GLOBAL ROUNDTABLE FOR® SUSTAINABLE BEEF

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Title Global Roundtable for Sustainable Beef Carbon Footprint Guideline

Date 14-2-2022

Recommended citation Global Roundtable for Sustainable Beef. (2022). Beef Carbon Footprint Guideline: Global Beef Life Cycle Assessment Guideline. Location: Blonk Consultants Groen van Prinsterersingel 45 2805 TD Gouda, The Netherlands

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Acronyms

List of acronyms and abbreviations used in document

AAP	Average Animal Population
BSI	British Standards Institution
CF	Characterization Factor
CFCs	Chlorofluorocarbons
CFP	Carbon Footprint
DE	digestible energy
DEI	digestible energy intake
dLUC	Direct Land Use Change
DM	Dry Matter
FAO	The Food and Agriculture Organization of the United Nations
FPCM	Fat and Protein Corrected Milk
GE	gross energy
GEI	gross energy intake
GHG	greenhouse gas
GRSB	Global Roundtable for Sustainable Beef
GWP	global warming potential
IDF	International Dairy Federation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
LCA	Life Cycle Assessment
LCI	life cycle inventory
LCIA	life cycle impact assessment
LEAP	Livestock Environmental Assessment and Performance
MMS	Manure Management System
NDF	Neutral detergent fibre
PCR	Product Category Rules
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
RF	reference flow

SB	system boundary
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

Glossary

Frequently used terms and their definition

Allocation – An approach to solving multi-functionality problems. It refers to “partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems” (ISO 14040:2006).

As is – When referring to ration, also known as “as fed”, meaning amounts to be reported fresh, as fed.

Beef Fattening system – A beef fattening system is an animal system where cattle is bought at a certain age and/or weight, and raised until a final target weight, after which the animal is sold to a subsequent growing/fattening stage or sold for slaughtering. This type of system is also representative of veal production.

Co-product – Any of two or more products resulting from the same unit process or product system (ISO 14040:2006).

Cow/calf system – A cow/calf system is an animal system where suckler cows are kept for production of calves. Part of the newborn calves will be used for cow replacement (female calves), while the male and other part of female calves will be grown until defined final target ages/weights. The calves are usually fed with the milk directly from the suckler cows (until weaning) and subsequently fed with on-farm cultivated feed and/or imported feeds. Once the final target weight is reached, the animal is sold to a subsequent growing/fattening stage or sold for slaughtering.

Cradle to Gate – A partial product supply chain, from the extraction of raw materials (cradle) up to the manufacturer’s “gate”. The distribution, storage, use stage and end of life stages of the supply chain are omitted.

Cradle to Grave – A product’s life cycle that includes raw material extraction, processing, distribution, storage, use, and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.

Direct land use change (dLUC) – The change from one land use category to another, which takes place in a unique land area and does not lead to a change in another system. Note that in some scientific literature, land-use change encompasses changes in land-use categories as well as changes in land management.

Global warming potential (GWP) – An index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon (e.g., GWP 20, GWP 100, GWP 500, for 20, 100, and 500 years), relative to that of the reference substance, carbon dioxide (CO2). The GWP thus represents the combined effect of the differing times these substances remain in the atmosphere and their effectiveness in causing radiative forcing.

Life cycle – Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal (ISO 14040:2006).

Life cycle Assessment (LCA) – Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040:2006).

Life cycle inventory (LCI) – The combined set of exchanges of elementary, waste and product flows in a LCI dataset.

Primary data – Primary data refers to directly measured or collected data representative of activities at a specific facility, set of facilities, regional or national system. It is synonymous of company, system or region-specific data. Primary data are product-specific, supply-specific (if multiple sites for the same product) or system specific. Primary data may be obtained through meter readings, purchase records, utility bills, direct monitoring, surveys, or other methods for obtaining data from specific processes in the value chain.

Secondary data – Secondary data refer to data not specific to the system under study. The data that is not directly collected, measured, or estimated for the region/system under study, but sourced from a third party LCI database or other sources. Secondary data includes industry average data, literature studies, and other generic data.

Tier 1 emissions modelling – emission modelling approach where calculations make use of default parameters and emission factors, based on previous studies.

Tier 2 emissions modelling – emission modelling approach where calculation parameters are country-specific and emission factors are calculated based on full or partial balances.

Tier 3 emissions modelling – emission modelling approach where calculations use complex biophysical models to estimate excretions, together with emission factors that are measured or based on more advanced country-specific methodologies, compared to defaults.

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Foreword

One of the biggest challenges facing the world today is climate change. Temperature increase, rainfall variation and the frequency and intensity of extreme weather events caused by climate change are increasingly affecting the agricultural sectors, undermining food security and the achievement of the UN Sustainable Development Goals. The beef sector acknowledges that change is needed to provide climate and food security for all. However, there is no silver bullet which means using a systems-based approach is critical when discussing agriculture.

To support the urgent word-wide ambition of limiting global temperature rises to 1.5 degrees by 2030, the Global Roundtable for Sustainable Beef has set a suite of ambitious goals around climate, land use and animal welfare. The goals reflect priority areas for advancement and improvement; with the intention to spur innovation and adoption of practices that support the beef industries role as being part of the climate solution. It is critical that any changes made at the farm level must be economically viable with a win-win solution for both climate impacts which improve environmental resilience, business viability, and the ability of supply chains to continue supplying nutritious food.

Both farming organizations and food processors within the international beef industry have recognized the need to calculate greenhouse gas emissions (GHG) for beef. More and more often a carbon footprint is used to monitor performance and further improvements. From national roundtables doing national assessments, to multi-national corporations (retailers, packers, and processors) evaluating scope three emissions, and researchers evaluating mitigation options.

Summarizing learnings from these many studies is difficult because of differences in system boundaries, allocation methodology and emission factors. It can also be difficult to identify where meaningful reductions in GHG emissions can be made when differences in results can depend more on the methodological variations than real differences in the production system or management.

It has become evident that the wide range of numbers reported result from differing methodologies and data, leading to inconsistencies. This poses a danger of confusion and contradiction, which in turn could create a false impression that the industry is failing to actively engage with the issue of climate change. Creating consistent and clear messaging is important for reputation management of the global beef industry reputation, to emphasize the high level of engagement that is already taking place in relation to climate change, and to identify practices that will further reduce greenhouse gas emissions. For this reason, the GRSB guideline was developed to allow for sector-wide alignment in the calculation of carbon footprint in the life cycle of beef cattle.

This guide:

- Identifies an approach, based on current best knowledge, for addressing common LCA challenges when calculating carbon footprints of beef cattle production to the farm gate or first processing
- Addresses the key areas in which there is currently ambiguity or differing views on approach
- Recommends a practical yet scientific approach that can be applied by a number of stakeholders conducting studies at various levels (e.g. national, supply chain and farm level)
- Adopts an approach that can be applied in any beef cattle production system across the world

The aim of this guide is to support the beef industry in mitigating climate change. Using this methodology enables:

- Reporting of GHG emissions from the farming and processing stages of the beef value chain
- Monitoring of emissions generation over time to demonstrate progress
- Identification of hotspots to focus mitigation actions

- Determination of the impact of different mitigation options

By developing an internationally harmonized methodology for calculating the carbon footprint of beef, the GRSB is aiming to:

- Support the production of consistent and comparable carbon footprint figures internationally
- Enable the evaluation of beef cattle and beef products on a consistent basis

This in turn will support the evolution of efficient and sustainable businesses that are on a pathway to climate neutrality, by continually reducing their GHG emissions.

Brenna Grant
Chair of the GRSB Climate Science Committee
January 2022

1. Introduction

1.1 About GRSB

The Global Roundtable for Sustainable Beef (GRSB) is a multi-stakeholder initiative with representation across the value chain in beef production and consumption regions. Through the process of broad-based engagement and various internal and external reviews, the Principles and Criteria were developed as a means to define sustainable beef. Since 2010, the GRSB has set about bringing people together to drive a more sustainable beef industry, by providing a forum that inspires and supports each other to create a shared ambition to continually improve and be bold in sharing these improvements with our consumers and stakeholders.

Vision:	**Mission:**
We envision a world where beef is a trusted part of a thriving food system in which the beef value chain is environmentally sound, socially responsible and economically viable.	The GRSB mission is to advance, support, and communicate continuous improvement in sustainability of the global beef value chain through leadership, science, and multi-stakeholder engagement and collaboration.

In June 2021, the GRSB launched its 2030 global sustainability goals. These are commitments to advance and improve the sustainability of the global beef value chain. The goals will be led and implemented by the GRSB members. In order to support the urgent global ambition of limiting global temperature rises to 1.5 degrees by 2030, GRSB members will implement and incentivize climate smart beef production, processing, and trade, while safeguarding and building upon the carbon stores in soil and landscapes. Reducing atmospheric greenhouse gases requires both emissions reduction and carbon sequestration, making agriculture a key player in positively sequestering carbon in soils.

Climate Goal:

- GRSB aims to globally reduce by 30% the net global warming impact of each unit of beef by 2030, on a pathway to climate neutrality.
- Be able to report measured progress by 2025.

Climate change arising from anthropogenic activity has been identified as one of the greatest challenges facing the world and will continue to affect business and citizens over future decades. Initiatives on mitigation rely on the quantification, monitoring, reporting and verification of greenhouse gas (GHG) emissions and/or removals

The first step, to being able to report measured progress by 2025, was to develop a standardized methodology that will address inconsistencies in calculating beef life cycle assessments (LCA) moving forward. These are outlined in this guideline. The guideline outlines the method to estimate emissions from each greenhouse gas from primary beef production up to the slaughterhouse (i.e. carbon dioxide, nitrous oxide, and methane); which can then be calculated in different ways (e.g. GWP100, GWP*, RF Footprint, etc.) depending on the goal set.

The second step, is to use the best available metrics that recognize short lived gases and sequestration, supporting the development and implementation of accounting and reporting frameworks. This second step was outside the scope of this project and will be addressed separately. It should be recognized that different goals will require different metrics for monitoring.

1.2 About this guideline

The Global Roundtable for Sustainable Beef Carbon Footprint Guideline (in short GRSB guideline) was commissioned by GRSB and approved on February 14, 2022. This guideline is valid until a new version is released. This GRSB guideline will review and update this document every 5 years.

Acknowledgement is given to the following organizations and individuals participating in the development of this guideline on the GRSB GHG Science Committee:

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This guideline describes a common approach based on international standards and current best knowledge to address methodological challenges for LCA of beef cattle production. Guidance provided in this document follows international standards of life cycle assessment. International standards and guidance referenced and implemented in this document include:

- ISO 14040, 14044 and 14067 (ISO, 2006a, 2006b, 2013)
- Publicly Available Specification PAS 2050:2011 & PAS 2050-1: 2012 (BSI, 2011, 2012)
- Greenhouse Gas protocol – Product Life cycle Reporting Standard (WBCSD & WRI, 2011)
- 2019 Refinement to the IPCC 2006 Guidelines for National Greenhouse Gas Inventories (IPCC, 2019a)
- IDF – A common carbon footprint approach for the dairy sector: Bulletin 479/2015 (International Dairy Federation, 2015)
- Product Environmental Footprint Category Rules (PEFCR) guideline (Zampori & Pant, 2019)
- FAO LEAP guidelines - *Environmental performance of large ruminant supply chains* (FAO LEAP, 2016)
- FAO LEAP guidelines - *Environmental performance of animal feeds supply chains* (FAO LEAP, 2015)
- PEFCR Feed for food producing animals (European Commission, 2020)

In the preparation of this document, it has been assumed that the execution of its provisions will be conducted by practitioners with a basic level of LCA understanding.

1.3 Guideline purpose

GRSB commissioned the development of this document to provide relevant and concrete guidance on the calculation of greenhouse gas emissions of beef cattle production with a life cycle perspective.

This guideline is focused on a single environmental impact, the emissions of GHG's and their contribution to climate change from beef cattle production.[1]

The purpose of this guideline is to provide rules to ensure ***alignment*** and ***consistency*** among studies performed for the quantification of GHG of beef cattle supply chains. This document addresses only a single impact category, climate change and the contribution of the life cycle of beef cattle production to this impact in a cradle-to-gate perspective.

[1] Mixed systems where milk and liveweight animals leave the systems are **not** in scope for this guideline. It is unclear if these systems are in scope of the dairy IDF guideline (see section 1.2).

The results calculated by this guideline cannot be communicated as an environmental footprint. A full environmental footprint entails reporting performance over multiple environmental impact categories additional to climate change (e.g water consumption, acidification, eutrophication).

Who is it for?

This guideline is developed for use in all countries for a wide range of stakeholders in the beef cattle production and processing sector. From livestock producers, supply chain partners to industry advocates and policy makers interested in accounting the climate change impact related to beef cattle. Practical recommendations applicable to most commercial beef cattle production systems are provided in this guideline.

Three main types of users can be distinguished:

A. National Roundtables in doing national assessments; this guideline will allow for all countries to perform calculations following the same rules, so at a global level, carbon footprint calculations can be published in a way that the whole industry can agree upon and understand.

B. Multi-national corporations (e.g. retailers or packers) doing Scope 3 emission calculations.

C. Researchers (secondary), when performing any type of investigation involving the carbon footprint of beef cattle they can align to a specific methodology.

Beef cattle systems in scope are; cow/calf systems which produce feeder calves for further feeding/grazing, and fattening systems which consider backgrounding and finishing until desired slaughter weight is reached.

In some cases, cattle from a dairy system may be integrated into a beef fattening system or directly for slaughter. In this case, the guideline does not elaborate on the modelling of the dairy farm, but takes the IDF carbon footprint guideline (International Dairy Federation, 2015) as the leading methodological approach.

What does it do?

The methodology is developed to:

- Quantify GHG emissions from cradle to farm exit gate or cradle to slaughtering exit gate.
- Identify main drivers for GHG emissions in the beef cattle life cycle.
- Allow comparisons within the context of the same study.
- Allow monitoring of GHG emissions through time of a production system (performance tracking).

What does it NOT do?

Comparing the quantitative results of separate studies conducted with this guideline is not possible as this guideline allows some flexibility in aspects that may lead to variations on absolute results. Nonetheless, following this guideline allows consistency and reproducibility of GHG calculations (by transparency of rules) which grants an intrinsic comparability of all studies performed in conformity to this guide.

This guideline does not provide a way to calculate net emissions after accounting for soil carbon sequestration.

This guideline does not provide instruction to perform carbon footprint calculations at the company/organization level, only at the product level.

For more detail on calculating carbon sequestration see the FAO "Measuring and modelling soil carbon stocks and stock changes in livestock production systems: Guidelines for assessment (Version 1)" from the Livestock environmental assessment and performance (LEAP) partnership and for details on calculating net emissions, see the "C-Sequ: LCA guidelines for calculating carbon sequestration in cattle production systems" lead by the Global Dairy Platform.

1.4 This guideline supports attributional LCA

An attributional LCA is a system modelling approach where all the inputs, outputs and derived impact from a system are attributed to the delivery of a specific product and function based on a defined normative rule. This provides information on the burdens associated to a product and its life cycle. The impacts calculated are strongly connected to the choices on how to handle co-products and system boundaries.

In contrast, consequential LCA estimates the related changes in inputs and outputs from a system, and their related impact, derived to these changes in the evaluated system. To evaluate changes system boundaries and allocation rules needs to be redefined depending on the type of change.

The ***GRSB guideline*** allows for the quantification of GHG emissions from beef cattle productions using an ***attributional LCA approach***.

1.5 Carbon footprint

GHG's can be emitted and removed throughout the life cycle of a product. These GHG emissions have an effect in increased global temperatures reflected in an impact to climate change. The quantification of these GHG emissions and removals in a product system expressed as CO_2 equivalents constitutes the carbon footprint (CFP) of a product. This guideline focuses on the CFP at the product level. Only inputs and outputs specifically relevant to the product under study **shall** be recorded.

The global warming potential (GWP) is an index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon (e.g., GWP 20, GWP 100, GWP 500, for 20, 100, and 500 years), relative to that of the reference substance, carbon dioxide (CO2). When emissions or removals are multiplied by their respective GWP, they become CO_2 equivalents. In their calculations, practitioners **shall** use GWP values from the Intergovernmental Panel for Climate Change (IPCC) Sixth Assessment Report, published in 2021 or the most recent values available (with carbon feedbacks, according to IPCC).

This guideline makes use of a 100-year GWP factor for GHG emissions and removals data to calculate results in units of CO_2 equivalents. This is an appropriate metric for evaluating emission intensity reduction goals (see the GRSB metrics fact sheet for more information about choosing a metric appropriate to one's goal).

To conform to this guideline, all GHG emissions and removals **shall** be calculated as if released or removed at the beginning of the assessment. Credits associated with temporary and permanent carbon storage and/or delayed emissions **shall** not be considered in the calculation of GHG emissions. There is no discounting of emissions over time (ISO, 2018).

