the cradle to farm gate approach of production.

5.4. Description of system boundary

The system boundaries of this guideline are a combination of boundaries of the different existing guidelines (feed production, feed additive production and livestock related guidelines) and makes the link to the production of feed containing additives and its uses along the feed chain and on the farm (cradle-to animal-farm-exit-gate). The analysis should also include all emissions associated with land use change, linked to the use of specific feed additives, particularly when the additive is used to modify the feed composition. Since volume and composition of manure is significantly influenced through feed composition and animal performance on the farm, all emissions related to the storage and reuse of the manure as organic fertilizer shall be considered as well (see LEAP Guidelines on Environmental performance of pig supply chains).
A flow diagram of all assessed processes should be drawn that indicates where processes were cut-off. For the main transformation steps within in system boundary, a material flow diagram shall be produced and used to account for all of the material flows.

5.5. Material contribution and threshold

In principle, all relevant exchanges in the inventory should be included, hence in general no cut-off applies. Effects of feed additives cannot be included if linked emissions to their production are excluded. Given the relative importance of different flows, cut-off criteria may be adopted to determine whether or not to expand significant project resources to include specific exchanges in the assessment. Exchanges in feed additive supply chains that contribute less than 1 percentage of mass or energy flow of a given unit process may be cut off from further assessment, but should not be omitted from the inventory. Larger thresholds shall be explicitly documented and justified by the project goal and scope definition. A minimum of 95 percent of the impact for each category shall be accounted for. Larger thresholds should be transparently documented and in compliance with ISO 14044. Flows that contribute less than 1 percentage of the environmental significance for a specific unit process may be included in a scoping analysis (See LEAP guideline (FAO, 2016) Section 8.2 for further details). The scoping analysis may also provide an estimate of the total environmental impact to evaluate against the 95 percent minimum.
Some environmental impact categories (e.g., ecotoxicity) may be sensitive to the flows that have small mass or energy contributions (e.g., processing agents fed to fermenter). Additional effort should be expended to reduce the uncertainty associated with these flows. Lack of knowledge regarding the existence of exchanges that are relevant for a particular system is not considered as a cut-off issue but rather a modeling mistake. The application of cut-off criteria in an LCA is not intended to support the exclusion of known exchanges, but to help guide the expenditure of

resources towards the reduction of uncertainty associated with those exchanges that matter the most in the system. According to ISO 14044, when the study is intended to be used in comparative assertions that will be disclosed to the public, the final sensitivity analysis of inputs and outputs shall be the cut-off criteria (ISO 14044). See 7.3. for details in sensitivity analysis.

5.6. Time boundary for data

The time boundary for data shall be representative. In general, data should be averaged over an appropriate period. For products derived from industrial processes, such as fermentation, extraction or chemical conversion annually averaged data should be used. For other processes such as algae or plant production at least the length of one or more production cycles should be used. If the additive characteristics change during the growing season or harvest periods, then classifications should be made on the basis of the harvest variations of the feed additives or the raw materials the additives are derived from. Further information for time boundary of data is available from LEAP guidelines on animal feeds supply chains section 8.4.9.

For the use phase of additive containing feed, the study shall use an 'equilibrium population' that shall include all animal classes and ages present over the 12-month period required to produce the given mass of product.

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

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

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

5.7. LIFE CYCLE INVENTORY

5.7.1. Overview

This section describes the key steps and requirements in quantifying emissions and in resource use of feed additive supply chains. The selection of LCI modelling, including the decisions on which data to collect, depends largely on the goal and scope of the study. The LCI analysis phase involves the collection and quantification of inputs and outputs throughout the life cycle stages covered by the system boundary of the individual study. This typically involves an iterative process (as described in ISO-14040 (ISO, 2006a)), with the first steps involving data collection using the principles as outlined in 2.2.3.

The subsequent steps in this process involve the recording and validation of the data; relating the data to each unit process and reference unit (including the allocation for different co-products); and aggregating the data, ensuring that all significant processes, inputs and outputs are included within the system boundary. For the feed additive production, the system boundary is defined from cradle to feed additive factory gate, including the on-site-transport, packaging and storage within the production plant. Transport to the feed mill is outside the system boundary of the feed additive production.

In many instances, inventory data are not the result of direct measurements but are a combination of activity-related measurements (primary activity data) as well as emission factors or parameterized emission factors (calculation models). To clarify the nature of the inventory data, it is useful to differentiate between 'measured' and 'modelled' foreground system LCI data.

This section describes the inventory analysis process for all stages and situations. A step-by-step approach in the life cycle modelling of the feed additives supply chain is recommended, starting with the flow chart shown in 1.5.4.

In cases where feed is part of the analysis of a livestock system, the process starts with a breakdown of the animal's ration into single feed products. For every feed additive used, the LCI data shall be collected in accordance with the goal and scope of the analysis. The goal and scope of the analysis affects data collection and the quality of the required data. Primary data shall be obtained for feed additive production processes LCA, whereas for a sectoral analysis, data may be obtained from secondary sources, such as statistical databases and other high-quality sources.

5.7.2. Compiling and recording inventory data

The compilation of the inventory data should be aligned with the goal and scope of the LCA. In general, an inventory of all materials, energy resource inputs and outputs, including products, co-products and emissions, for the product supply chain under study shall be compiled as indicated in 2.2.2. for unit processes. The data recorded in relation to this inventory shall include all processes and emissions occurring within the system boundary. When developing or using life cycle inventories, biogenic carbon emissions (CO_2 and CH_4 from biomass and soil) and carbon emission from fossil sources shall be separately reported. According to international LCA (ISO, 2013) and carbon-footprinting standards (BSI, 2008) biogenic GHG flows shall be included in the carbon footprint and also reported separately from the fossil based GHG flows.

When evaluating the data collection requirements for a project, the influence of the project scope shall be considered. Usually, foreground and background processes are distinguished. Foreground processes are being considered as under the control or direct influence of the study commissioner and primary data should be used for those processes if possible. As far as possible, primary inventory data shall be collected for all resources used and emissions associated with each life cycle stage considered. When possible, data collected directly from suppliers should be used for the most relevant input materials they supply. For processes where the practitioner does not have direct access to primary data, secondary data can be used. It is recommended to apply the materiality principle for data collection, meaning that effort shall focus on those aspects and parameters that are the most relevant in determining the environmental performance.

The procedure displayed in Figure 12 can be used to collect inventory data for the system under investigation. The first choice are representative primary data in the order of measured, modelled or collected from the supplier. If this data is not available, peer-reviewed data should be used. It might be necessary to adapt peer-reviewed data that does not follow the methodology outlined in this guideline.

Any data gaps shall be filled using the best available secondary or extrapolated data. When possible, an independent peer review of proxy data sets by experts should be sought, as errors in extrapolation at this point can be significant. Panel members should have sufficient expertise to cover the breadth of LCI data that is being developed from proxy data sets. The remaining data gaps can be filled with proxy data either derived from comparable processes, e.g. similar fermentation processes or with dummy data following the precautionary principle, e.g. data from the same data classification, e.g. organic chemicals, having the highest environmental impacts for the most relevant impact categories for the system under investigation. When such proxy data are utilized, it shall be reported and justified.

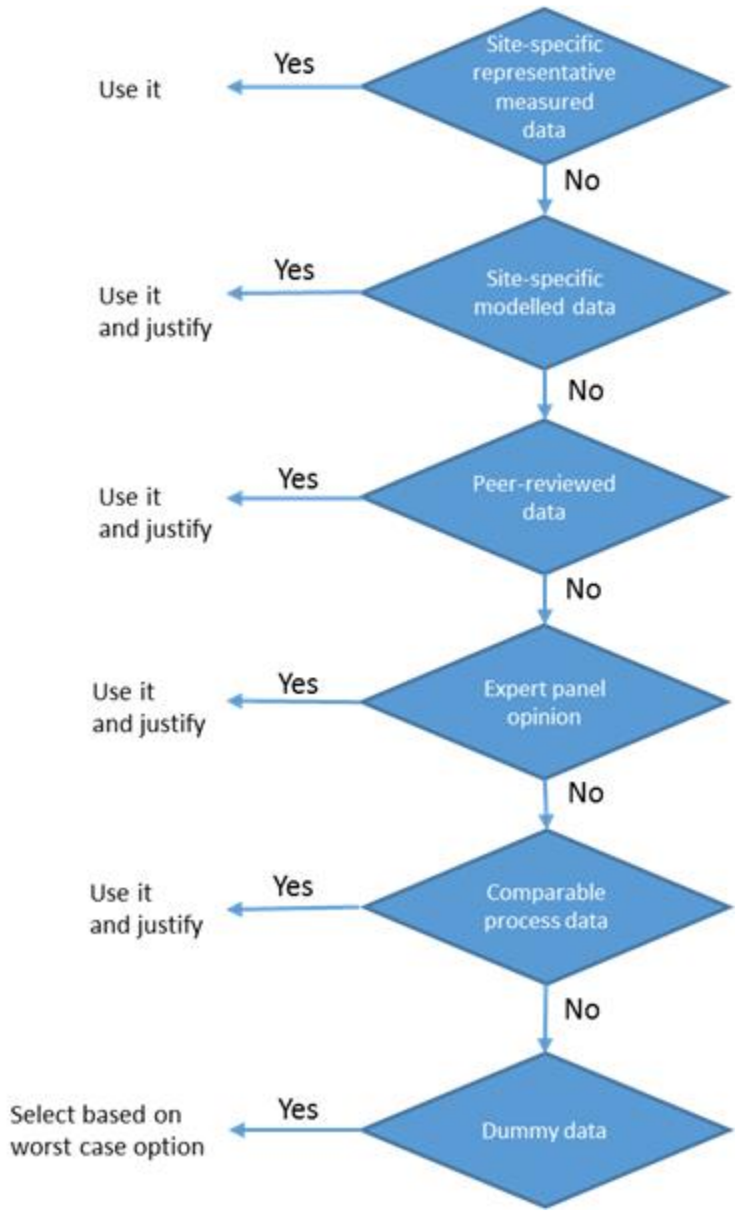

Figure 12. Decision tree for data collection and selection

If secondary data are more representative or appropriate than primary data for foreground processes (to be justified and reported), secondary data shall also be used for these foreground processes (e.g. the economic value of products over 5 years).

However, it is recognized that for projects with a larger scope, such as sectorial analyses at the national scale, the collection of primary data for all foreground processes may be impractical. In such situations, or when an LCA is conducted for policy analysis, foreground systems may be modelled using data obtained from secondary sources, such as national statistical databases, peer-reviewed literature or other reputable sources.

The LCA practitioner shall demonstrate that the following aspects in data collection have been taken into consideration in order to allow an appropriate data quality assessment (adapted from ISO14044):

1. **Representativeness**: qualitative assessment of the degree to which the data set reflects the true population of interest. Representativeness covers the following three dimensions:
    - *temporal representativeness:* age of data and the length of time over which data was collected;
    - *geographical representativeness:* geographical area from which data for unit processes was collected to satisfy the goal of the study;
    - *technology representativeness:* specific technology or technology mix;
2. **Precision**: measure of the uncertainty of the data values for each data expressed (e.g. standard deviation);
3. **Completeness**: percentage of flow that is measured or estimated;
4. **Consistency**: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
5. **Reproducibility**: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;
6. **Data sources**
7. **Uncertainty of the information** (e.g. data, models and assumptions). For significant processes, the LCA practitioner shall document data sources, data quality and any efforts made to improve data quality.
8. **Data gaps:** any data gap or exclusion of data shall be reported.

Compiling of inventory data for the use of feed additives is based on the same principles; the modelling rules for calculating emissions from livestock fed with additive containing feed are explained in Part 3 of this guideline.

5.7.3. Data quality assessment

LCA practitioners shall assess data quality by using data quality indicators. Assessing data quality is important for a number of reasons. It improves the inventory's data content for the proper communication and interpretation of results, and informs users about the possible uses of the data. Data quality refers to characteristics of data that relate to their ability to satisfy stated requirements (ISO, 2006a). Data quality covers various aspects, such as technological, geographical and temporal representativeness, as well as the completeness and precision of the inventory data. This section describes how data quality shall be assessed.

5.7.4. Data quality rules

Criteria for assessing LCI data quality can be structured by representativeness (technological, geographical and temporal), completeness in the inventory, the precision/uncertainty of the collected or modelled inventory data, and methodological appropriateness and consistency. Representativeness addresses how well the collected inventory data represents the 'true' inventory of the process for which they are collected regarding technology, geography and time. For data quality, the representativeness of the LCI data is a key component, and primary data gathered shall adhere to the data quality criteria.

A pedigree matrix can be used to assess the data quality. The pedigree matrix was initially introduced by Funtowics (1990) and adapted by Weidema and Wesnaes (1996) for LCA. The pedigree matrix is widely used for data quality assessment in LCI (Frischknecht, 2005) and slightly modified or adapted by others (Ciroth, 2009; Huijbregts et al., 2001). As another example, the Data Quality Rating (DQR) approach, as implemented in the Environmental Footprint methods developed by the European Commission can also be used. The DQR is a semi-quantitative assessment of the quality criteria of a dataset on technological representativeness, geographical representativeness, time-related representativeness and precision. Any deviations from the requirements outlined in 2.2.2 shall apply to both primary and secondary data.

PART 3: METHODOLOGY FOR QUANTIFICATION OF ENVIRONMENTAL IMPACTS FROM USING FEED ADDITIVES

This section provides specific recommendations on how to address the effect of using feed additives on the environmental performance of livestock systems. When such a study is performed, the impacts of the production of the feed additives at stake shall be included in the assessment, following recommendations provided in the previous section.

6.1. GOAL AND SCOPE DEFINITION

6.1.1. Goal scope of the study

The first step when initiating an LCA is to clearly set the goal or statement of purpose. The statement describes the goal pursued and the intended use of results. Within this guideline, the goal of the study is principally to evaluate the effect of using feed additive(s) on the environmental footprint (carbon footprint, eutrophication, acidification, etc.) of animal products (e.g. milk, meat and eggs), considering the impact of the manufacturing of the feed additive and on on-farm emissions linked to its use.

Numerous reasons for performing an LCA exist. LCAs can be used, for example, to serve the goal of GHG emission management by determining the carbon footprint of products and understanding the GHG emission hotspots to prioritize emissions-reduction opportunities along supply chains. However, LCAs can go beyond a carbon footprint and include other environmental impact categories, such as eutrophication or acidification, and provide detailed information on a product's environmental performance. They can also serve performance tracking goals and set progress and improvement targets. LCAs could also be used to support reporting on the environmental impacts of products. This guideline provides tools to compare the claimed impact (e.g. feed conversion rate, methane inhibition) of using feed additives, with a baseline scenario.

It is of paramount importance that the goal and scope be given careful consideration because these decisions define the overall context of the study. A clearly articulated goal helps ensure that aims, methods and results are aligned. For example, fully quantitative studies will be required for benchmarking or reporting, but somewhat less rigor may be required for hotspot analysis. Interpretation is an iterative process occurring at all steps of the LCA and ensuring that calculation approaches and data match the goal of the study. Interpretation includes completeness checks, sensitivity checks, consistency checks and uncertainty analyses. The conclusions (reported or not) drawn from the results and their interpretation shall be strictly consistent with the goal and scope of the study.

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

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

6.2. Scope of the LCA

The scope is defined in the first phase of an LCA, as an iterative process with the goal definition. It states the depth and breadth of the study. The scope shall identify the product system or process to be studied, the functions of the system, the functional unit, the system boundaries, the allocation principles and the impact categories. The scope should be defined so that the breadth, depth and detail of the study are compatible and sufficient to achieve the stated goal. While conducting an LCA of livestock products, the scope of the study may need to be modified as information is collected, to reflect data availability and techniques or tools for filling data gaps. Specific guidance is provided in the subsequent sections. It is also recognized that the scope definition will affect the data collection for the LCI.

6.3. Functional units and reference flows

The functional unit and reference flow in the early stage of the chain (i.e. manufacturing of the feed additive, incorporation of the feed additive in the feed and delivery to the animals) will be based on kg of feed additive accompanied with its main function and effects, such as incorporation rate of the feed additive in feed. The functional unit and reference flow at farm stage will depend on the livestock system in which the feed additive is used and shall correspond to the one defined in the different LEAP guidelines:

- 1 kg of live weight for meat producing animals (pigs, poultry, large and small ruminants)
- 1 kg of energy corrected (i.e. fat and protein corrected) of milk for milk producing animals (large and small ruminants)
- 1 kg of egg in shell (poultry)
- 1000 chicks produced
- 1 kg of greasy wool (small ruminants)

6.4. System boundary of feed additive use stage

The system boundaries of this guideline are a combination of the boundaries of the different existing guidelines (feed production, livestock related guidelines) and makes the link to the production of feed additives and its uses along the feed chain and on the farm, as described in Figure 1. The manufacturing processes are described on the basis of the different types of materials described in the feed processing guidelines:

- Phytogenic substances are included under the category crop processing, as defined in the feed guidelines. The particular impact of the extraction process and the possible formulation of the feed additives shall be taken into account, as described in Section 4.1.2.2. Example of plant extracts are essential oils.
- Animal extracts are included under the category animal by-products processing, as defined in the feed guidelines. The particular impact of the extraction/hydrolysis processes and the possible formulation of the feed additives shall be taken into account as described in Section 4. Examples of animal extracts are chondroitin sulphate, hydrolysed amino acids.
- Chemical production and fermentation production systems are both included under the category of non-biogenic substances, as defined in the feed guidelines. The particular impact of the production processes and the possible formulation of the feed additives shall be taken into account as described in Section 4.1.2.3. Examples of chemical products are trace elements salts and example of fermentation products are enzymes or live microorganisms.

In addition to the manufacturing processes, the different impact categories are indicated, such as:

- Preservation of crop products during storage in relation with the feed guidelines (modification of the crop product footprint due to reduced losses), e.g. silage agents, preservatives, etc.
- Impact on the feed formulation, due to the use of e.g. enzymes, in relation with the feed guidelines.

- Impact on the animal production system, e.g. by reducing feed conversion rate or reducing enteric methane emissions, in relation with the livestock relevant guidelines.
- The manure management will follow the livestock relevant guidelines

6.5. Transport and trade

Feed additives are transported to users and may be stored at various points along the supply chain. Transport and the related storage are intermediate steps within the feed production stages, In some situations traders also play an important role. The upstream and downstream system boundaries depend on the respective stages, which are given in detail in section 8.4.6 of the LEAP guideline on Environmental Performance of Animal Feeds Supply Chains.

6.6. Intermediate transport and trade

Transport is the connecting link between all phases of production. Transport distances are usually large, as the feed additive business is a global business with localized production. The major means of transport are road (mainly trucks), boat (mainly for transcontinental deliveries) and flights (in some instances for urgent deliveries). The load ranges from individual bags (around 20 kg), if deliveries by distributors, but usually refers to full truck loads (about 10 tons) and full container loads (about 30 tons). Although a limited quantity of feed additives may be delivered in bulk, the majority of feed additives are distributed in bags of different weight and with different packaging materials. Transport requires an energy carrier, such as fuels or electricity.

