AGRICULTURAL INNOVATION AUSTRALIA

April 2023

A Common Approach to Sector-Level Greenhouse-Gas Accounting for Australian Agriculture

Methods and Data Guidance

Prepared for Agricultural Innovation Australia by:

CSIRO, Queensland University of Technology, NSW Department of Primary Industries, University of Melbourne, Integrity Ag & Environment, Australian Wine Research Institute

Australia's National
Science Agency

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This document is an output the project *A Common Approach to Sector-Level GHG Accounting for Australian Agriculture* which was commissioned by Agricultural Innovation Australia (AIA) and funded through contributions from AIA, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), AgriFutures Australia, Australian Pork Limited, Cotton Research and Development Council (CRDC), Dairy Australia, Grains Research and Development Council (GRDC), Hort Innovation, Meat & Livestock Australia (MLA), Sugar Research Australia (SRA), Wine Australia, and the Western Australian Department of Primary Industries and Rural Development.

This Methods and Data Guidance document was written by a team of experts:

Maartje Sevenster (dairy, grains, horticulture, deer, buffalo), Marguerite Renouf (sugar, horticulture), Annette Cowie, Richard Eckard (red meat, deer, buffalo), Murray Hall, Kieran Hirlam (wine), Nazmul Islam (rice, cotton), Alison Laing, Mardi Longbottom (wine), Emma Longworth, Brad Ridoutt, Stephen Wiedemann (pork, wool).

Marguerite Renouf and Maartje Sevenster were overall technical leads and Alison Laing was project manager and consultation lead.

Feedback and inputs by Hiz Jamali (cotton) are acknowledged.

Citation

Sevenster M., Renouf M., Islam N., Cowie A., Eckard R., Hall M., Hirlam K., Laing A., Longbottom M., Longworth E., Ridoutt B., Wiedemann S. (2023). A Common Approach to Sector-Level GHG Accounting for Australian Agriculture; Methods and data guidance. CSIRO, Australia.

Important disclaimer

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Acknowledgements

This document is an output of the project *A Common Approach to Sector-Level GHG Accounting for Australian Agriculture*, which was funded through contributions from Agricultural Innovation Australia (AIA), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), AgriFutures Australia, Australian Pork Limited, Cotton Research and Development Council (CRDC), Dairy Australia, Grains Research and Development Council (GRDC), Hort Innovation, Meat & Livestock Australia (MLA), Sugar Research Australia (SRA), Wine Australia, and the Western Australian Department of Primary Industries and Rural Development.

1 Introduction

1.1 Background

A common approach for GHG accounting across agricultural sectors is essential to enhance consistency, transparency and confidence in sector-level GHG reporting. Internationally, there are approaches and tools that influence Australian farmers via market access criteria or product labelling, which do not always adequately reflect the reality of Australian farming. A common approach to GHG accounting will allow Australian agriculture to control the representation and communication of climate impacts and mitigation.

This Methods and Data Guidance provides a common framework for greenhouse gas (GHG) accounting of Australian agricultural activities at the sector level. The process that was followed to develop this framework is described in the Project Overview and Non-Technical Summary (Sevenster et al., 2023) . It describes how GHG accounting can be conducted to generate a transparent and trusted inventory of GHG emissions based on:

- a consistent set of principles
- a modular approach to account for differences between agricultural sectors
- general guidance on data
- consistent terminology and language.

Agricultural sectors, in the context of this document, refer to individual commodities (or commodity groups such as “grains”), as distinguished by the system of levies applied to primary production. They include forestry and fisheries. No existing standards or protocols exist for this context, which is the reason this guidance document was generated. Nevertheless, where possible and appropriate, the approaches and method choices recommended in this framework draw on relevant guidance from the following frameworks primarily:

- Australian National Greenhouse Gas Inventory (NGGI)
- ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines (ISO, 2006)
- ISO 14067:2018 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification (ISO, 2018)
- guidance provided by the Livestock Environmental Assessment and Performance (LEAP) Partnership (FAO, 2016)
- sector-specific guidance for product or corporate accounting, such as IDF (2022).

In addition, guidance for corporate accounting provided by the Greenhouse Gas Protocol (GHG-P)(GHG-P, 2015), guidance for product accounting provided by GHG-P(GHG-P, 2011), the Product Environmental Footprint (PEF) scheme (EU, 2021), and guidance from the ILCD Handbook (ILCD, 2010) is referenced for some aspects of the goal and scope principles (2.1).

1.2 How to use this guidance

This guidance can be used to develop GHG accounts for Australian agricultural sectors at national and/or regional level, representing the commodity(ies) produced. The general principles provided in Chapter 2 can be applied to all agricultural sectors as represented by the system of rural Research and Development Corporations (RDCs) including forestry and fisheries. Chapter 3 provides an elaboration of the general principles for a number of sectors, selected within the scope of the project funding.

Examples of applications of this guidance include:

- generating a sector or regional baseline, as a reference against which to track and report sector-level GHG emission reductions,
- generating GHG emissions accounts for annual reporting,
- informing national and international stakeholders.

It is not suited to the following applications:

- generating carbon footprints of products,
- generating farm-level or corporate GHG accounts,
- estimating carbon credits.

This guidance is not intended for use in formal corporate or product accounting, but may be helpful for informing some methodology choices regarding e.g. allocation and inventory calculation, when appropriate in the context of implementing protocols such as GHG-P or ISO standards for corporate or product-level GHG reporting. This could enhance transparency and consistency of GHG accounting at different levels.

The sector-level accounting informed by this guidance is not part of any third-party reporting obligations.

The Goal and scope section describes the intended applications and limitations in more detail. It also describes how methods such as Life Cycle Assessment are used for sector-level accounting.

Across this document, strict use is made of the following verbal forms to indicate the level of specific guidance or recommendations:

- “shall” indicates that the instruction is mandatory
- “should” indicates a strong recommendation that the instruction is implemented if possible, or justification provided if not implemented
- “can” indicates a factual statement
- “may” indicates that the instruction is optional and concerns e.g., sensitivity assessment or supplementary information

A limited set of terms very specific to this methodology-guidance document is defined in the glossary at the end of this document. A longer list of terms associated with GHG accounting

more broadly is provided in the Common Terminology document (Cowie et al., 2023) (Cowie et al., 2023).

2 General principles

2.1 Goal and scope

2.1.1 Goal

This document provides guidance for GHG accounting to support agricultural-sector-level reporting. The goal of such reporting may be to establish a complete GHG baseline for the sector, to produce a GHG account, to assess contributions of different emission sources or to track progress on GHG mitigation by evaluating both total emissions and measures of emission intensity per year.

This accounting framework seeks to align with the methods used in the national GHG inventory (NGG) and with relevant methods regarding product and corporate accounting (as outlined above) for non-NGGI aspects such as allocation and embedded emissions.

None of the current accounting or footprinting standards apply directly to a sector-level assessment and only the ILCD Handbook (ILCD, 2010) describes this as a potential application of LCA. See Sevenster et al. (2022b) for an extensive discussion. Drawing on the conclusion in that report:

> *An agricultural sector such as the grains sector (as defined by the 25 GRDC leviable crops) or the meat and livestock sector (as defined by MLA leviable production), is not a well-defined entity in either the organisational or the territorial sense. Especially the fact that many farms (the actual production units) are part of multiple sectors [e.g., producing wheat and sheep] means that there cannot be a strict territorial or organisational definition of what is "in" and what is "out". By linking the assessment system to the total production of the relevant commodity (group) as the functional unit, a sector assessment can be shaped as a product-level assessment, with some characteristics of organisational footprints, such as separating Scope 1, 2 and 3 emission sources, as well as with a direct link to land areas under production in the assessment year.*

An important choice is whether to take an attributional or consequential modelling approach in the reporting of GHG emissions, as these are fundamentally different. The two approaches answer different questions: whilst the attributional approach attributes a share of the global environmental burden to a product or activity, the consequential approach quantifies the consequences that an increase in supply or demand for a particular product are likely to have on the environment in a given context (Brandao et al., 2022).

In practice, there are diverging and confusing implementations of both approaches in life-cycle assessment. However, the purpose of a sector GHG baseline assessment as well as annual GHG reporting is clearly more aligned with the description of the attributional approach. As noted above, the purpose aligns with "accounting" as distinguished in the ILCD Handbook (ILCD, 2010): "Purely descriptive documentation of the system's life cycle under

analysis (e.g. a product, sector, or country), without being interested in any potential additional consequences on other parts of the economy". Attributional assessment is recommended for this purpose. In addition, most market-based requirements are based on attributional assessment, as is the national GHG inventory. Therefore, the attributional approach is adopted in this guidance.

Key decision

2.1.1a The attributional approach to LCA is adopted in this guidance for sector level GHG accounting.

2.1.2 System definition

For each assessment, the system shall be clearly defined in terms of production system, reporting year and accounting time period.

Production system

The agricultural sectors are defined by leviable commodities. All activities contributing to the production of those commodities, in the accounting time period, are included in the system. Those activities can take place in different types of farming systems, such as mixed farming or multi-crop rotations, and shall be separated from activities taking place in the same farming system but not contributing directly to the sector's leviable commodities. The guidance regarding multifunctionality in 2.1.6 provides the recommended approach for this separation. All constituent farming systems (e.g., organic, irrigated or rain-fed, feedlot or grass-fed) shall be reflected in the sector GHG account.

Reporting year and time period

For a sector GHG baseline assessment, one of the following reference years shall be chosen and clearly documented:

1. Calendar year 2005.
2. The financial year that includes the main harvest event in calendar year 2005 (if relevant).
3. The most recent calendar year or financial year that can be assessed following this method and data guidance.

The reference year is the reporting year for the GHG baseline account. The year 2005 is relevant in the context of Australia's national commitments under the Paris Agreement. Therefore, the choice of reference year can be relevant for communication of sector objectives and achievements.

The accounting time period is the period required to achieve an appropriate average GHG account that is representative of the production system in the reporting year. For many

sectors, the time period is one year. The time period shall be defined using the following considerations:

- Does sector-level spatial averaging result in appropriate reflection of the time-variability of the system? This can typically be assumed for relatively stable systems such as grain production, where spatial distribution of different crops reflects the rotations used.
- What is the intrinsic life cycle of the main[1] production system? For e.g. for beef production, production in a reporting year is linked to animals born up to 3 years earlier. This means that, when the sector is experiencing significant decline or increase in stock numbers such as during or following droughts, production lags compared to inputs and emissions.

To reduce the variability in the GHG account and enhance the link between emissions and production, an accounting time period of 3 years, preceding and including the reporting year, is recommended for cattle. For sheep and pigs, the recommended accounting time period is 2 years. For tree and vine horticulture, the intrinsic life cycle can be several decades, which is not an appropriate accounting time period. If a multi-year time period is appropriate because spatial averaging is not sufficient to achieve a representative average, e.g., if there is considerable expansion in planted area as is the case for almonds, it is recommended to limit the time period to the typical duration of the establishment phase for that crop as a maximum. For the horticulture sector as a whole, it is not feasible to use different time periods for each crop and a one-year time period is the most appropriate.

The same time period shall be used for the GHG baseline and for further GHG accounts. The minimum time period is one year. Note that choosing a single year as accounting time period does not necessarily mean that all data collection is restricted to that year. Data collection is dictated by data and data quality requirements for different emission sources (Section 2.2.2).

Key decision

2.1.2a Baseline reference (reporting) year is one of CY2005, FY2005, FY2006, or the most recent CY/FY.

2.1.2b A sector-specific accounting time period shall be defined to achieve an appropriate average GHG account that is representative of the production system in the reporting year.

[1] For cattle systems, bulls may live well over a decade but their contribution to a sectoral GHG account is minimal.

2.1.3 System boundaries

The system boundary shall include all on-farm activities and manufacture of inputs, including electricity, used in on-farm activities. The system boundary shall include off-farm processing of waste streams generated on farm. This system is referred to as “cradle-to-farm-gate”.

In addition, the system boundary may include post-farm activities when they are an inevitable part of the processing chain of the related products, or otherwise intrinsic to the definition of the sector. Examples of this are abattoir activities for meat, winemaking and bottling for the wine sector, ginning for the cotton sector or sugar cane processing for the cane sector. The post-farm system boundary is described in the sector-specific guidance in Chapter 3. When post-farm activities are included, the definition of the declared unit and the results shall be reported both for cradle-to-farm-gate and for the cradle-to-factory-gate system.

The details of the system as well as the outputs vary from sector to sector. Therefore, the scope of emissions needs to be reported as outlined below to ensure consistent terminology and to double counting of emissions.

Emissions can be defined as Scope 1, 2 and 3. The concept of the emission scope is used to indicate where emissions are generated in relation to the entity or facility that is the focus (proponent) of the GHG assessment. This guidance focuses on agriculture and therefore defines the scope of emissions relative to the farming system. Thus, on-farm emissions shall be defined as Scope 1, emission associated with purchased electricity used on the farm shall be defined as Scope 2 and any emissions associated with the supply of materials to the farm (‘upstream’ of the farm/pre-farm) or post-farm processing (‘downstream’ of the farm) shall be defined as Scope 3. Transport from farm gate is included in the post-farm processing system boundary. This is an accounting definition to clarify that anything after the farm gate is outside of the farm system boundary. Waste processing is included in the system boundary whether or not the treatment occurs on or off-site.

Figure 1 provides a diagram of the key terms for the system boundary and the flow of materials and energy, in line with the above definitions. The figure is used in Chapter 3 to illustrate the details for the various sectors.

The term ‘ecosphere’ refers to the environment where natural resources are drawn from and where impacts occur, such as air, water, land-based ecosystems as well as humans. The term ‘technosphere’ refers to the economy where processes take place that transform inputs from the ecosphere into products as well as transform wastes prior to emissions to the ecosphere.

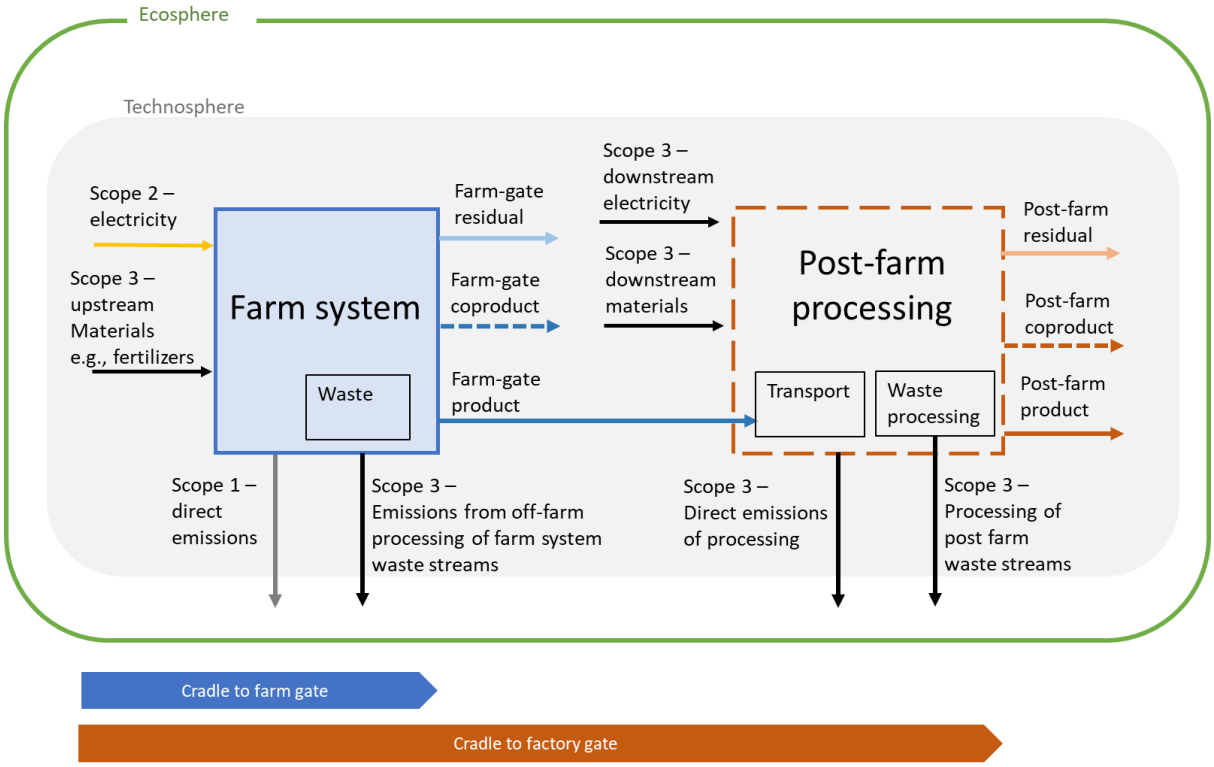

Figure 1 Defining the scope of emissions relative to the farm system as the anchor point of the analysis.