A simplified modelling approach of biogenic carbon emissions **may** be used, where only biogenic methane is modelled and no further biogenic emissions and removals from the atmosphere are modelled (Zampori & Pant, 2019).

The emissions and removals arising from direct land use change (dLUC) **shall** be assessed for any input to, and the direct activity of beef production.

Soil carbon sequestration is excluded from the carbon footprint in this guideline (see Section 1.3).

Carbon offsetting and its communication as part of the carbon footprint is not in scope of this document.

1.6 Guideline structure and conventions

This document is divided into five different chapters providing LCA practitioners with guidance to perform a CFP analysis and report of beef cattle production.

Chapter 1. Provides an introduction to the guideline purpose and application

Chapter 2. Gives practitioner guidance on how to set up their study

Chapter 3 Describes the data to be collected in order to compile the life cycle inventory and model emissions to calculate the CFP of beef cattle production. The inventory is described first for the foreground process which is the Animal Farm; then Feed and other farm inputs; last Slaughtering.

Chapter 4 Elaborates on the calculation of direct emissions coming from animal farm activities.

Chapter 5 Gives practitioners insight on best practice for reporting results from their carbon footrpint study.

In conformance to this guideline:

• The term '**shall**' is used to indicate what is required for a study to conform to the GRSB guideline

• The term '**should**' is used to indicate a recommendation rather than a requirement. Any deviation from a '**should**' requirement must be transparent and justified in the study.

• The term '**may**' is used to indicate a permissible option. If another available option is chosen, GRSB compliant studies must include adequate argumentation to justify the chosen option.

2. Setting up your study

2.1 Defining Goal & scope of your study

This quantification **may** support a range of objectives to be defined by the practitioner. In identifying the goal of the study, practitioner **shall** unambiguously identify the following:

- Intended application
- Reasons for carrying out the study
- Intended audience
- Intended communication

The scope of the study **shall** be established with the goal of the CFP in mind. As part of the scope of the study, practitioner **shall** declare:

- Systems under study
- Time scope
- System boundary, including geographical scope and cut-offs
- Reference flow
- Assumptions and limitations
- Allocation procedures used

Guidance is provided below on how to define most relevant aspects of the scope of a study under this guideline.

2.1.1 System boundary definition for your study

The system boundary of the study is the basis to determine which unit processes are included within the study.

Calculations under this guideline consider a cradle-to – gate perspective. The carbon footprint is calculated for all related processes to beef cattle production from resource extraction (cradle) to the farm (option 1) or first processing (option 2).

Depending on the option chosen by the practitioner, the system boundaries include all inputs and related emission necessary to breed, raise and fatten beef to the point they are ready to leave the farm, their delivery to slaughtering and all related activities to first processing.

Processes within the system boundary **shall** include:

Upstream production (outside animal farm system):

- Production of synthetic fertilizer
- Production of organic fertilizer
- Production of plant protection products
- Production of feed materials (crop and animal based)
- Production of feed additives
- Production of replacement animals
- Transport of goods to farm

Animal farm (foreground):

- Direct farm GHG emissions from feed cultivation at farm
- Direct farm GHG emission from animals, housing and manure management
- If relevant emissions from soil for oxidation of peat
- If relevant expansion of grass and crop land at the cost of forest land
- Activity data to define upstream production for feed, animals and manure management
- Activity data to define waste processing (mostly due to mortality of farm animals)

Slaughtering (downstream):

- Transport of animals to slaughterhouse
- Activity data to define GHG emissions by fuel burning) and upstream production inputs
- Activity data to define waste processing (not rendering or re-processing)

Figure 2-1 shows the system boundaries for studies performed using this guideline. Option 1 setting boundary at farm, or option 2 setting boundary at first processing.

Data for all processes within the system boundary **shall** be collected for the average of one calendar year activity. A steady state “equilibrium population” at the animal farm is assumed, practitioner **shall** include all animal classes and ages on average present in one calendar year period.

Capital goods and ancillary activities (such as veterinary services or office management) are excluded from the system boundary of studies performed under this guideline.

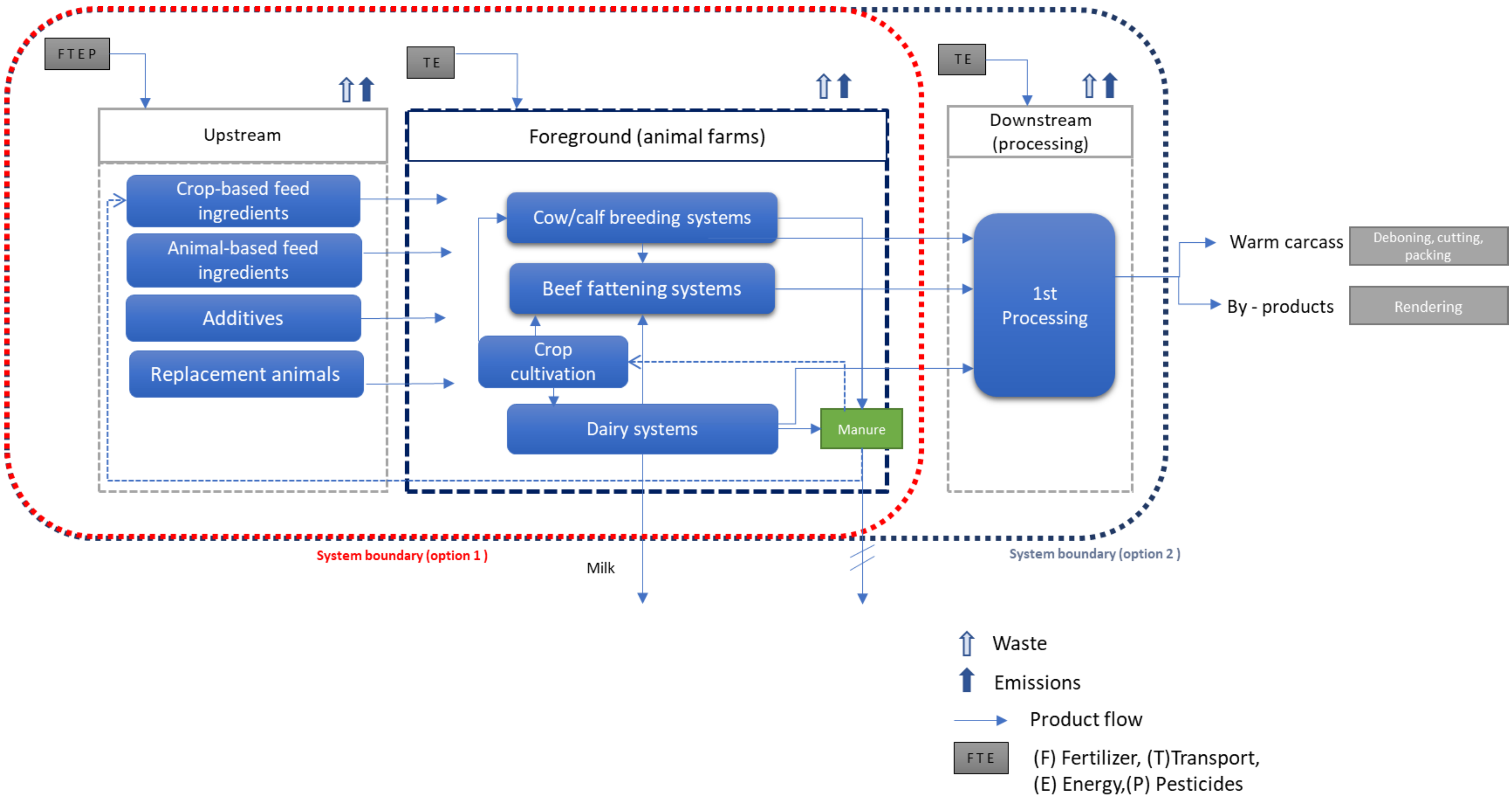

Figure 2-1 System boundary diagram for the life cycle of beef cattle from cradle to gate. Two options depicted for system modelled to farm gate or 1st processing.

2.1.2 Setting the reference flow for your study

The CFP study is structured around a reference flow (RF). All results are calculated relative to this reference flow.

The RF is a quantitative measure of the function of the system, in alignment to the defined goal and scope.

Practitioners performing studies in compliance to this guideline **may** select between two RFs, depending on the goal and scope of their study:

a) Option 1: Practitioner **may** choose to define the reference flow as 1 kilogram of live weight leaving the farm.
b) Option 2: Practitioner **may** choose to define the reference flow as 1 kilogram of warm carcass weight after first processing.

Practitioner **shall** couple the RF to the system boundary defined for the study. If the study is performed at the farm gate, practitioner **shall** define the RF as per option 1. When the study system boundary includes the transport and activities of first processing, the RF **shall** be option 2.

To ensure consistency among studies, when implementing this guideline, practitioner **shall** define and report results using at least option 1 or option 2 as RF.

2.1.3 Allocation

In multi-functional processes, the impact of inputs and emissions **shall** be shared among the multiple outputs of the multi-functional process. This is known as allocation.

The practitioner **shall** in principle follow ISO 14044 (ISO, 2006b) guidelines on good practice when handling multi-functionality, where allocation **should** be avoided by trying to assign inputs and emission that are associated only to the output of interest.

If allocation cannot be avoided, practitioner will require a method to do a proper assignment of inputs and emissions to output for which default methods are predefined which always **should** be reported.

Practitioners **shall** use the approach listed in Table 1 as a default.

Practitioners **may** choose to perform other methods of allocation on top of the default and report these results separately as part of a sensitivity assessment. If alternative allocation is applied, the reasoning, data used, and assumptions made for the alternative allocation **shall** be documented and reported in the CFP.

Practitioners **shall** document all variables and assumptions used for the allocation method performed. The data required and appropriate implementation of allocation is further explained in the appropriate sub-section of inventory section 3.

Table 1 Summary of default allocation methods to be implemented under this GRSB guideline.

Process	Default allocation method	Explanation	Basis
Transport (inbound and outbound)	Physical allocation	Allocation of transport emissions to transported products **shall** be done on mass share of total mass transported. The load factor **shall** account for empty transport distance, maximum load (mass for volume limited).	Default allocation based on common practice for transport in LCA and aligned to (Zampori & Pant, 2019).

Allocation of crop-co products at farm	Economic allocation	Inputs and outputs for crop production **shall** be allocated to all crop products based on economic allocation. See section 3.3.2.	Allocation method aligned to default approaches presented in (FAO LEAP, 2015) and (European Commission, 2020)
Processing of feed ingredients	Economic allocation	First, separate the activities specific to individual products where possible. Then use economic allocation. See section 3.3.2.	Allocation method aligned to default approaches presented in (FAO LEAP, 2015) and (European Commission, 2020)
Feed mill operations	Mass allocation	First, separate the activities specific to individual product lines. Then perform allocation based on mass. See section 3.3.2.	Allocation method aligned to default approaches presented in (European Commission, 2020)
Live animal outputs from animal farm	Mass allocation	First separate activities that are specific to an animal type. Then allocate all inputs and emission that cannot be attributed to a single animal on basis of their mass leaving the animal farm. See section 3.2.1.6	Mass allocation was chosen as default. This method will account for the live weight gain of the whole system, therefore all mass produced at farm is considered equal in this approach. Economic allocation **may** be used if practitioner is able to distinguish different prices for the various animal types leaving the system. If practitioner deviates from default this **shall** be communicated clearly.
Live animal outputs leaving a system with milk as co-product	Bio-physical allocation	First, separate activities specific to products (e.g. electricity for milking). Then use biophysical allocation according to energy requirements for animal physiological functions of growth, milk production, reproduction, activity and maintenance. See section 3.2.1.6	Allocation method aligned to default approaches presented in (International Dairy Federation, 2015)
Manure at animal farm	Residual approach	In this guideline, manure is approached as a residual. See section 3.2.1.6	The GRSB guideline considers the residual approach for allocation, where system is cut-off, and no burden is carried to downstream of manure. Residual approach was found most practical to implement in any beef-cattle system, compared to less well-developed allocation options. (biophysical allocation, price shadow allocation).
Slaughtering	Economic allocation	Allocation to warm carcass and by-products **shall** be performed based on the revenue of all products based on prices after first processing. See section 3.4	Default chosen as believed to best attribute the environmental impact of slaughter by-products based on those who “drive” the economic activity of the slaughterhouse, rather than considering all by-products the same (by mass).

3. Inventory data collection

Each sub-section describes the data to be collected to model the life cycle inventory (LCI), and additional data or parameters necessary to conduct allocation and model emissions as described in sections 4.2, 4.3 and 4.4. Practitioner **shall** properly document the sources and assumptions made in the compilation of the required data in each section.

3.1 General guidance on activity data collection

Depending on the defined goal of the study, data **may** be collected for one or several production locations (farm or supply chain assessment) or at region/nationwide level.

In principle, there are no differences in the modelling of a farm, a specific supply chain or an entire nation or region. The main difference lays in the data sources available to each, and the effort required for interpretation of the available data.

In case of a farm or supply chain specific assessment, most of foreground data **shall** be based on primary data. For few specific parameters, practitioner **may** use secondary data which are scientifically and technically valid and appropriate to the system under study (for which exact parameter this applies, will be clearly indicated in the following sections of this chapter). Upstream life cycles **may** be based on secondary data (background databases) or can be modelled with primary data.

In a farm or supply chain specific assessment primary data are farm and processing reports, data management systems of the operation, and measurement from installed equipment and direct information on management practices.

In case of a region/nationwide assessment, foreground data **should** be based on primary data (e.g., national survey performed for the specific assessment). If these are not available, practitioner **may** base the information on secondary data, for example:

- National Statistics Offices
- Sub-national or regional statistical agencies (e.g. provincial ministries or municipal governments that **may** have a mandate to collect relevant data)
- Expert information, such as from:

    (i) sectoral experts, institutional experts, stakeholder organizations (e.g., industry and trade organizations, large-scale industries such as energy producers and Petro-chemical plant);

    (ii) other international experts such as emission inventory sector experts from other countries with similar national circumstances.

- National Inventory Reports from Parties that are in the United Nations Framework Convention on Climate Change
- Other sources that are deemed appropriate and technically valid as long as they are properly documented and validated by practitioner.
- Background databases

In farm or supply chain specific, where site-specific primary data are used, the data collection process and assumptions **shall** be transparently documented in the CFP study report. If a national approach is used, the data sources **shall** be properly documented in the CFP study report.

In all instances, practitioner **shall** perform due diligence in verifying that data collected if complete and correct. Verification **may** take place in several ways including: on site checks, recalculation, mass balance revision or cross-checks with other sources.

6.Appendix I offers specific guidance for practitioners conducting a study at the national level.

3.2 Animal Farm

All parameters indicated below **shall** be collected and **should** be based, if possible, on 3-year average of the annual activity data of the system in scope.

3.2.1 Beef and cow/calf systems

3.2.1.1 Animal population and productivity

Since the growth of the animal might be shared through different producers, it is important to define the animal types relevant to the specific production system. Examples of animal types commonly applied to model a growth/finishing operation include but are not limited to:

- Male Calves <1 year old
- Male Calves 1-2 years old
- Beef > 2 years old

If more appropriate for the specific system under study, different or additional animal types **shall** be considered by the practitioner, as long a clear explanation of the animal type definition is given. Practitioner **shall** represent all animal types present in the system under study.

For example, in case of a cow/calf operation, additional animal types that **may** be considered are:

- Suckler cows (female reproductive animals)
- Heifers (female animal over 2 years, but before first calving/lactation)
- Female calves 1-2 years old
- Female calves <1 years old

For each animal type identified, data **shall** be gathered on different parameters as indicated in Table 2.

*Table 2 Animal population required parameters. The listed data **shall** be gathered on a calendar year basis for each defined animal type present.*

Parameter	Unit	Note for practitioner
Average number of animal present	head	
Average start weight	kg $head^{-1}$	Average weight of 1 head at start of the cycle
Average end weight	kg $head^{-1}$	Average weight of 1 head at end of the cycle
Average body weight	kg $head^{-1}$	Average weight of 1 head along the considered production period
Mature weight	kg $head^{-1}$	Potential weight of the considered animal at maturity
Weight gain	kg day^{-1}	**May** be calculated as a difference between start and end weight
Average milk production	kg $head^{-1}$ yr^{-1}	Only applicable for lactating cows if present in system.
Average milk protein content	%	
Average milk fat content	%	
Number of purchased animals	#	
Number of animals leaving the system	#	

The data on the number of average animals present **should** be based on:

- In case of a farm assessment, the farm registration of animal herd population **should** be used.
- In case of a national assessment, farm data **should** be based on national/regional census or sources as described in section 3.1.
- In case the above mentioned data sources are not available, the average animal present on farm **may** be estimated based on other measured information (see example box 1.0).

Data on animals start and end weight **should** be gathered as primary data (kg liveweight) or national/regional expert information (see 3.1). If these are not available, the practitioner **may** use default data based on secondary sources from scientifically and technically valid literature that **shall** be properly documented by the practitioner.