Transport can be organized by one of the stages itself (e.g. receiving or sending). However, it can also be organized by specialized transporters and traders, whose role may be limited to brokering between the stages in ways that do not affect the transport itself. But when transport is divided into two phases, they also can have a larger role. In the case of traders, intermediate storage may take place. The same system prevails where feed additives are produced on a continuous basis and feed additive demand is seasonal, (e.g. during the winter).

In the case of intermediate storage, energy may be required for conditioned storage (heating, cooling). The energy use shall be taken into account. Transport emissions for the first step from stage 1 to agent A, shall be attributed to the smaller amount (100 – x) percent when leaving the intermediate storage. Another scenario is one in which farmers go to the local agent to purchase feed additives, which they then transport themselves. In all cases, transport emissions shall be taken into account. For further information, the reader is referred to section 11.6.1 of the LEAP guideline on Environmental Performance of Animal Feeds Supply Chains.

6.7. Relevant inputs, resource use and emissions during transport and trade

Transported product:

The type of product can provide information about the type of transport required. Liquid products require tankers.

Activity data collection*:* Data shall be collected regarding the type of the transported product. When primary data about fossil fuel for transport are available, data shall be collected about the amount of transported product in order to calculate the fuel use per tonne of product.

Emission models and LCI data: Not relevant.

Fossil fuel use for transport

The data collection on fossil fuels shall be collected regarding direct fuel used, the amount used for transport per type of fuel and on the sulphur content. In the absence of primary data, secondary data on average fuel use per type of transport and per km and the transport distances shall be pulled together from internationally accepted databases.

Emission models and LCI data: When primary data on fossil fuel use are to be collected, information about the emission factor regarding the production and maintenance of transport means shall be made available.

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

Start and endpoint of transport

Activity data collection*:* Data shall be collected about the start and endpoint of the transport, to calculate the transport distance.

Emission models and LCI data*:* Not relevant.

Define transport means and capacity

There is wide range of possible means of transport with a broad range of transport capacity. They all have their own emission levels with regard to transport, production and maintenance.

Activity data collection: Data shall be collected about the means of transport between start and endpoint. When multiple means of transport are used, the starting-and endpoint per means shall be identified.

Transport data shall be collected (or defined) on:

- the capacity of the means of transport;
- the load factor per transport; and
- the empty transport distance (backhaul) per transport. When the transport means is returning empty for a new load, all ‘empty’ kilometers shall be allocated to the originally transported product.

Emission models and LCI data: Emission factors for transport means can be derived from databases. Assumptions on backhaul shall be checked, and emission factors shall be corrected when the assumptions differ from the transport under study.

Calculate transport distance

This is done after the start- and endpoint and the means of transport has been defined.

Activity data collection: Data shall be collected about the distance between every start- and endpoint in the whole chain of transport. The methodology for calculating transport distances is defined in other LEAP guidelines.

Emission models and LCI data: Emission can be calculated by multiplying the kilometers per means of transport by the emission factor for the transport means and accumulating all emissions for transporting the product from the original start point to the final endpoint.

Storage loss

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

Fossil fuel use for storage

The data collection on fossil fuels shall be collected regarding direct fuel used, the amount used for transport per type of fuel and on the Sulphur content. In the absence of primary data, secondary data on average fuel use per type of storage and per tonne and the storage durations shall be pulled together from internationally accepted databases,

Electricity use for storage

Data shall be collected on the basis of the total amount of electricity used, expressed in kilowatt-hours (kWh), on the fraction taken from the grid and the fraction produced locally. In the case of locally produced electricity the energy source shall be clearly documented.

For energy taken from the grid, the country specific energy mix and the related combustion emissions should be taken from the International Energy Agency (IEA) database. The upstream emissions for the production of the fuels present in the country's mix shall be taken from an internationally accepted database. It also should be noted that the IEA data also include the emissions from the production of heat, which likely leads to a decrease in totals.

For locally produced electricity, emission factors for fossil fuels, biomass, water, wind and solar power shall be taken from an internationally accepted database that takes into account all upstream emissions.

For further information the reader is referred to section 11.6.2 of the LEAP guideline on Environmental Performance of Animal Feeds Supply Chains.

6.8. General model for deriving inventory data

The average model per step is expressed by Equation 1.

Equation 1

$$(E,R)_T = \left(\sum_{i=1}^{a} km_a \times \left(\frac{EF}{tonkm}\right)_a\right) \times (1 - loss_a)^{-1} + \left(\sum_{i=1}^{b} km_b \times \left(\frac{EF}{tonkm}\right)_b\right) + (FF)_{st} + EL_{st} \qquad \text{Formula (3)}$$

where:

(E,R)T	Emissions and resource use of the transport T
ΣKma * (EF/tonkm)a	Transport emissions of step a (to the agent) in the transport and trade scheme for the different kinds of transport used
ΣKmb * (EF/tonkm)b	Transport emissions of step b (from the agent) in the transport and trade scheme for the different kinds of transport used
EF/tonkm	Emissions factor per tonne per km for a specific means of transport
Kma	the transport distance between the starting point and the endpoint of the agent. In case of suffix b, it is the distance from the agent to the next endpoint.
(1 – loss)n	Net amount of feed after conservation and storage losses
(FF)st	Fossil fuel emissions, for storage
(EL)st	Electricity emissions, for storage

6.9. Criteria for system boundary

Material system boundaries

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

Spatial system boundaries

The LCA of feed additives shall cover the cradle-to animal-farm-exit-gate, including raw materials, inputs, production, harvesting, storage, loss, feeding and relative impact. A LCA should also include all emissions associated with land use and land-use change, linked to the use of specific feed materials, particularly, when the feed additive is used to modify the feed composition. All emissions directly related to inputs and activities in the feed production chain stages shall be included, irrespective of their location.

6.10. Material contribution and threshold

See section 5.5

6.11. Time boundary for data

See section 5.6

6.12. Baseline estimations from feed ingredients without using feed additives for relevant impact categories

Feed production systems are a relevant part of the agricultural systems across the world, and they are a critical part of livestock supply chains. Details on feed types, systems, and material flows were covered in the LEAP Environmental Performance of Animal Feeds Supply Chains guidelines.

6.13. Life cycle inventory (diets including feed additives)

6.13.1. Overview

A simplified overview of the system boundary considered is shown in Figure 13. Each production system was divided into 5 processes: production of base feed ingredients, production of feed additives, preparation of feed, animal husbandry, and manure management (Figure 13). The analysis shall consider all "upstream" activities from the extraction of raw materials to manufacturing of basic intermediate products, including transportation as described in previous sections.

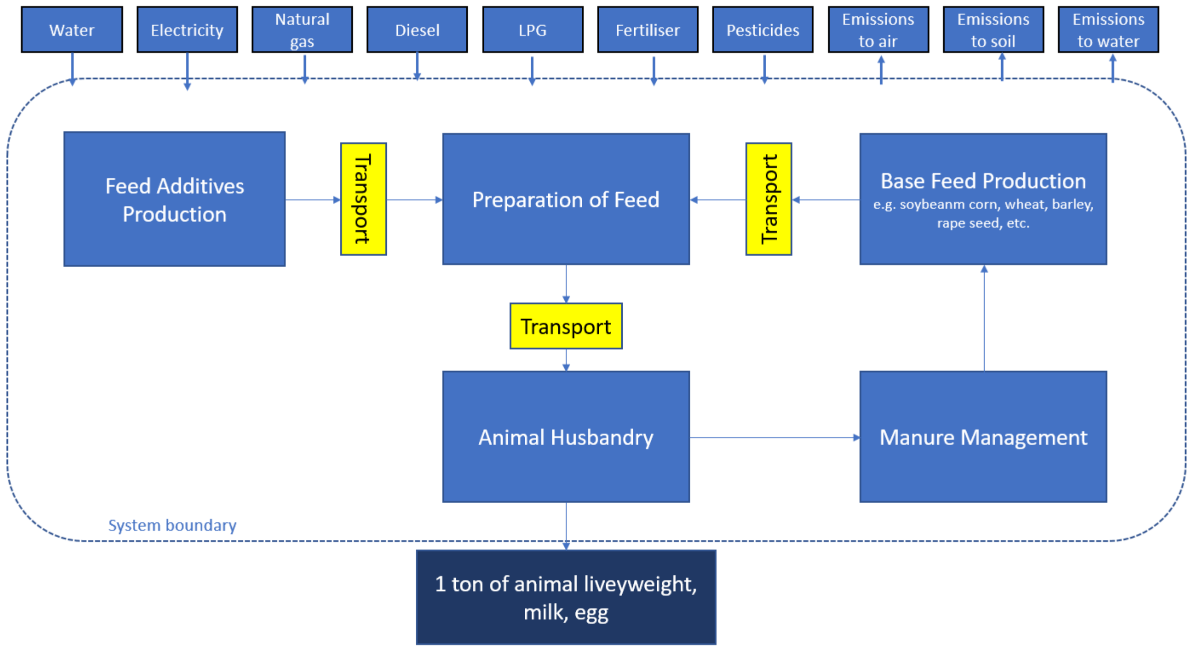

Figure 13. System boundary for producing 1 ton of animal live weight. LPG=liquid petroleum gas.

6.13.2. Compiling and recording inventory data

The function and the extent of the effect of the feed additive should be based on scientific data, related to the proposed conditions of use of the feed additive. Different levels of scientific data can be envisaged, depending whether the effect was measured on the specific farm where the LCA is run or is based on practical/research conditions and the number and quality of tests used. In the event scientific data do not exist for the particular feed additive, reference to similar types of feed additive may be used. However, such use shall be limited to the initial evaluation of the feed additive by its developer(s)

This section will explain when to apply different modelling rules for animal nutrition.

6.13.3. Baseline evaluation

This guideline aims at providing guidance to compare the environmental impact of the current situation on a farm, a region or a country where similar livestock systems are in place, with the scenario of using a specific feed additive or mixture of feed additives.

The livestock system is based on the type of feed used (e.g. feed ingredient composition, nutritional characteristics), the feeding system (e.g. ad libitum or restricted), the target animal species (e.g. type of animal, breed), the housing system (e.g. slatted floor or partly slatted floor for piglets) and the management system.

The granularity of the system will depend on the effect of the feed additive and the way it is used. As an example, it might be possible to extrapolate the introduction of amino acids in feed for poultry and pig from one livestock system to another, but this might not be the case for other types of additives, e.g. enzymes more depending on the feed composition.

Generally, the LCA will cover the whole production cycle of the animals:

- for production of milk, egg and wool: one year
- for reproductive animals (e.g. sukling cows, sows, breeding hens): one year
- for growing animals, either one production cycle (from entry into farm to exit from the farm) or one year (from birth to slaughter weight)

However, if the feed additive is only provided for a limited period within the production cycle and with an effect limited to the period of use, the baseline time may be modified accordingly. In that case, the evaluation shall use the same period of production in both cases.

The scenario to be evaluated with the feed additive should be based on the same livestock system as defined for the baseline. However, when the feed additive allows the modification of feed ingredient composition or the nutritional characteristics of the feed, this shall be considered.

6.13.4. Large Ruminants

The equations in Table 2 for the baseline were used for cattle, buffaloes and camels used for milk production. These equations are originated from the LEAP guidelines on environmental performance of large ruminant supply chains. Table 2 provides definitions of parameters and variables used in all equations for large ruminants, small ruminants, poultry and pigs.

Table 2. Definition of parameters and variables used in equations

Item	Description	Unit
% CP	Weighted average protein concentration in the diet, considering the protein concentration in each kg of dry matter of feed and their individual intake	%
% Cu eggs	Concentration of copper in the eggs	%
% Cu in tissues and bone	Concentration of copper in the total weight gain, including tissues and bones	%
% DE	Percentage of digestible energy in the feed	%
% P eggs	Concentration of phosphorus in the eggs	%
% P in milk	Concentration of phosphorus measured in the milk	%
% P in tissues and bone	Concentration of phosphorus in the total weight gain, including tissues and bones	%
% Protein in milk	Concentration of protein measured in the milk	%
% Protein in tissues	Concentration of protein in the total weight gain	%
% Zn eggs	Concentration of zinc in the eggs	%
% Zn in tissues and bone	Concentration of zinc in the total weight gain, tissues and bones	%
%Cu	Weighed average concentration of copper in the diet, considering the copper concentration in each kg of feed and their individual intake	%
$\%P_{total}$	Weighted average concentration of total phosphorus in the diet, considering the total phosphorus concentration in each kg of dry matter of feed and their individual intake	%
%Zn	Weighted average concentration of zinc in the diet, considering the zinc concentration in each kg of feed and their individual contribution	%
0.588	Retention factor for nitrogen for turkeys and laying hens	
0.602	Retention factor for nitrogen in chickens	
0.662	Methane density	kg/m^3
0.92	Default of 8% ash content in the cattle manure. This value shall be modified if measured or known system-specific values differ from this default.	
1.04	Default value based on the assumption that 4 % of the gross energy can normally be attributed to urinary energy excretion by most large ruminants.	
18.45	Default gross energy value of 1 kg of dry matter	MJ
44/28	Factor to convert mass of N_2O-N to mass of N_2O	
55.65	Energy content of methane	MJ/kg
6.25	Concentration of nitrogen in protein in feed and in the animal tissues	
6.38	Concentration of nitrogen in milk protein	
A	Ash content of the manure, expressed as a fraction (the range is usually between 0.1 and 0.2)	

Bo	Maximum methane production potential for the excreted manure	
$Cu_{excreted}$	Quantity of copper excreted during the evaluated period	kg
Cu_{intake}	Quantity of copper consumed by the animal during the evaluation period	g
$Cu_{product}$	Quantity of copper stored in the body during the evaluation period	kg
$Cu_{retention}$	Quantity of copper retained in the animal liveweight during the evaluation period	kg
DMD	Digestibility of the dry matter in the diet, expressed as a fraction	
DMI	Measured quantity of dry matter ingested from the different feeds	kg
DMI_{other}	Calculated dry matter intake of other feed sources, which intake is not measured, e.g. grazing pasture, forages	kg
ECM	Energy corrected milk, it is calculated according to the following equation: Milk x (0.1226 x % fat + 0.0776 x % true protein + 0.2534)	kg
EF	Emission factor referring to the loss of enteric methane based on the gross energy intake. The EF is on average of 6.5 percent ($\pm$ 1 percent) when large ruminants are feed with roughages. When large ruminants are fed more than 90 percent concentrate, diets are assigned an EF of 3.0 percent ($\pm$ 1 percent)	
EF_{MMS}	Emission factor for the relevant manure management system	
ENb	Number of eggs produced during the evaluation period	
EW	Average egg weight	g
FI	Feed intake, with a feed containing 88 % dry matter	kg
GE	Gross energy intake based on the total net energy	MJ
kg eggs in shell	Amount of egg produced	kg
MCF	Methane conversion factor for the manure management system	
ME/kg DM	Energy concentration per kg dry matter of the feed sources	MJ/kg
$ME_{intakeother}$	Amount of energy consumed from other feed sources, such as from grazing pasture forages	MJ
$Methane_{enteric}$	Quantity of enteric methane produced by the animal	CO_2e
$Methane_{housing}$	Quantity of methane emitted from the manure management system	CO_2e
Milk	Production of milk	kg
$NE_{activity}$	Net energy for activity, e.g. grazing	MJ
NE_{growth}	Net energy for growth	MJ
$NE_{lactation}$	Net energy for lactation	MJ

$NE_{maintenance}$	Net energy for maintenance	MJ
$NE_{pregnancy}$	Net energy for gestation	MJ
NE_{wool}	Net energy for wool production	MJ
$N_{excreted}$	Quantity of nitrogen excreted during the evaluation period	kg
N_{intake}	Amount of nitrogen consumed by the animal during the evaluation period	kg
$NitrousOxide_{housing}$	Amount of nitrous oxide emitted from the manure management system	CO_2e
$N_{product}$	Quantity of nitrogen exported via milk or stored in the body	kg
$P_{excreted}$	Quantity of phosphorus excreted	kg
P_{intake}	Amount of phosphorus consumed by the animal	kg
$P_{product}$	Quantity of phosphorus exported via milk or stored in the body	kg
$P_{retention}$	Quantity of phosphorus retained in the animal liveweight	kg
REG	Ratio of net energy for growth to the digestible energy consumed	%
REM	Ratio of net energy for maintenance to the digestible energy consumed	%
ResD	Digested fiber, estimated as the difference between digested organic matter and digested sugar, starch, fat and protein	
R_{MMS}	Fraction of nitrogen degraded in an animal manure management system	
Total ME requirement	Total amount of energy required for the maintenance and performance of the animal	MJ
TWG	Total weight gain of the animals during the considered period	
VS	Volatile solid excreted daily expressed in kg dry matter per animal per day	kg
WF	Fraction of feed that is not consumed	kg
$Zn_{excreted}$	Quantity of zinc excreted during the evaluation period	kg
Zn_{intake}	Quantity of zinc consumed by the animal during the evaluation period	g
$Zn_{product}$	Quantity of zinc stored in the body (tissues and bones) during the evaluation period	kg
$Zn_{retention}$	Quanity of zinc retained in the animal liveweight	kg

Table 3. Equations used for evaluating the baseline emissions for cattle, buffaloes and camels used for milk production

	Basis for Calculation	
Equation 1	$ME_{intakeother}$ (MJ) = Total ME requirement (MJ) - (DMI (Kg) x ME/kg DM (MJ/kg))$_{feed1}$ - (DMI(kg) x ME/kg DM (MJ/kg))$_{feed2}$	
Equation 2	DMI_{other}=$ME_{intakeother}$ / (ME/kg DM (MJ/kg))	
Equation 3	GE (MJ) = DMI (kg) x 18.45 MJ/kg DM	
Equation 4	N_{intake} (kg) = DMI (kg) x % CP / 6.25	
Equation 5	P_{intake} (kg) = DMI (kg) x % P_{total}	
Equation 6	$N_{product}$ = Milk (kg) x % Protein in milk / 6.38	
Equation 7	$P_{product}$ = Milk (kg) x % P in milk	
Equation 8	VS (kg) = DMI (kg) x (1.04 - DMD) x 0.92	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / ECM (kg)
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / ECM (kg)
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ/kg)	Enteric Methane (kg) / ECM (kg)
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / ECM (kg)
Equation 13	Manure Nitrous Oxide (see Figure 14 of the large ruminant guidelines))	Manure Nitrous Oxide (kg) / ECM (kg)

Table 4. Equations used for evaluating the baseline emissions for growing cattle (replacement heifers, beef cattle) and cattle, buffaloes and camels used for suckling purposes. Definition of parameters and variables used in the equations are given in Table 2.