Emissions associated with capital goods (equipment, infrastructure) shall be included in line with the cut-off criterion (Section 2.1.5). The contribution of capital goods to total emissions can be considerable where infrastructure with relatively short lifetime is involved. When the contribution is small (but not below the cut-off threshold), data with lower quality ranking (see 2.2.2) may be sufficient to achieve an appropriate estimate.

Existing protocols diverge on guidance regarding capital goods inclusion but significance and relevance (in the context of the goal of a GHG study) are generally used as key principles. The GHG-P for corporate accounting and reporting requires capital goods purchased by the reporter to be included. For a complete sector-level GHG baseline, capital goods are a relevant source of emissions (ISO (2018)). As a practical concession, the GHG-P allows some flexibility with respect to inclusion/exclusion of capital goods, noting that for some background data sourced from databases (e.g., Scope 3 embedded emissions of farm inputs) it may be difficult to change the system boundary. This guidance follows that pragmatic approach. For on-farm equipment and infrastructure, the general cut-off rule shall be applied (Section 2.1.5). For background processes, capital goods may be excluded if the selected data source does not include them. All inclusions and exclusions of capital goods shall be clearly documented.

Emissions associated with the provision of services, such as consultants or insurance, should be included but may be excluded if their exclusion is not expected to significantly influence the results or if appropriate data is not available (Section 2.2.1 and 2.2.2). Services in this context do not include contracted operations, such as contract spraying or harvesting, which do result in on-farm fuel use and Scope 1 emissions regardless of the contractual

arrangements. Transport is also not to be considered a service in this context. Contracted operations and transport of inputs shall be included in the GHG account. The term services refers here to any activities supporting agriculture without being linked to primary operations or material flows.

Existing studies show that services can contribute significantly to the GHG account of certain agriculture sectors but in practice there is a lack of data on associated emissions. Services are typically included using embedded emission factors that are derived using the environmentally-extended input-output (EEIO) approach. This approach has very different system boundaries and typically yields results with low accuracy (specificity). All inclusions and exclusions of services shall be clearly documented. If included, emissions associated with services shall be reported as a separate emission source category, to facilitate interpretation.

There are industries that fully or partially depend on harvesting animals from wild populations such as deer, fish or kangaroos. Emissions associated with wild animals are not included in the NGGI. In general, very little information is available on total numbers of animals or on numbers attributable to the production system. For any sector system where this is relevant, the system boundary shall clearly indicate whether harvesting of wild native or feral animals is within or outside the boundary. For feral ruminants such as buffalo, deer and camels, harvest from wild populations should be included in the system boundary if subsequent slaughter or export is subject to a levy.

When harvest from wild populations is within the system boundary, the number of animals harvested shall be reported. Wild native animals and wild fish shall be considered part of the ecosphere, without reportable emissions until the moment of harvest. For feral animals, an estimate of life-time emissions associated with animals harvested may be reported as supplementary information, as those emissions are not included in the NGGI.

Key decisions

2.1.3a The system boundary shall be “cradle-to-farm-gate.” In addition, results including processing may be reported for sectors where this is recommended and referred to as “cradle-to-factory-gate.”

2.1.3b The farming system is the anchor point for defining Scope 1 emissions, for all sectors, even when post-farm processes are included.

2.1.3c Emissions associated with capital goods shall be included in line with the cut-off criterion. Emissions associated with the provision of services should be included.

2.1.3d All inclusions and exclusions shall be clearly documented.

2.1.4 Declared unit

To allow for reporting on sector-level emission intensity (see 2.2.3), a measure of sector production is required. In most sectors this is a 'declared unit' such as a mass or value of total production (ILCD, 2010). This is because each sector may produce many different types of products (such as in horticulture) and sector output is generally measured in units of production. The declared unit is a useful measure to define the baseline and to track progress for a sector using total production.

The declared unit shall be linked to economic production (supply of products into the value chain), rather than biological production (e.g., live weight gain on farm). While it is the latter that drives emissions, on-farm losses can result in lower net output of products which is ultimately the aim of production. Where possible, products that are stockpiled should be included in the account for the year of their production, but where data do not allow for this, stockpiling should be acknowledged as giving rise to variability in the GHG account that is not necessarily due to variations in agronomic efficiency. As outlined in 2.1.2, such effects can occur for systems with longer intrinsic life cycles and the variability in reporting can be reduced by using multi-year averages.

It is important to note that in general the aim of the LCA methodology is to define a system in terms of its function and to define the output as a functional unit (ISO, 2006). For example, the function of food systems is to provide nutrition and the functional unit could be protein or calorie output, or even the provision of a healthy meal. This distinction is important because only systems with the same functional unit can be compared.

2.1.5 Exclusions and cut-off criterion

Inclusions and exclusions of emission sources in the chart of accounts shall be guided by significance of their contribution. Additionality criteria (as used in carbon credit schemes) are not a consideration in the context of this guidance.

Existing standards and protocols all refer to the need to define a significance cut-off (also called materiality threshold) in line with the goal of the study. Given the goal defined in this guidance (2.1.1), completeness of the inventory is an important aspect. Therefore, the cumulative completeness of the inventory shall be reported, in terms of a percentage of total climate change impacts.

Decisions around exclusion of individual inputs and outputs may be informed by the common cut-off threshold that is defined as 1% additional environmental impact (as defined in 2.3.1) compared to the GHG account excluding the specific input or output. However, the cumulative exclusions determine the completeness of the GHG account. PEF is currently the only framework using cumulative completeness, with the guidance requiring 97%

completeness (EU, 2021)[2] but it should be noted that the context for PEF assessments is at product level and therefore different from this sector level guidance.

For sector-level GHG accounts, completeness shall be estimated and reported for emissions and removals separately and include the effect of exclusion of services if relevant (see 2.1.3).

Key decision

2.1.5a Cumulative completeness of the inventory shall be reported, for emissions and removals separately, in terms of a percentage of total climate-change impact.

2.1.6 Accounting for multifunctionality

Multifunctional processes are processes that have multiple functions or products. The on-farm or post-farm activities can produce several types of outputs and these need to be classified as either main products, co-products, residual products or wastes (see Glossary). The definition of these terms follows international guidelines (FAO, 2016) and affects how emissions are allocated to those outputs. Figure 2 shows the decision points for classifying the outputs.

[2] The processes that (cumulatively) account for less than 3.0% of the material and energy flow, as well as the environmental impact for each impact category may be excluded from PEF study.

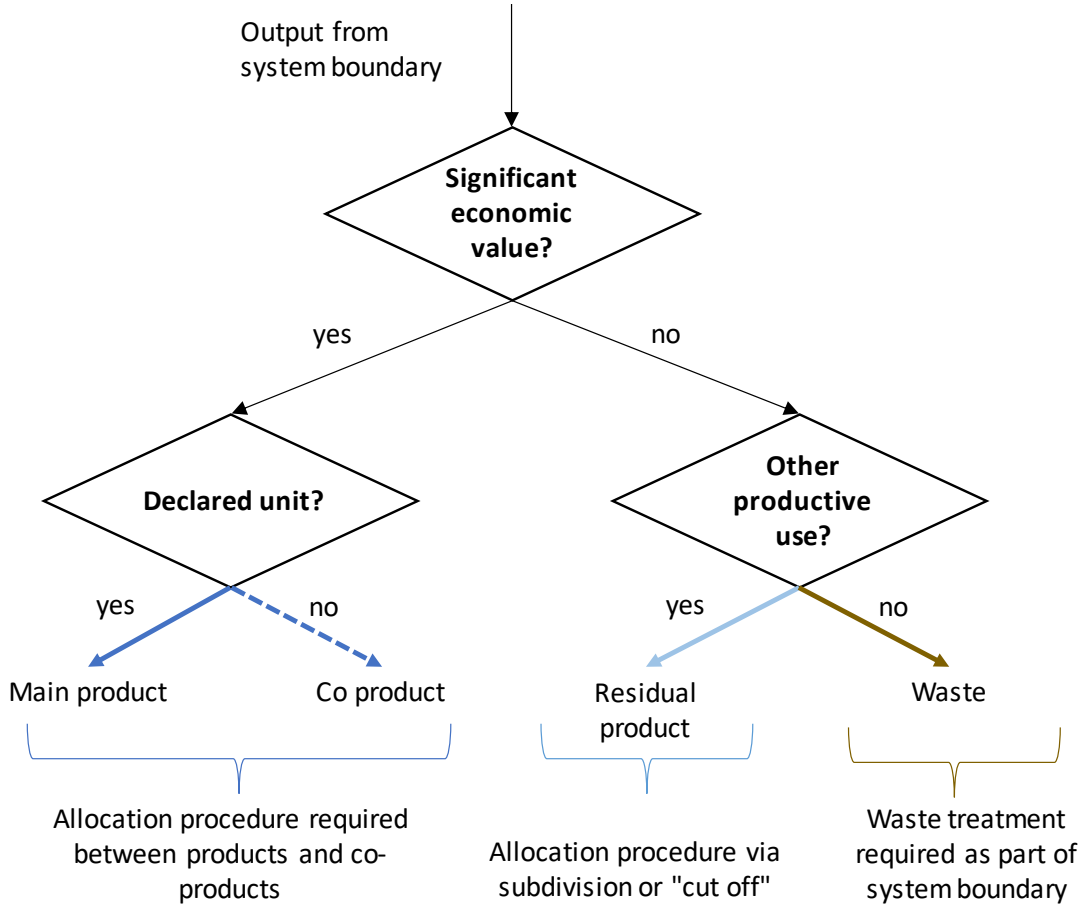

Figure 2 Decision diagram for classifying outputs as either main products, co-products, residual products or wastes.

The main product is an output with economic value (FAO, 2016; ISO, 2006) and is associated with the declared unit of the system (2.1.4). A co-product in this guidance is defined as an output with significant economic value that is not associated with the declared unit. For example, a dairy farm has a declared unit of Fat-and Protein-Corrected Milk associated with raw milk at the farm gate. The dairy farm also produces culled animals from herd management and surplus animals from calving. These outputs have economic value but are not associated with the declared unit and are classified as co-products.

A residual product is a substance that is not the end product(s) that a production process directly seeks to produce; see Glossary for details). More specifically, a residual product is any material with no or limited economic value leaving the sector system without any further processing, but which has a subsequent use. An output that has neither an economic value nor any other type of use is called a waste (FAO, 2016; ISO, 2006). An example of a residual product is manure which has no economic value at the farm gate but has subsequent use as a fertiliser/soil amendment. An example of a waste is effluent from a dairy factory which requires waste treatment and disposal.

The full definition of main product, co-product, residual product and waste shall be considered for classifying outputs for each sector and justification of the chosen classification provided. This classification informs allocation choices, with guidance provided in the sections below.

Allocation principles

Inputs and outputs (emissions) of multifunctional processes can be apportioned to those multiple functions in a way that reflects some underlying principle. This is called allocation. The following stepwise procedure from the international LCA standard(ISO, 2006) is the starting point for the recommendations for allocation:

1. Avoid allocation through the use of subdivision or system expansion. Subdivision refers to dividing processes into sub-processes to resolve multifunctionality. System expansion is not a practical option for sector-level baseline accounting, because the systems are strictly defined by those sectors. The common implementation of system expansion in the form of "substitution" is also inappropriate, given the attributional nature of this accounting guidance (see 2.1.2).
2. If 1) is not possible, inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system. In the context of this guidance, this is for instance implemented in the allocation between milk and meat production on dairy farms. This allocation is based on metabolic energy required for both processes in cattle and as such reflects an underlying physical relationship.
3. Where 1) and 2) are not possible, the inputs should be allocated between the products and functions in a way that reflects other relationships between them, such as relative mass or economic value. An average market price of products should be used to reduce the effect of price fluctuations. For example, an average price over a period of at least 3 years is recommended for allocation between meat and milk products (FAO, 2016). A period of 5 years is a general suggestion for economic values in existing guides and standards(BSI, 2012; FAO, 2016).

These principles are the basis for the additional allocation guidance for common multifunctional processes or systems in agriculture in the next two sections.

Farming systems shared between sectors

For farming systems that are shared between sectors, subdivision shall be applied to all inputs except to infrequent inputs such as lime. Inputs that are applied with a frequency that is less than the typical harvest frequency and that are not driven specifically by one of the functions of the system ("infrequent inputs") shall be allocated as a time average to all outputs. This approach can also be applied to e.g. systems where so-called nitrogen banking is practiced, with nitrogen applied in support of more than one production season, but this is considered to be too uncommon currently to require special treatment. In rotations, the

share in time of each crop or pasture phase shall be determined by including the preceding short fallow and by adding an equal share in any long fallow that is part of the rotation. Infrequent inputs also include any on-farm reforestation that may need to be reported by multiple sectors as GHG removals (see 2.2.4).

In the case of rotations (production on same land area but at different time) subdivision means that a division is applied in the temporal sense. Frequent inputs are counted when they are used or applied. No "credit" shall be applied to legumes (crops or pasture) to account for nitrogen fixation and potential reduction of fertiliser input in other crops[3].

For emissions and removals due to soil carbon change, subdivision is likely to require modelling the phases of a rotation separately (see 2.2.4).

In the case of integrated crop-livestock systems (production on same land at same time) subdivision means attributing emission sources in their entirety to one function or to the other, as they would be attributed in a non-integrated system. For example: in the case of livestock grazing in vineyards over winter, attribute enteric fermentation and (paddock) manure emissions to the livestock and all other emissions to the cropping system. Equivalent rules should be applied to intercropping, but this is currently too uncommon to influence any sector baselines or lead to significant double counting/leakage. Where intercropping does occur currently, there is typically no true multifunctionality involved in that only one cash crop is harvested.

It should be noted that this does not do justice to the real integration of those systems. Outside the scope of this guidance document, other methods (e.g., consequential LCA, simulations) should be used to assess e.g. the benefits in terms of GHG emissions of one rotation over another, or the benefits of integrated systems over separate ones. When it is likely that significant changes are made to the cropping system with a view to grazing (e.g., dual-purpose canola) it is recognized that the cut-off approach is not well aligned with best practise GHG accounting. However, at the scale of the grains sector, of which canola cultivation is part, it is expected to have minimal influence. At farm- or commodity level, different allocations are likely to be more appropriate.

Key decision

2.1.6a Subdivision shall be applied to farming systems that are shared between multiple agriculture sectors

[3] Note that a different choice has been made in the product-level life-cycle inventory database AusLCI. This is in line with the different purpose and scale of that database.