Data on animals bought and animals that every year reach the target weight (and therefore leave the system towards slaughtering facilities) **shall** be gathered from farm registration in case of a farm assessment, national census in case of a national assessment.

Example 1.0

*In a growth/finisher operation average population **may** be estimated with data on number of calves at the start of the production adjusted by mortality (assuming it happens at half of the cycle) and eventual empty periods in a lot:*

$$AAP_{animal} = In_{animal}\left(1 - \frac{t_{empty}}{(t_{production} + t_{empty})}\right)\left(1 - \frac{m}{2}\right)$$

Where:

- AAP_{calves} *= Average Annual Population (head),*
- In_{calves} *= Number of animals at the start of the production batch (feedlot)*
- t_{empty} *= Empty period (day) dedicated to cleaning and sanitizing,*
- $t_{production}$ *= Production period (day) dedicated to animal growth*
- m *= mortality rate (%), expressed as a ration between number of dead animals along the production batch divided by number of animals at the start of the production batch.*

For example, we consider a farm where calves are bought at 10 months and are grown and slaughtered at different target weight: 18 months (30% of the remaining herd), 24 months (30% of the remaining herd) and 30 months (40% of the remaining herd). At the end of the production 1 month is dedicated to cleaning the stable.

We can consider the following animal types, mortality rates and output of animals at the end of the cycle:

- *2% mortality rate for fattening calves 6-18 months.80 animals slaughtered at 18 months.*
- *1% for fattening calves 18-21 months. 80 animals slaughtered at 21 months.*
- *1% for fattening calves 21-24 months. 131 animals slaughtered at 24 months.*

At the start of the production, 300 animals are bought. The AAP for the fattening calves slaughtered at 18 months is:

$$AAP_{fat.calves.6-18} = 300 * \left(1 - \frac{2\%}{2}\right) * \frac{(18 - 6)}{(24 - 6 + 1)} = 187.6\ head$$

The number of animals entering the next fattening stage (18-21 months) is:

$$OUT_{fat.calves.6-18} = 300 * (1 - 2\%) - 80 = 214\ head$$

The AAP for the fattening calves slaughtered at 21 months is:

$$AAP_{fat.calves.18-21} = 214 * \left(1 - \frac{1\%}{2}\right) * \frac{(21 - 18)}{(24 - 6 + 1)} = 33.6\ v$$

The number of animals entering the next fattening stage (21-24 months) is:

$$OUT_{fat.calves.18-21} = 214 * (1 - 1\%) - 80 = 132\ head$$

The AAP for the fattening calves slaughtered at 21 months is:

$$AAP_{fat.calves.21-24} = 132 * \left(1 - \frac{1\%}{2}\right) * \frac{(24 - 21)}{(24 - 6 + 1)} = 20.7\ head$$

*In a cow/calf operation, the average population **may** be estimated with data on the suckler cow's replacement rate, number of output animals leaving the system, the various animal type's mortality rates and age of first calving.*

For example, we consider a farm where calves a grown in average up to 10 months before being sold, we have an average age of first calving of 2.2 years, and a suckler cow replacement rate of 25% (excluding mortality). Mortality is:

- *7% for fattening calves in their first 10 months.*
- *7% for female calves < 1 year*
- *2% for female calves 1-2 years*
- *0% for heifers (2-2.2 years = 73 days production period)*
- *4% for suckler cows*

Each year, 68 fattening calves (at the age of 10 months, 304 days) leave the system. The fattening calves AAP is:

$$AAP_{fat.calves} = \frac{68}{\left(1 - \frac{7\%}{2}\right)} * \frac{304}{365} = 58.69\ head$$

Each year 30 suckler cows are culled (this excludes mortalities). The suckler cows AAP is therefore:

$$AAP_{suckler.cows} = \frac{30}{25\%} = 120\ head$$

Therefore, the AAP for the other animal types is:

$$AAP_{heifers} = \frac{120 * (25\% + 4\%)}{\left(1 - \frac{0\%}{2}\right)} * \frac{73}{365} = 6.96\ head$$

$$AAP_{fem.calves1-2} = \frac{120 * (25\% + 4\%)}{(1 - 0\%)\left(1 - \frac{2\%}{2}\right)} * \frac{365}{365} = 35.15\ head$$

$$AAP_{fem.calves<1} = \frac{120 * (25\% + 4\%)}{(1 - 0\%)(1 - 2\%)\left(1 - \frac{7\%}{2}\right)} * \frac{365}{365} = 36.80\ head$$

3.2.1.2 Ration

Data on total feed intake, together with some feed nutritional characteristics, need to be gathered for each animal type defined as per section 3.2.1.1. This data is relevant for:

- Accounting for the impact of feed production (see section 3.3.2);
- Calculating animal GHG emissions at farm (e.g., methane from enteric fermentation and N_2O emissions related to N excretion).

Different types of feed intake will require various data gathering strategies. Two types can be distinguished:

- Measured feed intakes: the quantity of imported feed is normally known in weight units including nutritional information. Single ingredients fed to animals are generally fed in a known amount, dependent on specific feeding strategies. Roughages grown and stored on farm and fed to animals are mostly not weighted before feeding but estimated by the farmer.
- Non-measured feed intakes: typical for fresh grass and fresh roughages directly grazed by animals on pasture.

Data for studies performed at the farm/site level **shall** be based on primary activity data collected from the farm.

At national/regional level, the ration and characteristics **should** be determined from national/regional statistics when available. If these are not available, practitioner **may** define with local experts, associations, or any other relevant stakeholder with enough expertise an accurate estimate of the feed use in local beef cattle supply chains.

For the overall diet of an animal in the year of reference, data **shall** be gathered on:

- Diet gross energy intake (MJ head^{-1} yr^{-1}). This **may** be derived from the weighted average of the gross energy intake of the various feed types fed (compound feeds, forage fodder, single ingredients and grass). For each feed types, the gross energy intake **may** be calculated by multiplying the feed intake (kg-as-is head^{-1} yr^{-1}) times the dry matter content (kg-dm kg-as-is^{-1}) and gross energy content (MJ kg-dm^{-1}).
- Diet digestibility expressed as a fraction of gross energy (%). This **may** be derived from the weighted average of the digestibility of the various feed types fed (compound feeds, forage fodder, single ingredients and grass). For each feed types, the diet digestibility **may** be calculated by multiplying the feed intake (kg-as-is head^{-1} yr^{-1}) times the dry matter (kg-dm kg-as-is^{-1}) and digestible energy content (MJ kg-dm^{-1}), and dividing by the gross energy intake (MJ head^{-1} yr^{-1}).
- Urinary energy expressed as a fraction of gross energy (%). This **may** be derived from the weighted average of the diet urinary energy of the various feed types fed (compound feeds, forage fodder, single ingredients and grass).
- Crude protein content as percentage of dry matter intake (%). This **may** be derived from the weighted average of the crude protein content of the various feed types fed (compound feeds, forage fodder, single ingredients and grass).
- Non protein nitrogen sources (e.g. from added urea) (%) of dry mater intake.
- Neutral detergent fibre (NDF) content as percentage of dry matter intake (%). This **may** be derived from the weighted average of the NDF content of the various feed types fed (compound feeds, forage fodder, single ingredients and grass).
- Ash content as a percentage of dry matter intake (%). This values **should** be derived from the weighted average of the measured ash content of the various feed types fed. If measured values not available, values from available nutritional databases **may** be used.
- Feed forage content as percentage of dry matter intake (%). This **may** be derived by dividing the dry matter feed intake of forage fodder by the dry matter feed intake of the overall diet.

Data on feed losses **shall** be recorded. This can be based on data collected on site, sector averages or a default based on secondary scientifically and technically valid literature sources.

The next sections describe the specific data required for various types of animal feed fed to each animal type at farm. Information on where to source the data will also be given.

Instructions for modelling the LCI of crop cultivation in the farm is given in section 3.2.3. Instructions on modelling of the production of compound feed or other single ingredients produced outside of the farm is given in section 3.3.2.

3.2.1.2.1 Compound feed

A compound feed is a mix (formulation) of different processed and unprocessed ingredients usually imported from different locations and mixed in a feed mill. Compound feed formulations vary between different animals, different animal growth phases and compatibility to roughages fed at the same time. Formulations can change between different seasons, due to variation in ingredient availability or quality of the grass and roughages in the ration.

For each compound feed fed to the different animal types defined, data **shall** be gathered for the parameters summarized in Table 3 for one calendar year average activity.

Table 3 Compound feed parameters required per animal type defined at farm.

Parameter	Unit	Note for practitioner
Feed intake	kg-as-is head^{-1} yr^{-1}	For each animal type, the amount of compound feed(s) fed **shall** be collected (kg-as-is head^{-1} yr^{-1}).
Feed ingredients included in the formulation, and their share of the total mass as is	%	For each compound feed, the exact ingredient formulation (including additives) data **shall** be gathered. A formulation is a list of ingredients and their amounts used. The formulation **shall** be recorded on an "as is" mass base and **should** sum up to 100%. If practitioner does not have access to this type of information, secondary information based on literature **may** be used, as long it is technically representative of the actual system under study (this would require technical substantiation).
Dry matter content	kg-dm kg-as-is^{-1}	Data on feed characteristics **should** be based on information specific to the compound feed. Practitioner **may** use secondary data from literature sources (or available feed tables / databases).
Gross energy content	MJ kg-dm^{-1}	
Digestible energy content	MJ kg-dm^{-1}	
Urinary energy expressed as a fraction of gross energy	%	
Crude protein content as percentage of dry matter intake	%	
Neutral detergent fibre (NDF) content as percentage of dry matter intake	%	

Feed characteristics that are often not easily available are gross energy and urinary energy content of feed. In such case, practitioner **may** use a default conversion factor from IPCC: 18.45 MJ kg-dm^{-1} for gross energy content and 4% for UE (2% if more than 85% of the diet is grains).

3.2.1.2.2 Forage fodder and other single ingredients

Forage fodder is any type of forage (pasture, crop residue or cereal plant) that is harvested and fed to animals, usually after some kind of transformation during storage (e.g., fermentation, drying). Typical forage fodders are hay, silage and straw. Common forages used for fodder production are grass, maize, cereals, legume (e.g., alfalfa).

Single ingredients can be of various nature (cultivated at farm or purchased). Typical ingredients might be wet co-products (e.g., brewers spent grains), dried sugar molasses, or milk powder. These are usually not incorporated in the compound feed, but they are fed separately to the animal.

For each single ingredient and forage fodder used data **shall** be gathered on the parameters summarized in Table 4.

Table 4 Single ingredient and forage fodder parameters required per animal type defined at farm.

Parameter	Unit	Note for practitioner
Feed intake	kg-as-is head^{-1} yr^{-1}	For each single ingredient and forage fodder, data on the amount fed per head per year.
Dry matter content	kg-dm kg-as-is^{-1}	For each single ingredient and forage fodder, characteristics **shall** be gathered from best available source, either measured for instances where primary data is available, based on average regional/national data. If practitioner does not have access to this type of information, secondary information based on literature **may** be used, as long it is technically representative of the actual system under study (this would require technical substantiation).
Gross energy content	MJ kg-dm^{-1}	
Digestible energy content	MJ kg-dm^{-1}	
Urinary energy expressed as a fraction of gross energy	%	
Crude protein content as percentage of dry matter intake	%	
Neutral detergent fibre (NDF) content as percentage of dry matter intake	%	

3.2.1.2.3 Nutritional interventions by use of feed additives

Nutritional interventions related to the use of additives **shall** be recorded as kg-as-is head^{-1} yr^{-1} in compound feed or as a single input. Practitioner **shall** also record the adoption rate of feed additives in the ration for each specific animal type defined in 3.2.1.1.

Additives in the ration have zootechnical effects that **may** be categorized in two types: A) those visible in the production activity (e.g. feed formulation, productivity, longevity), in which case their effect is modelled by the practitioner in modelling the animal farm inventory. B) direct effect in emissions of GHGs. In the later, practitioner **shall** properly substantiate and document the effect of these additives based on scientifically and technically valid information. The effect **shall** be reflected adapting the direct emissions from the animal farm calculated as per section 4.1 and 4.2.

3.2.1.2.4 Grazing

For grass grazed data **shall** be gathered for the parameters summarized inTable 5.

Table 5 feed grazed parameters required per animal type defined at farm.

Parameter	Unit
Feed intake	kg-as-is head^{-1} yr^{-1}
Dry matter content	kg-dm kg-as-is^{-1}
Gross energy content	MJ kg-dm^{-1}
Digestible energy content	MJ kg-dm^{-1}
Urinary energy expressed as a fraction of gross energy	%
Crude protein content as percentage of dry matter intake	%
Neutral detergent fibre (NDF) content as percentage of dry matter intake	%

To estimate non-measured feed intakes such as grass, a method based on the animal energy requirements for growth, activity and maintenance **shall** be applied from V4, Ch 06 of IPCC 2006 and 2019 refinement (IPCC, 2019b).

The method requires data on:

- weight (kg) for each animal type,
- average weight gain per day (kg day^{-1}) for each animal type,
- the mature weight (kg) of the adult animal,
- the average number of hours worked per day
- The feeding status (stall, pasture or grazing on large scale). Based on IPCC definitions,
- Amount of milk produced per day, and its characteristic (e.g., fat content)

The list inputs are then used to estimate net energy requirements for maintenance, activity, growth, lactation, work and pregnancy. The overall net energy requirements are then converted into gross energy requirements with the use of feed digestibility data. A more detailed explanation of the method that **shall** be followed can be found in the Tier 2 paragraph of V4, Ch10 section 10.2.2 of 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019b).

Since the method allows estimating the overall gross energy intake requirements, by subtracting the gross energy intake, it is possible to estimate the unmeasured energy feed intake. To translate gross energy intake into amount of grass (kg dm), the energy content of the grass **should** be known. If sample analysis of grass or national/regional characteristics are not available to the practitioner, scientifically and technically valid literature information can be used (e.g., 18.45 MJ kg-dm^{-1} as suggested by IPCC).

3.2.1.3 Manure production and management

To model manure management, data **shall** be gathered per animal type on:

- Manure produced (kg yr^{-1})
- Time spent by animals on pasture, housing and feedlot (%)
- Manure management systems (mms) in place, and share of manure managed on a specific mms (%)
- In case of anaerobic digester: amount of methane gas used for energy and amount of methane flared.

If manure production (kg yr^{-1}) is not measured, default values **may** be based which represent the scope the study from scientifically and technically valid literature or expert judgement.

The amount of time spent by the animal on pasture will be usually known by the farmer. This input is used to estimate how much manure is released on pasture, and how much is released in housing or feedlot.

For each animal type, the practitioner **shall** estimate how much manure is managed with a certain manure management system (mms). This **may** be estimated based on the known time spent by animals in certain areas (e.g., 20% in drylot, 80% in housing) or based on known seasonal shift in management (e.g., 70% of the year manure is stored in pits, 30% of the year manure is directly applied on the land).

Manure management types **shall** be selected considering the categorization by (IPCC C. B., 2019), Chapter 10: Emissions from livestock and manure management.:

- **Daily spread:** manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
- **Dry lot (yard):** a paved or unpaved open confinement area without any significant vegetative cover where accumulating manure **may** be removed periodically.
- **Cattle and Swine deep bedding (no mixing/active mixing, more/less than 1 month):** as manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and **may** be combined with a dry lot or pasture.
- **Pit storage below animal confinements (1/2/3/4/6/12 month):** collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
- **Solid storage (covered or compacted/bulking agent addiction, additives):** the storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.

- **Composting – in vessel: c**omposting, typically in an enclosed channel, with forced aeration and continuous mixing.
- **Composting - Static pile:** composting in piles with forced aeration but no mixing.
- **Composting - Intensive windrow:** composting in windrows with regular (at least daily) turning for mixing and aeration.
- **Composting - Passive windrow: c**omposting in windrows with infrequent turning for mixing and aeration.
- **Liquid/Slurry (with cover/with natural crust cover/without natural crust cover, 1/2/3/4/6/12 months):** manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
- **Aerobic treatment (natural aeration system/forced aeration system):** the biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.
- **Uncovered anaerobic lagoon:** a type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon **may** be recycled as flush water or used to irrigate and fertilize fields. A more detailed way of modelling **should** also consider residence time to estimate MCF, not only temperature.
- **Anaerobic digester on farm (low/high leakage, high/low quality technology, low/high quality gastight technology/open storage):** animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO2 and CH4, which is captured and flared or used as a fuel.

  In case of anaerobic co-digestion, the input of nitrogen via co-digestate **shall** be known. This **should** be based on primary measurement, or national surveys. In case these are not available, **may** be based on secondary literature sources.

  Treatment of gas production **shall** follow section 3.2.1.4.