	Basis for Calculation	
Equation 1	$ME_{intakeother}$ (MJ) = Total ME requirement (MJ) - (DMI (kg) x ME/kg DM (MJ/kg))$_{feed1}$ - (DMI (kg) x ME/kg DM (MJ/kg))$_{feed2}$	
Equation 2	DMI_{other} (kg) = $ME_{intakeother}$ (MJ) / (ME/kg DM (MJ/kg))	
Equation 3	GE (MJ) = DMI (kg) x 18.45 (MJ/kg DM)	
Equation 4	N_{intake} = DMI(kg) x % CP / 6.25	
Equation 5	P_{intake} = DMI (kg) x % P_{total}	
Equation 6	$N_{product}$ = TWG (kg liveweight) x % Protein in tissues / 6.25	
Equation 7	$P_{product}$ = TWG (kg liveweight) x % P in tissues and bone	
Equation 8	VS (kg) = DMI (kg) x (1.04 - DMD) x 0.92	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$(kg)	$N_{excreted}$(kg) / TWG (kg liveweight)
Equation 10	$P_{excreted}$(kg) = P_{intak}(kg)$_{e}$ - $P_{products}$(kg)	$P_{excreted}$(kg) / TWG (kg liveweight)
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ/kg)	Enteric Methane (kg) / TWG (kg liveweight)
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / TWG (kg liveweight)
Equation 13	Manure Nitrous Oxide (kg) (see Figure 14 of the large ruminants guidelines)	Manure Nitrous Oxide (kg) / TWG (kg liveweight)

6.13.5. Small Ruminants

The equations in Table 5 for the baseline were used for cattle, buffaloes and camels used for milk production. These equations originated from the LEAP guidelines on environmental performance of small ruminant supply chains. Definition of parameters and variables used in the equations are given in Table 2.

Table 5. Equations used for evaluating the baseline emissions for dairy ewes and goats

	Basis for Calculation	
Equation 1	$ME_{intakeother}$ (MJ) = Total ME requirements$_t$ (MJ) - (DMI (kg) x ME/kg DM (MJ/kg))$_{feed1}$ - (DMI (kg) x ME/kg DM (MJ/kg))$_{feed2}$	
Equation 2	DMI_{other}(kg) = $ME_{intakeother}$ (MJ) / (ME (MJ)/kg DM)	
Equation 3	REG (%) = (1.164 - (5.160 x 10^3 x % DE) + (1.038 x 10^{-5} x % DE^2) - (37.4 / % DE))	
Equation 4	REM (%) = (1.123 - (4.092 x 10^3 x % DE) + (1.126 x $10^{-5\ -}$x % DE^2) - (25.4 / % DE))	
Equation 5	GE (MJ) = (($NE_{maintenance}$(MJ)+ $NE_{activity}$ (MJ)+ $NE_{lactation}$ (MJ)+ $NE_{pregnancy}$(MJ)) / REM (%) + (NE_{growth} (MJ) + NE_{wool}(MJ)) / REG (%)) / (% DE/100)	
Equation 6	N_{intake} (kg) = DMI (kg) x % CP / 6.25	
Equation 7	$N_{product}$ (kg) = Milk (kg) x % Protein in milk / 6.38	
Equation 8	P_{intake} (kg) = DMI (kg) x % P_{total}	
Equation 9	$P_{product}$ (kg) = Milk(kg) x % P in milk	
Equation 10	VS (kg) = DMI (kg) x (1.04 - DMD) x 0.92	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / ECM (kg)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / ECM (kg)
Equation 13	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ/kg)	Enteric Methane (kg) / ECM (kg)
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / ECM (kg)
Equation 15	Manure Nitrous Oxide (kg) (see Figure 11 of the small ruminants guidelines)	Manure Nitrous Oxide (kg) / ECM (kg)

Table 6. Equations used for evaluating the baseline emissions for lambs and kids. Definition of parameters and variables used in the equations are given in Table 2.

	Basis for Calculation	
Equation 1	$ME_{intakeother}$ (MJ) = Total ME requirements (MJ) - (DMI (kg) x ME (MJ/kg DM))$_{feed1}$ - (DMI (kg) x ME (MJ/kg DM)$_{feed2}$	
Equation 2	DMI_{other} (kg) = $ME_{intakeother}$ (MJ) / (ME (MJ)/kg DM)	
Equation 3	REG (%) = (1.164 - (5.160 x 10^3 x % DE) + (1.038 x 10^{-5} x % DE^2) - (37.4 / % DE))	
Equation 4	REM (%) = (1.123 - (4.092 x 10^3 x % DE) + (1.126 x 10^{-5} x % DE^2) - (25.4 / % DE))	
Equation 5	GE (MJ) = (($NE_{maintenance}$ (MJ) + $NE_{activity}$ (MJ) + $NE_{lactation}$ (MJ)+ $NE_{pregnancy}$ (MJ)) / REM + (NE_{growth} (MJ) + NE_{wool} (MJ)) / REG) / (% DE/100)	
Equation 6	N_{intake} (kg) = DMI (kg) x % CP / 6.25	
Equation 7	$N_{product}$ (kg) = TWG (kg liveweight) x % Protein in tissues / 6.25	
Equation 8	P_{intake} (kg) = DMI (kg) x % P_{total}	
Equation 9	$P_{product}$ (kg) = TWG (kg liveweight) x % P in tissues and bones	
Equation 10	VS (kg) = DMI (kg) x (1.04 - DMD) x 0.92	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 13	Enteric Methane (kg) = GE (MJ) x EF / 55.65 (MJ / kg)	Enteric Methane (kg) / TWG (kg liveweight)
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / TWG (kg liveweight)
Equation 15	Manure Nitrous Oxide (kg) (see Figure 111 of the small ruminants guidelines)	Manure Nitrous Oxide (kg) / TWG (kg liveweight)

6.13.6. Pigs

The equations in Table 7 for the baseline were used for pigs. These equations are originated from the guidelines on environmental performance of pigs supply chains. Definition of parameters and variables used in the equations are given in Table 2.

Table 7. Equations used for evaluating the baseline emissions for pigs

	Basis for Calculation	
Equation 1	N_{intake} (kg) = FI (kg) x % CP / 6.25	
Equation 2	$N_{retention}$ (kg) = TWG (kg liveweight) x % Protein in tissues /6.25	
Equation 3	P_{intake} (kg) = FI (kg) x % P_{total}	
Equation 4	$P_{retention}$ (kg) = TWG (kg liveweight) x % P in tissues and bones	
Equation 5	Cu_{intake} (kg) = FI (kg) x % Cu	
Equation 6	$Cu_{retention}$ (kg) = TWG (kg liveweight) x % Cu in tissues and bones	
Equation 7	Zn_{intake} (kg) = FI (kg) x % Zn	
Equation 8	$Zn_{retention}$ (kg) = TWG (kg liveweight) x % Zn in tissues and bones	
Equation 9	VS (kg) = FI (kg) x (1 - DMD) x (1 - A) + VS_{wf} (kg)	
Equation 10	VS_{WF} (kg) = FI (kg) x (1 - A) x WF (kg)	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 13	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 14	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 15a (growing phase)	$Methane_{enteric}$ (kg)= (ResD (kg) x 670 (J/kg ResD)) / 5.665e^7 (J / kg methane)	$Methane_{enteric}$ (kg) / TWG (kg liveweight)
Equation 15b (sows)	$Methane_{enteric}$ (kg)= (ResD (kg) x 1340 (J/kg ResD)) / 5.665e (J/kg methane)	$Methane_{enteric}$ (kg) / TWG (kg liveweight)
Equation 16	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.662 (kg/m^3)	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 17	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x (1 - R_{MMS}) x EF_{MMS} (%) x 44 / 28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

6.13.7. Poultry

The equations in Table 8 for the baseline were used for broiler chickens. These equations originated from the LEAP guidelines on environmental performance of pigs supply chains. Definition of parameters and variables used in the equations are given in Table 2.

Table 8. Equations used for evaluating the baseline emissions for broiler chickens

	Basis for Calculation	
Equation 1	P_{intake} (kg)= FI (kg) x % P_{total}	
Equation 2	$P_{retention}$ = TWG (kg) x % P in tissues and bone	
Equation 3	Cu_{intake} (kg)= FI (kg) x % Cu	
Equation 4	$Cu_{retention}$ = TWG (kg) x % Cu in tissues and bone	
Equation 5	Zn_{intake} (kg)= FI (kg) x % Zn	
Equation 6	$Zn_{retention}$ = TWG (kg) x % Zn in tissues and bone	
Equation 7	VS (kg) = FI (kg) x (1 - DMD) X (1 - A)	
	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x (1 - 0.602)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{retention}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{retention}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 11	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{retention}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.662	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 13	$NitrousOxide_{housing}$(kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

The equations in Table 9 for the baseline were used for broiler turkeys. Definition of parameters and variables used in the equations are given in Table 2.

Table 9 – Equations used for evaluating the baseline emissions for broiler turkeys

	Basis for Calculation
Equation 1	P_{intake} (kg) = FI (kg) x % P_{total}
Equation 2	$P_{retention}$ (kg) = TWG (kg liveweight) x % $P_{tissuebones}$
Equation 3	Cu_{intake} (kg)= FI (kg) x % Cu
Equation 4	$Cu_{retention}$ = TWG (kg) x % Cu in tissues and bone
Equation 5	Zn_{intake} (kg)= FI (kg) x % Zn
Equation 6	$Zn_{retention}$ = TWG (kg) x % Zn in tissues and bone
Equation 7	VS (kg) = FI (kg) x (1 - DMD) X (1 - A)

	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x (1 - 0.588)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{retention}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{retention}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 11	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{retention}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$Methane_{housing}$(kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.662	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 13	$NitrousOxide_{housing}$(kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

The equations in Table 10 for the baseline were used for laying poultry. Definition of parameters and variables used in the equations are given in Table 2.

Table 10. Equations used for evaluating the baseline emissions for laying poultry

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x % P_{total}	
Equation 2	$P_{retention}$ (kg) = EW (kg) x ENb x % P eggs	
Equation 3	Cu_{intake} (kg) = FI (kg) x % Cu_{l}	
Equation 4	$Cu_{retention}$ (kg) = EW (kg) x ENb x % Cu	
Equation 5	Zn_{intake} (kg) = FI (kg) x % Zn	
Equation 6	$Zn_{retention}$ (kg) = EW (kg) x ENb x % Zn eggs	
Equation 7	VS (kg) = FI (kg) x (1 - DMD) X (1 - A)	
	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x ((0.0182 x EW (kg)) x (ENb))	$N_{excreted}$ (kg) / Kg eggs in shell
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{retained}$ (kg)	$P_{excreted}$ (kg) / Kg eggs in shell
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{retained}$ (kg)	$Cu_{excreted}$ (kg) / Kg eggs in shell
Equation 11	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{retained}$ (kg)	$Zn_{excreted}$ (kg) / Kg eggs in shell
Equation 12	$Methane_{housing}$ (kg)= VS (kg) x Bo (m^3/kg) x MCF (%) x 0.662	$Methane_{housing}$ (kg) / Kg eggs in shell
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ / Kg eggs in shell

The equations in Table 11 for the baseline were used for breeding poultry. Definition of parameters and variables used in the equations are given in Table 2.

Table 11 – Equations used for evaluating the baseline emissions for breeding poultry

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x % P_{total}	
Equation 2	$P_{retention}$ (kg)= EW (kg) x ENb x % P Eggs	
Equation 3	Cu_{intake} (kg) = FI (kg) x % Cu	
Equation 4	$Cu_{retention}$ (kg)= EW (kg) x ENb x % Cu $eggs_{s}$	
Equation 5	Zn_{intake} (kg) = FI (kg) x % Zn_{total}	
Equation 6	$Zn_{retention}$ (kg)= EW (kg) x ENb x % Zn Eggs	
Equation 7	VS(kg) = FI (kg) x (1 - DMD) X (1 - A)	
	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg)= FI (kg) x % CP / 6.25 x ((0.0182 x EW(kg)) x (ENb))	$N_{excreted}$ (kg) / Nb hatched eggs
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg)- $P_{products}$(kg)	$P_{excreted}$ (kg) / Nb hatched eggs
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg)- $Cu_{products}$(kg)	$Cu_{excreted}$ (kg) / Nb hatched eggs
Equation 11	$Zn_{excreted}$ (kg) = Zn_{intake} (kg)- $Zn_{products}$(kg)	$Zn_{excreted}$ (kg) / Nb hatched eggs
Equation 12	$Methane_{housing}$(kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.662	$Methane_{housing}$ (kg)/ Nb hatched eggs
Equation 13	$NitrousOxide_{housing}$(kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg)/ Nb hatched eggs

6.13.8. Calculation based on the effects of feed additives

When considering the modification of equations linked to the effect of feed additive use, only the equations that need to be changed or have an impact on the emission are mentioned in the below tables.

6.13.9. Modification of feed composition

When the use of the feed additive allows a modification of the diet composition, the environmental impact of the feed production may also be modified. The evaluation of the environmental footprint of the feed should be calculated as described in the LEAP guidelines on animal feeds supply chains. Furthermore, feed being an input in the evaluation of the environmental impact of animal sourced product, this latter needs to be re-evaluated according to the relevant LEAP guidelines.

When the composition change leads also to a modification of the nutritional composition of the feed, such as crude protein content or total phosphorus content, equation modeling nitrogen and phosphorus excretion should be modified for cattle, buffaloes and camels used for milk production (Table 12,), cattle, buffaloes and camels used for suckling purposes (Table 13), dairy ewes and goats (Table 14), lambs and kids (Table 15), pigs (Table 16), broiler chickens (Table 17), broiler turkeys (Table 18), laying poultry (Table 19), breeding poultry (Table 20).

In the following equations, the variation between the baseline scenario and the scenario with the feed additive is described by Δ_{nc} (nc = nutritional characteristics), which represents the variation in the parameter linked to the use of the additive. Depending on the available data for the feed additives under evaluation, Δ_{nc} may be either superior to 1 (when the additive increases the parameter being multiplied), below 1 (when the additive decreases the parameter being multiplied) or equal to 1 (when the additive has no effect on the parameter being multiplied).

The equations below are numbered in line with Table 3 (used for the basic scenario) and the abbreviations used are described in Table 2. Only the equations that need a modification are listed below. For example, if the feed additive allows to reduce the protein content in the feed by 5%, the basal equation (Δ_{nc} = 0.95):

$N_{ingested}$ (kg)= FI (kg) x % Protein / 6.25 will be modified to $N_{ingested}$ (kg) = FI (kg) x % Protein (% CP) x Δ_{nc} (0.95) / 6.25.

Table 12. Adaptation of emissions equation when the concentration of protein and phosphorus is modified in the diet, because of feed composition change for cattle buffaloes and camels used for milk production

	Basis for Calculation	
Equation 4	N_{intake} (kg) = DMI (kg) x % CP x Δ_{nc} / 6.25	
Equation 5	P_{intake} (kg) = DMI (kg) x % P_{total} x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / ECM (kg)
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / ECM (kg)

Table 13. Adaptation of emissions equation when the concentration of protein and phosphorus is modified in the diet, because of feed composition change for cattle buffaloes and camels used for suckling purposes

	Basis for Calculation	
Equation 4	N_{intake}(kg)= DMI (kg) x % CP x Δ_{nc} / 6.25	
Equation 5	P_{intake} (kg)= DMI (kg) x % P_{total} (kg) x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{product}$ (kg)$_s$	$N_{excreted}$ (kg) / TGW (kg liveweight)
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)

Table 14. Adaptation of emissions equation when the concentration of protein and phosphorus is modified in the diet, because of feed composition change for dairy ewes and goats

	Basis for Calculation	
Equation 6	N_{intake} (kg) = DMI (kg) x % CP x Δ_{nc} / 6.25	
Equation 8	P_{intake} (kg) = DMI (kg) x % P_{total} x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / ECM (kg)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / ECM (kg)

Table 15. Adaptation of emissions equation when the concentration of protein and phosphorus is modified in the diet, because of feed composition change for lambs and kids

	Basis for Calculation	
Equation 6	N_{intake} (kg) = DMI (kg) x % CP x Δ_{nc} / 6.25	
Equation 8	P_{intake} (kg) = DMI (kg) x % P_{total} x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)

Table 16. Adaptation of emissions equation when the nutritional characteristics of the diet are modified because of feed composition change for pigs

	Basis for Calculation	
Equation 1	N_{intake} (kg) = FI (kg) x % CP x Δ_{nc} / 6.25	
Equation 3	P_{intake} (kg) = FI (kg) x % P_{total} x Δ_{nc}	
Equation 5	Cu_{intake} (kg) = FI (kg) x % Cu x Δ_{nc}	
Equation 7	Zn_{intake} (kg) = FI (kg) x % Zn x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 13	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 14	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 17	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x (1 - R_{MMS}) x EF_{MMS} (%) x 44 / 28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

Table 17. Adaptation of emissions equation when the nutritional characteristics of the diet are modified because of feed composition change for broiler chickens

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x % P_{total} x Δ_{nc}	
Equation 3	Cu_{intake} (kg) = FI (kg) x % Cu_{l} x Δ_{nc}	
Equation 4	Zn_{intake} (kg) = FI (kg) x % Zn x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 5	$N_{excreted}$ (kg) = FI (kg) x % CP x Δ_{nc} / 6.25 x (1 - 0.602)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 7	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{product}$ (kg)$_s$	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 8	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{product}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{product}$ (kg)$_s$	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%)x 44/28	$NitrousOxide_{housing}$ (kg)/ TWG (kg liveweight)

Table 18. Adaptation of emissions equation when the nutritional characteristics of the diet are modified because of feed composition change for broiler turkeys

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x % P_{total} x Δ_{nc}	
Equation 3	Cu_{intake} (kg) = FI (kg) x % Cu x Δ_{nc}	
Equation 5	Zn_{intake} (kg) = FI (kg) x % Zn x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 7	$N_{excreted}$ (kg) = FI (kg) x % CP x Δ_{nc} / 6.25 x (1 - 0.588)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 8	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 8	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

Table 19. Adaptation of emissions equation when the nutritional characteristics of the diet are modified because of feed composition change for laying poultry

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x % P_{total} x Δ_{nc}	
Equation 3	Cu_{intake} (kg) = FI (kg) x % Cu x Δ_{nc}	
Equation 5	Zn_{intake} (kg) = FI (kg) x % Zn x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 7	$N_{excreted}$ (kg) = FI (kg) x % CP x Δ_{nc} / 6.25 x ((0.0182 x EW (kg)) x (ENb))	$N_{excreted}$ (kg) / Kg eggs in shell
Equation 8	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / Kg eggs in shell
Equation 9	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / Kg eggs in shell
Equation 10	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / Kg eggs in shell
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / Kg eggs in shell

Table 20. Adaptation of emissions equation when the nutritional characteristics of the diet are modified because of feed composition change for breeding poultry

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI(kg) x % P_{total} x Δ_{nc}	
Equation 3	Cu_{intake} (kg) = FI(kg) x % Cu_{I} x Δ_{nc}	
Equation 5	Zn_{intake} (kg) = FI(kg) x % Zn_{I} x Δ_{nc}	
	Calculated impacts	
	Total	Intensity
Equation 7	$N_{excreted}$ (kg) = FI (kg) x % CP x Δ_{nc} / 6.25 x ((0.0182 x EW (kg)) x (ENb))	$N_{excreted}$ (kg) / Nb hatched eggs
Equation 8	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / Nb hatched eggs
Equation 9	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / Nb hatched eggs
Equation 10	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / Nb hatched eggs
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / Nb hatched eggs

6.14.10. Feed efficiency

When the use of feed additives leads to a modification of the feed efficiency, the evaluation of the environmental impact of animal production should be modified accordingly to consider the effect, substantiated for the given feed additive or combination of feed additives. The different approaches to be taken will depend on the extent to which the feed additives improve feed efficiency and on the animal species considered. The equations are described in the relevant guidelines (reference to guidelines for large ruminant, small ruminants, pigs and poultry).