Upstream multifunctional processes and products that leave the system boundary

Wherever a co-product or residual product of sector A is used in another sector B, the emissions allocated to the product by sector A shall equal the embedded emission counted by sector B. It is important that the producing and the receiving sector use the same allocation method and factors, to avoid leakage of emissions. Consensus between the relevant agriculture sectors on allocation is therefore required. However, the choice of allocation has consequences for similar allocation choices in the sectors involved, including those in background processes, as mismatches in allocation for "similar inputs and outputs" should be avoided. This means that products leaving a sector into non-agricultural sectors of the economy (e.g., electricity from manure) shall be treated similarly to products going into agricultural sectors (e.g., manure to cropping).

Emissions from waste treatment of any materials are attributable to the sector, even if the treatment takes place "outside" that sector's boundaries. For residual products, a subdivision (cut off) approach, separating the producing and receiving system, shall be applied. All emissions that arise before that cut off are attributed to the producing system. All emissions that arise after the cut off are attributed to receiving system. As the residual product leaves the producing system, it is considered to have zero Scope 3 embedded emissions.

For genuine co-products, a step 2 or step 3 allocation shall be applied (ISO, 2006), consistent with the consensus allocations below. Note that the distinction between residual products and co-products may change over time.

To achieve consistency in allocation across all agricultural sectors, the following consensus allocations shall be applied:

1. On-farm co-production:
    a. Live animals as co-product (dairy) Allocation using the default biophysical allocation recommended by the IDF guidelines (IDF, 2015) and supported by LEAP.
    b. Wool and meat as co-products (sheep). Allocation based on protein as recommended by Wiedemann et al. (2015).
    c. Litter and manure, as well as methane produced from manure treatment, shall be defined as residual products (cattle, pork, chicken). Allocation via subdivision as recommended by LEAP and IDF. Where the use of the residual product leads to abatement outside the sector's boundaries, such as biogas processed to replace natural gas outside the sector, the avoided emissions shall not be counted in the sector GHG account. However, avoided emissions may be reported separately as supplementary information (see 2.2.3). Calculation of avoided emissions is outside the scope of this guidance.
    d. Carbon credits generated under Emission Reduction Fund (ERF) methodologies or otherwise, from activities within the sector system boundary or from "displacement abatement" (avoided emissions), shall not be treated as co-

products. That is, no share of total emissions shall be allocated to the credit as an output with economic value. However, the amount of emission reduction or removal associated with credits sold to entities outside the sector should be reported as supplementary information as described in 2.2.3.

2. Post-farm processing co-production:

    a. Food/feed co-production (examples: oilseed cake, whey, grape marc, molasses, crop residue). Apply economic allocation using 5-year price averages as recommended by LEAP (FAO, 2016). Economic allocation factors shall be determined using a 5-year period including the reporting year. If the necessary information is not available for the baseline reference year, a more recent 5-year period may be used. If prices in any such 5-year period were highly variable, economic allocation may be determined by extrapolating longer-term trends (note that this is not the same as a longer-term average).

    b. Fuel/feed co-production (example: oilseed cake). In biofuel GHG accounting, allocation based on energy is not unusual, but this would create an inconsistency when applying a different allocation for the (equivalent) food/feed situation. Therefore, economic allocation as described under a) shall be applied for sector-level accounting.

    c. Fibre/feed/food co-production (examples: cotton seed, hides). Allocation based on economic value shall be applied as currently supported by cotton industry and by LEAP (FAO, 2016). See a) for detailed guidance.

    d. Abattoir paunch to cropping. Shall be treated as residual product, applying subdivision.

The listing above is not exhaustive. In any situations not explicitly mentioned, equivalent allocation approaches shall be applied. This includes background (upstream) processes such as imported livestock feed. Mismatches in allocation approach for “similar inputs and outputs” should be avoided whenever possible. However, if life-cycle inventory databases are used for those background processes (2.2.2) and it is impossible to change the allocation applied to those data, they may be used. A (qualitative) assessment of sensitivity to the allocation factors in the background process shall be included in the reporting.

Key decision

2.1.6b For multifunctional processes within a sector system boundary, a distinction between co-products, residual products and waste is made, following the LEAP guidelines. For residual products, subdivision (cut off) shall be applied.

2.2 Emission inventory

2.2.1 Inventory calculations

The emission inventory refers to the chart of accounts of all GHG emissions (e.g., N_2O, CO_2, CH_4) associated with the activity data collected (2.2.2) within the defined system boundary (2.1.3). A GHG inventory is often grouped by emission source category (e.g., Agriculture, Land Use, Energy). To calculate the GHG emissions inventory from activity data, the use of emission factors is common. Emission factors are applied either directly to activity data, such as in the case of Scope 3 embedded emissions, or to a quantity derived from activity data via a conversion calculation, such as the amount of nitrogen contained in crop residue retained in the field.

The equations used for this kind of calculation can be generalised as:

Emission = activity data quantum × conversion × emission factor

The NGGI methods are based on guidance by the International Intergovernmental Panel on Climate Change(IPCC, 2006; 2019) and for the generalised equation above follow a Tier-1 (default global emission factor) or Tier-2 (country or system specific emission factor) method. However, there are also non-linear relations between emissions and activity data and some emissions are simulated using dynamic models (Tier-3 methods). The latter is the case for most of the emission sources in the "Land Use, land Use Change and Forestry" (LULUCF) category in the NGGI, such as carbon stock change due to reforestation or soil carbon change.

For emission sources that fall in the Agriculture and LULUCF categories in the NGGI framework, emission inventory calculations shall be not inconsistent with the latest version of the NGGI. This means that e.g. emission factors, non-linear functions and simulations used in the NGGI may be disaggregated to better reflect particular crops or crop groups, regions or activities, when this can be done using the methods that underly NGGI reporting. Three examples are given in the textboxes below. For more guidance on emission inventory for LULUCF, see 2.2.4.

Where technology-specific (disaggregated) Agriculture or LULUCF emission factors are not available in the NGGI, and cannot be derived from NGGI methods, the default NGGI calculations shall be used. However, in some cases NGGI methods may lag behind due to formal evaluation and approval processes, even in the case of adoption of new Tier-1 emission factors from IPCC (2019). Where there are improved calculation methods and emission factors that are accepted and broadly supported by industry and (other) government departments, these methods should be used in the sector GHG inventory. This shall be supported by evidence that would at least meet the criteria for consideration for adoption in NGGI. For example, the Livestock Emissions Framework guidance should be applied for handling the calculation of enteric methane where supplements are used.

Where this exemption does not apply, well-documented alternative emission factors or calculations may be used in sensitivity assessments and recommendations for improvement

of NGGI could be made if the activity is found to have potential for significant change of the relevant emission factor or calculation (e.g., controlled traffic farming and soil N_2O emissions).

Example: N_2O emissions, cotton

In the NGGI all cotton is assumed to receive an (average) amount of 246 kg N/ha. The emission factor for direct N_2O emissions from agricultural soils is fixed at 0.0055. For more targeted GHG accounting, for example by valley or by management type, it may be appropriate to determine the actual N rate for the system and the associated emission factor by using the equation from Grace et al. (2016) upon which the NGGI approach is also based.

Example: N_2O emissions, grains

In the NGGI the emission factor for direct N_2O emissions from agricultural soils for non-irrigated crops is 0.002. This is a weighted average of 0.0005 (for mean annual rainfall below 600 mm) and 0.0085 (for mean annual rainfall above 600 mm). For the purpose of regional, sector- or crop-specific GHG accounting it would therefore be appropriate to apply these values separately to the relevant low- and high-rainfall areas because the weighted average may be different from the national average for all non-irrigated crops.

Example: Cropland remaining cropland emissions

The “Cropland remaining cropland” emissions, which relate to soil carbon change, are reported in the NGGI as a total for all annual crops, perennial crops and temporary pasture that is in rotation with crops (mixed farming). This means several sectors will need to include a fraction of those emissions in their GHG accounts. The value could be disaggregated by area, but it is likely that in reality the emissions per hectare are different for the different sectors. This area-based disaggregation may be valid for the sectors that constitute the largest area of Cropland remaining cropland (grains, temporary pasture) but unlikely to be representative for the sectors covering smaller areas (horticulture, irrigated cotton). It would be in line with the recommendations around allocation (see 2.1.6) to separate the systems more accurately. This could be achieved by using FullCAM (as is used for the NGGI) or an equivalent model to determine sector-specific values. Discussions with the relevant Department about more disaggregated reporting within the NGGI are ongoing.

For estimating emissions associated with energy inputs and wastes, the National Greenhouse Accounts (NGA) Factors[4] shall be the preferred source for emission factors. This document includes emission factors for grid electricity by year and by State, as well as emission factors for fuel combustion and production. Some of those emission factors are time dependent, and the values for the appropriate year shall be used. If the emission factors related to any materials, fuels, and energy inputs are not available in NGA Factors, factors should be generated using reputable and appropriate life-cycle inventory databases such as the Australian Life Cycle Inventory (AusLCI) or Ecoinvent.

For estimating emissions associated with provision of services no recommendation can be made with regards to emission factors (see discussion in 2.1.3).

A chart of accounts shall be used to report the detailed GHG emission inventory. The chart of accounts is detailed for each sector in Chapter 3. In each of the sector charts of accounts, the last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. Type NGGI stands for calculations that use the national inventory Tier-1 and Tier-2 methods. Type NGGI_s stands for values that are based on the Tier-3 simulation results in the national inventory or on an equivalent simulation run specifically for the sector. NGA refers to the National Greenhouse Accounts factors, that give detailed emission factors associated with fuel production and combustion including for electricity generation. LCI refers to emission inventory items that require the use of life-cycle inventory databases and derived embedded emission factors. Finally, AIA refers to emission inventory items that are sourced from another agricultural sector in Australia, which means the embedded emission per unit mass shall be identical to the emissions allocated to the product by the producing sector as described in 2.1.6.

Key decisions

2.2.1a Emission inventory calculations shall not be inconsistent with the latest version of the NGGI, with the exception of certain emissions sources for which a broadly accepted improved method or emission factor are available.

2.2.1b Where activity-specific disaggregated emission factors are not available in the NGGI, alternative factors or calculations may be used in sensitivity assessment.

2.2.2 Activity data

The following section provides guidance on the selection of activity data, required to calculate the emissions inventory for a sector. The following factors can guide the selection

[4] National Greenhouse Accounts Factors are published annually and available on the website of the relevant Commonwealth Department.

of data of the best quality and are typically used to assess the uncertainty in process level data (Ciroth et al., 2016) although data quality covers more than just uncertainty:

- Reliability: the degree that data is based on measurements for the sector.
- Completeness: the degree that data is representative of the market considered for the sector.
- Temporal correlation: degree that data represents the period considered for the sector.
- Geographic correlation: degree that data is representative of geographic area of the sector.
- Farm practices and technological correlation: degree that technology such as farming practices and technology for processing farm-gate outputs are representative of the sector.

Further detail for assessing each category is provided in Table 1 below. An assessment of the quality of activity data using the matrix, or a quantitative uncertainty assessment, shall be included in sector-level GHG reporting. It is acknowledged that the highest indicator scores may not be currently achievable with available sector data. However, the matrix makes this assessment transparent and also provides a way of flagging data with low quality and therefore potentially high uncertainty.

A low data quality score for a particular data point should be interpreted in relation to the contribution, measured in total climate change impact, of the associated GHG emissions, or removals, to the total GHG emissions, or removals, in the sector account. Efforts to improve data quality should be focused on emission sources (sinks) that contribute significantly to the account. A quantitative uncertainty assessment should be considered best practice for evaluating the integral effects of data quality on the final result, but it is acknowledged that this requires considerable extra effort. A qualitative assessment using the data quality matrix (Table 1) is therefore a good practical option.

Required activity data typically include:

- production area
- crop yields or livestock numbers
- quantities of livestock products such as wool or milk
- quantities of farming inputs such as fertilisers
- quantities of manure produced
- percentage of crop residues burnt
- energy use (fuels, electricity, gas)
- capital goods in use
- financial expenditure on services (if using EEIO method as outlined in 2.1.3)
- transportation distances and modes
- land conversion areas.

Product losses at any stage shall be considered appropriately. On-farm crop or animal losses may not be adequately accounted for when using production statistics, and therefore derived data for crop growth or live-weight gain may need to be corrected.

For sector-level accounting, primary data collection is typically not an option, although some existing farm surveys approximate primary data collection. Generally, secondary sources of data need to be used that have varying levels of detail and representativeness. The following list provides some typical sources for sector-level representative activity data. The list is ordered by decreasing data quality in a general sense, but actual quality does depend on sector as well as the data point. For each GHG assessment, an evaluation of the quality of data sources used needs to be made using Table 1. Typical data sources are:

- sector-focused farm surveys
- industry data (other, based on primary data collected for other purposes)
- commercial benchmark data
- ABS, ABARES
- NGGI (e.g., livestock numbers, feed composition, crop harvest indices)
- GIS (e.g., ABARES ALUM)
- stoichiometric or science-based calculations (e.g., energy required for pumping)
- gross margin budgets (e.g., pesticide data)
- reference LCI databases (e.g., for fuel use per operation, capital goods estimates)
- FAO (e.g., crops not reported by ABS)
- expert consultation
- reference LCI databases (e.g., for fuel use per operation, capital goods estimates)
- industry information (e.g., factsheets)
- estimation.

This means that activity data do not have to be aligned (consistent) with the NGGI. When another source of data is used for certain parameters for which the NGGI does provide values, this shall be described and justified in the reporting.

Secondary data sources are by necessity less current than primary data and may not be available for every year. This shall be considered when determining the reference and subsequent reporting years (Section 2.1.2).

Note that some emission source inventory calculations involve data representing years outside the accounting time period, such as for soil carbon change, but this is not an activity data parameter. Furthermore, infrequent inputs like lime may require collecting data beyond the accounting time period to achieve a representative value (see 2.1.6).

Table 1 Matrix for assessing data quality

INDICATOR SCORE	1	2	3	4	5 (DEFAULT)
Reliability	Data based on sector level surveys such as farm surveys, industry benchmarks, ABS and ABARES surveys and NGGI data	Data partly based on assumptions	Data partly based on qualified estimates	Qualified estimate (e.g., by industrial expert)	Non-qualified estimate
Completeness	Representative data from the whole area relevant to the sector for the whole year.	Representative data from >50 % of the area relevant to the sector, over an adequate period to even out extreme fluctuations	Representative data from <50% of the area or involving some extreme values.	Representative data from only one site/small area	Representativeness unknown or data from a small number of sites and from shorter periods
Temporal correlation	Annual data for the year reported	Less than 3 years of difference of the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Age of data unknown or more than 10 years of difference to the time period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown or distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Farm practices and technological correlation**	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study from different technology	Data on related processes or materials	Data on related processes on laboratory scale or from different technology

Adapted from Ciroth et al. (2016)

** Technological considerations can also include post farm processing of products such as abattoirs, dairy, sugar and wine production

2.2.3 Reporting requirements for the sector GHG account

A chart of accounts shall be used to report on the detailed emission inventory for the whole sector or separately for production regions, production systems or product groups that together make up the whole sector. The chart of accounts is detailed for each sector in Chapter 3. For Scope 3 emission sources, linked to embedded emissions of materials, energy and services, not all individual inputs or processes are specified separately. These emissions may be reported at a level of aggregation appropriate for the sector. This includes aggregating or disaggregating by GHG.

The Scope 1, on-farm (Agriculture and LULUCF) emissions shall be included disaggregated by GHG as indicated in the charts of accounts.

Overall CO_2-equivalent results shall be reported for total net emissions as well as for net emissions intensity, as defined by the declared unit. In any aggregated results other than the overall results, contributions of emission source categories shall be distinguished as suggested in this guidance. At a minimum, Scope 1, 2 and 3 contributions shall be separately reflected and, within Scope 1, emissions and removals as well as contributions from land use, land use change, forestry and services. Any additional guidance on reporting in 2.2.4 shall also be followed.