  Any activity performed within the system to reduce the GHG emissions from manure management **shall** be registered. The effect of these measures **shall** be transparently substantiated based on technically and scientifically valid sources. The effect **shall** be reflected in the emissions from the animal farm calculated as per sections 4.1 and 4.2.

3.2.1.4 Fuel and electricity use (including on farm electricity production)

Data on electricity and fuels used directly related to beef-cattle farming **shall** be gathered for the overall farm operations, on a yearly basis. This **shall** be derived from the purchasing/costs annual reports.

On farm there can also be generation of energy. When this energy generation is directly related to or derived from beef cattle farming, primary data **shall** be gathered on how much energy is produced. Based on these data, the energy produced **shall** be modelled as:

- When energy is used directly for farming-related activities, then the energy generation **shall** be included in the LCA boundaries.
- When energy is sold, the following modelling rules **shall** be applied:
  - Subdivision if the production for own use and export from farm can be reasonably estimated. This is the case for renewable energy (e.g., solar & wind electricity) that is produced on farm, and the excess is sold, for example, to the electricity grid. Another example is in case of anaerobic co-fermentation (co-digestion). In such situation, the cultivation co-products fed to the anaerobic digestor (e.g., straw) can be considered as a separate system from the manure fed to the anaerobic digester (separate inputs, biogas output and digestate output). In these

cases, the energy production can be accounted as for a separate system from the animal farming.

- Direct substitution **shall** be used, if subdivision is not possible. This **may** the case for heat recirculation and energy production from farming co-product (e.g., manure anaerobic fermentation). In these cases, the avoided production and use of e.g., national electricity grid or average heat source **may** be considered as an avoided production.

3.2.1.5 Other data to be gathered

Data on water use (tap water or other source to be specified) for animal farming **shall** be gathered, as kg or cubic metres used every year. Water is consumed by animals as drinking water and is also used for other purposes such as cleaning of housing and manure management facilities. When water is used for irrigation of on-farm cultivation, this **shall** be included in the cultivation LCI (see section 3.2.3.2). Only *blue water* use **shall** be monitored. This is water sourced from surface or groundwater resources that is actively used for one of the previously mentioned purposes. *Green water* use related to precipitation **shall** not be included in the inventory.

Use of bedding material **shall** be included in the inventory. Many types of bedding material can be used in different countries, some examples are straw (wheat, oat, other small grains), corn stocks or stover. The amount (kg every year per animal type) and type of bedding material used **shall** be colelcted for the specific system under study.

For some emission calculations (e.g., CH_4 emissions), the average external temperature **shall** be known. This **may** be based on the actual location measurement or based on regional or country average data. Also, the region of reference **shall** be known (e.g., North America, Western Europe), according to IPCC definition.

There are many inputs that have a negligible contribution to the overall animal productions footprint and **shall** not be included in the inventory (cut-off). These are capital goods depreciations (e.g., buildings and infrastructure), production of semen for artificial insemination, antibiotics and other veterinary products and services.

There are also other types of input that **shall** be excluded since out of the scope of the animal product supply chains; this is relevant for non-agricultural activities related to the producing company (e.g., accounting departments).

Transport distance tonne*km and type of transport mode **shall** be recorded by the practitioner for all inputs to the farm, including feed, replacement animals, fuels, bedding material and any other input to farm.

3.2.1.6 Dealing with co-products

The described beef systems can produce different types of co-products. Live animals are the main products of beef production. We can distinguish two main types of live animals that are leaving the system towards slaughtering:

- Animals grown for meat: calves and beef fattened for meat production. Possibly, different co-products could be considered for animals slaughtered at different ages.
- Culled animals grown for reproduction: bull and suckler cows that have been part of the system for reproduction and milk feeding of weaning calves. These animals are only relevant for the cow/calves system

Impact **should** be allocated to liveweight outputs using a mass allocation approach. As example, if a cow/calves system delivers 600 kg liveweight of culled cows and 1350 kg liveweight of 2-years old calves, the overall impact **should** be allocated with:

- a 600 / (600 + 1350) = 30.77% allocation factor to culled cows and
- a 1350 / (600 + 1350) = 69.23% allocation factor to 2-years old calves.

In case data on prices of such animal liveweight are available, the practitioner **may** follow an economic allocation. Following previous example, if culled cows have a value of 0.86 € (kg liveweight)$^{-1}$, and 2-years old calves have a value of 2.91 € (kg liveweight) $^{-1}$, the overall impact **should** be allocated with:

- a 600*0.86 / (600*0.86 + 1350*2.91) = 11.61% allocation factor to culled cows and
- a 1350*2.91 / (600*0.86 + 1350*2.91) = 88.39% allocation factor to 2-years old calves.

Manure leaving the farm **should** be treated by default as a residual. This means without allocation of an upstream burden. The emissions related to manure management up to farm gate are fully allocated to the activity of the farm.

3.2.2 Dairy systems providing young animals for fattening

It is common that calves are purchased from dairy farms and fattened in one or multiple fattening locations. In such case, the dairy farm LCI **should** be modelled by the practitioner using primary activity data. If this is not available, practitioner **may** rely on secondary data to model the dairy farm.

The modelling of the dairy farm **shall** be performed following the indications set by the International Dairy Federation (International Dairy Federation, 2015). Table 6 summarizes the main modelling approaches suggested and aligned to IDF guideline. An update to the IDF guideline is expected in 2022. In such a case the latest version of the guideline **shall** be used.

Table 6 Most relevant modelling choices for dairy systems based on IDF bulletin 479/2015: A Common Carbon Footprint Approach for the Dairy Sector.

Item	Modelling based on IDF guideline
Functional Unit	Kg of FPCM, kg of liveweight.
System boundary	All activities and processes required. From cultivation of raw materials to the delivery at animal farm.
Capital goods	Outside the scope of the study.
Allocation	Implement biophysical allocation between milk and meat, based on a specific IDF equation. Manure **shall** be treated as indicated in section 3.2.1.3 of this document.
Modelling emissions from animal farm	Follow latest IPCC guidelines, instructions provided in this guideline section 4.2
(direct) Land use change	Follow instructions provided in this guideline section 4.4.
(indirect) Land use change	Not in scope
GWP factors	GWP factors **should** be the same as indicated in 1.5.

3.2.3 Land management and crop management in animal farm

3.2.3.1 Land occupation and land use change.

Land occupation per land use type reported in m^2 yr is a necessary parameter for determining land use change and relates to soil carbon emissions or sequestration.

Land occupation refers to the gross land area occupied by grassland and crop production directly associated to animal production (including, for example, waterways, ditches, and fallow strips).

Practitioner **shall** estimate the land occupied directly associated to animal production (for crop production and grazing). The land occupied for other purposes (e.g. food crops; natural areas, protected forest) **shall** be excluded from the calculation.

Practitioner **shall** also indicate the area (ha) consisting of drained organic soils (e.g. peat), occupied for crop cultivation and/or grazing.

Land occupation for grazing and feed crop production **should** be determined based on direct farm records or survey data at regional/national level. Other indirect sources of estimating land use using satellite imagery or remote sensing **may** be collected if no direct farm records available. If none of the previous options are available, the practitioner **may** estimate the land occupation based on the average number of heads on farm, nutritional needs per head for grass and feed crops and the known yield of each commodity.

To calculate land use change emissions, practitioner **shall** record if in the 20 years prior to the reference year of the assessment, the area of land occupied for animal grazing or crop production (directly associated to beef cattle production) has changed from one type to another. Types of land use are: annual crop land, perennial crop land, grass land, forest land, wetland, and industrial land.

Data of current and prior land use **should** be demonstrated using reliable sources of information, such as satellite imagery and/or land survey data.

If the land use at the reference period is unknown, practitioner **shall** follow guidance from PAS 2050-1:2012 (BSI, 2012) for its estimation; see also section 4.4.

Guidance on the quantification of emissions arising from dLUC is given in section 4.4

Where it can be demonstrated that the land use change occurred more than 20 years prior to the assessment being carried out, no emissions from land use change **shall** be included in the assessment as all emissions resulting from the land use change would be assumed to have occurred prior to the year of assessment (BSI, 2011).

3.2.3.2 Feed crop cultivation

Detailed data about forage and other crop cultivation in the animal farm **shall** be collected. Practitioners **shall** differentiate between feed crops to be used at the animal farm and food or other crops cultivated on site and not destined for animal consumption or animal activities (the later **shall** not be included in the inventory for beef cattle).

The crops grown at farm can be classified into:

a. Annual crops (with one or multiple production cycles per year).
b. Perennial crops and grassland (with one or multiple production cycles per year).

Primary data **should** be collected over a period of at least three years. For annual crops, if data covering a three-year period is not available, practitioner **may** gather data for a shorter period, but this cannot be less than one year. For crops whose production cycle is less than one year, data **shall** be collected over a period of time that covers at least three production cycles.

The following economic outputs from cultivation **shall** be quantified per hectare:

a. Main crop product (mass, DM, financial value, gross energy content)
b. Co-product(s) (if applicable) (mass, DM, financial value, gross energy content)
c. Residual materials that remain on the field or in soil (mass, DM)
d. Residual materials that are burnt and associated emissions
e. Waste flows and destination

The impact to all co-products from cultivation **shall** be allocated based on economic allocation considering 5-year average prices for products and co-products from cultivation.

Activity data collected from cultivation at farm **shall** be representative of the average activity per ha cultivated for annual activity.
Table 7 provides details on the activity data to be collected for all crops cultivated at farm exclusively related to beef cattle husbandry.

Table 7 list of the inventory data to be collected for cultivation

Parameter	Unit	Note for practitioner
Crop yield	Kg ha^{-1} y^{-1}	Crop yield **shall** be reported "as is".
Crop dry matter content	kg-dm kg-as-is^{-1}	
Input of seed plant material	Kg ha^{-1}	
Input (total) of synthetic fertilizer	volume or weight ha^{-1}	Practitioner **shall** indicate the total amount and type of synthetic fertilizers used at farm.
Input (total) of plant protection products	volume or weight ha^{-1}	Practitioner **shall** indicate the total amount and plant protection products used at farm.
Input of N from synthetic fertilizer	kg N ha^{-1}	Total N input from all synthetic fertilizers used.
Input of P from synthetic fertilizer	kg P ha^{-1}	Total P input from all synthetic fertilizers used.
Input of K from synthetic fertilizer	kg K ha^{-1}	Total K input from all synthetic fertilizers used.
Input of lime	kg ha^{-1}	Average annual application of lime per ha **shall** be documented. Practitioner to register type.
Input of urea	kg ha^{-1}	
Input of pesticides	volume or weight/ha	
Fuel use	l ha^{-1}	Practitioner to register type of fuel used along with volume consumed in a year. This **shall** include fuel consumption in agricultural machines.
Total input of manure and method of application	kg N ha^{-1}	
Total input N from crop residues	kg N ha^{-1}	
Total input N from compost	kg N ha^{-1}	Default = 0 if not available
Total input N from sewage	kg N ha^{-1}	Default = 0 if not available
Total input N from other organic amendments used as fertilizer (e.g., rendering waste, guano, brewery waste, etc.)	kg N ha^{-1}	Default = 0 if not available
Area consisting of drained organic soils (e.g. peat)	ha	

3.3 Purchased feed and other farm inputs

3.3.1 Energy and material inputs

Data **shall** be collected on energy and material inputs to the farm following the indications in sections 3.2.1.4, 3.2.1.5 and 3.2.3.2. This **may** include the use of electricity from the grid, fuels, heat, but also inputs as water, bedding material, fertilizers or plant protection agents.

This data **shall** be connected to background datasets from commercially available databases in order to model upstream impacts associated to farm inputs.

The use of a specific database is not mandatory in this guideline. Practitioner **shall** properly document the database being used for all energy and material inputs to the farm. Background data used **shall** appropriately match the process, technology, and geography of the input modelled. The use of proxies **shall** be justified and documented by the practitioner.

3.3.2 Purchased feed

The total feed intake and feed composition **shall** be recorded following instructions from 3.2.1.2. To model the carbon footprint of the production of purchased feed (single ingredients, additives and compound feed), input data **may** be connected to background datasets from commercially available databases or modelled by the practitioner when primary data for feed production is available.

In the first instance, the use of a specific database is not mandatory in this guideline; however, the use of The Global Feed LCA Institute (GFLI) database is recommended. This publicly available database is collected using LCA methodology, regularly reviewed and updated.

Regional-specific data is always preferred to a global or generic proxy. Practitioner **may** use any other (more specific) database when available as long as the data is properly verified and validated.

The practitioner **shall** always indicate the database being used for feed inputs to the farm. Background datasets used **shall** appropriately match the process, technology, and geography of the product modelled. Exceptions, such as the use of proxies **shall** be documented and justified by the practitioner.

If primary data is available for the production of purchased feed, practitioner **may** model the purchased feed LCI following guidance from the FAO LEAP Environmental performance of animal feeds supply chains (FAO LEAP, 2015).

Some modelling choices in the FAO LEAP Environmental performance of animal feeds supply chains guideline are recommendations open for the practitioner's choice. For consistency, practitioners **shall** make the specific methodological choices provided below when modelling own feed LCI's.

Table 8 Most relevant modelling choices for purchased feed based on FAO LEAP guideline Environmental performance of animal feeds supply chains

Item	Modelling based on FAO LEAP
Functional Unit	Product amount as used at farm
System boundary	All activities and processes required. From cultivation of raw materials to the delivery at animal farm.
Capital goods	Outside the scope of the study
Allocation	- Implement economic allocation for crop co-products, five-year average prices are advised to account for price fluctuations. Other types of allocation (e.g. energy or mass dry matter) **may** be included as part of sensitivity assessment. - Implement economic allocation for co-products from individual feed processing **shall** be based on economic allocation. Five-year average prices to be implemented.

	- At the feed mill (compound feed production), the allocation approach **shall** be in alignment to the PEFCR for feed, which recommends performing mass allocation based on the total annual mass output of feed from the feed mill. (European Commission, 2020)
Modelling emissions from farming	Follow latest IPCC guidelines, instructions provided in this guideline see section 4.3.
(direct) Land use change	Follow instructions provided in this guideline see section 4.4
(indirect) Land use change	Not in scope

3.3.3 Transport to farm

Activity data on transport of all farm inputs, including replacement animals, fuels, fertilizers **shall** be modelled using secondary data to model the transport mode.

Databases provide processes for different truck/lorry types. Practitioner **shall** select the most representative type and capacity of transport for the modelled activity.

Data used for transport modes to the farm, **shall** consider the appropriate transport type and technology. Practitioner **shall** record vehicle type, capacity, load fraction and utilization rate, either from primary or expert assumptions on the transport modelled. This data **should** match the secondary data to be used to model transport. The load factor **shall** account for empty transport distance, maximum load (mass for volume limited).

If specific data cannot be obtained or estimated, practitioner **may** use a default load fraction of 80% and utilization rate of 50%. Truck transport **may** be assumed unless specific data is available.

3.4 Slaughtering

Slaughtering activities include transport of live animals to slaughterhouse, dressing of live animal to carcass and co-products and management of waste materials (when relevant). Energy required for these activities **shall** be included in modelling the inventory for slaughtering.

The inventory data **should** be collected for the slaughterhouse activity for an average of 3 calendar years from the year of assessment. If data is not available for 3 consecutive years, practitioner **shall** consider at least one calendar year.

For this time period, practitioner **shall** collect data for all parameters listed in Table 9 that are applicable to the modeled slaughterhouse activity.

Table 9 Slaughtering parameters required

Parameter	Unit	Note for practitioner
	Input	
Live animal weight	kg live animal weight yr^{-1}	If no direct data of live weight of incoming living animals in the slaughterhouse is available, live weight **shall** be determined on the basis of the method that is commonly used in the country of production and applicable for the animal type under study. E.g. dressing %.

Electricity use	kWh yr^{-1}	- Practitioner **shall** record electricity type (e.g. conventional grid mix, on site solar, CHP). - Electricity use **shall** only consider activities directly related to slaughtering.
Gas use	MJ LHV yr^{-1}	Practitioner **shall** record the amount and type of gas used.
Heat use	MJ LHV yr^{-1}	
Other fuel/energy inputs (Specify type)	MJ LHV yr^{-1}	Practitioner **shall** record all energy and fuel inputs associated to slaughtering activities only.
Water use (Specify type)	m^3 yr^{-1}	
	Transport	
Transport distance from farm to slaughter for living animals	km	- Distance **shall** be the weighted average for all suppliers for their input of animal weight. - Practitioner **shall** record vehicle type, capacity, load fraction and utilization rate, which **should** match the secondary data to be used to model transport.
	Waste management	
Wastewater to treatment	m^3	
Waste (Indicate type of waste management)	kg	- Practitioner **shall** separate waste material from by-products. - 'Waste' is material that is destined for disposal (e.g. incineration and land fill). -Practitioner **shall** collect amount of material and type of waste management system
	Energy outputs	
Biogas from digester	MJ LHV	If applicable, practitioner **shall** indicate biogas produced in excess of their own consumption.
Electricity from CHP	kWh	If electricity is produced in excess to the amount consumed on site, practitioner **shall** record the amount of electricity produced in excess.
Other energy outputs (indicate)	MJ LHV	If applicable, practitioner **shall** indicate any energy outputs in excess of their own consumption.
	Output carcass and by-products	
Carcass weight	kg carcass	- Carcass weight is defined as warm carcass weight. - Removal of head, hide, blood and internal organs. Only muscle, bone and fat left in carcass.
By-products from slaughter	kg	- Practitioner **shall** record the weight of by-products from slaughtering. This will be

dependent on the slaughterhouse/region/animal type.
-Activities related to further processing of meat (e.g. cutting ,deboning) or rendering are not within the system boundary defined in this guideline and therefore **shall** not be included as part of this inventory. E.g. If carcass by-products leave the slaughterhouse and are further processed into bio-diesel or fertilizers, the related activities are considered a separate system and **shall** not be attributed to the impact of the carcass or its by-products.