Feed efficiency is the ratio between feed intake and performance (milk production, growth, etc.). In the following tables, the modification of the equations takes one parameter at a time for simplification. Note that, if an additive affects both parameters, both tables should be considered, when it is demonstrated that the 2 impacts are simultaneous.

In the following equations, the ratio between the baseline scenario and the scenario with the feed additive is described by Δ_{fi} (fi = feed intake), Δ_{pc} (pc = performance change) or Δ_{apc}, (apc = animal product composition), which represents the variation in the parameter linked to the use of the additive. Depending on the available data for the feed additives under evaluation, Δ_{fi}, Δ_{pc} or Δ_{apc} may be either superior to 1 (when the additive increases the parameter being multiplied), below 1 (when the additive decreases the parameter being multiplied) or equal to 1 (when the additive has no effect on the parameter being multiplied). For example, if the feed additive increases the feed intake by 5 %, the basal equation (Δ_{fi} = 1.05):

N_{intake} (kg) = FI (kg) x % CP / 6.25 will be modified to N_{intake} (kg) = FI (kg) x Δ_{fi} (1.05) x % CP / 6.25

6.14.11. Large Ruminants

For cattle buffaloes and camels used for milk production, the basal equations indicated in the Table 3 should be adapted according to Table 21, when the effect is linked to a modification of the feed intake.

Table 21 – Adaptation of emissions equation, when feed additives modify feed intake of cattle buffaloes and camels used for milk production

	Basis for Calculation	
Equation 1	$ME_{intakeother}$ (MJ) = Total ME requirement (MJ) - (DMI (kg) x Δ_{fi} x ME (MJ/kg DM)$_{feed1}$ - (DMI (kg) x Δ_{fi} x ME (MJ/kg DM))$_{feed2}$	
Equation 2	DMI_{other}(kg) = $ME_{intakeother}$ (MJ) / (ME (MJ/kg DM))	
Equation 3	GE (MJ) = DMI (kg) x Δ_{fi} x 18.45 (MJ/kg)	
Equation 4	N_{intake} (kg) = DMI (kg) x Δ_{fi} x % CP / 6.25	
Equation 5	P_{intake} (kg) = DMI (kg) x Δ_{fi} x % P_{total}	
Equation 8	VS (kg) = DMI (kg) x Δ_{fi} x (1.04 - DMD) x 0.92	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / ECM (kg)
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / ECM (kg)
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ/kg)	Enteric Methane (kg) / ECM (kg)
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / ECM (kg)
Equation 13	Manure Nitrous Oxide (see Figure 14 of the guidelines on large ruminants)	Manure Nitrous Oxide (kg) / ECM (kg)

For cattle buffaloes and camels used for suckling purposes, the basal equations indicated in Table 4 should be adapted according to Table 22, when the effect is linked to a modification of the feed intake.

Table 22. Adaptation of emissions equation, when feed additives modify feed intake of cattle buffaloes and camels used for suckling purposes

	Basis for Calculation	
Equation 1	$ME_{intakeother}$ (MJ) = Total ME requirement (MJ) - (DMI (kg) x Δ_{fi} x ME (MJ/kg DM))$_{feed1}$ - (DMI (kg) x Δ_{fi} x ME (MJ/kg DM))$_{feed2}$	
Equation 2	DMI_{other} (kg) =$ME_{intakeother}$ (MJ)/ ME (MJ/ kg DM)	
Equation 3	GE (MJ) = DMI (kg) x Δ_{fi} x 18.45 (MJ/kg)	
Equation 4	N_{intake} (kg) = DMI (kg) x Δ_{fi} x % CP / 6.25	
Equation 5	P_{intake} (kg) = DMI (kg) x Δ_{fi} x % P_{total}	
Equation 8	VS (kg) = DMI (kg) x Δ_{fi} x (1.04 - DMD) x 0.92	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ/kg)	Enteric Methane (kg) / TWG (kg liveweight)
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m_3)	Manure Methane (kg) / TWG (kg liveweight)
Equation 13	Manure Nitrous Oxide (see Figure 14 of the guidelines on large ruminants)	Manure Nitrous Oxide (kg) / TWG (kg liveweight)

For cattle buffaloes and camels used for milk production, the basal equations indicated in the Table 3 should be adapted according to Table 23, when the effect of the feed additive is linked to a modification of animal performance.

Table 23. Adaptation of emissions' equation, when feed additives modify performance of cattle buffaloes and camels used for milk production

	Basis for Calculation	
Equation 6	$N_{product}$ (kg) = Milk (kg) x Δ_{pc} x % Protein in milk / 6.38	
Equation 7	$P_{product}$ (kg) = Milk (kg) x Δ_{pc} x % P in milk	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / (ECM (kg) x Δ_{pc})
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (ECM (kg) x Δ_{pc})
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ / kg)	Enteric Methane (kg) / (ECM (kg) x Δ_{pc})
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg / m^3)	Manure Methane (kg) / (ECM (kg) x Δ_{pc})
Equation 13	Manure Nitrous Oxide (see Figure 14 of the guidelines on large ruminants)	Manure Nitrous Oxide (kg) / (ECM (kg) x Δ_{pc})

For cattle buffaloes and camels used for suckling purpose, the basal equations indicated in the Table 4 should be adapted according to Table 24, when the effect of the feed additive is linked to a modification of animal performance or an effect on animal health and welfare.

Table 24. Adaptation of emissions' equation, when feed additives modify performance of cattle buffaloes and camels used for suckling purpose

	Basis for Calculation	
Equation 6	$N_{product}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Protein in tissues / 6.25	
Equation 7	$P_{product}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % P in tissues and bone	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{product}$ (kg)	$N_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ/kg)	Enteric Methane (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 13	Manure Nitrous Oxide (see Figure 14 of the guidelines on large ruminants)	Manure Nitrous Oxide (kg) / (TWG (kg liveweight) x Δ_{pc})

For cattle buffaloes and camels used for milk production, the basal equations indicated in the Table 3 should be adapted according to Table 25, when the effect of the feed additive is linked to a modification of milk characteristics (e.g. milk protein content), as appropriate.

Table 25- Adaptation of emissions' equation, when feed additives modify the characteristic of milk produced by cattle buffaloes and camels used for milk production

	Basis for Calculation	
Equation 6	$N_{product}$ (kg) = Milk (kg) x % Protein in milk x Δ_{apc}/ 6.38	
Equation 7	$P_{product}$ (kg) = Milk (kg) x % P in milk x Δ_{apc}	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / (ECM (kg) x Δ_{apc})
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (ECM (kg) x Δ_{apc})
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ/kg)	Enteric Methane (kg) / (ECM (kg) x Δ_{apc})
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg / m^3)	Manure Methane (kg) / (ECM (kg) x Δ_{apc})
Equation 13	Manure Nitrous Oxide (see Figure 14 of the guidelines on large ruminants)	Manure Nitrous Oxide (kg) / (ECM (kg) x Δ_{apc})

For cattle buffaloes and camels used for suckling purpose, the basal equations indicated in the Table 4 should be adapted according to Table 26, when the effect of the feed additive is linked to a modification of characteristic of meat (e.g. fat content of the carcass).

Table 26- Adaptation of emissions' equation, when feed additives modify the characteristic of meat produced by cattle buffaloes and camels used for suckling purpose

	Basis for Calculation	
Equation 6	$N_{product}$ (kg) = TWG (kg liveweight) x % Protein in tissues x Δ_{apc} / 6.25	
Equation 7	$P_{product}$ (kg) = TWG (lg liveweight) x % P in tissues and bone x Δ_{apc}	
	Calculated impacts	
	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{producst}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)

6.14.12. Small Ruminants

For dairy ewes and goats, the basal equations indicated in the Table 5 should be adapted according to Table 27, when the effect is linked to a modification of the feed intake.

Table 27. Adaptation of emissions' equation, when feed additives modify feed intake of dairy ewes and goats

	Basis for Calculation	
Equation 1	$ME_{intakeother}$ (MJ) = Total ME Requirement (MJ) - (DMI (kg) x Δ_{fi} x ME (MJ/kg DM)$_{feed1}$ - (DMI (kg) x Δ_{fi} x ME (MJ /kg DM))$_{feed2}$	
Equation 2	DMI_{other} (kg) =$ME_{intakeother}$ (MJ) / (ME (MJ/kg DM)	
Equation 6	N_{intake} (kg) = DMI (kg) x Δ_{fi} x % CP / 6.25	
Equation 8	P_{intake} (kg) = DMI (kg) x Δ_{fi} x % P_{total}	
Equation 10	VS (kg) = DMI (kg) x Δ_{fi} x (1.04 - DMD) x 0.92	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / ECM (kg)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / ECM (kg)
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m_3)	Manure Methane (kg) / ECM (kg)
Equation 15	Manure Nitrous Oxide (see Figure 11 of the guidelines on small ruminants)	Manure Nitrous Oxide (kg) / ECM (kg)

For lambs and kids, the basal equations indicated in Table 6 should be adapted according to Table 28, when the effect is linked to a modification of the feed intake.

Table 28 - Adaptation of emissions' equation, when feed additives modify feed intake of lambs and kids

	Basis for Calculation	
Equation 1	$ME_{intakeother}$ (MJ) = Total ME Requirement - (DMI (kg) x Δ_{fi} x ME (MJ /kg DM))$_{feed1}$ - (DMI x Δ_{fi} x ME (MJ /kg DM))$_{feed2}$	
Equation 2	$DMI_{other(}$ (kg) = $ME_{intakeother}$ (MJ) / (ME (MJ/kg DM))	
Equation 6	N_{intake} (kg) = DMI (kg) x Δ_{fi} x % CP / 6.25	
Equation 8	P_{intake} (kg) = DMI (kg) x Δ_{fi} x % P_{total}	
Equation 10	VS (kg) = DMI (kg) x Δ_{fi} x (1.04 - DMD) x 0.92	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / TWG (kg liveweight)
Equation 15	Manure Nitrous Oxide (see Figure 11 of the guidelines on small ruminants)	Manure Nitrous Oxide (kg) / TWG (kg liveweight)

For dairy ewes and goats, the basal equations indicated in the Table 6 should be adapted according to Table 29, when the effect of the feed additive is linked to a modification of animal performance.

Table 29- Adaptation of emissions' equation, when feed additives modify performance of dairy ewes and goats

	Basis for Calculation	
Equation 7	$N_{product}$ (kg) = Milk (kg) x Δ_{pc} x % Protein in milk / 6.38	
Equation 9	$P_{product}$ (kg) = Milk (kg) x Δ_{pc} x % P in milk	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / (ECM (kg) x Δ_{pc})
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (ECM (kg) x Δ_{pc})
Equation 13	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ /kg)	Enteric Methane (kg) / (ECM (kg) x Δ_{pc})
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / (ECM (kg) x Δ_{pc})
Equation 15	Manure Nitrous Oxide (see Figure 11 of the guidelines on small ruminants)	Manure Nitrous Oxide (kg) / (ECM (kg) x Δ_{pc})

For lambs and kids, the basal equations indicated in the Table 6 should be adapted according to Table 30, when the effect of the feed additive is linked to a modification of animal performance or an effect on animal health and welfare.

Table 30. Adaptation of emissions' equation, when feed additives modify performance or health and welfare conditions of lambs and kids

	Basis for Calculation	
Equation 7	$N_{product}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Protein in tissues / 6.25	
Equation 9	$P_{product}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % P in tissues and bones	
	Calculated impacts	
	Total	**Intensity**
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{product}$ (kg)$_s$	$P_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 13	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ / kg)	Enteric Methane (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m$_3$/kg) x MCF (%) x 0.67 (kg/m$_3$)	Manure Methane (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 15	Manure Nitrous Oxide (see Figure 11 of the guidelines on small ruminants)	Manure Nitrous Oxide (kg) / (TWG (kg liveweight) x Δ_{pc})

For dairy ewes and goats, the basal equations indicated in the Table 6 should be adapted according to Table 31, when the effect of the feed additive is linked to a modification of milk characteristics (e.g. milk protein content), as appropriate.

Table 31. Adaptation of emissions' equation, when feed additives modify the characteristic of milk produced by ewes and goats

	Basis for Calculation	
Equation 7	$N_{product}$ (kg) = Milk (kg) x % Protein in milk x Δ_{apc} / 6.38	
Equation 9	$P_{product}$ (kg) = Milk (kg) x % P in milk x Δ_{apc}	
	Calculated impacts	
	Total	**Intensity**
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / (ECM (kg) x Δ_{apc})
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (ECM (kg) x Δ_{apc})
Equation 13	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ / kg)	Enteric Methane (kg) / (ECM (kg) x Δ_{apc})
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg / m^3)	Manure Methane (kg) / (ECM (kg) x Δ_{apc})
Equation 15	Manure Nitrous Oxide (see Figure 11 of the guidelines on small ruminants)	Manure Nitrous Oxide (kg) / (ECM (kg) x Δ_{apc})

For lambs and kids, the basal equations indicated in the Table 6 should be adapted according to Table 32, when the effect of the feed additive is linked to a modification of characteristic of meat (e.g. fat content of the carcass).

Table 32. Adaptation of emissions' equation, when feed additives modify the characteristic of meat produced by lambs and kids

	Basis for Calculation	
Equation 7	$N_{product}$ (kg) = TWG (kg liveweight) x % Protein in tissues x Δ_{apc} / 6.25	
Equation 9	$P_{product}$ (kg) = TWG (kg liveweight) x % P in tissues and bones x Δ_{apc}	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 15	Manure Nitrous Oxide (see Figure 11 of the guidelines on small ruminants)	Manure Nitrous Oxide (kg) / TWG (kg liveweight)

6.14.13. Pigs

For pigs, the basal equations indicated in Table 7 should be adapted according to Table 33, when the effect is linked to a modification of the feed intake.

Table 33- Adaptation of emissions equation, when feed additives modify feed intake of pigs

	Basis for Calculation	
Equation 1	N_{intake} (kg) = FI (kg) x Δ_{fi} x % CP / 6.25	
Equation 3	P_{intak} (kg)$_{e}$ = FI (kg) x Δ_{fi} x % P_{total}	
Equation 5	Cu_{intak} (kg)$_{e}$ = FI (kg) x Δ_{fi} x % Cu	
Equation 7	Zn_{intak} (kg)$_{e}$ = FI (kg) x Δ_{fi} x % Zn	
Equation 8	VS (kg) = FI (kg) x Δ_{fi} x (1 - DMD) x (1 - A) + VS_{swf} (kg)	
Equation 9	VS_{WF} (kg) = FI (kg) x Δ_{fi} x (1 - A) x WF (kg)	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$P_{excrete}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 13	$Cu_{excrete}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 14	$Zn_{excrete}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 16	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.662 (m^3 / kg)	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 17	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x (1 - R_{MMS}) x EF_{MMS} (%) x 44 / 28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

For pigs, the basal equations indicated in the Table 7 should be adapted according to Table 34, when the effect of the feed additive is linked to a modification of animal performance or an effect on animal health and welfare.

Table 34- Adaptation of emissions' equation, when feed additives modify performance or health and welfare conditions of pigs

	Basis for Calculation	
Equation 2	$N_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Protein in tissues / 6.25	
Equation 4	$P_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % P in tissues and bones	
Equation 6	$Cu_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Cu in tissues and bones	
Equation 8	$Zn_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Zn in tissues and bones	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (TWG (kg liveweight x Δ_{pc})
Equation 13	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / (TWG (kg liveweight x Δ_{pc})
Equation 14	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / (TWG (kg liveweight x Δ_{pc})
Equation 15a (growing phase)	$Methane_{enteri}$ $(kg)_c$ = (ResD (kg) x 670 (J/kg ResD)) / 5.665e^7 (J/kg methane)	$Methane_{enteric}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 15b (sows)	$Methane_{enteric}$ (kg)= (ResD (kg) x 1340 (J/kg ResD)) / 5.665e^7 (J/kg methane)	$Methane_{enteric}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 16	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 17	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x (1 - R_{MMS}) x EF_{MMS} (%) x 44 / 28	$NitrousOxide_{housing}$ (kg) / (TWG (kg liveweight) x Δ_{pc})

For pigs, the basal equations indicated in the Table 7 should be adapted according to Table 35, when the effect of the feed additive is linked to a modification of characteristic of meat (e.g. fat content of the carcass).

Table 35. Adaptation of emissions' equation, when feed additives modify the characteristic of meat produced by pigs

	Basis for Calculation	
Equation 2	$N_{retention}$ (kg) = TWG (kg liveweight) x % Protein in tissues x Δ_{apc} / 6. 25	
Equation 4	$P_{retention}$ (kg) = TWG (kg liveweight) x % P in tissues and bones x Δ_{apc}	
Equation 6	$Cu_{retention}$ (kg) = TWG (kg liveweight) x % Cu in tissues and bones x Δ_{apc}	
Equation 8	$Zn_{retention}$ (kg) = TWG (kg liveweight) x % Zn in tissues and bones x Δ_{apc}	
	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 13	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 14	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 17	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x (1 - R_{MMS}) x EF_{MMS} (%) x 44 / 28	$NitrousOxide_{housing}$ (kg)/ TWG (kg liveweight)

6.14.14. Poultry

For broiler chickens, the basal equations indicated in Table 8 should be adapted according to Table 36, when the effect is linked to a modification of the feed intake.