Uptake and re-emission of short-cycle CO_2 shall not be reported separately in the accounts.

Results for the cradle-to-farm gate boundary shall be reported separately from those for cradle-to-factory gate (as defined in 2.1.3). It should be considered best practice to construct a full time series for each year from the reference year onwards, but current data availability may make this difficult. When an accounting time period of more than one year is defined (see 2.1.2) annual reporting results in a rolling average GHG account.

It should be noted that changes in certain elements on the GHG inventory calculation can apply retrospectively. This is the case when e.g. emission factors (2.2.1) or characterisation factors (2.3.1) are revised by the relevant organisations. These revisions reflect improvements in scientific understanding and therefore they are valid for preceding accounts. Changes that reflect new practices do not apply retrospectively.

In addition to the chart of accounts and the overall results, reporting of supplementary information may be required or desirable. As double-counting and double-claiming of carbon credits is increasingly under scrutiny, supplementary information should be provided on any carbon credits (ACCU or otherwise) from activities within the sector system boundary, that are sold to entities outside the sector boundary as defined for the GHG account (see Figure 1, 2.1.3). The total CO_2-equivalent abatement traded as credits should be reported in physical units, distinguishing separately credits sold to the Australian government, credits sold to other entities and credits bought, as well as distinguishing separately credits for emission reduction and for removals.

If data sufficient to estimate (see 2.2.2) these GHG trades are not available, a justification shall be included in the report if claims regarding progress toward a target are made (see textbox). Given the increasing importance of land sector GHG trades, appropriate effort shall be made to achieve transparency and avoid double counting. It should be noted that certain Emission Reduction Fund (ERF) methods are sector-specific (dairy, pork, cattle, cotton) and associated credits are easier to

attribute, but it is acknowledged that quantitative data on complete GHG trades is difficult to access.

Further supplementary information may be reported for emissions avoided outside the sector system boundaries and for emission storage in technosphere carbon pool of harvested wood products (see 2.2.4), if calculated in line with existing ERF or NGGI methods.

Targets or claims

Recommendations regarding claims for sector-level "net zero" or similar, are outside the scope of this guidance, but it is noted that in that case GHG accounts would typically need to be adjusted for traded credits. Any abatement associated with credits sold to (retired by) the Australian government may be counted toward a "net zero" industry claim because these credits are not claimed by any other sector or entity. Abatement associated with credits sold (retired) on a secondary market outside the sector should not be counted towards 'net zero' industry claims.

The below example illustrates how the "account" emissions calculated using this guidance would differ from "target" emissions.

GHG account (Mt CO2e)		**Supplementary information (Mt CO2e)**	
Total emissions	19	Emission reduction credits sold to private entity outside sector system boundary	3
Total removals	-3	Removal credits sold to private entity outside sector system boundary	1
		Removal credits sold to Australian government	(2)
Net "account" emissions	16	- →	16
		Net "target" emissions	20

Strictly speaking, credits are not claimed until retired but in practice it can be even harder to obtain data on sector-relevant credits retired (by other parties) than data on sector-relevant credits sold in the reporting year.

Key decisions

2.2.3a Carbon credits from activities within the sector system boundary sold to entities outside the sector should be reported. When reported, they shall be reported as supplementary information only and the GHG account shall not be adjusted to reflect credits sold.

2.2.3b Emissions avoided outside the sector system boundary as a result of the use of outputs of the sector, and carbon sequestration through increasing the wood products pool, may be reported as supplementary information. Calculations shall be consistent with existing ERF or NGGI methods.

2.2.4 Land use, land use change and forestry

The three relevant NGGI emission source categories in this category are land use, land use change (land that has been converted from one land use to another in the previous 50 years) and harvested wood products. The GHG fluxes reported in the LULUCF category are GHG emissions and carbon sequestration associated with changes in carbon stock in woody vegetation and soil due to change in land use or land management, and non-CO_2 emissions from land use change and some land management practices. Other non-CO_2 emissions, such as N_2O from fertiliser use, CO_2 from lime application, and non-CO_2 emissions from stubble burning are reported in the Agriculture category.

Land use

Land use (LU) emissions shall be included in the baseline. While it is recognised that this emission source is variable and uncertain, it is too important to exclude in current context. The NGGI or equivalent simulation approach shall be used to calculate emissions for a particular year for the Scope 1 LU of the sector concerned. Note that the NGGI evaluates the emissions of land use (reported under categories such as "Cropland remaining cropland") including changes in soil carbon stocks associated with some land management changes such as long-term changes in fertiliser application or shifts in rotation within the annual crop land use type.

In practice, the land use categories reported in the NGGI are shared by several sectors. In particular, "Cropland remaining cropland" is relevant to almost all sectors as it includes row crops, perennial crops and temporary pastures as well as fallow. Therefore, allocation rules as determined in Section 2.1.6 apply. In practice, subdivision is likely to require sector-specific modelling and it is acknowledged that this is not straightforward. Ideally, more disaggregated reporting of the NGGI source categories could allow for consistent inclusion of these emissions in the sector GHG accounts (see also textbox "Example: Cropland remaining cropland emissions" and recommendations in the Project Overview and Non-technical Summary (Sevenster et al., 2023). For "Grassland remaining grassland" the distinction between native arid grasslands and high rainfall improved pastures does allow for some level of disaggregation by sector.

Any LU removals (carbon sequestration) that contribute to a carbon credit (ACCU or otherwise) that is sold to an entity outside the sector shall be reported as supplementary information in line with 2.2.3.

Emissions due to LU shall be clearly reported as a separate emission source and (high) uncertainty acknowledged. For LU emissions that fall under Scope 3 (e.g., as part of embedded emissions of feed in livestock sectors) the assumption may be made that these are zero if the best available life cycle inventory databases do not include this emission source. Where the feed is sourced from an Australian sector applying this same guidance the embedded LU emissions as calculated for that feed shall be included as Scope 3 emissions (see section on co-products that leave the system boundary in 2.1.6). For imported feed it is likely that all changes in carbon stocks are captured under direct land use change emissions (area expansion & amortisation approach) in relevant life cycle inventory databases.

Land use change

Direct LUC emissions shall be included in the sector baseline and can be positive or negative. The NGGI or equivalent simulation approach shall be used to calculate emissions for each particular year for the "Scope 1" dLUC of the sector concerned. Allocation rules as determined in Section 2.1.6 apply. As described for Land Use above, this is not straightforward in practice. State- and land-use-level activity data are available that allow for some level of disaggregation of this source category, but the same recommendation applies here (Recommendation 2.2.1b).

Emissions due to dLUC shall be clearly reported as a separate emission source and uncertainty acknowledged. For dLUC emissions that would fall under "Scope 3" (e.g., embedded emissions of imported feed in livestock sectors) the equivalent shall be applied if data is available with reasonable effort. If data is not available, available information from life cycle inventory databases (area expansion & amortisation approach) shall be used. Scope 3 dLUC shall be reported separately from Scope 1 dLUC.

Negative emissions (i.e., considerable additional removal of carbon dioxide from the atmosphere due to a long-term increase in carbon stock in biomass or soil) may occur when there is conversion to forestland or under changed land management such as a change from annual crops to a perennial crop. This is covered in the emission source category "Perennial woody crops" for tree horticulture. Replanting or renewing of an existing land management system (orchard, forestry) shall not count as a change in long-term average carbon stock.

On-farm reforestation, for example in the context of carbon or biodiversity farming, could take this land area out of the system boundary of the original sector. However, as reforestation is seen as one of the main options for mitigation of GHG emission in the land-based sector, it is essential to evaluate the effect of this on sector annual emissions. Where reforestation is part of the production system, as may be the case in grazing systems, associated GHG removals and emissions shall be reported as removal and emissions due to land use change within the production system. Where reforestation is outside the production system, but takes place on farms that do have some area within the sector system boundary (such as reforestation on a property that also produces cotton and/or grains), associated GHG removals and emissions shall be appropriately allocated and reported as GHG removals and emissions due to land use change outside the production system. These removals and emissions outside the production system may be included in the GHG account as a separate item. However, reforestation that results in productive forest shall only be reported by the Forestry sector.

An overview of a range of land-use change contexts is given in Figure 3.

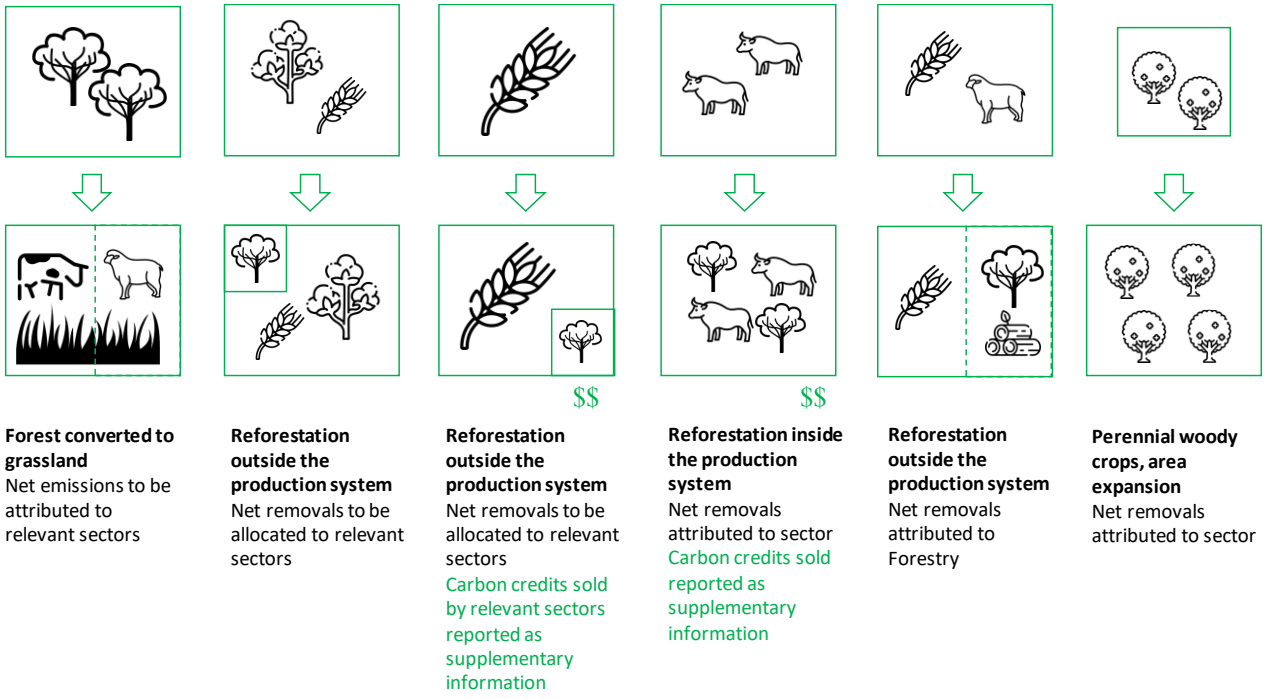

Figure 3 Simplified overview of different situations that give rise to emissions and removals that are counted in land use change source categories. Trades of carbon credits are shown in green to indicate this information is not part of the GHG account. Attribution: icons sourced from www.flaticon.com

Most on-farm reforestation is likely to be shared between multiple sectors (in the case of mixed farming, see 2.1.6) and the appropriate allocation shall be applied. As this source of GHG removals has been identified as an "infrequent input" in 2.1.6, the full sequestration potential of the reforestation project shall be divided by the number of years of the project (and area of the farm) to yield an annual value that can be attributed to each of the sectors involved. If a project period is not defined, a model such as FullCAM can be used to estimate the average annual sequestration, associated with forest growth until equilibrium is reached. It is recognized that it is not possible to do this in detail for each farm involved and therefore these sector-attributable offsets are expected to be well-documented estimates.

Any carbon sequestration that contributes to a carbon credit (ACCU or otherwise) that is sold to an entity outside the sector should be reported as supplementary information in line with the guidance in 2.2.3.

Indirect LUC shall not be included in sector GHG accounts, but a decrease in production relative to consumption should be flagged as a risk factor for indirect effects.

Note that this approach to LUC may not be applicable to commodity level footprints, or when meeting product carbon footprint standards that require the area expansion and amortisation approach.

Harvested wood products

It is optional to report carbon sequestration in harvested wood products. If this source category is evaluated, it shall be reported only as supplementary information. The net contribution to the carbon pool in the technosphere, and associated removal of GHG, shall be evaluated using the methods of the NGGI, noting that for the national reporting the pools are corrected for imports

and exports. Any other carbon sequestration in crop biomass shall not be counted unless as part of land use change.

Carbon sequestration in annual crop biomass and associated products (e.g., wheat, meat, cotton) is not counted in national greenhouse gas inventories on the basis that the carbon is soon returned to atmosphere, so counting these fluxes presents a large unnecessary burden. However, it is acknowledged that other commodities are associated with carbon pools in the technosphere, such as textile fibres, leather or bagasse insulation materials. Changes in these carbon pools are not part of the NGGI and, where they have been evaluated, are found to be negligible in the overall GHG account (below 1%). In line with the recommendations in 2.2.1, an evaluation of these effects could be included as a sensitivity assessment.

Key decisions

2.2.4a Direct LUC emissions shall be included, using the NGGI or equivalent simulation approach.

2.2.4b LU emissions shall be included, using the NGGI or equivalent simulation approach

2.2.4c Carbon sequestration in crop biomass shall only be reported, as supplementary information, for harvested wood products and evaluated using the relevant NGGI method.

2.3 Impact assessment (climate change metrics)

2.3.1 Global warming potential

Global warming potential (GWP) is a metric for the climate change indicator of "infrared radiative forcing". GWP measures the radiative forcing from an emission of a GHG, accumulated over a chosen time horizon (commonly 100 years), relative to that of CO_2. The IPCC provides, and updates, GWP values for all GHGs in its assessment reports.

The GWP100 from the Fifth Assessment Report IPCC (IPCC, 2013) is the designated metric under the Paris Agreement, and NGGI reporting from reporting year 2021 will use those values. This is also adopted in this guidance. GWP100 IPCC AR5 shall be used in baseline assessments, with values as listed in DCCEEW (2022) until this changes for NGGI reporting. Alternative metrics may be used for sensitivity assessment.

Key decision

2.3.1 The GWP100 according to the Fifth Assessment Report (IPCC, 2013) shall be used in preparing the GHG account. Alternative metrics may be used for sensitivity assessment.

2.3.2 Other metrics

Australian agriculture is a source of various GHG emissions, including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Each GHG has a different climate change impact over time as they differ in atmospheric lifetime, as well as in radiative efficiency (strength of greenhouse effect). Metrics that quantify climate change impacts are used to establish an equivalence between the different types of GHG, with results typically reported as CO_2-equivalent emissions. It is important to note that there is no absolute equivalence in climate change effects. Depending on the climate metric chosen, the relative importance of the various GHGs varies (Ridoutt and Mayberry, 2021).

GWP100 is the most commonly used metric and recognised as the prescribed metric in international conventions and agreements. In the science community as well as in LCA (UNEP/SETAC, 2016), other metrics are used, including global temperature-change potential (GTP) and GWP* (Allen et al., 2018), as well as other methods such as a cumulative radiative forcing footprint (Ridoutt, 2021) . For all of these, a time period needs to be defined, either as a time horizon or as a target year (e.g., the year 2100). The difference in estimated climate change effects between the different metrics is strongest for systems that include substantial methane emissions, since the lifetime of methane is much shorter than that of CO_2 and N_2O. Therefore, the carbon dioxide equivalence for methane is very sensitive to the choice of climate metric.

Climate metrics other than GWP100 may be used for sensitivity assessment, selected based on their relevance for specific sector objectives. This shall be accompanied by transparent discussion regarding the interpretation and application of any of the alternative metrics used.