The inventory data collected from Table 9 **shall** be allocated to the different outputs of the slaughterhouse, dressed carcass and by-products. To do so, practitioner **shall** implement economic allocation, which means that all inputs, outputs and emissions will be attributed to the dressed carcass and other by-products on basis of the total associated revenue.

To perform allocation, practitioner **shall** collect data of mass of warm carcass and all its by-products along with their price at the point of slaughtering. Price data **shall** be based on average annual prices for at least a 5-year to account for market fluctuations. There **may** be instances where a by-product has zero value (e.g. contaminated products). In this case the product receives zero allocation from the upstream activities (cut-off). Table 10 provides an example of how to determine the economic allocation factor for each by-product.

Table 10 Example data requirement and calculation of economic allocation at slaughtering.

Output product	Mass (kg)	Price (value kg^{-1})	Economic allocation (%)
1. Dressed carcass			(Mass*Price)/total revenue
2. Hide			(Mass*Price)/total revenue
3. Offal			(Mass*Price)/total revenue
4. Blood			(Mass*Price)/total revenue
5. ...			(Mass*Price)/total revenue
6. ...			(Mass*Price)/total revenue
Total	**Total mass**	**Total revenue**	**100%**

Mass and prices **shall** all be based on values directly after first processing. There **may** be zero value products that are not treated as waste but further processed in e.g. rendering. These products have zero impact allocated to them and all activities associated to rendering **shall** be considered a separate system from the slaughterhouse, thus no impact from these activities is associated to the carcass or by-products.

The mass and prices for dressed carcass and by-products **should** be defined by the practitioner based on the slaughterhouse activity. If direct data from the slaughterhouse is not available, the practitioner **may** opt for two different options:

1. National/Regional data: Practitioner **may** consult with national/regional experts or literature sources on most common by-products and their mass fractions leaving the slaughterhouse.
   Based on this information, the practitioner **should** determine the value of dressed carcass and each by-product that is most representative of the market being modelled.
   Practitioners **shall** document and report all sources and assumptions made to define the mass fractions and prices for dressed carcass and by-products in specific market being modelled.
   The minimum level of detail required for by-products for which mass fraction and price **should** be determined are a) Dressed carcass, b) Hide, c) edible by-products and d) non edible by-products.
2. Practitioner **may** choose for a simplified approach. As the relevant reference flow for the study is carcass weight, most important is to define how much impact is to be attributed to the carcass, regardless of other by-products obtained. In this simplified approach, practitioner **should** allocate 90% of the inventory impact to carcass and 10% to other by-products. This simplified approach **should** only be implemented if no better information is available, and practitioner **shall** transparently report the reasons for implementing this simplified approach.

When energy is produced at the slaughterhouse and consumed on site, practitioner **shall** attribute the input of fuel and required activities for energy production to the carcass and other slaughtering by-products.
If electricity or energy is produced at the slaughterhouse in excess of the amount consumed on-site, practitioner **shall** follow the next rules:

1. Practitioners **shall** apply subdivision. This means the practitioner **shall** separate electricity or energy production from the carcass and animal by-products.
2. If subdivision is not possible, when upstream impacts or direct emissions are closely related to the carcass and by-products, the practitioner **shall** consider direct substitution of the energy streams produced (e.g. country-specific residual consumption electricity mix). This credit from substitution **shall** be allocated to carcass and other by-products the same way as all other inputs and waste from slaughterhouse.

4. Emission modelling

The following section provides a breakdown of emissions to be modelled and instructions for each. The Calculation Aid Document (available in Excel) provides all Tier 2 calculations, addressing the animal farm and crop cultivation, and Tier 1 for crop cultivation if that is the data available. Data required are outlined in Section 3 of this Guideline. This Calculation Aid is designed to be used in conjunction with LCA modelling software.

4.1 Minimum GHG to be modelled

The practitioner **shall** define the data and subsequent data quality in line with the goal and scope of the assessment. The assessment can be specific (primary data) or based on country averages or generic data (proxy). Depending on the Tier level, the considered models calculate emissions with different approaches

The practitioner **shall** as a minimum use Tier 2 approach when calculating the emissions from the animal farm. When calculating emissions from cultivation, Tier 2 approach **should** be used; however, when country-specific data are not available, the practitioner **may** adopt Tier 1 approach.

Effects of nutritional interventions or any other emission abatement activities at farm **shall** be rigorously substantiated and then either implemented as an effect in the parameters for the emission calculation based on section 4.2 or introduced as a reduction to the emissions calculated. Practitioner **shall** pay particular attention in making sure that if the effect is already captured in the parameters for the Tier 2 calculation modelling, a net reduction is not implemented on top of the emission result, avoiding double counting. If there is a higher Tier level modelling that would better reflect the effect of interventions and practitioner has the data to implement it, this **shall** be preferred over the default Tier 2 modeling approach.

4.2 Direct emissions animal farm

This content of this chapter is entirely based on (IPCC C. B., 2019), Chapter 10: Emissions from livestock and manure management.

The emissions that **shall** be modeled are the following:

- Methane (CH_4) from enteric fermentation;
- Methane (CH_4) from manure management;
- Direct nitrous oxide (N_2O) from manure management;
- Indirect nitrous oxide (N_2O) from leaching of manure;
- Indirect nitrous oxide (N_2O) from volatilization of ammonia (NH_3) and nitrogen oxides (NO_x);

4.2.1 CH_4 emissions from enteric fermentation

The methane emissions due to enteric fermentation **shall** be calculated according to the following equations:

$$CH_{4\ ent} = \sum_T CH_{4\ ent,T} \tag{4.2.1}$$

$$CH_{4\ ent,T} = EF_{met,ent,T} \cdot AAP_T \tag{4.2.2}$$

where:

- $CH_{4\ ent}$ is the total methane emission from enteric fermentation (*kg yr^{-1}*);
- The sum in equation (4.2.1) is calculated over several livestock categories and the subscript *T* indicates that the variables are relative to a specific livestock category *T*;
- $CH_{4\ ent,T}$ is the methane emission from enteric fermentation for the livestock category T (*kg yr^{-1}*);
- $EF_{met,ent,T}$ is the emission factor for methane (*kg head^{-1} yr^{-1}*) and it is calculated according to equation (4.2.3) below;
- AAP_T is the average annual population (*head*) and it **shall** be provided by the practitioner.

The emission factor **shall** be calculated using equation (4.2.3):

$$EF_{met,ent,T} = \frac{GE_T \cdot \frac{Y_{m,T}}{100} \cdot 365}{55.65} \tag{4.2.3}$$

where:

- All variables are defined for a specific livestock category *T*;
- $EF_{met,ent,T}$ is the emission factor for methane (*kg head^{-1} yr^{-1}*)
- GE_T is the gross energy intake (*MJ head^{-1} day^{-1}*) and it **shall** be provided by the practitioner;
- $Y_{m,T}$ is the methane conversion factor, i.e. the percentage of gross energy in feed converted to methane (%) and it is given as a default;
- *55.65* (*MJ kg^{-1}*) is the energy content of methane.

Practitioners **should** use country-specific values of $Y_{m,T}$, based on the analysis of the interactions between feed (type and quality) and animals (breed and genetics). When such values are unavailable, the ones provided in Table 10.12 of (IPCC C. B., 2019) **shall** be used. In the table, $Y_{m,T}$ is linked to annual milk production levels and to feed quantity and quality.

4.2.2 CH_4 emissions from manure management

The calculation of methane emissions from manure management are dependent on two main factors: the manure characteristics and the manure management system used. The manure characteristics include the amount of volatile solids (VS) excreted by the animals and the theoretical methane production. The manure management system influences the proportion of the theoretical methane production that is achieved.

The calculation of methane emissions from manure management **shall** follow the equations:

$$CH_{4\,man} = \sum_T CH_{4\,man,T} \tag{4.2.4}$$

$$CH_{4\,man,T} = AAP_T \cdot 365 \cdot VS_T \cdot B_{0,T} \cdot \rho_{met} \cdot \sum_S Frac_{S,T} \cdot MCF_S \;/\; 100 \tag{4.2.5}$$

where:

- $CH_{4\,man}$ is the total methane emission from manure management (*kg yr^{-1}*);
- The sum in equation (4.2.4) is calculated over several livestock categories and the subscript *T* indicates that the variables are relative to a specific livestock category *T*;
- $CH_{4\,man,T}$ is the methane emission from manure management for the livestock category *T* (kg yr^{-1});
- AAP_T is the average annual population (*head*) and it **shall** be provided by the practitioner;
- VS_T is the daily volatile solid excretion per animal (*kg head^{-1} yr^{-1}*) and it is calculated using equation (4.2.6) below;
- $B_{0,T}$ is the maximum methane producing capacity for manure produced (*m^3 kg^{-1}*) and it is given as a default value;
- ρ_{met} is the density of methane (0.67 *kg m^{-3}*);
- The sum is calculated over several manure management systems and the subscript *S* indicates that the variables are relative to a specific system *S*;
- $Frac_{S,T}$ is the fraction of manure that is managed in the manure management system *S* (*dimensionless*) and it **shall** be provided by the practitioner;
- MCF_S is the integrated methane conversion factor dependent on manure management system (*%*) and temperature and it is given as a default value.

Default values for the parameters $B_{0,T}$, in case country-specific measurements are not available, can be found in Table 10.16 of (IPCC C. B., 2019). Default MCF values are reported in Table 10.17 of (IPCC C. B., 2019).

Volatile Solids (VS) excretion **shall** be calculated through equation (4.2.6):

$$VS_T = \left[GE_T \cdot \left(1 - \frac{DE_T}{100}\right) + (UE_T \cdot GE_T)\right] \cdot \frac{1 - ASH_T}{18.45} \tag{4.2.6}$$

where:

- All variables are defined for a specific livestock category *T*;
- VS_T is the daily volatile solid excretion per animal (*kg head^{-1} yr^{-1}*);
- GE_T is the gross energy intake (*MJ head^{-1} yr^{-1}*) and it **shall** be provided by the practitioner;
- DE_T is the diet digestibility expressed as a fraction of gross energy (*%*) and it **shall** be provided by the practitioner;
- UE_T is the urinary energy expressed as a fraction of gross energy (*dimensionless*) and it **shall** be provided by the practitioner;
- ASH_T is the ash content of feed (*dimensionless*) and it **shall** be provided by the practitioner;
- 18.45 (*MJ kg^{-1}*) is a constant representing the energy content of methane.

4.2.3 Direct N_2O emissions from manure management

The estimation of direct N_2O emissions entails multiplying the total amount of nitrogen excretion in each type of manure management system by an emission factor for that type of system, and summing the obtained values. The emissions **shall** then be calculated using the following equations:

$$N_2O_{dir} = \sum_T N_2O_{dir,T} \tag{4.2.7}$$

$$N_2O_{dir,T} = \sum_S \left[(AAP_T \cdot N_{ex,T} \cdot Frac_{S,T} + N_{cdg,s}) \cdot EF_{nit,S} \right] \cdot \frac{44}{28} \tag{4.2.8}$$

where:

- N_2O_{dir} is the total nitrous oxide emission from manure management (*kg yr⁻¹*);
- The sum in equation (4.2.7) is calculated over several livestock categories and the subscript *T* indicates that the variables are relative to a specific livestock category *T*;
- $N_2O_{dir,T}$ is the nitrous oxide emission from manure management for the livestock category *T* (*kg yr⁻¹*);
- The sum in equation (4.2.8) is calculated over several manure management systems and the subscript *S* indicates that the variables are relative to a specific system *S*;
- AAP_T is the average annual population (*head*) and it **shall** be provided by the practitioner;
- $N_{ex,T}$ is the annual average N excretion per animal (*kg head⁻¹ yr⁻¹*) and it is calculated using equation (4.2.9) below;
- $Frac_{S,T}$ is the fraction of manure that is managed in the manure management system *S* (*dimensionless*) and it **shall** be provided by the practitioner;
- $N_{cdg,s}$ is the annual nitrogen input via co-digestate for the anaerobic digestion (*kg yr⁻¹*) and it **shall** be provided by the practitioner;
- $EF_{nit,S}$ is the emission factor for direct nitrous oxide emissions from the manure management system *S* (*dimensionless*) and it is given as a default value;
- $\frac{44}{28}$ is the conversion factor between $N_2O - N$ emissions and N_2O emissions.

Default values for the parameters $EF_{nit,S}$ (referred to as EF_3), in case country-specific measurements are not available, can be found in Table 10.21 of (IPCC C. B., 2019).

Rates of annual N excretion **shall** be derived as follows:

$$N_{ex,T} = N_{intake,T} \cdot (1 - N_{retention\ frac,T}) \cdot 365 \tag{4.2.9}$$

where:

- All variables are defined for a specific livestock category *T*;
- $N_{ex,T}$ is the annual average N excretion per animal (*kg head⁻¹ yr⁻¹*);
- $N_{intake,T}$ is the daily nitrogen intake per animal (*kg head⁻¹ day⁻¹*) and it is calculated using equation (4.2.10);
- $N_{retention\ frac,T}$ is the fraction of daily N intake that is retained by the animal (*dimensionless*) and it is calculated using equation (4.2.11) below.

The daily nitrogen intake rate **shall** be calculated according to the equation:

$$N_{intake,T} = \frac{GE_T}{18.45} \cdot \frac{CP_T/100}{6.25} \tag{4.2.10}$$

where:

- All variables are defined for a specific livestock category *T*;

- $N_{intake,T}$ is the daily nitrogen intake per animal (*kg head⁻¹ day⁻¹*);
- GE_T is the overall diet gross energy intake per animal (*MJ head⁻¹ day⁻¹*) and it **shall** be provided by the practitioner;
- 18.45 is the conversion factor for dietary GE in kg of dry matter (*MJ kg⁻¹*);
- CP_T is the crude protein content in the overall diet (*%*) and it **shall** be provided by the practitioner;
- 6.25 is the conversion factor from kg of dietary crude protein to kg of dietary N (*dimensionless*).

The fraction of nitrogen retained by the animal **shall** be calculated according to equation (4.2.11):

$$N_{retention\ frac,T} = \frac{MILK \cdot \left(\frac{MILK_{pr}}{100}\right)}{6.38} + \frac{WG_T \cdot \frac{268 - \frac{7.03 * NE_{g,T}}{WG_T}}{1000}}{6.25} \qquad (4.2.11)$$

where:

- Most of the variables are defined for a specific livestock category *T*;
- $N_{retention\ frac,T}$ is the fraction of daily N intake that is retained by the animal (*dimensionless*);
- $MILK$ is the milk production per animal (*kg head⁻¹ day⁻¹*), applicable to suckler cows only, and it **shall** be provided by the practitioner;
- $MILK_{pr}$ is the percentage of protein in the milk (*%*), applicable to suckler cows only, and it is given as a default value;
- 6.38 is the conversion factor from milk protein to milk nitrogen (*dimensionless*);
- WG_T is the animal weight gain (*kg day⁻¹*), and it **shall** be provided by the practitioner;
- 1000 is the conversion factor from *g* to *kg*;
- $NE_{g,T}$ is the net energy for growth (*MJ day⁻¹*) and it is calculated using equation (4.2.12) below;
- 6.25 is the conversion factor from kg of dietary crude protein to kg of dietary N (*dimensionless*).

The default value for the parameter $MILK_{pr}$ is 3.04%; alternatively, it can be found in Table 10A.1 of (IPCC C. B., 2019).

Finally, the net energy for growth **shall** be derived as follows:

$$NE_{g,T} = 22.02 \cdot \left(\frac{BW_T}{C_T \cdot MW_T}\right)^{0.75} \cdot WG_T^{1.097} \qquad (4.2.12)$$

where:

- All variables are defined for a specific livestock category *T*;
- $NE_{g,T}$ is the net energy for growth (*MJ day⁻¹*);
- BW_T is the average live body weight of the animals in the population (*kg*) and it **shall** be provided by the practitioner;
- C_T is a coefficient (*dimensionless*) with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls;
- MW_T is the mature body weight of an adult animal in moderate body condition (*kg*) and it **shall** be provided by the practitioner;
- WG_T is the animal weight gain (*kg day⁻¹*), and it **shall** be provided by the practitioner.