Table 36. Adaptation of emissions equation, when feed additives modify feed intake of broiler chickens

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x Δ_{fi} x % P_{total}	
Equation 2	Cu_{intake} (kg) = FI (kg) x Δ_{fi} x % Cu	
Equation 3	Zn_{intake} (kg) = FI (kg) x Δ_{fi} x % Zn	
Equation 5	VS (kg) = FI (kg) x Δ_{fi} x (1 - DMD) X (1 - A)	
	Calculated impacts	
	Total	**Intensity**
Equation 8	$N_{excreted}$ (kg) = FI (kg) x Δ_{fi} x % CP / 6.25 x (1 - 0.602)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 11	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

For broiler turkeys, the basal equations indicated in Table 9 should be adapted according to Table 37, when the effect is linked to a modification of the feed intake.

Table 37 - Adaptation of emissions' equation, when feed additives modify feed intake of broiler turkeys

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x Δ_{fi} x % P_{total}	
Equation 3	Cu_{intake} (kg) = FI (kg) x Δ_{fi} x % Cu	
Equation 5	Zn_{intake} (kg) = FI (kg) x Δ_{fi} x % Zn	
Equation 7	VS (kg) = FI (kg) x Δ_{fi} x (1 - DMD) X (1 - A)	
	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x Δ_{fi} x % CP / 6.25 x (1 - 0.588)	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{product}$ $(kg)_s$	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{product}$ $(kg)_s$	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{product}$ $(kg)_s$	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$Methane_{housing}$ (kg)= VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg/ m^3)	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 13	$NitrousOxide_{housing}$ (kg)= $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

For laying poultry, the basal equations indicated in Table 10 should be adapted according to Table 38, when the effect is linked to a modification of the feed intake.

Table 38 - Adaptation of emissions' equation, when feed additives modify feed intake of laying poultry

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x Δ_{fi} x % P_{total}	
Equation 3	Cu_{intake} (kg) = FI (kg) x Δ_{fi} x % Cu	
Equation 5	Zn_{intake} (kg) = FI (kg) x Δ_{fi} x % Zn	
Equation 7	VS (kg) = FI (kg) x Δ_{fi} x (1 - DMD) X (1 - A)	
	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x Δ_{fi} x % CP / 6.25 x ((0.0182 x EW (kg)) x (ENb))	$N_{excreted}$ (kg) / Kg eggs in shell
Equation 9	$P_{excreted}$ (kg)= P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / Kg eggs in shell
Equation 10	$Cu_{excreted}$ (kg)= Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / Kg eggs in shell
Equation 9	$Zn_{excreted}$ (kg)= Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / Kg eggs in shell
Equation 12	$Methane_{housing}$ (kg)= VS (kg) x Bo (m^3 /kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ (kg) / Kg eggs in shell
Equation 13	$NitrousOxide_{housing}$ (kg)= $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / Kg eggs in shell

For breeding poultry, the basal equations indicated in Table 11 should be adapted according to Table 39, when the effect is linked to a modification of the feed intake.

Table 39. Adaptation of emissions' equation, when feed additives modify feed intake of breeding poultry

	Basis for Calculation	
Equation 1	P_{intake} (kg) = FI (kg) x Δ_{fi} x % P_{total}	
Equation 3	Cu_{intake} (kg) = FI (kg) x Δ_{fi} x % Cu	
Equation 5	Zn_{intake} (kg) = FI (kg) x Δ_{fi} x % Zn	
Equation 7	VS (kg) = FI (kg) x Δ_{fi} x (1 - DMD) X (1 - A)	
	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x Δ_{fi} x % CP / 6.25 x ((0.0182 x EW (kg)) x (ENb))	$N_{excreted}$ (kg) / Nb hatched eggs
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / Nb hatched eggs
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / Nb hatched eggs
Equation 11	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / Nb hatched eggs
Equation 12	$Methane_{housing}$ (kg)= VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ (kg) / Nb hatched eggs
Equation 13	$NitrousOxide_{housing}$ (kg)= $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / Nb hatched eggs

For broiler chickens, the basal equations indicated in the Table 8 should be adapted according to Table 40, when the effect of the feed additive is linked to a modification of animal performance or an effect on animal health and welfare.

Table 40. Adaptation of emissions equation, when feed additives modify performance or health and welfare conditions of broiler chickens

	Basis for Calculation	
Equation 2	$P_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % P Tissues and bones	
Equation 4	$Cu_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Cu Tissues and bones	
Equation 6	$Zn_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Zn Tissues and bones	
	Calculated impacts	
	Total	**Intensity**
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x (1 - 0.602 x Δ_{pc})	$N_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (TWG (liveweight) x Δ_{pc})
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / (TWG (liveweight) x Δ_{pc})
Equation 9	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / (TWG (liveweight) x Δ_{pc})
Equation 12	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / (TWG (kg liveweight) x Δ_{pc})

For broiler chickens, the basal equations indicated in the Table 9 should be adapted according to Table 41, when the effect of the feed additive is linked to a modification of animal performance or an effect on animal health and welfare.

Table 41. Adaptation of emissions equation, when feed additives modify performance or health and welfare conditions of broiler turkeys

	Basis for Calculation	
Equation 2	$P_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % P Bones and tissues	
Equation 4	$Cu_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Cu Bones and tissues	
Equation 6	$Zn_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Zn Bones and tissues	
	Calculated impacts	
	Total	**Intensity**
Equation 4	$N_{excrete}$ (kg) = FI (kg) x % CP / 6.25 x (1 - 0.588 x Δ_{pc})	$N_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 5	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 6	$Methane_{housing}$ (kg)= VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 7	$NitrousOxide_{housing}$ (kg)= $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / (TWG (kg liveweight) x Δ_{pc})

For laying poultry, the basal equations indicated in the Table 10 should be adapted according to Table 42, when the effect of the feed additive is linked to a modification of animal performance.

Table 42. Adaptation of emissions equation, when feed additives modify performance of laying poultry

	Basis for Calculation	
Equation 2	$P_{retention}$ (kg) = EW (kg) x Δ_{pc} x ENb x Δ_{pc} x % P Eggs	
Equation 4	$Cu_{retention}$ (kg) = EW (kg) x Δ_{pc} x ENb x Δ_{pc} x % Cu Eggs	
Equation 6	$Zn_{retention}$ (kg) = EW (kg) x Δ_{pc} x ENb x Δ_{pc} x % Zn Eggs	
	Calculated impacts	
	Total	**Intensity**
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x ((0.0182 x EW (kg) x Δ_{pc}) x (ENb x Δ_{pc}))	$N_{excreted}$ (kg)/ (Kg eggs in shell x Δ_{pc})
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (Kg eggs in shell x Δ_{p})
Equation 12	$Methane_{housing}$ (kg)= VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (m^3 / kg)	$Methane_{housing}$ (kg) / (Kg eggs in shell x Δ_{pc})
Equation 13	$NitrousOxide_{housing}$ (kg)= $N_{excreted}$ x EF_{MMS} (%) x 44/28	$NitrousOxide_{housin}$ (kg)$_{g}$ / (Kg eggs in shell x Δ_{pc})

For breeding poultry, the basal equations indicated in the Table 11 should be adapted according to Table 43, when the effect of the feed additive is linked to a modification of animal performance.

Table 43. Adaptation of emissions equation, when feed additives modify performance of breeding poultry

	Basis for Calculation	
Equation 2	$P_{retention}$ (kg) = EW x Δ_{pc} x ENb x Δ_{pc} x % P Eggs	
	Calculated impacts	
	Total	**Intensity**
Equation 4	$N_{excreted}$ (kg) = FI x % CP / 6.25 x ((0.0182 x EW x Δ_{pc}) x (ENb x Δ_{pc}))	$N_{excreted}$ (kg) / (Nb hatched eggs x Δ_{pc})
Equation 5	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / (Nb hatched eggs x Δ_{pc})
Equation 6	$Methane_{housing}$ (kg)= VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ / (Nb hatched eggs x Δ_{pc})
Equation 7	$NitrousOxide_{housing}$ (kg)= $N_{excreted}$ (kg) x EF_{MMS} x 44/28	$NitrousOxide_{housin}$ (kg)$_{g}$ / (Nb hatched eggs x Δ_{pc})

For broiler chickens, the basal equations indicated in the Table 8 should be adapted according to Table 44, when the effect of the feed additive is linked to a modification of characteristic of meat (e.g. fat content of the carcass).

Table 44 - Adaptation of emissions’ equation, when feed additives modify the characteristic of meat produced by broiler chickens

	Basis for Calculation	
Equation 2	$P_{retention}$ (kg) = TWG (kg liveweight) x % P Tissues and bones x Δ_{apc}	
Equation 4	$Cu_{retention}$ (kg) = TWG (kg liveweight) x % Cu Tissues and bones x Δ_{apc}	
Equation 6	$Zn_{retention}$ (kg) = TWG (kg liveweight) x % Zn Tissues and bones x Δ_{apc}	
	Calculated impacts	
	Total	**Intensity**
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x (1 - 0.602 x Δ_{apc})	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{product}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{product}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{product}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)

For broiler turkeys, the basal equations indicated in the Table 9 should be adapted according to Table 45, when the effect of the feed additive is linked to a modification of characteristic of meat (e.g. fat content of the carcass).

Table 45. Adaptation of emissions equation, when feed additives modify the characteristic of meat produced by broiler turkeys

	Basis for Calculation	
Equation 2	$P_{retention}$ (kg) = TWG (kg liveweight) x % P Tissues and bones x Δ_{apc}	
Equation 4	$Cu_{retention}$ (kg) = TWG (kg liveweight) x % Cu Tissues and bones x Δ_{apc}	
Equation 6	$Zn_{retention}$ (kg) = TWG (kg liveweight) x % Zn Tissues and bones x Δ_{apc}	
	Calculated impacts	
	Total	**Intensity**
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x (1 - 0.588 x Δ_{apc})	$N_{excreted}$ (kg) / TWG (kg liveweight)
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 11	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)

For laying poultry, the basal equations indicated in the Table 10 should be adapted according to Table 46, when the effect of the feed additive is linked to a modification of characteristic of eggs (e.g. fat content).

Table 46. Adaptation of emissions equation, when feed additives modify the characteristic of eggs produced by laying poultry

	Basis for Calculation	
Equation 2	$P_{retention}$ (kg) = EW (kg) x ENb x % P eggs x Δ_{apc}	
Equation 4	$Cu_{retention}$ (kg) = EW (kg) x ENb x % Cu eggs x Δ_{apc}	
Equation 6	$Zn_{retention}$ (kg) = EW (kg) x ENb x % Zn eggs x Δ_{apc}	
	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x ((0.0182 x Δ_{apc} x EW(kg)) x (ENb))	$N_{excreted}$ (kg) / Kg eggs in shell
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{product}$ (kg)$_s$	$P_{excreted}$ (kg) / Kg eggs in shell
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{product}$ (kg)$_s$	$Cu_{excreted}$ (kg) / Kg eggs in shell
Equation 10	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{product}$ (kg)$_s$	$Zn_{excreted}$ (kg) / Kg eggs in shell

Emission Factors

This section applies to feed additives that can have <u>direct</u> effect on the emissions from enteric fermentation or from manure management system. In that case, the ratio between the emission linked to additive and the emission from the baseline will be affected to the Emission Factor.

In the following equations, the ratio between the baseline scenario and the scenario with the feed additive is described by Δ_{ef} (ef = emission factor) which represents the variation in the parameter linked to the use of the additive. Depending on the available data for the feed additives under evaluation, Δ_{ef} may be either superior to 1 (when the additive increases the parameter being multiplied), below 1 (when the additive decreases the parameter being multiplied) or equal to 1 (when the additive has no effect on the parameter being multiplied). For example, if the feed additive decreases the emission factor by 5 %, the basal equation (Δ_{ef} = 1.05):

Enteric methane (kg) = GE (MJ) x (EF (%) /55.65) will be modified to Enteric methane (kg) = GE (MJ) x (EF (%) x Δ_{ef} /55.65).

Table 47. Adaptation of emissions equation when the emissions factors for methane and nitrous oxide are modified for large ruminants

	Calculated impacts	
	Total	Intensity
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) x Δ_{ef} / 55.65 (MJ/kg)	Enteric Methane (kg) / ECM (kg)
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%)x Δ_{ef} x 0.67 (kg/m^3)	Manure Methane (kg) / ECM
Equation 13	Manure Nitrous Oxide (see Figure 14 of the large ruminant guidelines))	Manure Nitrous Oxide (kg) / ECM (kg)
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) x Δ_{ef} / 55.65 (MJ/kg)	Enteric Methane (kg) /TWG (kg liveweight)
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%)x Δ_{ef} x 0.67 (kg/m^3)	Manure Methane (Kg) / TWG (kg liveweight)
Equation 13	Manure Nitrous Oxide (see Figure 14 of the large ruminant guidelines))	Manure Nitrous Oxide (kg) / TWG (kg liveweight)

Table 48. Adaptation of emissions equation when the emissions factors for methane and nitrous oxide are modified for small ruminants

	Calculated impacts	
	Total	Intensity
Equation 13	Enteric Methane (kg) = GE (MJ) x EF (%) x Δ_{ef} / 55.65 (MJ/kg)	Enteric Methane (kg) / ECM (kg)
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x Δ_{ef} x 0.67 (kg/m^3)	Manure Methane (kg) / ECM (kg)
Equation 15	Manure Nitrous Oxide (kg) (see Figure 11 of the small ruminants guidelines)	Manure Nitrous Oxide (kg) / ECM (kg)
Equation 13	Enteric Methane (kg) = GE (MJ) x EF (%) x Δ_{ef} / 55.65 (MJ/kg)	Enteric Methane (kg) / TWG (kg liveweight)
Equation 14	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x Δ_{ef} x 0.67 (kg/m^3)	Manure Methane (kg) / TWG (kg liveweight)
Equation 15	Manure Nitrous Oxide (kg) (see Figure 11 of the small ruminants guidelines)	Manure Nitrous Oxide (kg) / TWG (kg liveweight)

Table 49. Adaptation of emissions equation when the emissions factors for methane and nitrous oxide are modified for pigs

	Calculated impacts	
	Total	Intensity
Equation 16	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x Δ_{ef} x 0.662 (kg/m^3)	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 17	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x (1 - R_{MMS}) x EF_{MMS} (%) x Δ_{ef} x 44 / 28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

Table 50. Adaptation of emissions equation when the emissions factors for methane and nitrous oxide are modified for poultry

	Calculated impacts	
	Total	Intensity
Equation 12	$Methane_{housing}$(kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x Δ_{ef} x 0.662	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 13	$NitrousOxide_{housing}$(kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x Δ_{ef} x 44/28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)
Equation 12	$Methane_{housing}$(kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x Δ_{ef} x 0.662	$Methane_{housing}$ (kg) / Kg Eggs in shell
Equation 13	$NitrousOxide_{housing}$(kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x Δ_{ef} x 44/28	$NitrousOxide_{housing}$ (kg) / Kg Eggs in shell
Equation 12	$Methane_{housing}$(kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x Δ_{ef} x 0.662	$Methane_{housing}$ (kg) / Nb Hatched Eggs
Equation 13	$NitrousOxide_{housing}$(kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x Δ_{ef} x 44/28	$NitrousOxide_{housing}$ (kg) / Nb Hatched Eggs

6.14.15. Data quality assessment/rules

Previous section defines data needs, this section describes how to assess data quality

- effects based on *in vivo* data should allow statistical analysis, using proper methodology. The ratio between the use of additive and baseline will define the Δ used in the equations
- Peer reviewed publication in reputable journals is favoured. However, if reports are not published, they should be made available, including raw data for scientific evaluation by qualified independent reviewers, such as regulatory bodies, academia, third parties, or certification bodies.
- in the evaluation of the results, the dosage of the additive should be considered and LCA should be done on this basis

- Primary data are favoured (i.e. measurements on farm)
- number of trials is not pre-defined but it should be indicated in the LCA report, to enable scientific evaluation of the results (from one trial providing assumptions to meta-analysis providing the possibility for further extrapolation)
- information providing a description of the mode of action explaining the effect can be used to improve the potential extrapolation from one livestock system to another.

Time representativeness (data relative to mode of action are valid without limitation, data relative to the effect envisaged should be comparable to the current situation, more recent studies have a bigger weight of evidence).

Technological representativeness (data relative to mode of action shall be applicable to the type of diets and type of animals concerned, data relative to zootechnical results shall be obtained on similar ration (feed formulation) and similar strain of animals (e.g. fast-growing chickens vs slow-growing chickens)).

Geographical representativeness (data relative to mode of action shall be extrapolated with care, as regards to the farm management, data relative to zootechnical results should be issued from similar farming practices and if climatic conditions are possibly affecting the performance (e.g. animals raised outside of the barns), the conditions of the trials should be comparable to the practice).

Cases where primary data on production with and without additives is available: if data are available for the farm(s) part of the LCA, the results from the farms before using the additives and after using them should be considered

Cases where primary data is not available the following secondary data considerations shall be evaluated: substantiation through regulatory bodies if available, meta-analysis, and literature (peer reviewed journals, data provided by reliable research groups to ensure scientific quality).

Considering the above-mentioned qualitative aspects of the results (representativity of the zootechnical results), it could be considered that one trial would provide a limited level of substantiation and 3 trials could be a consensus (already used by different regulatory instances). In the case the mode of action is demonstrated, a scientific peer review could be sufficient and applicability to the particular case of the LCA should be provided. Practitioner is required to use feed additives according to the specification provided by the manufacturer and in the conditions substantiated by the data (e.g. same dose, same mode of application).

Part 4: INTERPRETATION OF LCA RESULTS

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

- At all steps of the LCA, the calculation approaches and data shall match the goals and quality requirements of the study. In this sense, interpretation of results may inform an iterative improvement of the assessment until all goals and requirements are met.
- The second purpose of the interpretation is to develop conclusions and recommendations, for example, in support of environmental performance improvements. The interpretation entails three main elements detailed in the following subsections: 'Identification of important issues', 'Characterizing uncertainty' and 'Conclusions, limitations and recommendations'.

7. Identification of key issues

Identifying important issues encompasses the identification of most significant inventory data, impact categories and life cycle stages, and the sensitivity of results to methodological choices. The first step is to identify the life cycle stage processes and elementary flows that contribute most to the LCIA results, as well as the most relevant impact categories. Contribution analysis shall be conducted to quantify the relative contribution of the different stages/categories/items to the total result. Such contribution analysis can be useful for various interests, such as focusing on data collection or mitigation efforts on the processes that contribute the most to the LCIA results.

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

- Completeness checks: Evaluate the LCI data to confirm that it is consistent with the defined goals, scope, system boundaries and quality criteria and that the cut-off criteria have been met. This includes: completeness of process, i.e. at each supply chain stage, the relevant processes or emissions contributing to the impact have been included and exchanges, i.e. all significant energy or material inputs and their associated emissions have been included for each process.
- Plausibility checks: Plausibility is part of the overall quality criteria. Its aim is to ensure that the unit process dataset results and the raw data are reasonable and, therefore, acceptable. Based on the practitioner's previous experience and existing knowledge, if unusual or surprising deviations from expected or normal results are observed, such deviation should be examined for relevance.