3 Sector specific guidance

The sector-specific guidance in this section has been developed to provide additional interpretation of the key aspects of GHG accounting. The sections in this chapter elaborate the general principles provided in Chapter 2 to clarify implementation of those principles within agriculture sectors.

3.1 Livestock

3.1.1 Dairy

System definition

The dairy sector consists primarily of dairy cattle farmers (levied by Dairy Australia) but increasingly there are goat, sheep, buffalo and camel milk farmers (levied by Agrifutures). This guidance will have dairy cattle as the main focus but the methodology for other dairy production is the same (in line with e.g., IDF (2022)).

Dairy farming takes place in more densely populated, high-rainfall coastal or inland areas with access to water, primarily in the Murray-Darling basin. Given the importance of fresh milk in domestic consumption, distribution distances to major cities are relatively short. This also gives access to ports for export products.

Year-round production systems with calving spread throughout the year (approx. one third) supply milk for domestic consumption and more seasonal production systems (seasonal, split batch) may service longer shelf-life outputs (DA, 2020; PWC, 2011).

The large majority of dairy cattle are on pasture year-round (Smid et al., 2020) but there is supplementary feeding and more intensive permanent feed-pad systems exist. On average, about 57% of feed dry matter is from pasture (Gollnow et al., 2014). Concentrates and supplementary forage may be produced on farm or sourced off farm. Mixed farming, producing multiple outputs to market (excluding identified co-products) is uncommon.

Transport and raw milk processing are an integral part of the dairy sector. Dairy at factory-gate consists of many products such as cream, regular milk, butter, skim milk, milk powders, cheese, yoghurt and ice-cream. Milk processing plants are diverse and the range of products they manufacture varies between locations.

System boundary

Transport and raw milk processing are an integral part of the dairy sector and shall be included in the assessment (Section 2.1.3). This is in line with the Australian Dairy Industry Sustainability Framework which sets a 2030 goal to reduce GHG emissions intensity by 30% across farming and manufacturing on 2015 levels. The system boundary shall be cradle-to-factory-gate.

Separate cradle-to-farm-gate reporting (see 2.1.3 and 2.2.3) includes only processes up to farm gate, excluding transport to processing facility. For milk collection, see IDF (2022).

The system boundary of dairy production shall include raw material production and use (e.g. fertiliser, lime, pesticides, and fuel use for producing feed), transportation of agricultural inputs to the farm, land management including any pasture improvement and crop production, herd management, milking and cooling (on farm) as well as inputs to manufacture (Figure 4). This may include additional food ingredients (e.g., yoghurt, ice-cream, flavoured milks) as well as primary, secondary and tertiary packaging materials.

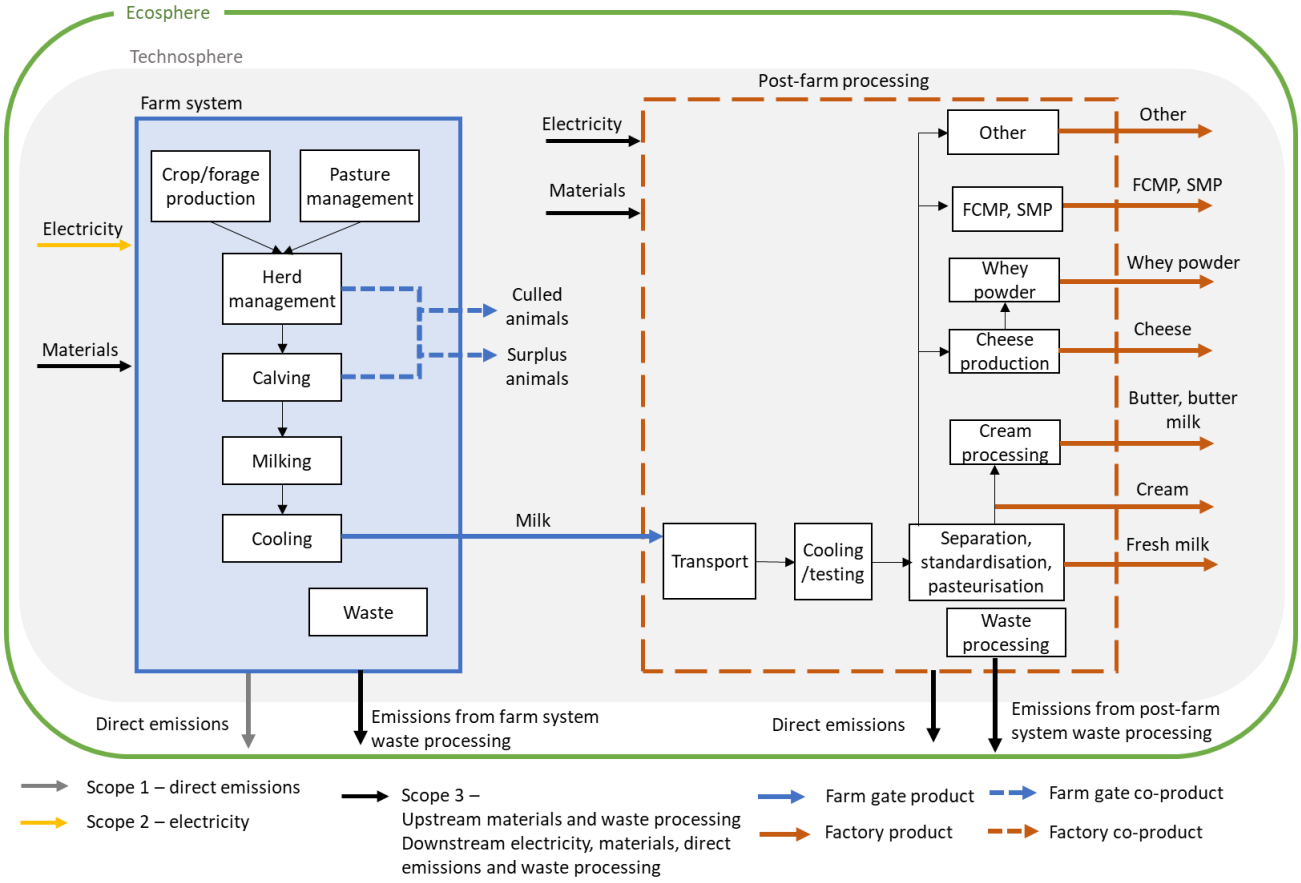

Figure 4 Cradle-to-factory-gate system boundary of dairy production in Australia. FCMP, SMP: full-cream, skim milk powder

Declared unit

Currently, the Australian Dairy Industry Sustainability Framework uses Fat-and Protein-Corrected Milk kg FPCM (IDF, 2022) as a declared unit for dairy farm intensity (DA, 2021). For GHG intensity of manufacturing, the declared unit is ML processed milk.

The use of kg FPCM at farm gate is in line with the international guidance (IDF, 2022). IDF (2022) does not address sector-level reporting and the issue of the diversity of products that are outputs from manufacturing is not addressed.

To report an integrated value for the cradle-to-factory-gate emissions and emission intensity, a common declared unit shall be used. The recommended declared unit is mass of FPCM processed (corrected for losses during manufacturing), as this captures all dairy production and manufacture in a unit that reflects a commonly accepted measure of standardized milk. An alternative would be to use (factory gate) revenue as a denominator for sector GHG intensity. The associated mix of

final products may be reported for additional information and transparency, with contributions by e.g. milk-solids content.

For non-cattle dairy, the same approach should be applied but the definition of FPCM may differ.

Accounting for multifunctionality

Allocation in case of multifunctional processes shall follow the guidance provided in Section 2.1.6.

The dairy sector is less likely to share farming systems with several other sectors. There are on-farm co-products, however, in culled and surplus animals that are sold to other industries. Allocation of emission to those products shall follow the guidance provided, using the default biophysical allocation recommended by the IDF guidelines (IDF, 2015; 2022). If manure leaves the system boundary as a residual product, this shall also be treated according to the guidance in Section 2.1.6.

Whey is a co-product of the manufacturing process that may be an input to livestock industry as feed. In line with the guidance, this shall be handled using economic allocation, except for the standardisation and separation step, including the raw milk and pasteurisation if relevant, which shall be allocated based on milk-solids content (IDF, 2022). This allocation is not necessary for the dairy sector assessment because whey is considered to be part of the system. However, to facilitate accounting consistently for those material flows between sectors and correcting for double counting if at any point sector-level GHG accounts are to be combined to give an all-of-agriculture baseline, an assessment could be made of this allocation and the quantity of whey flowing from the dairy sector to other livestock sectors.

The same allocation rationale shall be applied if there is a need to report sector-level emissions or emissions intensities by product (group). This approach uses the IDF (2022) recommendations where they are in line with the general guidance provided in this document. The allocation of raw milk and initial processing steps that are shared by all products uses milk solids as a semi-physical allocation basis. Subsequent processing steps are more likely to be driven by a main product and co-products, which is addressed by economic allocation. Note that IDF guidance should be followed in subdividing the manufacturing processes as much as possible to prevent the need for allocation, rather than treating facilities as a “black box”.

For inputs that are generated in upstream multifunctional processes, such as feed, the guidance in Section 2.1.6 shall be applied. Where feed ingredients are sourced from Australian sectors (e.g., cotton seed) allocation shall be done using identical factors as those applied by the producing sector, preferably by using the producing sector’s reported emission intensity for the product or co-product.

Emission inventory

The chart of accounts (Table 2) lists all the emission sources that shall be investigated in the emission inventory for dairy. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

To calculate emissions associated to services, no definitive guidance can be provided. Where possible, these emissions should be included in the accounts if relevant (see 2.1.3) but currently

no single source of data can be recommended. Typically, emission factors from environmentally-extended input-output data would be applied to financial activity data.

For all calculations of emission in the Agricultural Soils category, on-farm activities could fall in any of the categories Irrigated or non-irrigated crop or pasture. For Land use, land use change and forestry, dairy pastures may fall under cropland (cropland remaining cropland or land converted to cropland) or under grassland (grassland remaining grassland or land converted to grassland), depending on whether the pastures are temporary (in rotational use between grassland and cropland) or permanent.

Disaggregation of elements of the emission calculation, compared to the calculations in the NGGI, may be applied when not inconsistent with the methods underlying NGGI calculations (see 2.2.1). Specifically, this could be relevant to the value of emissions or removals in the Source Category Cropland remaining cropland. This category includes all crops including perennial crops and temporary pastures in mixed farming rotations. Disaggregation by region as well as sector could be achieved by running targeted simulations using FullCAM or equivalent (see 2.2.4).

Table 2 Chart of accounts for GHG emissions from dairy production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Enteric fermentation	CH_4 emissions from enteric fermentation	1	NGGI
		Manure management	CH_4 emissions from manure management	1	NGGI
			N_2O emissions from manure management (direct)	1	NGGI
			N_2O emissions from manure management, atmospheric deposition (indirect)	1	NGGI
			N_2O emissions from manure management, leaching and run off (indirect)	1	NGGI
		Agricultural soils (direct)	N_2O emissions- fertilisers (inorganic, organic) applied to crop	1	NGGI
			N_2O emissions- animal waste and sewage sludge applied to crop	1	NGGI
			N_2O emissions- fertilisers (inorganic, organic) applied to pasture	1	NGGI
			N_2O emissions- animal waste and sewage sludge applied to pasture	1	NGGI
			N_2O emissions-urine and dung deposited by grazing animals	1	NGGI
			N_2O emissions- crop residue (crops and pastures)	1	NGGI
			N_2O emissions-cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions-mineralisation due to loss of soil organic carbon	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition	1	NGGI
			N_2O emissions – Leaching and run off	1	NGGI
		Residue burning	CH_4 and N_2O emissions from field burning of stubble	1	NGGI
		Application of lime and urea	CO_2 emissions-lime and urea application	1	NGGI
	Energy and Materials	Inputs for agriculture processes	CO_2-equivalent emissions on farm fuel use for pasture management and crop and forage production (for tractors, agricultural aircraft, harvester, etc.)	1	NGA
			CO_2-equivalent emissions grid-supplied electricity	2	NGA
			CO_2-equivalent emissions grid-supplied electricity (pre-combustion)	3	NGA
			CO_2-equivalent emissions for feed produced off farm	3	L

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			CO_2-equivalent emissions embedded in farm inputs (fertiliser, pesticides, fuel, etc.)	3	LCI, NGA
			CO_2-equivalent emissions transport of fuel, fertilisers, pesticides, and other inputs to farm (if not included in above)	3	LCI
			CO_2-equivalent emissions-services (insurance, consultants, etc.)	3	See 2.1.3
	Land use, land use change, forestry	Forestland converted to cropland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in dead organic matter (DOM)	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions- N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions-Leaching and run-off from mineralised N	1	NGGI
		Forestland converted to grassland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions- N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions- Leaching and run-off from mineralised N	1	NGGI
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Wetlands converted to grassland	CO_2-equivalent emissions wetlands converted to grassland (permanent pasture)	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission from other Constructed Water Bodies (dams)	1	NGGI
		Cropland remaining cropland	CO_2 emission due to change in soil organic carbon (crops and temporary pasture)	1	NGGI_s
		Grassland remaining grassland	CO_2 emission due to change in soil organic carbon (permanent pasture)	1	NGGI_s
			CO_2-equivalent emissions- Sparse woody vegetation transition (permanent pasture)	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			CO_2-equivalent emissions due to controlled burning (permanent pasture)	1	NGGI_s
			N_2O emissions- N mineralization (direct) (permanent pasture)	1	NGGI
			N_2O emissions-N mineralized, leaching and run off (indirect)(permanent pasture)	1	NGGI
	Capital goods and services		CO_2-equivalent emissions-capital goods on farm and off-farm storage (equipment, tractor, sheds, harvester, etc.)	3	LCI
			CO_2-equivalent emissions-capital goods on manufacturing stages (equipment, sheds, chiller, etc.)	3	LCI
	Waste treatment		CO_2-equivalent emissions from all off-farm solid waste disposal (transport, composting, landfill)	3	LCI, NGA
			CO_2-equivalent emissions from all on-farm solid waste disposal (transport, spreading, composting)	1	LCI, NGA
			CO_2-equivalent emissions from all wastewater disposal and treatment during manufacturing.	3	LCI, NGA
	Energy and Materials	Dairy manufacture	CO_2-equivalent emissions fuel use	3	NGA
			CO_2-equivalent emissions electricity	3	NGA
			CO_2-equivalent emissions embedded in fuel used	3	NGA
			CO_2-equivalent emissions electricity (pre-combustion)	3	NGA
			CO_2-equivalent emissions embedded in material inputs (packaging, ingredients, etc)	3	LCI
			CO_2-equivalent emissions embedded in capital goods	3	LCI
			CO_2-equivalent emissions embedded in services	3	See 2.1.3
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in living biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Grassland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in living biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Cropland remaining cropland	CO_2 removal due to change in soil organic carbon (crops and temporary pasture)	1	NGGI_s
		Grassland remaining grassland	CO_2 removal due to change in soil organic carbon (permanent pasture)	1	NGGI_s
Sub-total removals					
Net-GHG emission					

Exclusions and cut-off criterion

To determine whether certain emission sources may be excluded, refer to 2.1.3 and 2.1.5. These sections provide guidance regarding the inclusion of capital goods and services, as well as the general cut-off criterion.

Activity data

Table 3 lists typical activity data needed for the emission inventory calculation, as well as suggested sources based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data if available (e.g., DairyBase), are likely to be preferred due to representative coverage and repeatability.