4.2.4 Indirect N_2O emissions from leaching of manure

Nitrogen is lost through runoff and leaching into soils from the solid storage of manure at outdoor areas and in feedlots. The amount of nitrous oxide emitted through leaching **shall** be calculated equation (4.2.13):

$$N_2O_{ind,leach} = N_{leach} \cdot EF_{leach} \cdot \frac{44}{28} \qquad (4.2.13)$$

where:

- $N_2O_{ind,leach}$ is the total indirect nitrous oxide emission from leaching of manure (*kg yr⁻¹*);

- N_{leach} is the total amount of manure lost due to leaching (*kg yr⁻¹*) and it is calculated using equation (4.2.14) below;
- EF_{leach} is the emission factor for N_2O emissions from nitrogen leaching and runoff, (*dimensionless*) and it is given as a default value;
- $\frac{44}{28}$ is the conversion factor between $N_2O - N$ emissions and N_2O emissions.

The default values for EF_{leach} is given in Table 11, obtained from Table 11.3 of (IPCC C. B., 2019).

The total amount of manure lost due to leaching and run off **shall** be derived as follows:

$$N_{leach} = \sum_{T} N_{leach,T} \tag{4.2.14}$$

$$N_{leach,T} = \sum_{S} \left[(AAP_T \cdot N_{ex,T} \cdot Frac_{S,T} + N_{cdg,s}) \cdot Frac_{leach,S,T} \right] \tag{4.2.15}$$

where:

- N_{leach} is the total amount of manure lost due to leaching (*kg yr⁻¹*);
- The sum in equation (4.2.14) is calculated over several livestock categories and the subscript *T* indicates that the variables are relative to a specific livestock category *T*;
- $N_{leach,T}$ is the amount of manure lost due to leaching for the livestock category *T* (*kg yr⁻¹*);
- The sum in equation (4.2.15) is calculated over several manure management systems and the subscript *S* indicates that the variables are relative to a specific system *S*;
- AAP_T is the average annual population (*head*) and it **shall** be provided by the practitioner;
- $N_{ex,T}$ is the annual average N excretion per animal (*kg head⁻¹ yr⁻¹*) and it is calculated using equation (4.2.9) above;
- $Frac_{S,T}$ is the fraction of manure that is managed in the manure management system *S* (*dimensionless*) and it **shall** be provided by the practitioner;
- $N_{cdg,s}$ is the annual nitrogen input via co-digestate for the anaerobic digestion (*kg yr⁻¹*) and it **shall** be provided by the practitioner;
- $Frac_{leach,S,T}$ is the fraction of managed manure nitrogen that is leached from the manure management system *S* (*dimensionless*) and it is given as a default value.

Default values for the parameters $Frac_{leach,S,T}$ (referred to as $Frac_{leach\_MS}$) can be found in Table 10.22 of (IPCC C. B., 2019).

4.2.5 Indirect N_2O emissions from volatilization of NH_3 and NO_x

Nitrogen in the volatilized form of ammonia **may** be deposited at sites downwind from manure handling areas and contribute to indirect N_2O emissions. The amount of nitrous oxide emitted through volatilization in forms of NH_3 and NO_x **shall** be calculated using equation (4.2.16):

$$N_2O_{ind,vol} = N_{vol} \cdot EF_{vol} \cdot \frac{44}{28} \tag{4.2.16}$$

where:

- $N_2O_{ind,vol}$ is the total indirect nitrous oxide emission from volatilization of NH_3 and NO_x (*kg yr⁻¹*);
- N_{vol} is the total amount of manure lost due to volatilization (*kg yr⁻¹*) and it is calculated using equation (4.2.17) below;
- EF_{vol} is the emission factor for N_2O emissions from nitrogen volatilization (*dimensionless*) and it is given as a default value;

- $\frac{44}{28}$ is the conversion factor between $N_2O - N$ emissions and N_2O emissions.

The default value for EF_{vol} is given in Table 11, obtained from Table 11.3 of (IPCC C. B., 2019).

The amount of manure lost due to volatilization **shall** be derived as follows:

$$N_{vol} = \sum_T N_{vol,T} \tag{4.2.17}$$

$$N_{vol,T} = \sum_S \left[(AAP_T \cdot N_{ex,T} \cdot Frac_{S,T} + N_{cdg(s)}) \cdot Frac_{vol,S,T} \right] \tag{4.2.18}$$

where:

- N_{vol} is the total amount of manure lost due to volatilization (*kg yr*$^{-1}$);
- The sum in equation (4.2.17) is calculated over several livestock categories and the subscript *T* indicates that the variables are relative to a specific livestock category *T*;
- $N_{vol,T}$ is the amount of manure lost due to volatilization for the livestock category *T* (*kg yr*$^{-1}$);
- The sum in equation (4.2.18) is calculated over several manure management systems and the subscript *S* indicates that the variables are relative to a specific system *S*;
- AAP_T is the average annual population (*head*) and it **shall** be provided by the practitioner;
- $N_{ex,T}$ is the annual average N excretion per animal (*kg head*$^{-1}$ *yr*$^{-1}$) and it is calculated using equation (4.2.9);
- $Frac_{S,T}$ is the fraction of manure that is managed in the manure management system *S* (*dimensionless*) and it **shall** be provided by the practitioner;
- $N_{cdg,s}$ is the annual nitrogen input via co-digestate for the anaerobic digestion (*kg yr*$^{-1}$) and it **shall** be provided by the practitioner;
- $Frac_{vol,S,T}$ is the fraction of managed manure nitrogen that is volatilized from the manure management system *S* (*dimensionless*) and it is given as a default value.

Default values for the parameters $Frac_{vol,S,T}$ (referred to as $Frac_{Gas\_MS}$) can be found in Table 10.22 of (IPCC C. B., 2019).

Table 11: Default values for emission factors for leaching and volatilization of manure, to calculate indirect nitrous oxide emissions (from Table 11.3 of (IPCC C. B., 2019)).

EF_{leach}	EF_{vol}
0.011	0.010

4.3 Emissions from feed crop cultivation

This content of this chapter is mostly based on (IPCC C. B., 2019), Chapter 11: N_2O emissions from managed soils, and CO_2 emissions from lime and urea application.

The emissions that **shall** be modeled are the following:

- Direct nitrous oxide (N_2O) from managed soil;
- Indirect nitrous oxide (N_2O) from managed soil;
- Carbon dioxide (CO_2) from liming;
- Carbon dioxide (CO_2) from urea fertilization;
- Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions from drained organic soils (peat).

4.3.1 Direct N2O emissions from managed soil

Direct N_2O emissions from managed soils **shall** be estimated using equation (4.3.1):

$$N_2O_{soil,dir} = \left(N_2O\text{-}N_{input} + N_2O\text{-}N_{PRP}\right) \cdot \frac{44}{28} \tag{4.3.1}$$

where:

- $N_2O_{soil,dir}$ is the total direct nitrous oxide emission from managed soils (*kg yr^{-1}*);
- $N_2O\text{-}N_{input}$ is the direct $N_2O\text{-}N$ emission from N inputs to managed soils (*kg yr^{-1}*) and it is calculated using equations (4.3.2) below;
- $N_2O\text{-}N_{PRP}$ is the direct $N_2O\text{-}N$ emission from urine and dung inputs to grazed soils (*kg yr^{-1}*) and it is calculated using equations (4.3.3) below;

The $N_2O\text{-}N$ emissions are calculated using the following equations:

$$N_2O\text{-}N_{input} = \sum_i (F_{SN} + F_{ON})_i \cdot EF_{1,i} + F_{CR} \cdot EF_1 \tag{4.3.2}$$

$$N_2O\text{-}N_{PRP} = \sum_i F_{PRP,i} \cdot EF_{3,i} \tag{4.3.3}$$

where:

- The sums in equation (4.3.2) and (4.3.3) are calculated over different conditions (e.g. wet or dry climates) and the subscript *i* indicates that the variables are relative to a specific condition *i*;
- $F_{SN,i}$ is the annual amount of synthetic fertilizer N applied to soils (*kg yr^{-1}*) and it **shall** be provided by the practitioner;
- $F_{ON,i}$ is the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (*kg yr^{-1}*) and it is calculated using equations (4.3.4) below;
- F_{CR} is the annual amount of N in crop residues (above and below ground), including N-fixing crops, and from forage/pasture renewal, returned to soils (*kg yr^{-1}*) and it is calculated using equations (4.3.5) below;
- $EF_{1,i}$ is the emission factor developed for N_2O emissions from synthetic fertiliser and organic N application (*dimensionless*) and it **should** be provided by the practitioner;
- $F_{PRP,i}$ is the annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock (*kg yr^{-1}*) and it is calculated using equations (4.3.9) below;
- $EF_{3,i}$ is the emission factor developed for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals (*dimensionless*) and it **should** be provided by the practitioner.

Values for $EF_{1,i}$ and $EF_{3,i}$ **should** be country-specific and possibly retrieved from national inventories. If such values are not available, default values can be found in Table 11.1 of (IPCC C. B., 2019).

Organic fertilizers ($F_{ON,i}$) include applied animal manure, sewage sludge applied to soil, compost applied to soils, as well as other organic amendments of regional importance to agriculture (e.g., rendering waste, guano, brewery waste, etc.), and they **shall** be estimated following equation (4.3.4):

$$F_{ON,i} = F_{AM,i} + F_{SEW,i} + F_{COMP,i} + F_{OOA,i} \tag{4.3.4}$$

where:

- All variables are defined under a certain condition *i;*
- $F_{ON,i}$ is the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (*kg yr^{-1}*);
- $F_{AM,i}$ is the annual amount of animal manure N applied to soils (*kg yr^{-1}*) and it **shall** be provided by the practitioner;
- $F_{SEW,i}$ is the annual amount of total sewage N applied to soils (*kg yr^{-1}*) and it **shall** be provided by the practitioner;

- $F_{COMP,i}$ is the annual amount of total compost N applied to soils (*kg yr^{-1}*) and it **shall** be provided by the practitioner;
- $F_{OOA,i}$ is the annual amount of other organic amendments used as fertilizer (e.g., rendering waste, guano, brewery waste, etc.) (*kg yr^{-1}*) and it **shall** be provided by the practitioner.

The practitioner **shall** ensure that the amounts $F_{SEW,i}$ and $F_{COMP,i}$ are not double-counted. If values for $F_{AM,i}$ are not available, the quantity **may** be determined using equation 11.4 of (IPCC C. B., 2019).

The amount of N in crop residues (above-ground and below-ground), including N-fixing crops, returned to soils annually (F_{CR}) **shall** be estimated following equation (26):

$$F_{CR} = \sum_{C} AGR_C \cdot N_{AG,C} \cdot \left(1 - Frac_{remove,C} - Frac_{burnt,C} \cdot C_f\right) + BGR_C \cdot N_{BG,C} \tag{4.3.5}$$

where:

- F_{CR} is the amount of N in crop residues returned to soils (*kg yr^{-1}*);
- The sum is calculated over different crops and the subscript *C* indicates that the variables are relative to a specific crop *C*;
- AGR_C is the annual total amount of above-ground crop residue (*kg yr^{-1}*) and it **shall** be provided by the practitioner;
- $N_{AG,C}$ is the N content of above-ground residues (*dimensionless*) and it given as a default value;
- $Frac_{remove,C}$ is the fraction of above-ground residues of crop removed annually for purposes such as feed, bedding and construction (*dimensionless*) and it **shall** be provided by the practitioner (based on a survey of experts in the country). If this is not available, no removal **shall** be assumed;
- $Frac_{burnt,C}$ is the fraction of annual harvested area of crop burnt (*dimensionless*) and it **shall** be provided by the practitioner;
- C_f is a combustion factor (*dimensionless*) and it is given as a default value;
- BGR_C is the annual total amount of below-ground crop residue (*kg yr^{-1}*) and it is calculated using equations (4.3.6) below;
- $N_{BG,C}$ is the N content of below-ground residues (*dimensionless*) and it given as a default value.

Crop-specific default values for $N_{AG,C}$ and $N_{BG,C}$, if not available, can be found in Table 11.1A of (IPCC C. B., 2019) (referred to as $N_{AG(T)}$ and $N_{BG(T)}$, respectively). Values for C_f are given in Table 2.6 of (IPCC C. B., 2019).

The value of BGR_C **shall** be calculated using equation (4.3.6):

$$BGR_C = \left(Crop_C + AG_{DM,C}\right) \cdot RS_C \cdot Area_C \cdot Frac_{renew,C} \tag{4.3.6}$$

with

$$Crop_C = Yield\ Fresh_C \cdot DRY_C \tag{4.3.7}$$

and

$$AG_{DM,C} = Crop_C \cdot R_{AG,C} \tag{4.3.8}$$

where:

- All variables are defined for a specific crop *C;*
- $Crop_C$ is the harvested dry matter yield (*kg ha^{-1}*);
- $AG_{DM,C}$ is the above-ground residue dry matter (*kg ha^{-1}*);
- RS_C is the ratio of below-ground root biomass to above-ground shoot biomass (*dimensionless*), and it given as a default value;
- $Area_C$ is the total annual area harvested (*ha*) and it **shall** be provided by the practitioner;
- $Frac_{renew,C}$ is the fraction of total area that is renewed annually (*dimensionless*): for countries where pastures are renewed on average every X years, $Frac_{renew,C}$ = 1/X, whereas for annual crops $Frac_{renew,C}$ = 1;
- $Yield\ Fresh_C$ is the harvested fresh yield (*kg yr^{-1}*) and it **shall** be provided by the practitioner;

- DRY_C is the dry matter fraction of harvested crop (*dimensionless*) and it given as a default value;
- $R_{AG,C}$ is the ratio of above-ground residue dry matter to harvested yield (*dimensionless*) and it given as a default value;

Crop-specific default values for RS_C, DRY_C and $R_{AG,C}$, if not available, can be found in Table 11.1A of (IPCC C. B., 2019) (referred to as $RS_{(T)}$, DRY and $R_{AG(T)}$, respectively).

The annual amount of N deposited on pasture, range and paddock soils by grazing animals ($F_{PRP,i}$) **shall** be calculated as follows:

$$F_{PRP,i} = \sum_T AAP_{T,i} \cdot N_{ex,T,i} \cdot MS_{PRP,T,i} \tag{4.3.9}$$

where:

- All variables are defined under a certain condition *i;*
- $F_{PRP,i}$ is the amount of urine and dung N deposited by grazing animals (*kg yr^{-1}*);
- The sum is calculated over several livestock categories and the subscript *T* indicates that the variables are relative to a specific livestock category *T*;
- $AAP_{T,i}$ is the average annual population (*head*) and it **shall** be provided by the practitioner;
- $N_{ex,T,i}$ is the annual average N excretion per animal (*kg head^{-1} yr^{-1}*) and it is calculated using equation (4.2.9) above;
- $MS_{PRP,T,i}$ is the fraction of total annual N excretion for each livestock species/category *T* that is deposited on pasture, range and paddock (dimensionless) and it **shall** be provided by the practitioner (it is equivalent to the fraction of time spent by the animal on pasture, range and paddock).

4.3.2 Indirect N_2O emissions from managed soil

N_2O is also emitted from the N volatilisation/deposition and N leaching, as illustrated in section 4.2.

The N_2O emissions from atmospheric deposition of N volatilised from managed soil **shall** be estimated using equation (4.3.10):

$$N_2O_{soil,ind,vol} = \sum_i \left[F_{SN,i} \cdot Frac_{GASF,i} + (F_{ON} + F_{PRP})_i \cdot Frac_{GASM,i}\right] \cdot EF_{4,i} \cdot \frac{44}{28} \tag{4.3.10}$$

where:

- $N_2O_{soil,ind,vol}$ is the total indirect nitrous oxide emission from volatilization of N from managed soil (*kg yr^{-1}*);
- The sum is calculated over different conditions (e.g. wet or dry climates) and the subscript *i* indicates that the variables are relative to a specific condition;
- $F_{SN,i}$ is the annual amount of synthetic fertilizer N applied to soils (*kg yr^{-1}*) and it **shall** be provided by the practitioner;
- $Frac_{GASF,i}$ is the fraction of synthetic fertiliser N that volatilises as NH_3 and NO_x under a certain condition (*dimensionless*) and it **should** be provided by the practitioner;
- $F_{ON,i}$ is the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (*kg yr^{-1}*) and it is calculated using equations (4.3.4) above;
- $F_{PRP,i}$ is the annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock (*kg yr^{-1}*) and it is calculated using equations (4.3.9) above;
- $Frac_{GASM,i}$ is the fraction of organic fertiliser N that volatilises as NH_3 and NO_x under a certain condition (*dimensionless*) and it **should** be provided by the practitioner;
- $EF_{4,i}$ is the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (*dimensionless*) and it **should** be provided by the practitioner;

Values for $Frac_{GASF,i}$, $Frac_{GASM,i}$ and $EF_{4,i}$ **should** be country-specific and possibly retrieved from national inventories. If such values are not available, default values can be found in Table 11.3 of (IPCC C. B., 2019).