- Sensitivity checks: Assess the extent to which the results are determined by specific methodological choices and the impact of implementing alternative, defensible choices where these are identifiable. This is particularly important with respect to allocation choices. It is useful to structure sensitivity checks for each phase of the study: goal and scope definition, the LCI model and impact assessment.

Table 51. Guide for decision robustness from sensitivity and uncertainty

sensitivity	Uncertainty	Robustness
High	High	Low
High	Low	High
Low	High	High
Low	Low	High

- Consistency checks: Ensure that the principles, assumptions, methods and data have been applied consistently with the goal and scope throughout the study. In particular, ensure that the following are addressed: (i) the data quality along the life cycle of the product and across production systems; (ii) the methodological choices (e.g. allocation methods) across production systems; and (iii) the application of the impact assessments steps with the goal and scope.

7.1. Characterizing uncertainty

This section is related to Section 5.7.3. Data Quality Assessment and 5.7.4. Data Quality Rules. There are several sources of uncertainty in LCA, such as knowledge uncertainty and process uncertainty. Knowledge uncertainty reflects limits of what is known about a given datum; while process uncertainty reflects the inherent variability of processes. Knowledge uncertainty can be reduced by collecting more data, but often limits on resources restrict the breadth and depth of data acquisition. Process uncertainty can be reduced by breaking complex systems into smaller parts or aggregations, but inherent variability cannot be eliminated completely. The LCIA characterization factors used to combine and convert the large number of inventory data into impacts also introduce uncertainty into the estimation of impacts. In addition, bias may be introduced if the LCI model misses processes or does not represent the modeled system accurately.

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

7.2. Monte Carlo Analysis

In a Monte Carlo analysis, parameters (LCI) are considered as stochastic variables with specified probability distributions, quantified as probability density functions (PDF). In each iteration, the Monte Carlo analysis creates an LCA model with one particular value from the PDF of every parameter and calculates the LCA results. The statistical properties of the samples of LCA results after a large number of iterations are then investigated. For normally distributed data, variances are typically described in terms of an average and standard deviation. Some databases, notably ECOINVENT, use a lognormal PDF to describe the uncertainty. Other distributions (e.g., triangle and uniform) may also be used based on the uncertainty assessment in specific projects. The choices of data distribution and rationale should be documented and reported. Some software tools (e.g. OpenLCA) allow the use of Monte Carlo simulations to characterize the uncertainty in the reported impacts as affected by the uncertainty in the input parameters of the analysis.

7.3. Sensitivity analysis

Choice-related uncertainties arise from a number of methodologies, including modeling principles, system boundaries, cut-off criteria, the choice of footprint impact assessment methods and other assumptions related to time, technology and geography. Unlike the LCI and characterization factors, these uncertainties are not amenable to statistical description. However, the sensitivity of the results to these choice-related uncertainties can be characterized through scenario assessments (e.g. comparing the footprint derived from different allocation choices) and/or uncertainty analysis (e.g. Monte Carlo simulations). In addition to choice-related sensitivity evaluation, the relative sensitivity of specific activities (e.g., LCI datasets) can also be evaluated by measuring the percentage change of impact arising from a known change in input parameters (Hong et al., 2010)

7.4. Normalization

According to ISO 14044:2006, normalization is an optional step in impact assessment. Normalization is a process in which an impact associated with the functional unit is compared against an estimate of the entire regional impacts in that category (Sleeswijk et al., 2008). For example, livestock supply chains have been estimated to contribute 14.5 percent of global anthropogenic GHG emissions (Gerber et al., 2013). Similar assessments can be made at regional or national scales, provided that there exists a reasonably complete inventory exists of all emissions in that region that contribute to the impact category. However, given the intricately linked supply chains of feeds additive and animal feeds, it would make more sense to perform normalization (if needed for additional insights) for the overall LCA of animal feeds incorporating feed additives instead. See Section 12.2.3 Normalization in LEAP guideline on environmental performance of animal feeds supply chains (FAO, 2016). More details can be found from UNEP (2011).

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APPENDICES

Appendix 1

Examples of application of feed additives and their functions

This annex provides some examples of feed additives groups that can have an impact on animal production and thus the environmental impact intensity of animal sourced products. It is not aimed to be exhaustive and should provide a better understanding for the reader of the type of effects.

Modification of Feed Composition

Phytase

Poultry diets are primarily formulated based on plant ingredients and more than 60% of the total phosphorus in plants represent as phytate phosphorus, which is poorly digested by poultry (Nelson et al., 1971; Waldroup et al., 2000). The poor utilization of phytate-phosphorus in feeds causes three major problems:

- The environmental pollution from unabsorbed phosphorus
- The need for adding diets with inorganic phosphorus
- The reduction of rock phosphate sources (Xin et al., 2013).

Phytase (myo-inositol hexakisphosphate phosphohydrolase) catalyzes the stepwise removal of phosphates from phytic acid (myo-inositol hexakisphosphate) or its salt phytate. The first phytase was reported in 1907 (Suzuki et al., 1907). Development of commercial phytases as a feed additive was initiated by a feed mineral company in 1962 (Wodzinski and Ullah, 1996). The rest of half century ago has been intensified on screening microorganisms and cloning of the phytase gene and its overexpression in the native host. Nutritional equivalency values of phytases in replacing inorganic phosphorus supplementation and in improving bioavailability of calcium, iron, zinc amino acids and energy are well documented (Wu et al., 2003; Selle and Ravindran, 2007; Adeola and Cowieson, 2011; Zaghari et al., 2015). The aim of using phytase has recently shifted from partial release of phosphorus to the complete depletion of myo-inositol hexakisphosphate. Implementing high doses of phytase may allow for the degradation of IP6, as well as lower esters, such as inositol triphosphate and inositol diphosphate (Cowieson et al., 2016; Gautier et al., 2018). The IP1 ester serves as a substrate for endogenous alkaline phosphatases and broilers are able to remove the last P from IP1 to produce the nutrient inositol

(Zyla et al., 2004; Cowieson et al., 2011; Walk et al., 2014). Achieving maximum degradation of phytate, in addition to minimize need for inorganic phosphorus, reduce phosphorus emission and impact of poultry systems on environment. Use of phytase in pig feed allows a 30% decrease in zinc emissions from animal production (EFSA, 2014;12(5);3668). The incorporation of phytase preparation is of the order of magnitude of 100 mg/kg feed compared with the reduction of phosphate incorporation in feed of up to 1.5 %. As a consequence, the feed formulation may be changed as the diet density may be decreased. An LCA study described by Kebreab et al. (2016) exemplifies this possibility in diets for pigs and poultry, in different regions. Example of feed composition modification is provided in Table A1. In this example the total phosphorus concentration in the diet was reduced by 15 to 22%, while the digestible phosphorus level was kept similar. A more general example of how enzymes affect animal production is given in Figure A1.

Table A1 – Example of diet composition modification linked to the use of phytase in poultry feed, in Europe, United States of America and Brazil.

Feed Ingredients	Europe		United States of America		Brazil	
	Control	With phytase	Control	With phytase	Control	With phytase
Wheat	454	454				
Corn	242	242	623	618	684	693
Rapeseed meal	18	18				
Soybean meal	223	223	221	238	271	270
Soybean oil			21	25	11	8
Rapeseed oil	20	20				
Corn DDGS			64	64		
Meat meal			52	30		
Monocalcium phosphate	11	7				
Defluorinated phosphate			3	0.2		
Dicalcium phosphate					12	7

Calcium carbonate	18	22	5	12	8	8
Salt	4	4	1	2	4	4
Sodium bicarbonate	0.4	0.4				
Sulfur carbonate			1	2		
Lysine	3	3	2	2	2	2
Threonine	0.7	0.6	0.6	0.6	0.3	0.2
Methionine	2	2	3	3	2	2
Phytase	0	0.1	0	0.2	0	0.1
Vitamin Premix	5	5	2	2	5	5
Nutritional composition						
CP, g/kg	179	179	199	195	187	187
Total P, g/kg	6.1	5.1	5.9	4.6	5.61	4.78
ME kcal/g	3082	3082	3124	3124	3047	3047

Amino acids

Monogastric animals have specific amino acids requirements. Usually, the amino acid profile in the plant feed ingredient is different from the one of the animal sourced product, such as meat or eggs. For this reason, the necessary provision of essential amino acids, such as methionine, lysine, tryptophane, threonine, leads to formulation of feed containing a relatively high level of proteins. Excess of proteins in the diet will be excreted and leads to potential leaching or production of nitrous oxide and ammonia.

The provision of individual amino acids has allowed the improved supply of the amino acid content of the feed and the animals' requirements. Hence, the total level of protein in the diet can be reduced, leading to a reduced use of high protein content feed ingredients, such as soybean meal or rapeseed meal.

An LCA study described by Kebreab et al. (2016) exemplifies this possibility in diets for pigs and poultry in different regions. The details of the feed composition modification are provided in Table 2. Furthermore, based on the European diet, it was necessary to reduce the energy content of the diet, leading to reduced feed efficiency.

Table A2 - Example of diet composition modification linked to the use of amino acids in poultry feed, in Europe, United States of America and Brazil.

Feed Ingredients	Europe		United States of America		Brazil	
	Control	With amino acids*	Control	With amino acids	Control	With amino acids
Wheat	0	454				
Corn	392	242	554	623	497	684
Wheat bran	28	0				
Rapeseed meal	78	18				
Soybean meal	449	223	283	221	273	271
Soybean oil			33	21	0	11
Rapeseed oil	20	20				
Corn DDGS			64	64		
Corn gluten					200	0
Meat meal			52	52		
Monocalcium phosphate	11	11				
Defluorinated phosphate			3	3		
Dicalcium phosphate					12	12
Calcium carbonate	18	18	5	5		8
Salt	4	4	2	1		4
Sodium bicarbonate	0.4	0.4				

Sulfur carbonate			2	1		
Lysine	0	3	0	2	0	2
Threonine	0	0.7	0	0.6	0	0.3
Methionine	0	2	0	3	0	2
Vitamin Premix	5	5	2	2	5	5
Nutritional composition						
CP, g/kg	265	179	219	195	293	187
Total P, g/kg	7.29	6.1	6.0	5.9	5.14	5.61
ME kcal/g	2831	3082	3124	3124	3047	3047

*the amino acids used were limited to lysine, threonine and methionine

Proteases

Protein contained in feed ingredients, essentially in plant-based feed ingredients, is only partially digested by monogastric animals, leading to increased total protein content in the diets, to fulfil the animals' requirements. Excess of proteins in the diet will be excreted and lead to potential leaching or production of nitrous oxide and ammonia.

Proteases degrade protein in the digestive tract of monogastric animals, increasing the amount of digestible amino acids, hence increasing the provision of amino acids to the animal. This allows reducing the concentration of proteins in the diet and a modification of its composition.

Amylases

Depending of the feed ingredients, starch digestibility is highly variable. Starch digestibility depends on the type of feed ingredients used and on its quality. Starch is the primary source of energy for monogastric and therefore its digestibility is a key element of its efficiency to cover animal's requirements.

Amylases support the degradation of starch in the digestive tract of the animal, hence enhancing the energy value of the feed ingredients. Hence, the feed ingredients, with a lower starch digestibility, appear more competitive compared to their counterparts and their incorporation in feed is modified.

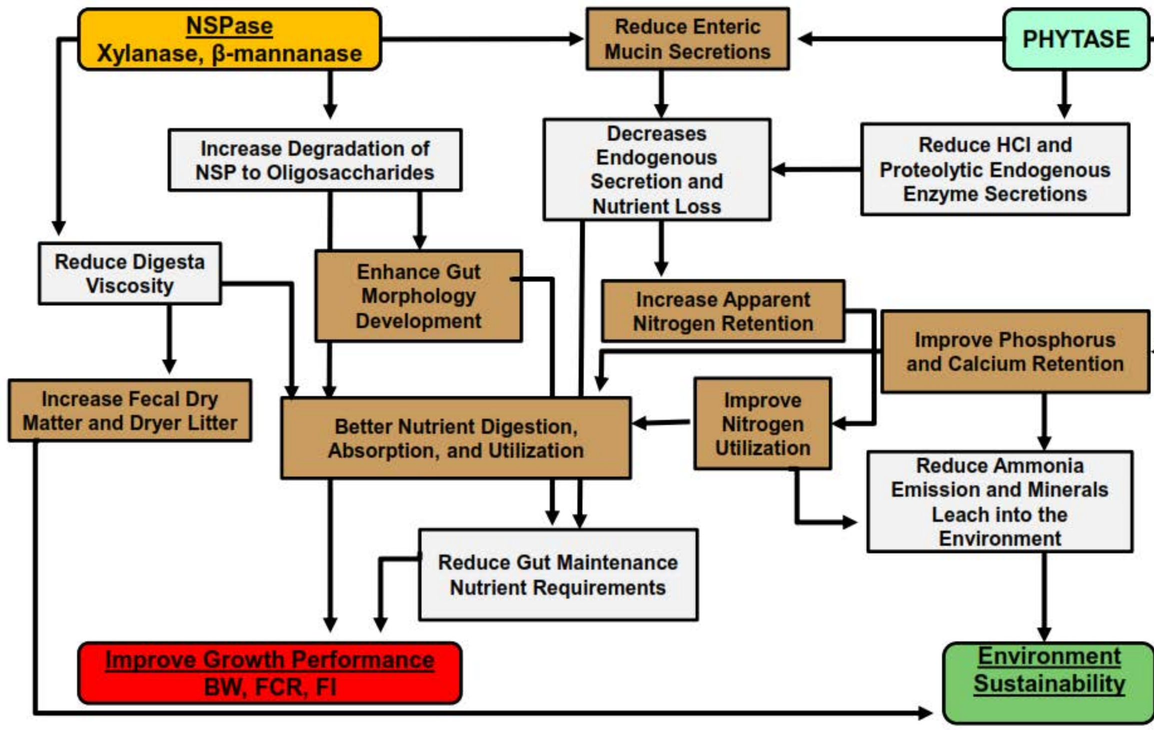

Figure A1 Schematic representation of impact of enzymes on nitrogen and phosphorus emission.

Improved feed efficiency

Phytogenic substances

Phytogenic substances in ruminants' nutrition are nominated to improve ruminal protein metabolism, to reduce enteric methane production and to enhance animal performance. However, effectiveness in ruminant performance has not been proved in a consistent and conclusive manner. Phytogenic substances and their components have been shown to affect ruminal N metabolism in a dose-dependent manner but only in short-term in vitro experiments (Newbold et al., 2004; Busquet et al., 2006; Castillejos et al., 2008). Effects reported from in vitro studies must be interpreted with caution since they do not account for eventual shifts in microbial populates that may occur as a result of exposure of rumen microbes to phytogenic substances.

Very little *in vivo* research has been published testing the effect of phytogenic substances in the performance of ruminants. Some of the observed effects on ruminants performance were increased average daily gain (Valero et al 2014; Yang et al 2010; Meyer et al 2009; Chaves et al 2008) or feed conversion efficiency (Valero et al 2014; Meyer et al 2009; Benchaar et al 2006). Evidence on the fact that phytogenic substances can auspiciously alter ruminal fermentation is based on in vitro experiments but type and optimizing doses deserves further research. There is an urgent need to conduct in vivo long-term studies to determine the safety use of phytogenic substances in livestock nutrition and human feed production, the potential adaptation of the rumen, and possible side effects such as residues in edible products.

Wati et al (2015) showed that Chinese herbal feed additives are claimed to exert antioxidant, enhancing immune functions, antimicrobial and growth-promoting effects in livestock. Moreover, the current experimental results seem to justify the assumption that Chinese herbal feed additives may have the potential to be good candidates to promote production performance and productivity of animal.

Probiotics

The use of probiotics in small ruminant nutrition to confirm the improvement of animal health, productivity and immunity was shown by El-Tawab et al. (2017). Probiotics improved growth performance through enhancing of rumen microbial ecosystem, nutrient digestibility and feed conversion rate. Moreover, probiotics have been reported to stabilise rumen pH, increase volatile fatty acids production and to stimulate lactic acid utilising protozoa, resulting in a highly efficient rumen function.

Other substances

Like evidenced by Liu et al (2018), the possible use of prebiotics, direct-fed microbials, yeast, and nucleotides may have positive impacts on pig performance, but results have been less consistent and there is a need for more research in this area.

Improved quality of animal products

Considerable research has been conducted to evaluate the potential animal performance as demonstrated by Zawadzki et al (2017) that used the extract of Mate (*Ilex paraguariensis A.St.-Hil.*) in diet for broilers feed to increase the oxidative stability of chicken meat recognizing his safety and source of high content of alkaloids, saponins, and phenolic acids. Otherwise, the addition of mate extract in the diet of feedlot cattle did not affect animal performance and carcass characteristics, but these animals presented more tender beef, which was well-received by consumers.

Modification of emission factors

Phytogenic substances may modify rumen microbiota, reduce methane emissions or increase carcass characteristics in monogastrics. Antibiotic growth promoters use is now forbidden in many regions of the world (i.e. European Union) leaving room for natural alternatives to effectively affect feed efficiency and animals performance. This section summarises documented effects of the use of essential oils as feed additives in ruminants and monogastrics nutrition. It should be noted that there are more than 3000 essential oils and their components available (Van de Braak and Leijten, 1999).

Inhibitory effect on methanogenesis has been extensively verified using essential oils in several in vitro experiments as shown in Table 3. When tested in vivo, effectiveness has not been proved in a consistent manner. For example in an experiment conducted by Beauchemin and

McGinn (2006), steers fed during three weeks with a TMR containing a mixture of essential oils (1g day^{-1}) showed no evidence of effect on methanogenesis but feeding sheep during two weeks with a mixture of essential oils (0,25g day^{-1}), Wang et al (2009) confirmed a reduction in methane emissions. Long term in vivo experiments are needed to confirm not only the effectiveness of essential oils to inhibit rumen methanogenesis but its persistence.

Table A3. Maximum methane inhibition reported using essential oils on *in vitro* rumen incubation.