Table 3 Activity data required and suggested sources for the dairy sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Animal Numbers by region, types (Milking Cows, Heifers>1 y, Heifers < 1 y, Dairy Bulls > 1 y, Dairy Bulls < 1 y)	Dairy Australia (annual data frequency), ABARES Agricultural Commodities (quarterly data frequency), ABS Agricultural Commodities (annual data frequency),
1.2	Production areas	ABS, industry data
	Area of crops grown on dairy farm by crop type, system (rainfed, irrigated) and/or region as needed	Farm surveys, ABARES land use data (ALUM), ABS, industry data
	Area of pastures by type (rainfed, irrigated)	ABARES land use data and Land Management Practices Data
Agriculture (for each type and area defined under 1.2)		
2.1	Liveweight	Table 5.A.1 of National Inventory Report as per industry data
2.2	Live weight gain (LWG)	Table 5.A.2 of National Inventory Report as per industry data
2.3	Standard reference weights (Milking Cows, Heifers, Dairy Bulls)	Table 5.A.3 of National Inventory Report as per industry data
2.4	Dry matter digestibility and crude protein content of feed intake	Table 5.A.4 of National Inventory Report as per industry data
2.5	Manure management by type (Pasture, Anerobic lagoon, Sump and Dispersal, Drain to Paddocks, Solid Storage)	Table 5.A.8 of National Inventory Report as per industry data
2.6	Average milk production (kg/head/year)	Industry data
2.7	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.8	Nitrogen and carbon content of crop residue	For pasture renewal as well as crops: Derive from 1.1 using NGGI equations and factors (Agricultural Soils - Crop Residues)
2.9	Fraction of residue burnt, removed, or left in field	For pasture renewal as well as crops: Derive from 1.1 using NGGI equations and factors (Agricultural Soils - Crop Residues and Field Burning of Agricultural Residues)
2.10	Urea applied	As collected for 4.1
2.11	Lime, dolomite applied	As collected for 4.3

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
2.12	N mineralised	Derive from 3.1 and 3.2 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	Crop area (1.2) minus area determined under 3.3. Note that this emission source needs to be attributed/disaggregated between sectors, see 2.1.6 and 2.2.4.
3.2	Fraction of area that qualifies as “grassland remaining grassland”	Pasture area (1.2) minus area determined under 3.4. Note that this emission source needs to be attributed/disaggregated between sectors, see 2.1.6 and 2.2.4.
3.3	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of crop area (1.2) to NGGI total cropland area, or well documented sector-specific attribution
3.4	Fraction area that qualifies as “forest converted to grassland” or “wetlands converted to grassland”	Derive from NGGI relevant areas using ratio of grassland area (1.2) to NGGI total grassland area, or well documented sector-specific attribution
3.5	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Feed sourced off farm	Farm surveys, industry data, commercial benchmark data
4.2	Inorganic fertilisers applied, quantity and type	Farm surveys, expert consultation, commercial benchmark data, ABS, Fertilizer Australia
4.3	Organic amendments applied, quantity and type	Farm surveys, expert consultation, commercial benchmark data, ABS
4.4	Other amendments applied (e.g., lime), quantity, frequency, and type	Farm surveys, expert consultation, commercial benchmark data, ABS
4.5	Pesticides applied, quantity and type	Farm surveys, expert consultation, commercial benchmark data
4.6	Fuel use requirements for field operations, quantity, and type	Farm surveys total fuel use if available, gross margin budgets
	Cultivation, sowing, fertiliser spreading, harvesting, etcetera	Estimates of fuel use per operation reference LCI databases
	Irrigation pumping if applicable	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.7	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.8	Energy (fuel, electricity) use for milking	Farm surveys, expert consultation.
4.9	Capital goods, type, and lifetime	Expert consultation, reference LCI databases, academic literature

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.10	Services, type, and expenditure	Farm surveys, gross margin budgets
4.11	Waste flows	Expert consultation, reference LCI databases, academic literature
Energy and materials, processing		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Transport, distance, and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

3.1.2 Pork

System definition

In Australia, pig production occurs in all states, with large scale commercial operations in New South Wales, Queensland, South Australia, Western Australia and Victoria. Over the last 50 years, production has transitioned from small farm enterprises to large scale, specialist pig farming operations. This change has profoundly influenced production efficiency (e.g., weaning rates, live weight produced per sow, average daily live weight gain and feed conversion ratio) and the environmental impacts of the industry.

System boundary

The estimation of GHG emissions from pork shall follow the general system boundary guidance (Section 2.1.3). Cradle-to-farm-gate system boundary of pork production shall include feed production (scope 3), farm services (e.g., fuel, electricity, repairs and maintenance, administration) and manure management emissions (Figure 5Figure 5). The cradle-to-factory-gate system boundary shall also include transport to processing, factory services (e.g., fuel, electricity, repairs and maintenance, administration), wastewater emissions and consumables (cleaning and packing) (Figure 5).

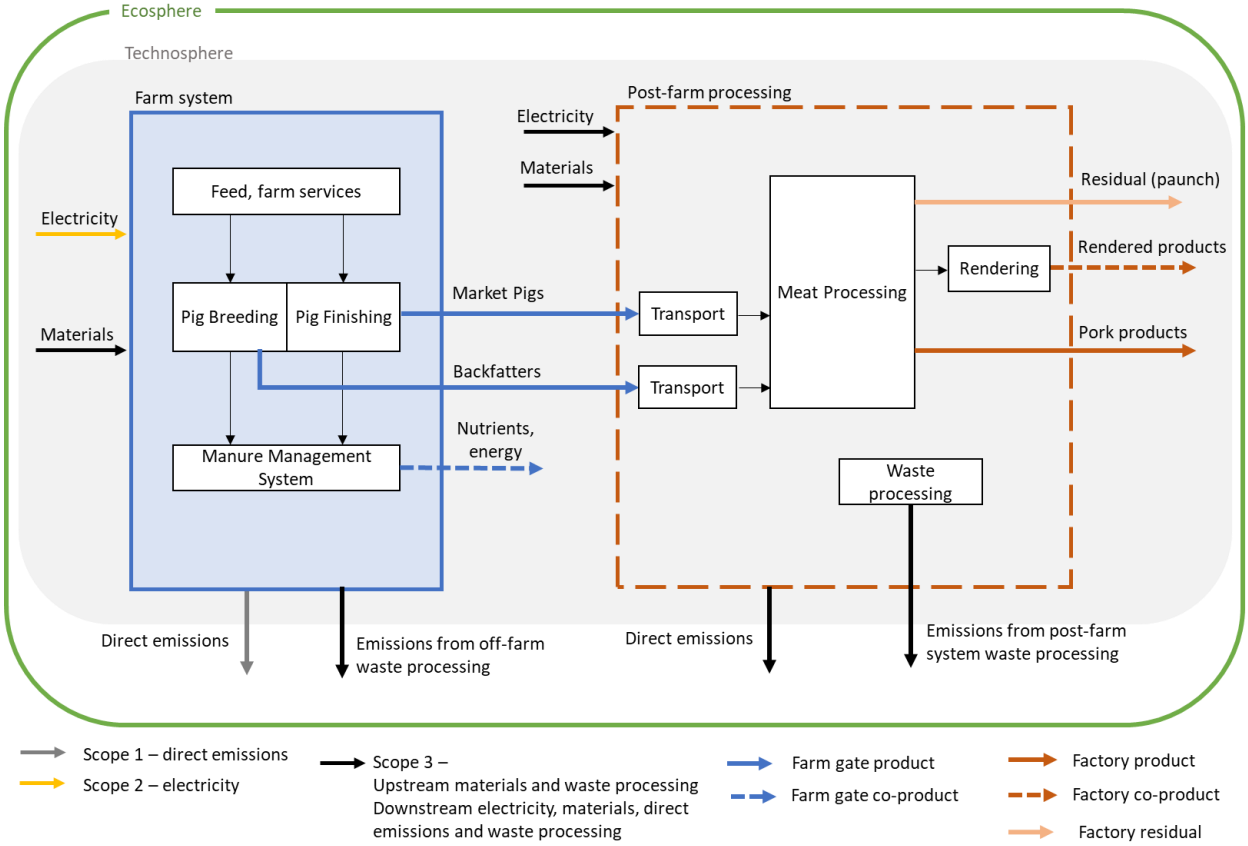

Figure 5 Cradle-to-factory-gate system boundary of pork production in Australia

Declared unit

The declared unit recommended at the farm gate is mass of pork live weight. If the system boundary is extended to include processing, the recommended declared unit is mass of wholesale pork at the processor/abattoir gate.

Accounting for multifunctionality

Overarching guidance for dealing with multifunctional processes is described in Section 2.1.6. The allocation of inputs and emissions associated with feed and manure often require consideration when assessing pig production system. The multi-functionality of feed should be handled in accordance with Section 2.1.6.

In accordance with the guidance, manure and spent litter should be classified as a residual products if destined for use outside the system boundary. If these products are 'disposed of' within the system, they shall be classified as waste and emissions included in sector account.

Emission inventory

The emissions inventory for pork shall include those emissions listed in the chart of accounts (Table 4). The chart of accounts lists all the emission sources that shall be investigated in the emission inventory for pork. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

Table 4 Chart of accounts for GHG emissions for pork production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Enteric fermentation	CH_4 emissions from enteric fermentation	1	NGGI
		Manure management	CH_4 emissions from manure management	1	NGGI
			N_2O emissions from manure management (direct)	1	NGGI
			N_2O emissions from manure management, atmospheric deposition (indirect)	1	NGGI
			N_2O emissions from manure management, leaching and run off (indirect)	1	NGGI
		Agricultural soils (if applicable)	N_2O emissions associated with outdoor paddock management (direct)	1	NGGI
			N_2O emissions associated with outdoor paddock management (indirect)	1	NGGI
	Energy and Materials	Inputs for agriculture processes	CO_2-equivalent emissions on farm fuel use (for breeder, weaner, etc.)	1	NGA
			CO_2-equivalent emissions grid-supplied electricity	2	NGA
			CO_2-equivalent emissions grid-supplied electricity (pre-combustion)	3	NGA
			CO_2-equivalent emissions for feed produced off farm	3	LCI, AIA
			CO_2-equivalent emissions embedded in farm inputs (for example fuel)	3	LCI, NGA
			CO_2-equivalent emissions transport of inputs to farm (if not included in above)	3	LCI
			CO_2-equivalent emissions-services (insurance, consultants, etc.)	3	See section 2.1.4
		Post-farm processing	CO_2-equivalent emissions fuel use	3	NGA
			CO_2-equivalent emissions electricity use	3	NGA
			CO_2-equivalent emissions embedded in fuel used	3	NGA
			CO_2-equivalent emissions embedded in electricity supply chain	3	NGA
			CO_2-equivalent emissions embedded in material inputs (packaging, ingredients, etc)	3	LCI
			CO_2-equivalent emissions embedded in services	3	See section 2.1.4
	Capital goods and services		CO_2-equivalent emissions-capital goods on farm and off-farm storage (equipment, etc.)	3	LCI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			CO_2-equivalent emissions-capital goods on manufacturing stages (equipment, sheds, chiller, etc.)	3	LCI
	Waste treatment		CO_2-equivalent emissions from all off-farm solid waste disposal (transport, composting, landfill)	3	LCI, NGA
			CO_2-equivalent emissions from all on-farm solid waste disposal (transport, spreading, composting)	1	LCI, NGA
			CO_2-equivalent emissions from all wastewater disposal and treatment during manufacturing.	3	LCI, NGA
	Land use, land use change, forestry	Forestland converted to cropland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions- N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions- Leaching and run-off from mineralised N	1	NGGI
		Forestland converted to grassland (deforestation)	CO_2 emission due to change in soil organic carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions- N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions-Leaching and run-off from mineralised N	1	NGGI
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Wetlands converted to grassland	CO_2-equivalent emissions wetlands converted to grassland (permanent pasture)	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission from other Constructed Water Bodies (dams)	1	NGGI
		Cropland remaining cropland	CO_2 emission due to change in soil organic carbon (crops and temporary pasture)	1	NGGI_s
		Grassland remaining grassland	CO_2 emission due to change in soil organic carbon (permanent pasture)	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			CO_2-equivalent emissions- Sparse woody vegetation transition (permanent pasture)	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning (permanent pasture)	1	NGGI_s
			N_2O emissions-N mineralization (direct) (permanent pasture)	1	NGGI
			N_2O emissions-N mineralized, leaching and run off (indirect)(permanent pasture)	1	NGGI
Sub-total emissions					
Removal	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon n	1	NGGI_s
			CO_2 removal due to change in living biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Grassland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon n	1	NGGI_s
			CO_2 removal due to change in living biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Cropland remaining cropland	CO_2 removal due to change in soil carbon (crops and temporary pasture)	1	NGGI_s
		Grassland remaining grassland	CO_2 removal due to change in soil carbon (permanent pasture)	1	NGGI_s
Sub-total removals					
Net-GHG emission					

Exclusions and cut-off criterion

To determine whether certain emission sources may be excluded, refer to 2.1.3 and 2.1.5. These sections provide guidance regarding the inclusion of capital goods and services, as well as the general cut-off criterion.

Activity data

Table 5 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 5 Activity data required and suggested sources for pork sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Animal Numbers by region, and types	ABARES Agricultural Commodities (quarterly data frequency), ABS Agricultural Commodities (annual data frequency), ABARES Meat and Livestock Australia farm survey data (annual),
Agriculture (for each type and area defined under 1.1)		
2.1	Avg live weight	Table 5.E.1 of National Inventory Report, farm surveys, industry data
2.2	Dry matter digestibility and crude protein content of feed intake	Table 5.E.2 of National Inventory Report, farm surveys, industry data
2.3	Manure and litter management system	Table 5.E.5 of National Inventory Report, farm surveys, industry data
2.4	Feed waste	Table 5.E.1 of National Inventory Report, farm surveys, industry data
Land use, land use change and forestry		
	Not relevant in foreground (farm) system	If relevant, see other sectors for suggested sources
Energy, materials and other inputs, farm		
4.1	Feed sourced off farm	Farm surveys, industry data, commercial benchmark data
4.2	Fuel use requirements for operations, quantity, and type	Farm surveys total fuel use if available, gross margin budgets
4.3	Capital goods, type, and lifetime	Expert consultation, reference LCI databases
4.4	Services, type, and expenditure	Farm surveys, gross margin budgets
4.5	Waste flows	Expert consultation, reference LCI databases
Energy and materials, processing		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Transport, distance, and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

3.1.3 Red meat

System definition

The Australian red meat industry encompasses the production and processing of beef cattle, sheep and goats, for both export and domestic consumption. Beef cattle and sheep are the dominant livestock industries in Australia. Figure 6 and Figure 7Figure 7 show the number of cattle and sheep in Australia and their national distribution.

This section also addresses GHG accounting for deer and for buffalo, which have very similar GHG emission sources. However, deer and buffalo are also harvested from feral populations, which is very different in terms of production system. Note that this is also the case for goats and some cattle, especially in the North.

The cattle industry is the largest agricultural industry in Australia, with 24.4 million head of cattle and 17% of total agricultural and forestry production by value (MLA, 2022)), and 52,410 agricultural businesses involved with the cattle industry in Australia (2019 - 2020). In 2020, beef cattle farming alone had a turnover of $21,315 million (MLA, 2020a).

The beef cattle industry generally divides into the northern tropical industry, dominated by *Bos indicus* or composite type animals, while the southern industry is typically dominated by *Bos taurus* cattle. Introduced pastures typically underpin the higher rainfall grazing zones, being more European grasses in southern Australia and African introduced grasses in northern Australia. In the drier inland regions and northern Australia, most livestock production would be based on rangelands systems. In the higher rainfall regions, beef steers are finished off improved pastures, whereas in more arid rangeland systems is seldom finish at pasture and need to be sent to a feedlot before market. Most rangeland cattle are either sent for live export, typically out of northern Australia, or sent in an integrated supply chain model from the breeder herd to a steer growing property, through to a backgrounding property his preparation for entering a feedlot for finishing.