The N_2O emissions from leaching and runoff in regions where leaching and runoff occurs **shall** be estimated using equation (4.3.11):

$$N_2O_{soil,ind,leach} = \sum_i (F_{SN} + F_{ON} + F_{PRP} + F_{CR})_i \cdot Frac_{leach-H,i} \cdot EF_{5,i} \cdot \frac{44}{28} \qquad (4.3.11)$$

where:

- $N_2O_{soil,ind,leach}$ is the total indirect nitrous oxide emission from leaching of N from managed soil (*kg yr^-1^*);
- The sum is calculated over different conditions (e.g. wet or dry climates) and the subscript *i* indicates that the variables are relative to a specific condition;
- $F_{SN,i}$ is the annual amount of synthetic fertilizer N applied to soils ($kg\ yr^{-1}$) and it **shall** be provided by the practitioner;
- $F_{ON,i}$ is the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils ($kg\ yr^{-1}$) and it is calculated using equations (4.3.4) above;
- $F_{PRP,i}$ is the annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock ($kg\ yr^{-1}$) and it is calculated using equations (4.3.9) above;
- $F_{CR,i}$ is the annual amount of N in crop residues (above and below ground), including N-fixing crops, and from forage/pasture renewal, returned to soils ($kg\ yr^{-1}$) and it is calculated using equations (4.3.5) above;
- $Frac_{leach-H,i}$ is the fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff (*dimensionless*) and it **should** be provided by the practitioner;
- $EF_{5,i}$ is the emission factor for N_2O emissions from N leaching and runoff (*dimensionless*) and it **should** be provided by the practitioner;

Values for $Frac_{leach-H,i}$ and $EF_{5,i}$ **should** be country-specific and possibly retrieved from national inventories. If such values are not available, default values can be found in Table 11.3 of (IPCC C. B., 2019).

4.3.3 CO_2 emissions from liming

Adding lime to soils leads to CO2 emissions as the carbonate limes dissolve. The emissions are calculated following equation (4.3.12):

$$CO_{2,soil,liming} = (M_{limestone} \cdot EF_{limestone} + M_{dolomite} \cdot EF_{dolimite}) \cdot \frac{44}{12} \qquad (4.3.12)$$

where:

- $CO_{2,soil,liming}$ is the carbon dioxide emission from lime application ($kg\ yr^{-1}$);
- $M_{limestone}$ and $M_{dolomite}$ are the annual amount of calcic limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) used ($kg\ yr^{-1}$), respectively, and they **shall** be provided by the practitioner;
- $EF_{limestone}$ and $EF_{dolomite}$ are the emission factors for CO_2 emissions from liming (dimensionless) and they **should** be provided by the practitioner.

Values for $EF_{limestone}$ and $EF_{dolomite}$ **should** be country-specific (and hence entail, for example, differentiation of sources with variable compositions of lime) and possibly retrieved from national inventories. If such values are not available, the default values are, respectively, 0.12 for limestone and 0.13 for dolomite.

4.3.4 CO_2 emissions from urea fertilization

Adding urea to soils during fertilisation leads to a loss of CO_2 that was fixed in the industrial production process. The emissions are calculated following equation (4.3.13):

$$CO_{2,soil,urea} = M_{urea} \cdot EF_{urea} \cdot \frac{44}{12} \tag{4.3.13}$$

where:

- $CO_{2,soil,urea}$ is the carbon dioxide emission from urea application (*kg yr^{-1}*);
- M_{urea} is the annual amount of urea used (*kg yr^{-1}*) and it **shall** be provided by the practitioner;
- EF_{urea} is the emission factor for CO_2 emissions from urea application (dimensionless) and it **should** be provided by the practitioner.

The value for EF_{urea} **should** be country-specific and possibly retrieved from national inventories. If such value is not available, the default value is 0.20.

4.3.5 Carbon dioxide (CO2), methane (CH4) and nitrous oxide (N_2O) emissions from drained organic soils (peat)

4.3.5.1 Tier 1 approach

Greenhouse gas emissions from drained peat soils **should** be included in the LCI, following (IPCC, 2014) chapter 2.2.1.1 (CO_2), chapter 2.2.2.1 (CH_4) and chapter 2.2.2.2 (N_2O).

For all GHG emissions estimations of drained organic soils, the calculation is based on the factor A, which for each crop-country combination is defined as the share of cultivated area on organic soils and estimated with equation (4.3.14):

$$A = \frac{area\ of\ crop\ in\ country\ on\ drained\ organic\ soils}{total\ area\ of\ crop\ in\ country} \tag{4.3.14}$$

This parameter **should** be based on primary data, or on national surveys. If these are not available, secondary data sources **may** be used (country specific National Inventory Report submission).

Once *A* is determined per crop and country, greenhouse gases emissions can be calculated.

For CO_2 emissions, the following equation **shall** be used:

$$CO_{2,soil,organic} = \sum_{c,n,d} \left(A \cdot EF_{CO_2,organic}\right)_{c,n,d} \cdot \frac{44}{12} \tag{4.3.15}$$

where:

- $CO_{2,soil,organic}$ is the annual on-site CO_2 emissions/removals from drained organic soils in a land-use category (*kg yr^{-1}*);
- The sum is calculated over different climate domains (subscript c), nutrient statuses (subscript n) and drainage classes (subscript d);
- $A_{c,n,d}$ is the share of cultivated area on organic soils for climate domain c, nutrient status n and drainage class d (*ha*) and it **shall** be provided by the practitioner;
- $EF_{CO_2,organic\ (c,n,d)}$ is the emission factor for drained organic soils, for climate domain c, nutrient status n and drainage class d (*kg ha^{-1} yr^{-1}*). This can be based on default values from Table 2.1 of (IPCC, 2014) (Tier 1). When country specific EFs are available, they **shall** be used (Tier 2).

For CH_4 emissions, the following equation **shall** be used:

$$CH_{4,soil,organic} = \sum_{c,n,d} \left(A_{c,n,d} \cdot \left((1 - Frac_{ditch}) \cdot EF_{CH_4,land_{c,n,d}} + Frac_{ditch} \cdot EF_{CH_4,ditch_{c,d}} \right) \right) \quad (4.3.16)$$

where:

- $CH_{4,soil,organic}$ is the annual CH4 loss from drained organic soils (*kg yr^{-1}*);
- $A_{c,n,d}$ is the share of cultivated area on organic soils for climate domain c, nutrient status n and drainage class d (*ha*) and it **shall** be provided by the practitioner;
- $EF_{CH_4,land_{c,n,d}}$ is the emission factor for direct CH_4 emissions from drained organic soils, for climate zone c and nutrient status n, and drainage class d (*kg ha^{-1} yr^{-1}*). This can be based on default values from Table 2.3 of (IPCC, 2014) (Tier 1). When country specific EFs are available, they **shall** be used (Tier 2).
- $EF_{CH_4,ditch_{c,d}}$ is the emission factor for direct CH_4 emissions from drainage ditches, for climate zone c and drainage class d (*kg ha^{-1} yr^{-1}*). This can be based on default values from Table 2.4 of (IPCC, 2014) (Tier 1). When country specific EFs are available, they **shall** be used (Tier 2).
- $Frac_{ditch}$ is the fraction of the total area of drained organic soil which is occupied by ditches, where "ditches" are considered to be any area of manmade channel cut into the peatland (*dimensionless*). The ditch area **may** be calculated as the width of ditches multiplied by their total length. Where ditches are cut vertically, ditch width can be calculated as the average distance from bank to bank. Where ditch banks are sloping, ditch width **should** be calculated as the average width of open water plus any saturated fringing vegetation. This can be based on default values from Table 2.4 and Table 2A.1 of (IPCC, 2014) (Tier 1). When country specific EFs are available, they **shall** be used (Tier 2).

For N_2O emissions, the following equation **shall** be used:

$$N_2O_{soil,organic} = \sum_{c,n,d} \left(A_{c,n,d} \cdot EF_{N_2O,organic} \right) \cdot \frac{44}{28} \quad (4.3.17)$$

where:

- $N_2O_{soil,organic}$ is the total direct nitrous oxide emission from managed soils (*kg yr^{-1}*);
- $A_{c,n,d}$ is the share of cultivated area on organic soils for climate domain c, nutrient status n and drainage class d (*ha*) and it **shall** be provided by the practitioner;
- $EF_{N_2O,organic}$ is the emission factor for drained organic soils, for climate domain c, nutrient status n and drainage class d (*kg ha^{-1} yr^{-1}*). This can be based on default values from Table 2.5 of (IPCC, 2014) (Tier 1). When country specific EFs are available, they **shall** be used (Tier 2).

4.4 Inclusion and treatment of direct land use change

All carbon emissions and removals derived from changes in carbon stocks (changes in soil carbon and changes in above- and below-ground biomass) as a direct result of land use change, **shall** be modelled following the modelling guidelines of PAS 2050:2011 (BSI 2011) and PAS2050-1:20 (BSI 2012) for horticultural products.

The assessment of the impact of land use change **shall** include all direct land use change occurring not more than 20 years, or a single harvest period, prior to undertaking the assessment (whichever is the longer). The total GHG emissions and removals arising from direct land use change over that period **shall** be included in the quantification of GHG emissions of products arising from this land on the basis of equal allocation to each year of the period. PAS 2050:2011 (BSI 2011)

When calculating GHG emissions resulting from direct land use change, the following hierarchy **shall** be followed:

1) When the previous land and country of production is known, the GHG emissions and removals occurring as a result of direct land use change (dLUC) within a period of 20 years **shall** be assessed in accordance with the relevant sections of the IPCC Guidelines for National Greenhouse Gas Inventories (V4, Ch 02, Ch 04, Ch 06,Ch 07), considering the appropriate land use and climate type.

2) For arable or perennial feed crops, when the previous land use is unknown, practitioner **shall** refer to of PAS 2050-1: 2012 (BSI, 2012).

   In PAS 2050-1: 2012 (BSI, 2012) the procedure to calculate emissions is calculated by deriving a weighted country average of transformation of land use categories in the country to perennial or annual cropland.

   The rate of expansion and contraction of forest and grassland per country within 20 years are based on data from FAO (FAO, 2021) considering a 3 year average.

   Expansion and contraction of specific crop is based on FAO harvested area change in 20 years considering a 3-year average.

   For each crop the share of expansion in relation to the total crop area is assessed (ha expanded/ha crop). This share is expansion is associated to a specific land transformation, based on the weighted average of the land transformation in a country in hectares at the expense of forest, grassland, perennial crop and annual crop are calculated.

   Emissions **shall** be subsequently calculated following guidance from the relevant sections of the IPCC Guidelines for National Greenhouse Gas Inventories and included in the CFP. An example of this calculation is provided in in Annex B of of PAS 2050-1: 2012 (BSI, 2012).

3) For grassland, where the country of production is known, but the former land use is not known or it can not be demonstrated that no land use change occurred, the GHG emissions arising from land use change **shall** be the estimated of average emissions from the land use change grassland in that country.

The net dLUC GHG emissions and removals **shall** be documented separately in the CFP study report.

If the practitioner can prove and document that land use change occurred more than 20 years prior to the year of assessment, no emissions from direct land use change (dLUC) **shall** be included in the CFP.

5. Reporting

5.1 Results

Once data collection for all life cycle stages is complete and appropriately allocated, practitioner **shall** quantify the total inventory results of total emissions per type of GHG and CO_2equivalents for the chosen RU.

To calculate the CO_2 equivalent, practitioner **shall** calculate results using the GWP-100 year time horizon from the most recently published IPCC report (e.g. IPCC, 2021). Practitioner **may** choose to calculate results using GWP-100 considering factors from another Assessment Report, these **shall** be reported separately.

CO_2 equivalents due to dLUC **shall** always be reported separately.

In additional to the total results, practitioner **shall** breakdown results per life cycle stage, as a minimum: Feed production, animal farm, slaughtering. A more detailed contribution analysis **may** be used to get better insight on the main drivers of the CFP of the system under study. The granularity of this analysis **may** be chosen by the practitioner in alignment to the goal and scope of the study.

This guideline provides a default approach for allocation in several instances of multi-functionality. Practitioners wishing to implement an alternative approach **may** do so. The underlying data and methodology implemented for any alternative approach **shall** be carefully documented and reported. Results of GHG emissions and CO_2 equivalents obtained following an alternative approach **shall** be reported separately.

5.2 Reporting requirements

The reporting of studies following this guideline depends on the practitioner and the goal and scope of the analysis.

As a minimum, practitioner **shall** integrate the following elements to the CFP report:

1. General information:
    - System description
    - Contact of study commissioner and practitioner
    - Reference to version of GRSB guideline used

2. Goal and scope:
    - Location or geographical scope
    - Reference year
    - Reference flow
    - System diagram of processes included in life cycle

3. Inventory:
    - All decisions concerning data collection and assumptions made in modelling **shall** be documented in a way that allows an independent practitioner to reproduce results.
    - All data sources **shall** be properly documented.
    - Practitioner **shall** also indicate databases used as background for modelling, and to which data point these are related.
    - Data quality **shall** be evaluated by the practitioner at least in a qualitative manner. This **shall** consider:
        - representativeness: qualitative assessment of the degree to which the data collected reflects the system in scope (i.e. geographical coverage, time period and technology coverage)
        - consistency: qualitative assessment of whether or not the study methodology is applied uniformly and consistent with the instructions set in this guideline

4. Results
    - Report of absolute results in CO2 equivalent for the chosen reference flow (including separately for dLUC and organic soils)
    - Report of absolute results per GHG as: Carbon dioxide (kgCO2), Carbon dioxide (kgCO2) from dLUC, Carbon dioxide (kg CO2) from organic soil, Methane fossil (kgCH4), Methane biogenic (kgCH4), Nitrous Oxide (kgN2O), Other (as kgCO2eq)
    - Contribution analysis: Breakdown of results per life cycle stage
    - Additional results/sensitivity: Calculations performed following an approach other that the default **shall** be reported additionally as part of, for example, a sensitivity assessment. The justification and documentation of any alternative approach implemented **shall** be provided and this deviation from the default approach in this guideline communicated.

5.3 Review requirements

A critical review process by an independent reviewer is an optional step. It is recommended in instances where results are to be communicated to an external audience.

The critical review process **shall** ensure that:

- The inventory data collection and methods implemented in the study align to this GRSB guideline;
- Method used to compile the inventory are scientifically and technically valid;
- The inventory is transparent and consistent;
- Data used is appropriate and reasonable for public reporting.

Practitioners **may** choose to conduct a critical review by only one (internal or external) independent expert or a review panel (minimum 3 members). After a critical review process, a review statement **shall** be issued providing assurance that the study was conducted in conformance to this guideline and that assumptions, limitations and results are reasonable for public reporting.

Depending on the goal of the study, practitioners **may** require additionally a specific review process to ensure alignment to ISO 14040/44. In this case, practitioner **shall** refer to specific guidance of ISO 14040 (section 7) and ISO 14044 (section 6) and additional requirements in ISO/TS 14071 (ISO, 2014).

In this case, there are several options as to how to perform a critical review for a given study, including the following:

a) the review is performed based on expert review (see ISO 14044:2006, 6.2) or panel review (see ISO 14044:2006, 6.3);

b) the review is performed concurrently or at the end of the study;

c) the review includes or excludes an assessment of the life cycle inventory (LCI) model;

d) the review includes or excludes an assessment of individual data sets.

The critical review process shall clearly define and document which options have been covered

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Appendix I

Complimentary to the carbon footprint guideline, advise is given to the practitioner conducting a study for a country of supply chain. Appendix I.I provides suggestions for the practitioner performing a country assessment, while Appendix I.II discusses considerations for assessments at the supply chain.

Appendix I.I Carbon footprint at national level

Practitioners performing a carbon footprint for a country (rather than directly for specific beef cattle farm(s)), may encounter difficulties determining the best course of action to perform such an assessment.

The decision tree in Figure A- 1 aids the practitioner determining how to best proceed with the assessment.