Essential oil (EO)	Dosage tested	Maximum CH_4 inhibition	Reference
Carvacrol	1.5 to 5 mM	88.9%	Macheboefur et al 2008
Cinnamaldehyde	1 to 5 mM	89.3%	Macheboefur et al 2008
Cinnamon oil	250 mL^{-1}	70.9%	Chaves et al 2008
Garlic oil	300 mg L^{-1}	74%	Busquet et al 2005
Origanum oil	1g L^{-1}	86.9%	Patra & Yu 2012
Eucalyptus oil	0,33 to 2 ml L^{-1}	78,6%	Sallam et al 2009
Peppermint oil	0,33 to 2 ml L^{-1}	75,6%	Agarwal et al 2009
Thymol	50 to 400 mg L^{-1}	94%	Evans & Martin 2000

Phytogenic substances such as tannins and saponins may have methane mitigating potential. Tannins, as feed supplements or as tanniferous plants, have frequently been shown to have potential for reducing methane emissions by up to 20% (Mohammed et al., 2011; Waghorn et al., 2002). The reduction in methane is due to the inhibitory effect on methanogens, protozoa and other hydrogen- producing microbes (Patra & Saxena, 2010; Tavendale et al., 2005). At the same time, reduced digestibility is common for diets containing condensed tannins at high levels (Patra & Saxena, 2010; Waghorn, 2008). In addition, intake and animal health can be negatively affected if tannin inclusion rate is more than 50 g/kg feed (Mueller-Harvey, 2006). Temperate plants rich in tannins can replace other forages and in hot and arid regions many legumes are rich in tannins and represent a valuable feed resource. There is a large diversity within different types of tannins depending on chemical structure, which together with level of intake partly explains differences in mitigation potential for CH_4 production observed with different sources of tannins (Morgavi et al., 2013; Mueller Harvey, 2006). Tannins are also used in ruminant nutrition to increase protein utilisation. This effect is obtained though tannins binding to dietary proteins, which can then become 'rumen-escape' proteins that are further utilised in the intestine instead (McSweeney et al., 2001). Saponins influence CH_4 production and protein metabolism in the rumen by their toxic effect on protozoa (Patra & Saxena, 2010; Jouany & Morgavi, 2007). In a meta-analysis by Goel and Makkar (2012), six of the nine studies investigated reported a decrease in CH_4 production from about 6 to 27% (per unit body weight (BW) or DMI). In sheep, decreases of 10-15% in CH_4 production have been reported with *Yucca schidigera* and *Quillaja saponaria* saponin sources (Wang et al., 2009; Pen et al., 2007) and similar results have been reported for tea saponins (Mohammed et al., 2011). The effect over time is unknown and it has been observed that there may be an inactivation of rumen bacterial populations (Newbold et al., 1997), which may give a reduced effect over time.

Methane inhibitors

Inhibitors such as bromochloromethane, 2-bromo-ethane sulfonate and chloroform have been shown to reduce methane emissions, but with a harmful effect on the animal, which makes them unsuitable for use on commercial farms (McAllister & Newbold, 2008). Recently, the use of 3-nitrooxypropanol (3NOP) was shown to reduce methane emissions in dairy cows by 30% without any effect on milk production or feed intake (Hristov et al., 2015). A metaanalysis conducted by Dijkstra et al. (2018) showed that 3NOP reduced enteric methane emissions by about 39% in dairy cattle and 22% in beef cattle. The authors used 11 studies reported in the literature. In contrast to the above-mentioned inhibitors, the results indicate that 3NOP shows no signs of toxic effects on the animal and no or a minor effect on DMI. The effect of 3NOP is due to blockage of methane production by inhibition of the last step of methanogenesis (Haisan et al., 2014).

Ionophores

Ionophores are lipid-soluble ion carriers that transfer ions over the cell membrane and thus disrupt the membrane potential, specifically in grampositive bacteria, and as a consequence affect methane production (Wolin and Miller, 2006). Monensin is the most commonly applied ionophore and it is routinely used in beef production and dairy cattle nutrition in North America to increase feed efficiency (Hristov et al., 2013a). It promotes the production of propionate at the expense of acetate and hydrogen (Johnson & Johnson, 1995). However, the use of monensin has been shown to cause a reduction in feed intake, which may explain part of the lowering effect on methane through less feed being fermented (Hegarty, 1999; Johnson & Johnson, 1995). Monensin does not appear to have a consistent direct effect on methane production in dairy or beef cattle, but due to the increase in production a reduction in methane emissions per unit of meat (Goodrich et al., 1984) and milk (Duffield et al., 2008) may be obtained for a short period. Ionophores are banned in the European Union for ruminants due to the potential risk of antibiotic resistance.

Appendix 2

CASE STUDIES

The objective of this section is to clarify and explain how to use the guidelines for different types of needs, considering that the guidelines is based on comparison between a baseline scenario and a scenario using the specific feed additive or feed additive mixture.

Case Study 1: Modification of feed composition for reducing the environmental impact of poultry meat

Background

A feed miller in Germany is producing a feed mainly composed of corn (imported from Spain) and soybean meal (imported from Brazil). The feed is used by poultry farm within an integrated organization. The management of the integrated organization is willing to communicate on the improved environmental footprint of the poultry meat he produces, while modifying the feed formulation using more locally produced feed ingredients, with the help of feed additives.

Before changing the feed formulation, he is evaluating the actual impact of this change on the environmental performance of his farms.

Baseline Scenario

The feed formulation is based on corn and soybean meal. The feed ingredients used and the nutritional characteristics of the feeds (starter feed from 1 to 21 days and then grower feed from 22 to 42 days) are described in Table B1

Table B1 - Initial feed composition and nutritional characteristic of the feed.

Ingredients	Starter feed	Grower feed
Composition (g/kg)		
Corn	535	588
Soybean meal	355	315
Fish Meal	39.9	36.3
Vegetable Oil	35.2	30.2
Limestone	15.2	12.7

Salt	3.0	3.0
Monocalcium phosphate	9.2	7.8
Vitamin Premix	2.0	2.0
Mineral Premix	2.0	2.0
DL-methionine	1.5	1.0
L-lysine	1.0	0.6
Choline Chloride	0.5	0.5
Calculated chemical composition (/kg wet weight)		
Metabolisable Energy (MJ)	12.9	12.8
Dry Matter (g)	88.9	88.7
Crude protein (g)	222	206
Lysine (g)	11.2	9.5
Methionine + Cystine (g)	8.5	7.6
Calcium (g)	10.2	8.7
Total Phosphorus (g)	6.9	6.9

Based on this composition, the expected animal performance of the poultry in the organization is described in Table B2

Table B2. Expected poultry performance in the organization

Poultry Performance index	Performance
Final bodyweight (g)	2480
Daily weight gain (g/j)	56
Total Feed Consumption	5431
Feed Conversion Rate	2.19
Mortality (%)	2

Evaluated Scenario

The feedmill is willing to replace partially imported corn and soybean meal by locally produced wheat, barley, rapeseed, and sunflower. In order to keep the same nutritional characteristic of his feed, the feed mill is incorporating a mixture of endo-1,3-beta-xylanase and endo-1,3-beta-glucanase to increase the digestibility and the energy value of wheat and barley. In addition, he will incorporate additional amino acids, to compensate the different amino acid balance from the feed ingredients used, as well as a serine protease to increase the protein digestibility of the protein based feed ingredients, i.e. rapeseed meal and sunflower meal.

It is assumed that by maintaining the same level of crude protein and amino acids balance and of energy in his diet, the poultry performance will be kept unchanged.

To evaluate the impact of his scenario on the environmental footprint of 1 kg of poultry liveweight, the feed miller will use the following steps, as described in the guidelines:

- Step 1: collect data on the environmental footprint of the new feed ingredients used following the requirement of the LEAP guidelines on the environmental footprint of feed
- Step 2: collect data on the environmental footprint of:
    - the enzyme (endo-1,3-beta-xylanase, endo-1,3-beta-glucanase, and serine protease) preparations used (see chapter 4.1.2.4 for the fermentation process and chapter 4.1.3 for the production of the preparation)
    - the amino acids produced by fermentation (e.g. lysine, threonine) (see chapter 4.1.2.4 for the fermentation process)
    - the amino acids produced by chemical synthesis (e.g. methionine) (see chapter 4.1.2.3 for the chemical process)
- Step 3: calculate the environmental footprint of the formulated feed following the requirement of the LEAP guidelines in the environmental footprint of feed
- Step 4: Calculate the difference induced by the change of formulation:

Feed Conversion Rate x (Environmental impact of the newly formulated feed - Environmental impact of the initial formulated feed) = (Environmental footprint of 1 kg poultry live weight with the newly formulated feed - Environmental footprint of 1 kg poultry live weight with the initial formulated feed)

Example: if the Global Warming Potential (including Land Use Change) (LUC-GWP) of the new formulation is reduced by 5 %, the LUC-GWP reduction linked to the modification of the feed composition is calculated as follows for 1 kg of poultry liveweight:

2.19 x (0.95 x LUC-GWP initial feed - 1.00 x LUC-GWP initial feed) = - 0.1095 x LUC-GWP initial feed = LUC-GWP new feed formulation

Considering that feed represents 70 % of the environmental footprint of 1 kg of poultry liveweight, i.e.

LUC-GWP 1 kg poultry liveweight = LUC-GWP feed / 0.7, the reduction of the LUC-GWP of 1 kg poultry live weight linked to the modification of the feed formulation will be 0.7 x -0.1095 = - 0.07665 (i.e. 7.7 % reduction)

Sensitivity Analysis

It is advised, unless there is sufficient evidence that the animal performance would remain unchanged, to organize for a sensitivity analysis, where the animal performance modification linked to the new formulation is considered.

As an example, if we assume that the new feed formulation has an impact on animal performance such as feed conversion ratio (5 % increase), the new animal performance data are modified as indicated in Table B3.

Table B-4 - Expected poultry performance in the organization

Poultry Performance index	Initial Performance	New Performance	Variation (D)
Final bodyweight (g)	2480	2480	0 %
Daily weight gain (g/j)	56	56	0 %
Total Feed Consumption	5431	5702	+ 5%
Feed Conversion Rate	2.19	2.30	+ 5%
Mortality (%)	2	2	0 %

In that example, the impact of the new feed formulation is calculated as described in Chapter 6.4.15 and the equations of Table 41 (see table B5)

Table B5. Evaluation of the variation in emissions and environmental impacts

	Basis for Calculation
Equation 1	P_{intake} (kg) = FI (kg) x Δ_{fi} x % P_{total}
	initial: P_{intake} (kg) = 5.702 kg x 0.65 % = 0.037 kg
	new: P_{intake} (kg) = 5.702 kg x 1.05 x 0.65 % = 0.039 kg
Equation 2	Cu_{intake} (kg) = FI (kg) x Δ_{fi} x % Cu
Equation 3	Zn_{intake} (kg) = FI (kg) x Δ_{fi} x % Zn
Equation 5	VS (kg) = FI (kg) x Δ_{fi} x (1 - DMD) X (1 - A)
	initial: VS (kg) = 5.702 x (1 - 0.8) x (1 - 0.1) = 1.026 kg
	VS (kg) = 5.702 x 1.05 x (1 - 0.8) x (1 - 0.1) = 1.078 kg

	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x Δ_{fi} x % CP / 6.25 x (1 - 0.602) initial: $N_{excreted}$ (kg) = 5.702 x 0.218 / 6.25 x (1 - 0.602) = 0.500 kg new: $N_{excreted}$ (kg) = 5.702 x 1.05 x 0.218 / 6.25 x (1 - 0.602) = 0.525 kg	$N_{excreted}$ (kg) / TWG (kg liveweight) initial: 0.500 / 2.480 = 0.202 kg / kg lw new: 0.525 / 2.480 = 0.212 kg / kg
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / TWG (kg liveweight)
Equation 10	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / TWG (kg liveweight)
Equation 11	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / TWG (kg liveweight)
Equation 12	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ (kg) / TWG (kg liveweight)
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / TWG (kg liveweight)

Based on the above mentioned assumption, the following variation will be observed:

- increased phosphorus excretion by 0.02 / 2.480 = 0.008 kg per kg liveweight
- increased nitrogen excretion by 0.10 kg per kg liveweight

leading to increased eutrophication and acidification potential;

- increased methane production from the manure linked to increased excretion of volatile solids (+ 5 %)
- increased nitrous oxide production linked to increased nitrogen excretion (+ 5 %) leading to increased global warming potential.

These effects should then be deducted from the modified environmental footprint (e.g. decreased LU-GWP) achieved with the change in formulation.

Conclusion

The net results shall then inform the choice of the poultry production organization, whether the proposed formulation change improve the environmental footprint of 1 kg of poultry liveweight.

Case Study 2: Decrease enteric methane production from dairy cow using a feed additive

Background

A dairy cooperative is willing to reduce the environmental footprint, and more particularly the Global Warming Potential (GWP), of the milk it sells globally. Considering that the vast majority of the GWP is originating from the cow digestive system (enteric methane production), the dairy cooperative requests its feed suppliers to produce a feed containing a feed additive reducing enteric methane, when incorporated into the dairy cows daily ration.

The feed millers shall then evaluate the potential reduction linked to the use of a methane inhibitor. The methane inhibitor reduces the enteric methane of dairy cows by an average of 25%, with a parallel improved feed conversion ratio of 2%. The information relative to the methane emission is issued from a meta-analysis based on more than 15 trials, while the effect of the feed conversion has been seen only in certain trials and is not completely consistent.

Baseline Scenario

The dairy daily ration in the region, where the introduction of the methane inhibitor, is based on ensiled roughages (variable depending on the on-farm availability) and the use of protein rich and mineral rich complements. The methane inhibitor is to be incorporated in the protein rich supplement, before delivery to the farms. The protein rich supplement is then incorporated in the total dairy ration.

In the region, where the study is organized, the dairy cooperative has selected farms, which have on average the following performance (Table B6).

Table B6. Expected dairy cow performance for the group of farms, where the methane inhibitor will be used

Dairy Performance index	Performance
Bodyweight (kg)	680
Annual energy corrected milk production (kg)	9000
Total Feed Consumption (kg dry matter)	7800
Feed Conversion Rate	0.87
Estimated Methane emission (kg)	120

Evaluated Scenario

The mitigation method consists to incorporate in the complementary feed the methane inhibitor (a chemically synthesized molecule), in the form of a preparation. The incorporation rate of the preparation is around 500 mg / kg dry matter in the total dairy ration. Hence, this does not modify the general composition of the daily ration.

It is assumed in the original scenario to not consider the potential effect of the methane inhibitor on feed efficiency.

To evaluate the impact of his scenario on the environmental footprint of 1 kg of energy corrected milk before delivery to the dairy, the feed miller will use the following steps, as described in the guidelines:

- Step 1: collect data on the environmental footprint of the methane inhibitor incorporated in the feed supplement (see chapter 4.2.1.3 on chemical synthesis and chapter 4.1.3. for the further preparation of the substance)
- Step 2: add the data collected on the methane inhibitor preparation to the environmental footprint of the daily ration
- Step 3: Calculate the impact on the Global Warming Potential linked to the reduction of methane due to the use of the methane inhibitor.

Table B7. Calculated impact of enteric methane emission reduction using a methane inhibitor in feed

	Calculated impacts	
	Total	Intensity
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) x Δ_{ef} / 55.65 (MJ/kg)	Enteric Methane (kg) / ECM (kg)
	Initial: Enteric Methane (kg) = 102738 x 0.065 / 55.65 = 120 kg	Initial: 120 / 9000 = 0.013 kg / kg milk
	New: Enteric Methane (kg) = 102738 x 0.065 x 0.75 / 55.65 = 90 kg	New: 90 / 9000 = 0.10 kg / kg milk
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%)x Δ_{ef} x 0.67 (kg/m^3)	Manure Methane (kg) / ECM
Equation 13	Manure Nitrous Oxide (see Figure 14 of the large ruminant guidelines))	Manure Nitrous Oxide (kg) / ECM (kg)
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) x Δ_{ef} / 55.65 (MJ/kg)	Enteric Methane (kg) /TWG (kg liveweight)
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%)x Δ_{ef} x 0.67 (kg/m^3)	Manure Methane (Kg) / TWG (kg liveweight)
Equation 13	Manure Nitrous Oxide (see Figure 14 of the large ruminant guidelines))	Manure Nitrous Oxide (kg) / TWG (kg liveweight)

As the effect is only on enteric methane emission, the other values remain unchanged. The reduction of the GWP is linked to the 25 % reduction of enteric methane emission.

Sensitivity Analysis

As the supplier of the methane inhibitor indicates an improved feed conversion ratio of about 2 %, linked to a reduction of the feed intake, a sensitivity analysis on the potential additional effect of the feed efficiency changes may be considered. If this is the case, the performance element provided in Table B8 should be used.

Table B-8 - Expected dairy cow performance for the group of farms, where the methane inhibitor will be used

Dairy Performance index	Initial Performance	New Performance	Variation (D)
Bodyweight (kg)	680	680	0 %
Annual energy corrected milk production (kg)	9000	9000	0 %
Total Feed Consumption (kg Dry matter)	7800	7644	-2 %
Feed Conversion Rate	0.87	0.85	-2 %
Estimated Methane emission (kg)	120	90	-25 %

The impact of the change in feed intake will be calculated as described in Chapter 6.14.12 and the equations of Table 24 (see Table B9)

Table B9. Evaluation of the variation in emissions and environmental impacts

	Basis for Calculation
Equation 1	$ME_{intakeother}$ (MJ) = Total ME requirement (MJ) - (DMI (kg) x Δ_{fi} x ME (MJ/kg DM)$_{feed1}$ - (DMI (kg) x Δ_{fi} x ME (MJ/kg DM))$_{feed2}$
	measured
Equation 2	DMI_{other}(kg) = $ME_{intakeother}$ (MJ) / (ME (MJ/kg DM))
	measured
Equation 3	GE (MJ) = DMI (kg) x Δ_{fi} x 18.45 (MJ/kg)
	measured
Equation 4	N_{intake} (kg) = DMI (kg) x Δ_{fi} x % CP / 6.25

$$\text{initial } N_{intake} \text{ (kg)} = 7800 \times 0.17 / 6.25 = 212.16 \text{ kg}$$

$$\text{new: } N_{intake} \text{ (kg)} = 7800 \times 0.98 \times 0.17 / 6.25 = 207.92 \text{ kg}$$

Equation 5 $$P_{intake} \text{ (kg)} = DMI \text{ (kg)} \times \Delta_{fi} \times \% P_{total}$$

$$\text{initial: } P_{intake} \text{ (kg)} = 7800 \times 0.0037 = 28.86 \text{ kg}$$

$$\text{new: } P_{intake} \text{ (kg)} = 7800 \times 0.98 \times 0.0037 = 28.28 \text{ kg}$$

Equation 8 $$VS \text{ (kg)} = DMI \text{ (kg)} \times \Delta_{fi} \times (1.04 - DMD) \times 0.92$$

$$\text{initial: } VS \text{ (kg)} = 7800 \times (1.04 - 0.75) \times 0.92 = 2081.04 \text{ kg}$$

$$\text{new: } VS \text{ (kg)} = 7800 \times 0.98 \times (1.04 - 0.75) \times 0.92 = 2039.42 \text{ kg}$$

Calculated impacts

	Total	Intensity
Equation 9	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg)	$N_{excreted}$ (kg) / ECM (kg)
Equation 10	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / ECM (kg)
Equation 11	Enteric Methane (kg) = GE (MJ) x EF (%) / 55.65 (MJ/kg)	Enteric Methane (kg) / ECM (kg)
Equation 12	Manure Methane (kg) = VS (kg) x Bo (m^3/kg) x MCF (%) x 0.67 (kg/m^3)	Manure Methane (kg) / ECM (kg)
Equation 13	Manure Nitrous Oxide (see Figure 14 of the guidelines on large ruminants)	Manure Nitrous Oxide (kg) / ECM (kg)

Based on the above mentioned assumption, the following variation will be observed:

- Decreased phosphorus excretion by 0.58 / 9000 = 0.000065 kg per kg energy corrected milk
- Decreased nitrogen excretion by 86.76 / 9000 = 0.0085 kg per kg energy corrected milk leading to potential decreased eutrophication and acidification potential;
- decreased methane production from the manure linked to decreased excretion of volatile solids (-2.3 %)
- Decreased nitrous oxide production linked to increased nitrogen excretion (-2 %) leading to a small additional effect on global warming potential.