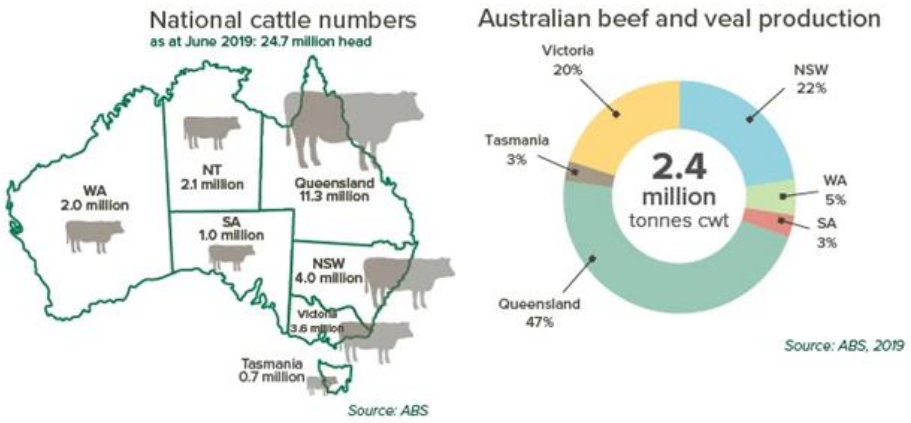

Figure 6 National beef cattle numbers, beef and veal production, and their distribution by State across Australia. Figure source MLA (2020a)

The sheep industry contributes 6% of total agricultural and forestry production by value in Australia, with 68 million head of sheep over 17,700 Australian farms in 2020 (MLA, 2022). The off-farm meat value (domestic expenditure plus export value, including live export) of the Australian

sheep meat industry was approximately $7.2 billion in 2019 up 24% on the 2018 period (MLA, 2020b).

The majority of Australia's sheep population are located in New South Wales (34%), Western Australia (22%), Victoria (21%) and South Australia (16%). Tasmania and Queensland accounted for the remaining 4% and 3% respectively (MLA, 2020a). Main products from this industry would be mutton and prime lamb, the latter generally being in the higher rainfall regions closer to the coast. Overlapping with the wool sector (3.1.4) would be those sheep systems that are dual purpose, thus producing both meat and wool as co-products.

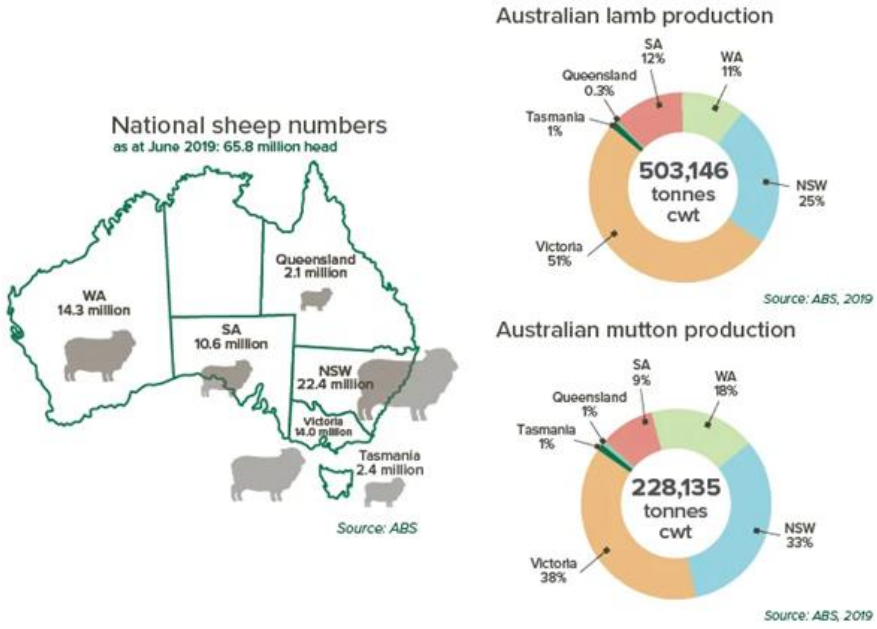

Figure 7 National sheep numbers, mutton and lamb production and their distribution by State across Australia. Figure source MLA (2020a)

For goats, the majority of meat is harvested from semi-wild rangeland goats. A 2017 survey of NSW goatmeat producers found that 71% of the 454 enterprises producers who responded had a harvest enterprise, while 29% operated a managed or semi managed enterprise (MLA, 2020c; NSWDPI, 2017). According to National Livestock Identification System (NLIS) data, NSW was the largest contributor to goat production, supplying over 60% of total goats in 2018. The state slaughter figure for NSW nearly halved from 2017 to total 67,860 head, due to Victoria processing over 50% of the state's goats and Queensland picking up 30% of NSW's production. Australian goat slaughter totalled 1,210,837 head in 2021 (MLA, 2022).

The two main meat goat breeds in Australia are the Boer goat and a feral rangelands goat. There are a number of other goat breeds in smaller numbers, particularly dairy goats (DGSA, nd) and angora goats, but these make up a very small proportion of the national goat herd. In terms of greenhouse gas accounting, goat production systems shall be treated in a similar way to sheep production, with co-products (meat, mohair, milk) requiring recognition. Goat milk and goat fibre are subject to separate levies managed by AgriFutures.

System boundary

The estimation of life cycle GHG emissions of livestock shall follow the general system boundary guideline (Section 2.1.3). The cradle-to-farm gate system boundary of livestock production shall include raw material production and use (e.g. fertiliser, lime, pesticides, and fuel use for producing feed), transportation of agricultural inputs to the farm, land preparation, sowing pasture maintenance, harvesting, and post-harvest processes within the farm gate as shown in Figure 8Figure 8.

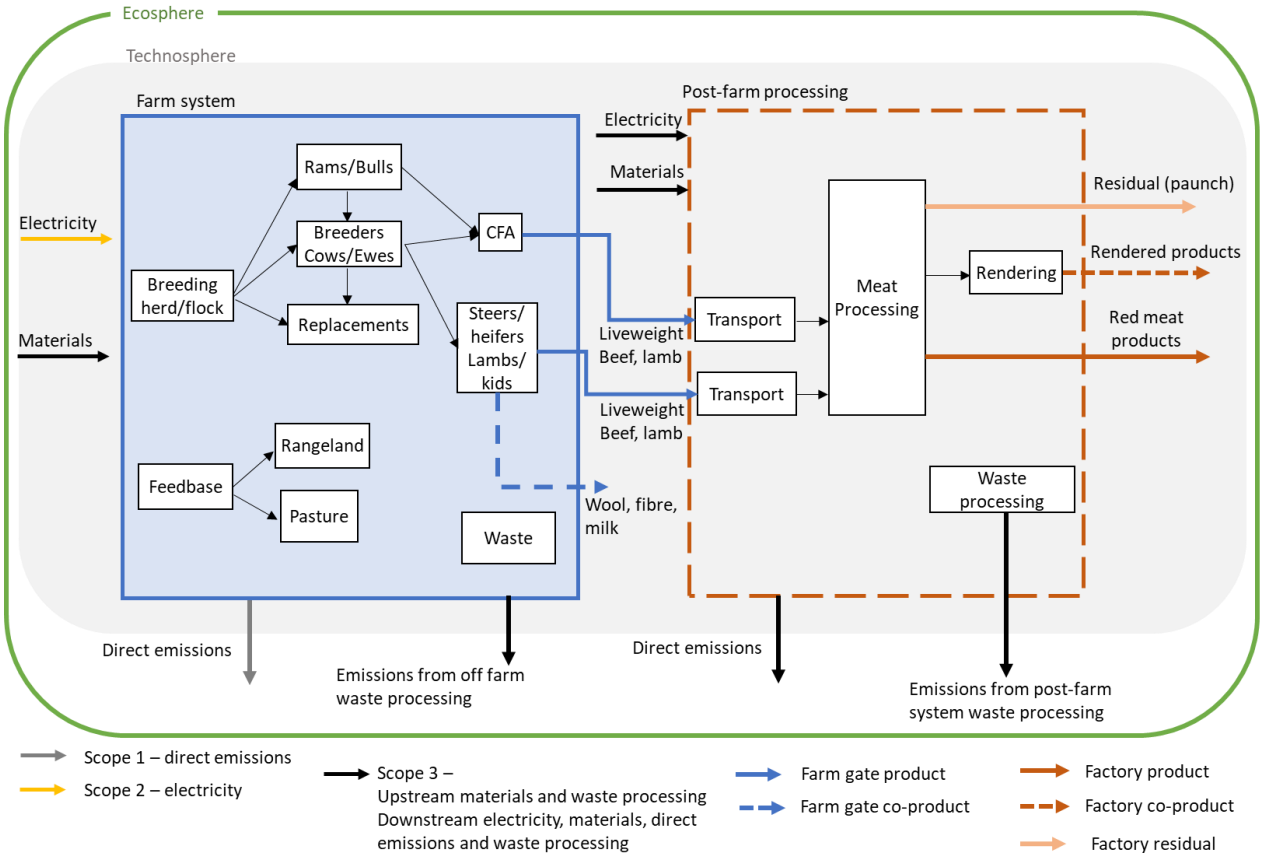

Figure 8 Cradle-to-factory-gate system boundary of red meat production in Australia

Declared unit

Considering the cradle-to-farm-gate system boundary, the declared unit for red meat should be mass of live weight at the farmgate, as a production-weighted average of the key sub-systems that make up the sector. If the system boundary is extended to the factory gate, the declared unit should be carcass weight/dressed weight at the factory gate.

Accounting for multifunctionality

Overarching guidance for dealing with multifunctional processes is described in Section 2.1.6. Where there are co-products that may be part of another sector (levying system) such as milk or wool, allocation shall be identical to what is used in that sector. Please refer to the relevant sections in this chapter (3.1.1, 3.1.4).

Emission inventory

The emissions inventory for red meat production shall include the emissions listed in the chart of accounts (Table 6). The chart of accounts lists all the emission sources that shall be investigated in the emission inventory for red meat. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

Table 6 Chart of accounts for GHG emissions for red meat production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Enteric fermentation	CH_4 emissions from enteric fermentation	1	NGGI
		Manure management	CH_4 emissions from manure management	1	NGGI
			N_2O emissions from manure management (direct)	1	NGGI
			N_2O emissions from manure management, atmospheric deposition (indirect)	1	NGGI
			N_2O emissions from manure management, leaching and run off (indirect)	1	NGGI
		Agricultural soils (direct)	N_2O emissions- fertilisers (inorganic, organic) applied to crop	1	NGGI
			N_2O emissions- animal waste and sewage sludge applied to crop	1	NGGI
			N_2O emissions- fertilisers (inorganic, organic) applied to pasture	1	NGGI
			N_2O emissions- animal waste and sewage sludge applied to pasture	1	NGGI
			N_2O emissions- urine and dung deposited by grazing animals	1	NGGI
			N_2O emissions- crop residue (crops and pastures)	1	NGGI
			N_2O emissions from cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions- mineralisation due to loss of soil organic carbon from cropland remaining cropland	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition	1	NGGI
			N_2O emissions – Leaching and run off	1	NGGI
		Residue burning	CH_4 and N_2O emissions from field burning of stubble	1	NGGI
		Application of lime and urea	CO_2 emissions - lime and urea application	1	NGGI
	Energy and Materials	Inputs for agriculture processes	CO_2-equivalent emissions on farm fuel use for pasture management and crop and forage production (for tractors, agricultural aircraft, harvester, etc.)	1	NGA
			CO_2-equivalent emissions grid-supplied electricity	2	NGA
			CO_2-equivalent emissions grid-supplied electricity (pre-combustion)	3	NGA
			CO_2-equivalent emissions for feed produced off farm	3	LCI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			CO_2-equivalent emissions embedded in farm inputs (fertiliser, pesticides, fuel, etc.)	3	LCI, NGA
			CO_2-equivalent emissions transport of fuel, fertilisers, pesticides, and other inputs to farm (if not included in above)	3	LCI
			CO_2-equivalent emissions-services (insurance, consultants, etc.)	3	See 2.1.3
	Land use, land use change, forestry	Forestland converted to cropland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions- N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions-Leaching and run-off from mineralised N	1	NGGI
		Forestland converted to grassland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions-N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions- Leaching and run-off from mineralised N	1	NGGI
			CH_4, and N_2O emissions from savanna burning	1	NGGI_s
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Wetlands converted to grassland	CO_2-equivalent emissions wetlands converted to grassland (permanent pasture)	1	NGGI_s
		Cropland remaining cropland	CO_2 emission due to change in soil organic carbon (crops and temporary pasture)	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission from other Constructed Water Bodies (dams)	1	NGGI
		Grassland remaining grassland	CO_2 emission due to change in soil organic carbon (permanent pasture)	1	NGGI_s
			CO_2-equivalent emissions -Sparse woody vegetation transition (permanent pasture)	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning (permanent pasture)	1	NGGI_s
			N_2O emissions-N mineralization (direct) (permanent pasture)	1	NGGI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			N_2O emissions-N mineralized, leaching and run off (indirect)(permanent pasture)	1	NGGI
			CH_4, and N_2O emissions from savanna burning	1	NGGI_s
	Capital goods and services		CO_2-equivalent emissions-capital goods on farm and off-farm storage (equipment, tractor, sheds, harvester, etc.)	3	LCI
			CO_2-equivalent emissions-capital goods on manufacturing stages (equipment, sheds, chiller, etc.)	3	LCI
	Waste treatment		CO_2-equivalent emissions from all off-farm solid waste disposal (transport, composting, landfill)	3	LCI, NGA
			CO_2-equivalent emissions from all on-farm solid waste disposal (transport, spreading, composting)	1	LCI, NGA
			CO_2-equivalent emissions from all wastewater disposal and treatment during manufacturing	3	LCI, NGA
	Energy and Materials	Post-farm processing	CO_2-equivalent emissions fuel use	3	NGA
			CO_2-equivalent emissions electricity use	3	NGA
			CO_2-equivalent emissions embedded in fuel used	3	NGA
			CO_2-equivalent emissions embedded in electricity supply chain	3	NGA
			CO_2-equivalent emissions embedded in material inputs (packaging, ingredients, etc)	3	LCI
			CO_2-equivalent emissions embedded in capital goods	3	LCI
			CO_2-equivalent emissions embedded in services	3	See 2.1.3
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to Forestland (On-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in living biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Grassland converted to Forestland (On-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in living biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Cropland remaining cropland	CO_2 removal due to change in soil organic carbon (crops and temporary pasture)	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Grassland remaining grassland	CO_2 removal due to change in soil organic carbon (permanent pasture)	1	NGGI_s
Sub-total removals					
Net-GHG emission					

Exclusions and cut-off criterion

To determine whether certain emission sources may be excluded, refer to 2.1.3 and 2.1.5. These sections provide guidance regarding the inclusion of capital goods and services, as well as the general cut-off criterion.