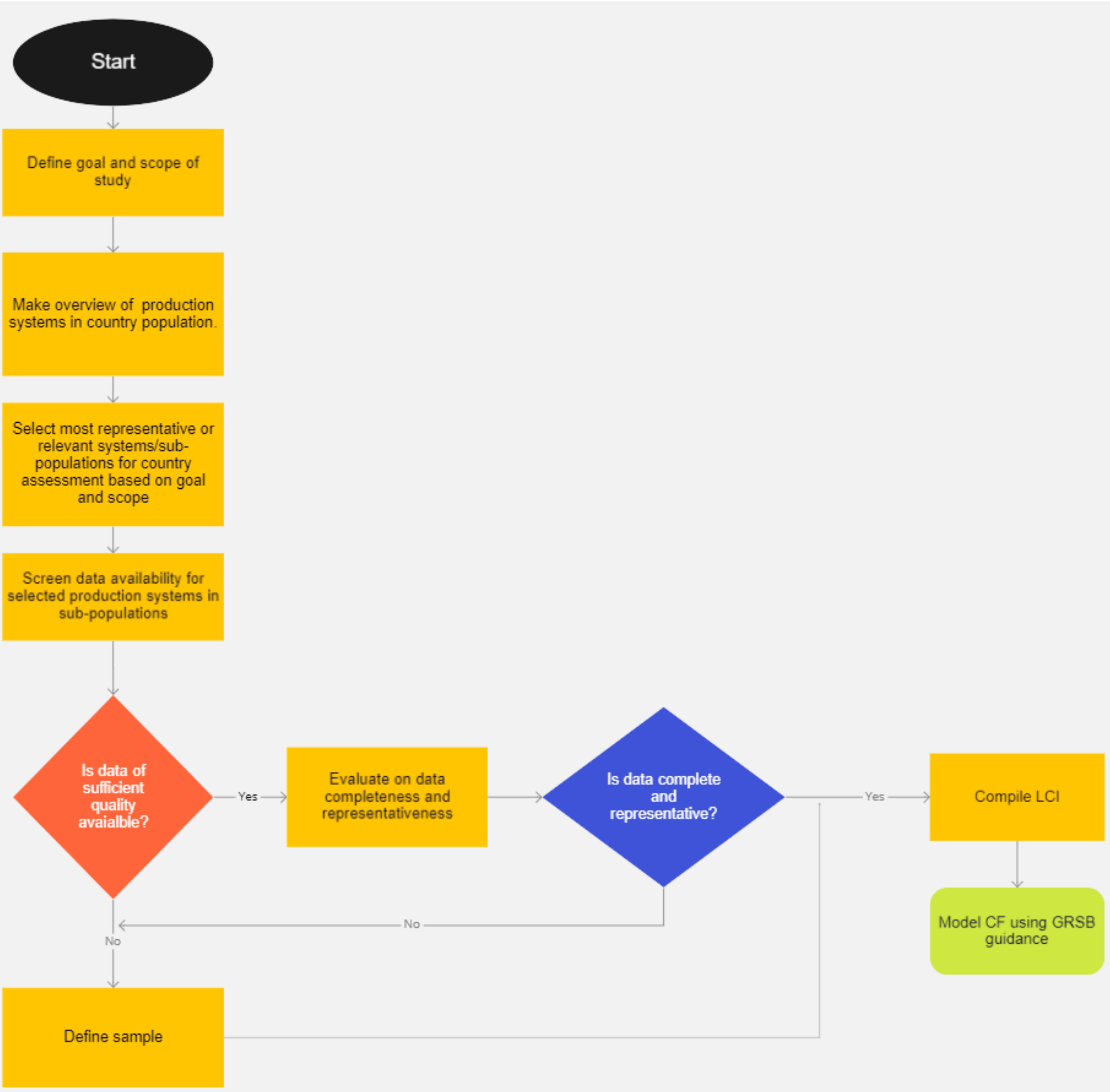

Figure A- 1 Decision tree for the development of a country assessment using GRSB guidelines for carbon footprint.

a. Overview of national beef cattle production population

The first step in performing any LCA or carbon footprint is defining the goal and scope of the study. This is explained in detail in section 2.1 of this guideline. GHG assessments for beef cattle on a national level can have multiple purposes, such as reporting GHG performance for external (marketing) communication, monitoring progress in GHG performance (often initiated by industry associations independent of cooperation with national governments), or identifying potential improvement options related to management systems and technologies. These goals determine the type of system that needs to be modelled and the data required for it. For instance, if reporting of national performance is the goal of the study, then the system should consider the most representative production systems for the national beef cattle production, but if the goal of the study was to compare specific improvements or innovations introduced in national practice for beef cattle, then the system to be modelled should include farms implementing such innovation, and representative national production is less relevant for the assessment.

Having the goal and scope of the study in mind, the practitioner should begin the assessment by making a thorough overview of the beef cattle population in a country for the time, system boundary and goal defined.

The practitioner shall make a comprehensive mapping of the country's population:

i) Which types of (sub) production system are present in the nation/supply chain?
ii) What is the share of the production from the production systems to the total national/supply chain production (live weight or carcass weight)?
iii) What are the animal flows between the production systems?
iv) Identify the common production activities and more specific production characteristics of the systems present, such as organic, nature conservation, welfare, manure management, other production criteria
v) What are the typical production routes for further quantification in relation to the goal of the study?

Practitioner may, for example, make a flow diagram including the insights of this overview.

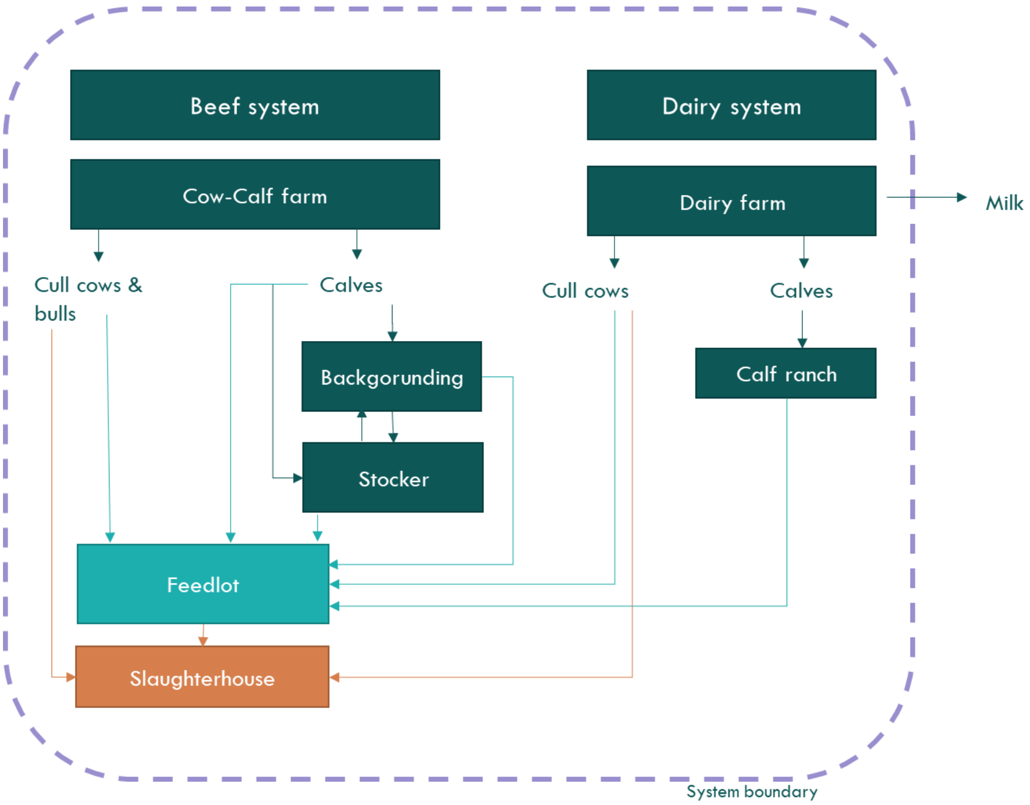

Figure A- 2 Example diagram of common beef cattle production systems in a country population

To get a more accurate representation of the national system, practitioner may group the different beef cattle production systems into appropriate sub-populations. This helps refine the country population for a more representative assessment at a national level. E.g. not only defining cow-calf operations, but cow-calf operations within a certain size range and using a specific manure management system, all grouped together.

This sub-aggregation can be based on several aspects such as type of operation, (e.g. cow-calf, backgrounding, feed lot), size of the operation, (e.g. number of heads of cattle), feeding activities, (e.g. mainly grazing or compound feed). This sub aggregation should be defined by the practitioner with the goal and scope of the study in mind and considering the relevant attributes driving the carbon footprint of beef cattle activities; e.g. sub aggregating systems based on economic revenue, may not be as relevant as classifying per manure management type.

A good rule of thumb to define relevant sub-populations within a country, is to look at the relevant categories defined in the country for their National Greenhouse Gas Inventory reporting from livestock and manure management (https://unfccc.int/ghg-inventories-annex-i-parties/2021) .

Defining the beef cattle production systems in the country and its sub-populations may be an iterative process. The practitioner can always go back to re-define the country system after gaining insights from an initial screening assessment. It is, in fact, recommended to start with a high over estimation of common beef-cattle production systems in the country population and refine the system classification into sub-populations after insights are gained from a first quick assessment.

Once the national population of beef cattle production has been mapped, the practitioner shall decide which sub-populations shall be included in the national assessment to fulfil the goal and scope of the study.

Selecting the sub-populations to be included in the analysis may depend on a number of factors, like: prioritizing the inclusion of sub-populations based on their estimated significance to GHG emissions, the number of farms belonging to that sub-population, the size of the sub-population (heads yr^{-1}), its geographical distribution and goal and scope of study (e.g. time scope or system boundary and purpose of the assessment).

Often, compromises need to be made in the selection of sub-populations in scope, e.g. selecting sub-populations with most number of farms or with most productive farms (in mass live weight) in a national assessment, may lead to not enough geographical representation if most common production systems or most productive farms are concentrated in a specific region. These compromises should be documented, and practitioner may choose to evaluate its implications in a sensitivity assessment depending on the goal and scope of the study.

The practitioner should make a selection plan documenting the selection process and reasoning for inclusion or exclusion of sub-populations containing certain production systems in the GHG assessment.

b. Gathering and scrutinizing available data sources

Once the production systems to be included in the assessment are selected, the practitioner should identify if there are data sources of sufficient quality available to conduct the GHG modelling, and which are they.

In many instances, data will already be available for the practitioner. Potential sources can be:

1. Publications or census of national institutes,
2. Sector organization statistics
3. Industry surveys
4. Interviews with country experts
5. Etc.

Practitioner should look first at the information that is at hand, as often sampling and collection of data has been done by other national agencies or industry parties.

When compiling data sources, practitioner should be critical in evaluating if the data source is reliable, verified and if it is correctly representing the sub-groups and relevant parameters defined in the country's population. E.g. available data collected based on economic criteria may not fully reflect all manure management technologies in scope, which can be a relevant driver to the GHG emissions. A combination of different sources will often be the best solution to represent your system.

The following data sources may be used to populate the GRSB GHG LCI requirements (all sources shall be documented):

1. Quantifying flow and stock information of cattle herds and animal flows from available data sources
    a. Parameters: See methodology section 3.2.1.1.
        Animal numbers, Growth, Mortality, Fertility, Transactions
    b. Searching in available data sources for:
        i. Herd statistics
        ii. Land use statistics
        iii. Slaughtering statistics
        iv. Industry data
        v. Available GHG assessments of beef production (literature, industry company/sector publications)
        vi. Available GHG assessments of dairy production
        vii. Other performance assessments (literature, industry company/sector publications)
        viii. Expert judgement

The obtained data shall render quantified flows and stocks for the systems in scope in accordance with the activity data required in section 3.2.1.1.

2. Collecting data on feed intake from available data sources
    a. Parameters: See methodology section 3.2.1.2
        i. Feed intake in GE/NE and mass of eaten grass, silage, roughage, wet feeds and dry feeds
    b. Searching in available data sources for:
        i. Grazing: country methodology, statistics and tools on GE intake and data on pasture/roughage NPP
        ii. Beef farm and cultivation: statistics on feed inputs per animal type
        iii. Beef Farm GHG assessments in literature and publications
        iv. Other beef farm assessments

The data sources gathered shall render quantitative data on rations per relevant production type.

3. Collecting data on feed production from available data sources
    a. Parameters: See methodology section 3.2.3 and 3.3.1
        i. Cultivation of feed crops and management of grassland at beef farms
        ii. Cultivation of other feed crops and feed materials in country in scope
        iii. Imported feed materials
    b. Searching in available data sources for:
        i. Grazing (country tools and data on pasture energy NPP)
        ii. Beef farm and cultivation statistics on inputs and outputs
        iii. Farm and cultivation GHG assessments
        iv. Other farm and cultivation assessments

Sources shall provide sufficient data on activities related to feed production on and off farm.

If all data is available, practitioner may start with modelling following specifications provided in the GRSB carbon footprint methodology.

If available data sources are not enough to complete the inventory partially or fully, practitioner may need to collect data for the defined production systems.

Data collection may be done by directly engaging all farms in a population, or when not feasible, via sampling. Sampling is discussed in c.

c. Sampling

Sampling may be necessary when not enough information is available for practitioners to complete the assessment (partially) or when practitioner needs to completely define a population where no data is available (fully).

How to determine a representative sample of a certain population?

On a country level, different sampling methods may be available or recommended for national census. Practitioner may follow these approaches as long as properly documented, suggestions of different methods are available in FAO Statistical Development Series as described in IPCC 2006 and 2019 refinement Annex 2A.2 V1 Ch 02.(IPCC, 2019b).

A simple sampling approach suggested in the PEFCR methodology (Zampori & Pant, 2019) is described below.

Following what described in the PEFCR guidance, the selection of a representative sample involves four main steps:

1. The population needs to be defined. When carrying out a national assessment, the population is constituted by all producer in a certain country.
2. The population needs to be subdivided into homogeneous sub-populations. The sub-division has to take into account at least three main aspects:
    a. Geographical distribution of production sites.
    b. Technologies and farming practices involved.
    c. Production capacity of the sites.

    As a consequence, the total number of sub-populations is given by the product of the number of geographical areas, technologies and production capacities, respectively and the sub-populations defined by the practitioner when mapping the country beef cattle system.
3. For each sub-population, sub-samples need to be defined. In order to select a representative sample out of certain sub-population, two different approaches can be taken:
    a. The cumulative production of the producers in the sample needs to account for at least 50% of the total production in the sub-population.
    b. The number of producers in the sample needs to be equal to the square root of the total number of producers in the sub-population.
4. The representative sample of the overall population is constituted by the combination of all samples defined for each sub-population.

<u>Example (adapted from PEFCR guidance):</u>

A national assessment needs to be undertaken in Country X. 400 beef producers are distributed over the country, two different farming techniques are used (technique A and B, respectively) and farm size varies in a certain range: in particular, the farm size into three classes: lower than 500 head yr^{-1} (class A), between 500 and 850 head yr^{-1} (class B) and higher than 850 kg head yr^{-1} (class C). According to the procedure described above, it can be assumed that:

1. all farmers are located in one country, therefore there is only one geographical area which producers belong to;
2. there exist two farming techniques;

3. there exist three production capacities;

therefore, we can identify six sub-populations in the overall populations, which are summarized in Table 12.

Table 12. Sub-division of milk producers in Country X. The values in the last column are calculated following item 3-b of the procedure described above.

Sub-population	Country	Technology	Capacity	Total number of producers	Number of producers in the sub-sample
1	X	Technique A	Class A	80	9
2	X	Technique A	Class B	100	10
3	X	Technique A	Class C	10	3
4	X	Technique B	Class A	75	9
5	X	Technique B	Class B	45	7
6	X	Technique B	Class C	90	9

Following the second approach for the definition of the sub-samples (item 3-b in the procedure above), the number of producers in the sub-sample of each sub-population can be determined by calculating the square root of the total number of producers in the sub-population. The values are shown in the last column of Table 12. Finally, a representative sample of the overall population can be determined as the combination of all defined sub-samples. The sample is constituted by 47 beef cattle producers, out of 400 producers in the whole country.

After the items of sub-population to be sampled are defined, practitioner shall collect data for these, following guidance from the GRSB guideline inventory modelling section 3.

In case data response is limited within the defined sample, practitioner should document these limitations and sampling data may be refined over time.

After data collection from the defined samples is done, practitioner may start with modelling following specifications provided in the GRSB carbon footprint methodology.

Appendix I.II Considerations for the supply chain

Appendix I.II gives guidance on how to begin a carbon footprint assessment at a national level. In the supply chain level (e.g performing a carbon footprint of a beef- cattle integrator) assessments can be performed in a similar way to the country level but with some considerations.

The main overlap between an assessment at a country and supply chain level is the population overview. Understanding what the production systems integrating the supply chain are and evaluating how and if they can be further aggregated into sub-populations for analysis in alignment to the goal and scope, should be performed specific to the supply chain as recommended for the national level in Appendix I.I.

Available data sources at the national level will likely not correctly represent the specific supply chain. It is estimated that in most cases, at the supply chain level, practitioner will have to build the study LCI by collecting data directly from all farms in the relevant sub-populations defined for the study, or conduct sampling following recommendations as in Appendix I.Ic.

After data collection from the defined samples is done, practitioner may start with modelling following specifications provided in the GRSB carbon footprint methodology.

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