These effects should then be added to the modified environmental footprint (e.g. decreased LU-GWP) achieved with the effect on enteric methane only.

Conclusion

The net results shall then inform the choice of the dairy production organization, whether the proposed addition of this methane inhibitor in dairy daily ration improves the environmental footprint of 1 kg of energy corrected milk, at the desired order of magnitude.

Case Study 3: Modification of performance for reducing the environmental impact of pig production

Background

A farmer is approached by a feed producer, who promotes the use of a combination of probiotics (microorganism) and of phytogenic substances for improved weight gain in pig production (from 25 to 100 kg). The farmer wants to ensure that this new feed has a positive impact on the environmental footprint of this farm. The farmer is producing his feed on the farm. According to the feed producer, the composition of the feed (feed ingredients produced on the farm and bought on the market) remain unchanged and the mixture is introduce at an incorporation rate of 700 mg / kg feed.

Baseline Scenario

The feed formulation is based on feed ingredients that are produced on the farm and bought on the market place. The farmer has already made an evaluation of the environmental footprint of his feed, based on the LEAP guidelines for the assessment of the environmental footprint of feed. The current performance on the farm are described in Table B10.

Table B10 - Actual pig performance on the farm

Pig Performance index	Performance
Initial bodyweight (kg)	27.5
Final bodyweight (kg)	112
Duration (d)	100
Average Daily Gain (g/d)	850
Mortality (%)	2.7
Feed Consumed (kg)	234
Feed Conversion Rate	2.77

Evaluated Scenario

The feed producer promoting his product has organized three comparison trials in the same area as the farmers and with a similar type of diets. Hence, the results provided seem to be applicable on the farm, as such. According to the information provided, the mixture proposed increases the average daily gain by 2.5% and reduce the feed conversion rate by 3%.

The results to be expected by the farmer using the mixture are described in Table B11.

Table B11. Expected pig performance on the farm with the incorporation of the proposed mixture

Pig Performance index	Actual Performance	Expected Performance	Variation (D)
Initial bodyweight (kg)	27.5	27.5	0 %
Final bodyweight (kg)	112	112	0 %
Duration (d)	100	97	- 3 %
Average Daily Gain (g/d)	850	871	+ 2.5 %
Mortality (%)	2.7	2.7	0 %
Feed Consumed (kg)	234	227	- 3 %
Feed Conversion Rate	2.77	2.69	- 3 %

To evaluate the impact of his scenario on the environmental footprint of 1 kg of pig liveweight, the farmer will use the following steps, as described in the guidelines:

- Step 1: collect data on the environmental footprint of the mixture from the feed producer. This environmental footprint is calculated, considering:
    - the environmental footprint of each of the phytogenic substances (see chapter 4.1.2.4 for the plant extraction)
    - the environmental footprint of the microorganism preparation used in the mixture (see chapter 4.1.2.4 for the fermentation process and chapter 4.1.3. for the production of the preparation)
    - the environmental footprint of the mixture (using the guidelines on the environmental assessment of feed production, including the footprint of eventual carriers)
- Step 2: Add the environmental footprint of the mixture to the calculated environmental footprint of the diet
- Step 3: Calculate the potential impact of the performance improvement on the environmental footprint of the pig production (chapter 6.14.14 and tables 38 and 39)

The changes in the basis for calculation linked to the changes in feed intake is described in Table B12. The changes related to the change in growth rate is described in Table B13. The calculated impact are indicated in Table B14.

Table B-12 Evaluation of the variation in emissions linked to the change in feed intake

	Basis for Calculation
Equation 1	N_{intake} (kg) = FI (kg) x Δ_{fi} x % CP / 6.25
	initial: N_{intake} (kg) = 234 x 0.135 / 6.25 = 5.05kg
	new: N_{intake} (kg) = 234 x 0.97 x 0.135 / 6.25 = 4.90kg
Equation 3	P_{intak} $(kg)_e$ = FI (kg) x Δ_{fi} x % P_{total}
	initial: P_{intak} $(kg)_e$= 234 x 0.004 = 0.936 kg
	new: P_{intak} $(kg)_e$= 234 x 0.97 x 0.004 = 0.908 kg
Equation 5	Cu_{intak} $(kg)_e$ = FI (kg) x Δ_{fi} x % Cu
Equation 7	Zn_{intak} $(kg)_e$ = FI (kg) x Δ_{fi} x % Zn
Equation 8	VS (kg) = FI (kg) x Δ_{fi} x (1 - DMD) x (1 - A) + VS_{Swf} (kg)
	initial: VS (kg) = 234 x (1 - 0.80) x (1 - 0.1) + 4.212 = 46.332 kg
	new: VS (kg) = 234 x 0.97 x (1 - 0.80) x (1 - 0.1) + 4.086 = 44.942 kg
Equation 9	VS_{WF} (kg) = FI (kg) x Δ_{fi} x (1 - A) x WF (kg)
	initial: VS_{WF} (kg) = 234 x (1 - 0.1) x 0.02 = 4.212 kg
	new: VS_{WF} (kg) =234 x 0.97 x (1-0.1) x 0.02 = 4.086 kg

Table B-13 Evaluation of the variation in emissions linked to the change in weight gain

	Basis for Calculation
Equation 2	$N_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Protein in tissues / 6.25
	initial: $N_{retention}$ (kg) = (112 - 27.5) x 0.25 / 6.25 = 3.38 kg
	new: $N_{retention}$ (kg) = (112 - 27.5) x 1 x 0.25 / 6.25 = 3.38 kg
Equation 4	$P_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % P in tissues and bone
	initial: $P_{retention}$ (kg) = (112 - 27.5) x 0.002 = 0.169 kg
	new: $P_{retention}$ (kg) = (112 - 27.5)x 1 x 0.002 = 0.169 kg
Equation 6	$Cu_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Cu in tissues and bones
Equation 8	$Zn_{retention}$ (kg) = TWG (kg liveweight) x Δ_{pc} x % Zn in tissues and bones

Table B-14 Evaluation of the impact on the environmental footprint linked to performance improvement

	Calculated impacts	
	Total	Intensity
Equation 11	$N_{excreted}$ (kg) = N_{intake} (kg) - $N_{products}$ (kg) initial: $N_{excreted}$ (kg) = 5.05 - 3.38 = 1.67 kg new: $N_{excreted}$ (kg) = 4.90 - 3.38 = 1.52 kg	$N_{excreted}$ (kg) / (TWG (kg liveweight) x Δ_{pc}) initial: 1.67 / (112 - 27.5) = 0.019 kg new: 1.52 / (112 - 27.5) = 0.018 kg
Equation 12	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg) initial: $P_{excreted}$ (kg) = 0.936 - 0.169 = 0.767 kg new: $P_{excreted}$ (kg) = 0.908 - 0.169 = 0.739 kg	$P_{excreted}$ (kg) / (TWG (kg liveweight x Δ_{pc}) initial: 0.767 / (112 - 27.5) = 0.0090 kg new: 0.739 / (112 - 27.5) = 0.0087 kg
Equation 13	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / (TWG (kg liveweight x Δ_{pc})
Equation 14	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / (TWG (kg liveweight x Δ_{pc})
Equation 15a (growing phase)	$Methane_{enteri}$ $(kg)_c$ = (ResD (kg) x 670 (J/kg ResD)) / 5.665e^7 (J/kg methane)	$Methane_{enteric}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 16	$Methane_{housing}$ (kg) = VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (kg / m^3)	$Methane_{housing}$ (kg) / (TWG (kg liveweight) x Δ_{pc})
Equation 17	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x (1 - R_{MMS}) x EF_{MMS} (%) x 44 / 28	$NitrousOxide_{housing}$ (kg) / (TWG (kg liveweight) x Δ_{pc})

The use of the mixture results during the production phase results in:

- a reduction of the nitrogen excretion, linked to the reduced feed intake (- 9 %)
- a reduction of the phosphorus excretion, linked to the reduced feed intake (- 4 %) leading to a reduction of the risk for eutrophication and acidification.

In addition, the reduction of volatile solids by 3 % leads to a reduction of methane emission, hence the Global Warming Potential of the production.

Furthermore, the reduction of the time to market (less 3 days in the building) may reduce further the impact linked to housing.

Sensitivity Analysis

Based on the substantiation of the claim, it is not necessary to run a sensitivity analysis. A post-application evaluation, based on actual data from the farm might be appropriate.

Conclusion

The net results shall then inform the choice of the pig farmer, whether the proposed mixture would be appropriate for his farm.

Case Study 4: Modification of the nutritional composition of the feed through feed additives

Background

A brand owner of eggs is evaluating the potential mitigation measures to be taken to reduce the environmental footprint of its eggs and egg products commercialized in Latin America. For this purpose and with the help of one of his feed supplier, he envisages to reduce the crude protein and the total phosphorus concentration of the feed provided to the animals. The feed miller supplies the brand owner with a study demonstrating the potential effect of the use of amino acids and phytase as a tool to modify his feeds.

Baseline Scenario

The current feed for layers used in the brand owner supplying farms is based on corn and soybean meal (Table B15).

Table B15. Composition and Nutritional Characteristic of the current layer feed

Ingredients	
Composition (g/kg)	
Corn	54.9
Soybean meal	29.7
Limestone	9.36
Vegetable oil	3.43
Dicalcium phosphate	1.67
Salt	0.417
Premix	0.310
dl-methionine	0.211

L-Lysine	0.005
Nutritional characteristics (kg)	
Metabolisable Energy (kcal)	2871
Protein (%)	18.5
Lysine (%)	1.02
Methionine (%)	0.52
Calcium (%)	3.30
Total phosphorus (%)	0.50

With this diet the following average performance on the farm is achieved (Table B16).

Table B-16 Average performance of layer hens on 42 weeks with the current diet

Layer Performance Index	Layer Performance
Egg production (42 weeks)	265
Egg weight (g/egg)	52.6
Total Egg Weight (kg)	13.9
Feed Intake (kg)	26.3
Feed Conversion Ratio	1.89

Evaluated Scenario

Based on the request from the egg brand owner, the feed producer proposes to reduce the crude protein concentration, using additional amino acids, now available on the market, from 18.5 % to 17.5 %. As a consequence, the diet composition will change with a reduction of the quantity of soybean meal and fat and increased concentration of corn. In addition, by using phytase, the concentration of phosphorus is reduced from 0.5 to 0.36. This is related to the decreased use of dicalcium phosphate, increased use of limestone.

The final nutritional characteristics of the diet is described in the Table B17.

Table B-17 Modification of the nutritional characteristics of the diet, when additional amino acids and phytase are added to the diet

Nutritional characteristics (kg)	Current Diet	Revised diet	Variation (D)
Metabolisable Energy (kcal)	2871	2871	0 %
Protein (%)	18.5	17.5	- 5.4 %
Lysine (%)	1.02	1.02	0 %
Methionine (%)	0.52	0.52	0 %
Calcium (%)	3.30	3.30	0 %
Total phosphorus (%)	0.50	0.36	- 28 %

Based on the new nutritional characteristics, it is expected that the layer performance will remain unchanged compared to the baseline scenario.

To evaluate the impact of his scenario on the environmental footprint of 1.000 kg of eggs in shell, the feed producer will use the following steps, as described in the guidelines:

- Step 1: collect data on the environmental footprint of the additional amino acids used in the diet (see chapter 4.1.2.4 for the fermentation process)
- Step 2: collect data for the environmental footprint of the phytase preparation used in the diet (see chapter 4.1.2.4 for the fermentation process and chapter 4.1.3. for the production of the preparation.
- Step 3: Recalculate the environmental footprint of the new feed, considering the different ingredients used, following the guidelines on the environmental evaluation of feed.
- Step 3: Calculate the potential impact of the modification of the diet nutritional characteristics on the environmental footprint of the egg production (chapter 6.14.10 and Table 22)

The result of the evaluation on egg production is provided in Table B18.

Table B18. Evaluation of the modification of the environmental footprint linked to the use of additional amino acids and phytase.

Equation 1

$$P_{intake}\ (kg) = FI\ (kg) \times \%\ P_{total} \times \Delta_{nc}$$

$$\text{initial: } P_{intake}\ (kg) = 26.3 \times 0.005 = 0.1315\ kg$$

$$\text{new: } P_{intake}\ (kg) = 26.3 \times 0.005 \times 0.72 = 0.0947\ kg$$

Equation 3

$$Cu_{intake}\ (kg) = FI\ (kg) \times \%\ Cu \times \Delta_{nc}$$

	Calculated impacts	
Equation 5	Zn_{intake} (kg) = FI (kg) x % Zn x Δ_{nc}	
	Total	Intensity
Equation 7	$N_{excreted}$ (kg) = FI (kg) x % CP x Δ_{nc} / 6.25 x ((0.0182 x EW (kg)) x (ENb))	
	initial: $N_{excreted}$ (kg) = 26.3 x 0.185 / 625 x ((0.0182 x 0.0526 x 265) = 0.1975 kg initial: $N_{excreted}$ (kg) = 26.3 x 0.185 x 0.946 / 625 x ((0.0182 x 0.0526 x 265) = 0.1868 kg	$N_{excreted}$ (kg) / Kg eggs in shell initial: 0.1975 / 13.9 = 0.0142 new: 0.1868 / 13.9 = 0.0134
Equation 8	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg)	$P_{excreted}$ (kg) / Kg eggs in shell
Equation 9	$Cu_{excreted}$ (kg) = Cu_{intake} (kg) - $Cu_{products}$ (kg)	$Cu_{excreted}$ (kg) / Kg eggs in shell
Equation 10	$Zn_{excreted}$ (kg) = Zn_{intake} (kg) - $Zn_{products}$ (kg)	$Zn_{excreted}$ (kg) / Kg eggs in shell
Equation 13	$NitrousOxide_{housing}$ (kg) = $N_{excreted}$ (kg) x EF_{MMS} (%) x 44/28	$NitrousOxide_{housing}$ (kg) / Kg eggs in shell

The use of additional amino acids and phytase during the production results in:

- a reduction of the nitrogen excretion, linked to the reduced crude protein content in the diet (- 5.4 %)
- a reduction of the phosphorus excretion, linked to the reduced phosphorus content in the diet (variation of - 0.0368 kg per layers) leading to a reduction of the risk for eutrophication and acidification.

In addition, due to the reduction of the nitrogen content in the manure, the emission of nitrous oxide is decreased by 5.4 %, leading to a reduction of the Global Warming Potential on farm.

The combination of the modification of the environmental footprint of the new feed formulation and the positive impact on the farm provides the overall environmental footprint of the production of egg, with the new formulation.

Sensitivity Analysis

It is advised, unless there is sufficient evidence that the animal performance would remain unchanged, to organize for a sensitivity analysis, where the animal performance modification linked to the new formulation is considered.

As an example, if we assume that the new feed formulation has an impact on the production of eggs (5 % decrease), the new animal performance data are modified as indicated in Table B19.

Table B19. Influence of the change of performance (number of eggs laid) on the environmental footprint of laying production, when additional amino acids and phytase are used.

	Basis for Calculation	
Equation 2	$P_{retention}$ (kg) = EW (kg) x Δ_{pc} x ENb x Δ_{pc} x % P Eggs	
	initial: $P_{retention}$ (kg) = 0.0526 x 265 x 0.002 = 0.0279 kg	
	new: $P_{retention}$ (kg) = 0.0526 x 1 x 265 x 0.95 x 0.002 = 0.0265 kg	
Equation 4	$Cu_{retention}$ (kg) = EW (kg) x Δ_{pc} x ENb x Δ_{pc} x % Cu Eggs	
Equation 6	$Zn_{retention}$ (kg) = EW (kg) x Δ_{pc} x ENb x Δ_{pc} x % Zn Eggs	
	Calculated impacts	
	Total	Intensity
Equation 8	$N_{excreted}$ (kg) = FI (kg) x % CP / 6.25 x ((0.0182 x EW (kg) x 1/Δ_{pc}) x (ENb x 1/Δ_{pc})) initial: $N_{excreted}$ (kg) = 26.3 x 0.185 / 6.25 x ((0.0182 x 0.0526 x 265)) = 0.1974 kg new: $N_{excreted}$ (kg) = 26.3 x 0.175 / 6.25 x ((0.0182 x (0.0526 x 1) x (265 x 1/0.95)) = 0.1966 kg	$N_{excreted}$ (kg)/ (Kg eggs in shell x Δ_{pc}) initial: 0.1974 / 13.9 = 0.142 new: 0.1966 / (13.9 x 0.95) = 0.149
Equation 9	$P_{excreted}$ (kg) = P_{intake} (kg) - $P_{products}$ (kg) initial: $P_{excreted}$ (kg) = 0.1315 - 0.0279 = 0.1036 kg new: $P_{excreted}$ (kg) = 0.0947 - 0.0265 = 0.0682 kg	$P_{excreted}$ (kg) / (Kg eggs in shell x Δ_{pc}) initial: 0.1036 / 13.9 = 0.0074 new: 0.0682 / (13.9 x 0.95) = 0.0052
Equation 12	$Methane_{housing}$ (kg)= VS (kg) x Bo (m^3 / kg) x MCF (%) x 0.662 (m^3 / kg)	$Methane_{housing}$ (kg) / (Kg eggs in shell x Δ_{pc})
Equation 13	$NitrousOxide_{housing}$ (kg)= $N_{excreted}$ x EF_{MMS} (%) x 44/28	$NitrousOxide_{housin}$ $(kg)_g$ / (Kg eggs in shell x Δ_{pc})

Based on this sensitivity analysis, it appears that the reduction by 5 % of the number of eggs produced lead to a total eradication of the effect on excreted nitrogen and a strong reduction of the excreted phosphorus.

Conclusion

Based on the analysis of the change (considering the change of formulation and the impact on the farm), the feed miller will be able to provide to the egg brand owner an evaluation of the potential effect of the formulation change.

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