Activity data

Table 7 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 7 Activity data required and suggested sources for the red meat sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Animal Numbers by region, season, category (beef cattle, sheep, Goats,), types (e.g. Bulls, Cows, etc as per inventory), system (Pasture fed, lot-fed- Domestic, Export mid-fed, Export long-fed, etc.)	ABARES Agricultural Commodities (quarterly data frequency), ABS Agricultural Commodities (annual data frequency), Australian Lot Feeders Association (quarterly data frequency), Meat and Livestock Australia farm survey data (annual), Australian Lot Feeders Association,
	Production areas by system	ABS, industry data
Agriculture (for each type and area defined under 1.1)		
2.1	Liveweight	Table 5.B.1, 5.D.1 of National Inventory Report
2.2	Live weight gain (LWG)	Table 5.B.2, 5.D.5 of National Inventory Report, ABS slaughter weight
2.3	Dry matter digestibility and crude protein content of forage on offer	Table 5.B.3&4, 5.D.2&4 of National Inventory Report as per industry data
2.4	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.5	Urea applied	As collected for 4.1
2.6	Lime, dolomite applied	As collected for 4.3
2.7	N mineralised	Derive from 3.1 and 3.2 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
2.8	Fraction of savanna burning to red meat	Expert consultation, ERF registry
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland" (e.g., mixed farming)	Crop area (1.2) minus area determined under 3.3. Note that this emission source needs to be attributed/disaggregated between sectors, see 2.1.6 and 2.2.4.
3.2	Fraction of area that qualifies as “grassland remaining grassland”	Pasture area (1.2) minus area determined under 3.4. Note that this emission source needs to be attributed/disaggregated between sectors, see 2.1.6 and 2.2.4.
3.3	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of crop area (1.2) to NGGI total cropland area, or well documented sector-specific attribution
3.4	Fraction area that qualifies as “forest converted to grassland” or “wetlands converted to grassland”	Derive from NGGI relevant areas using ratio of grassland area (1.2) to NGGI total grassland area, or well documented sector-specific attribution

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
3.5	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.0	Feed sourced off farm	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data
4.1	Inorganic fertilisers applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS, Fertilizer Australia
4.2	Organic amendments applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime), quantity, frequency, and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.4	Pesticides applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys total fuel use if available, gross margin budgets
	Cultivation, sowing, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g. AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g. AusLCI)
	Irrigation pumping if applicable	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.6	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.7	Capital goods, type and lifetime	Expert consultation, reference LCI databases
4.8	Services, type, and expenditure	Farm surveys, gross margin budgets
4.9	Waste flows	Expert consultation, reference LCI databases
Energy and materials, processing		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Transport, distance, and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

3.1.4 Wool

System definition

The Australian wool-producing sheep flock is categorised into two main breeds: (1) Merinos, (2) dual-purpose and composite breeds (dual-purpose breeds). Australian sheep production can be categorised into three regions: the high rainfall zone, wheat-sheep zone, and pastoral sheep zone.

Other fibre-producing animals such as goats or alpacas are not considered part of the wool sector.

System boundary

The estimation of GHG emissions from wool shall follow the general system boundary guideline (Section 2.1.3). The system boundary shall include wool-producing sheep, farm services (e.g., purchased feed, fuel, electricity, repairs and maintenance, administration) and other purchased inputs (e.g., purchased sheep, herbicides, pesticides, drench) (Figure 9). The system boundary excludes shedding sheep (e.g., Dorpers) as they do not produce wool.

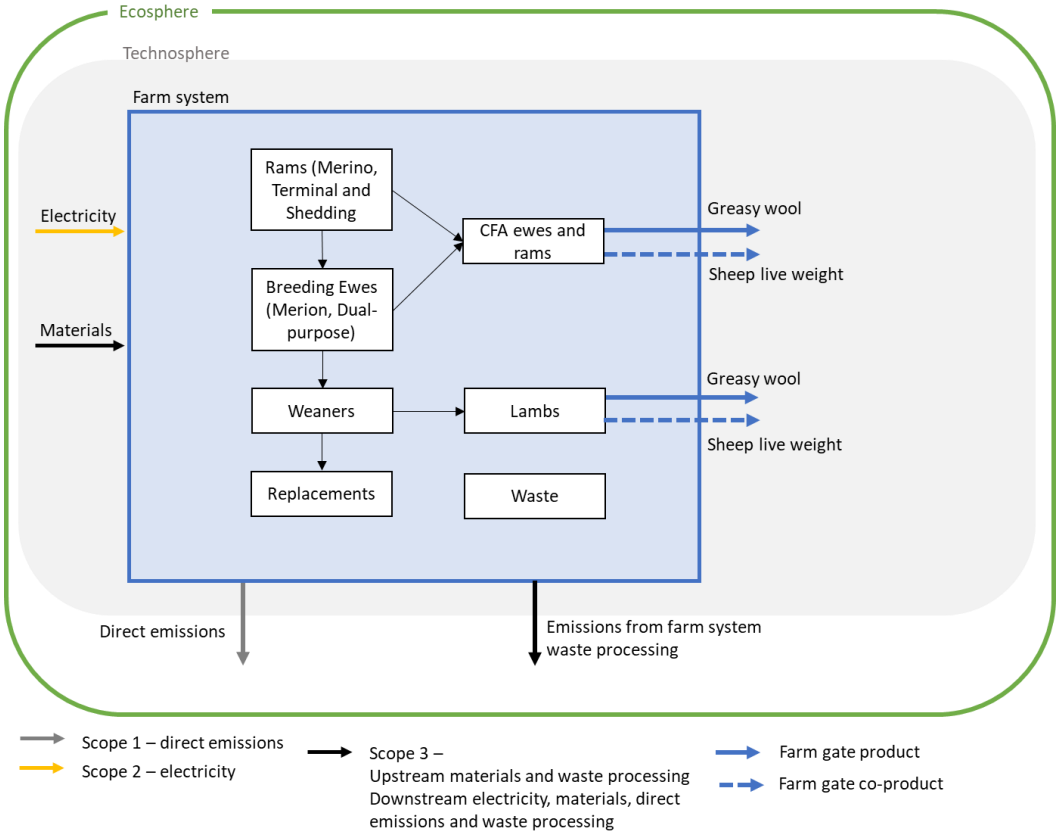

Figure 9 Cradle-to-factory-gate system boundary of wool production in Australia

Declared unit

The recommended declared unit is mass of greasy wool on-farm (the point at which wool leaves the farm gate).

Accounting for multifunctionality

Inputs that are shared between farming systems (e.g., sheep and beef), such as overhead costs or fertiliser inputs shall be first divided based on predicted dry matter intake (DMI) as a measure of land occupation.

Handling co-production of wool and live weight (for meat) shall be modelled using protein mass allocation (Wiedemann et al., 2015). The protein mass of greasy wool is calculated by multiplying the greasy wool by clean wool content, with clean, dry wool being 100% protein (Wiedemann et al., 2015) . The protein content for LW is assumed to be 18% (Wiedemann et al., 2015) .

Emission inventory

The emissions inventory for wool production shall include the emissions listed in the chart of accounts (Table 8). The chart of accounts lists all the emission sources that shall be investigated in the emission inventory for wool. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

Table 8 Chart of accounts for GHG emissions for wool production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Enteric fermentation	CH_4 emissions from enteric fermentation	1	NGGI
		Manure management	CH_4 emissions from manure management	1	NGGI
			N_2O emissions from manure management (direct)	1	NGGI
			N_2O emissions from manure management, atmospheric deposition (indirect)	1	NGGI
			N_2O emissions from manure management, leaching and run off (indirect)	1	NGGI
		Agricultural soils (direct)	N_2O emissions fertilisers to crop (inorganic, organic)	1	NGGI
			N_2O emissions fertilisers to crop (animal waste applied to soil)	1	NGGI
			N_2O emissions fertilisers to pasture (inorganic, organic)	1	NGGI
			N_2O emissions fertilisers to pasture (animal waste applied to soil)	1	NGGI
			N_2O emissions, urine and dung deposited by grazing animals	1	NGGI
			N_2O emissions crop residue, crops and pastures	1	NGGI
			N_2O emissions from cultivation of histosols	1	NGGI
			N_2O emissions from N mineralisation due to loss of soil carbon from cropland remaining cropland	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition (all relevant sources)	1	NGGI
			N_2O emissions – Leaching and run off (all relevant sources)	1	NGGI
		Residue burning	CH_4, N_2O emissions from field burning of stubble (on farm crops)	1	NGGI
		Application of lime and urea	CO_2 emissions of lime and urea application	1	NGGI
	Energy and Materials	Inputs for agriculture processes	CO_2-equivalent emissions on farm fuel use for pasture management and crop and forage production (for tractors, agricultural aircraft, harvester, etc.)	1	NGA
			CO_2-equivalent emissions grid-supplied electricity	2	NGA
			CO_2-equivalent emissions grid-supplied electricity (pre-combustion)	3	NGA
			CO_2-equivalent emissions for feed produced off farm	3	LCI, AIA

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			CO_2-equivalent emissions embedded in farm inputs (fertiliser, pesticides, fuel, etc.)	3	LCI, NGA
			CO_2-equivalent emissions transport of fuel, fertilisers, pesticides, and other inputs to farm (if not included in above)	3	LCI
			CO_2-equivalent emissions-services (insurance, consultants, etc.)	3	See section 2.1.3
	Land use, land use change, forestry	Forestland converted to cropland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI
		Forestland converted to grassland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI
		Cropland remaining cropland	CO_2 emission due to change in soil carbon (crops and temporary pasture)	1	NGGI_s
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Wetlands converted to grassland	CO_2-equivalent emissions wetlands converted to grassland (permanent pasture)	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission other Constructed Water Bodies (dams)	1	NGGI
		Grassland remaining grassland	CO_2 emission due to change in soil carbon (permanent pasture)	1	NGGI_s
			Sparse woody vegetation (permanent pasture)	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning (permanent pasture)	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			N_2O emissions from N mineralization (direct)(permanent pasture)	1	NGGI
			N_2O emissions from N mineralized, leaching and run off (indirect)(permanent pasture)	1	NGGI
	Capital goods and services		CO_2-equivalent emissions-capital goods on farm and off-farm storage (equipment, tractor, sheds, harvester, etc.)	3	LCI
			CO_2-equivalent emissions-capital goods on manufacturing stages (equipment, sheds, chiller, etc.)	3	LCI
	Waste treatment		CO_2-equivalent emissions from all off-farm solid waste disposal (transport, composting, landfill)	3	LCI, NGA
			CO_2-equivalent emissions from all on-farm solid waste disposal (transport, spreading, composting)	1	LCI, NGA
			CO_2-equivalent emissions from all wastewater disposal and treatment during manufacturing (transport, spreading, composting)	3	LCI, NGA
	Energy and Materials	Post-farm processing	CO_2-equivalent emissions fuel use	3	NGA
			CO_2-equivalent emissions electricity use	3	NGA
			CO_2-equivalent emissions embedded in fuel used	3	NGA
			CO_2-equivalent emissions embedded in electricity supply chain	3	NGA
			CO_2-equivalent emissions embedded in material inputs (packaging, ingredients, etc)	3	LCI
			CO_2-equivalent emissions embedded in capital goods	3	LCI
			CO_2-equivalent emissions embedded in services	3	See section 2.1.3
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to Forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil carbon	1	NGGI_s
			CO_2 removal due to change in living biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Grassland converted to Forestland (On-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in living biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Cropland remaining cropland	CO_2 removal due to change in soil carbon (crops and temporary pasture)	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Grassland remaining grassland	CO_2 removal due to change in soil carbon (permanent pasture)	1	NGGI_s
Sub-total removals					
Net-GHG emission					

Activity data

Table 9 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 9 Activity data required and suggested sources for the wool sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Animal Numbers by region, season, types (Rams, Wethers, Maiden ewes, Breeding ewes, Other ewes, Lambs and hoggets, etc.)	ABARES Agricultural Commodities (quarterly data frequency), ABS Agricultural Commodities (annual data frequency), Australian Wool Testing Authority
	Production areas by system	ABS, industry data
Agriculture and livestock (for each type and area defined under 1.1)		
2.1	Liveweight	Table 5.C.1, 5.D.1 of National Inventory Report
2.2	Live weight gain (LWG)	Table 5.B.2 of National Inventory Report
2.3	Dry matter digestibility and crude protein content of feed intake	Table 5.A.4 of National Inventory Report
2.4	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.5	Nitrogen and carbon content of crop residue	Derive from 1.1 using NGGI equations (Agricultural Soils, Crop Residues)
2.6	Fraction of residue burnt, removed or left in field	Farm survey data
2.7	Urea applied	As collected for 4.1
2.8	Lime, dolomite applied	As collected for 4.3
2.9	N mineralised	Derive from 3.1 and 3.2 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland" (e.g., mixed farming)	Crop area (1.2) minus area determined under 3.3. Note that this emission source needs to be attributed/disaggregated between sectors, see 2.1.6 and 2.2.4.
3.2	Fraction of area that qualifies as “grassland remaining grassland”	Pasture area (1.2) minus area determined under 3.4. Note that this emission source needs to be attributed/disaggregated between sectors, see 2.1.6 and 2.2.4.
3.3	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of crop area (1.2) to NGGI total cropland area, or well documented sector-specific attribution
3.4	Fraction area that qualifies as “forest converted to grassland” or “wetlands converted to grassland”	Derive from NGGI relevant areas using ratio of grassland area (1.2) to NGGI total grassland area, or well documented sector-specific attribution

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
3.5	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Inorganic fertilisers applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS, Fertilizer Australia
4.2	Organic amendments applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime), quantity, frequency and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.4	Pesticides applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys total fuel use if available, gross margin budgets
	Cultivation, sowing, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g. AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g. AusLCI)
	Irrigation pumping if applicable	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.6	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.7	Capital goods, type, and lifetime	Expert consultation, reference LCI databases
4.8	Services, type, and expenditure	Farm surveys, gross margin budgets
4.9	Waste flows	Expert consultation, reference LCI databases
Energy and materials, processing		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Transport, distance, and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

3.1.5 Buffalo and deer

System definition

The buffalo industry is based on both the Northern Territory (NT) free-range industry and the dairy sector. Australia has two types of water buffalo: the swamp buffalo and the riverine buffalo. The largest number is in the Northern Territory (NT), where they were first introduced in the 19th century (Lemcke, 2015). Their distribution to other states mainly occurred after 1990. The swamp buffalo is the most common, but the proportion of the riverine type has been increasing steadily with increased interest in the dairy aspects of Riverine buffalo around Australia. The Australian population of riverine buffalo, originally imported in small numbers in 1994-97, has now grown to an estimated 3,000 head. Live export numbers of mostly free-range buffalo have been steadily building, and in 2020, passed 10,000 head for the first time (AgriFutures, 2021). In terms of GHG accounting, buffalo production systems can be treated in a similar way to beef production with elements of the dairy production system added, following the further guidance below.

Deer were introduced to Australia during the 19th century and six species now form the basis of the Australian deer industry. Deer farms in Australia primarily farm Red and Fallow deer (Williams and Pattinson, 2014) (Williams and Pattinson, 2014). In 2016, about 40,000 head were on deer farms in Australia, with annual slaughter about 7,000 head, significantly down from record numbers around 2003 (ADA, 2020). Wild populations exist at various locations across Australia, of Red, Fallow, Rusa, Sambar, Chital and Hog deer, and hunting of wild animals results in carcasses processed in similar numbers to farmed deer (Australian Deer Magazine, 2020) but not subject to the industry levy. In addition to venison (meat), velvet antler is a valuable deer product, and some herds specialise in velvet antler production. Other co-products include skins, tails and blood used in e.g., traditional Eastern medicine. Approximately 85 per cent of venison and more than 95 per cent of velvet antler is exported (Williams and Pattinson, 2014).

In terms of greenhouse gas accounting, deer production systems can be treated in a similar way to beef production. Details are provided in the following sections.

System boundary

The GHG account shall at least include the cradle-to-farm-gate system covering the entire sector for buffalo or for deer farming (see also under Declared unit). For buffalo, post-farm processing may be included covering both meat and milk processing as within the system boundary.

For buffalo and deer, significant wild (feral) populations exist and are harvested. In line with the recommendation in 2.1.3, the GHG report shall clearly describe whether harvesting from wild populations is included in the system boundary. If it is, the number of animals harvested shall be reported and an estimate of life-time emissions associated with animals harvested may be reported as supplementary information.

The system boundary diagrams below do not include harvesting from wild populations (Figure 10 and Figure 11).

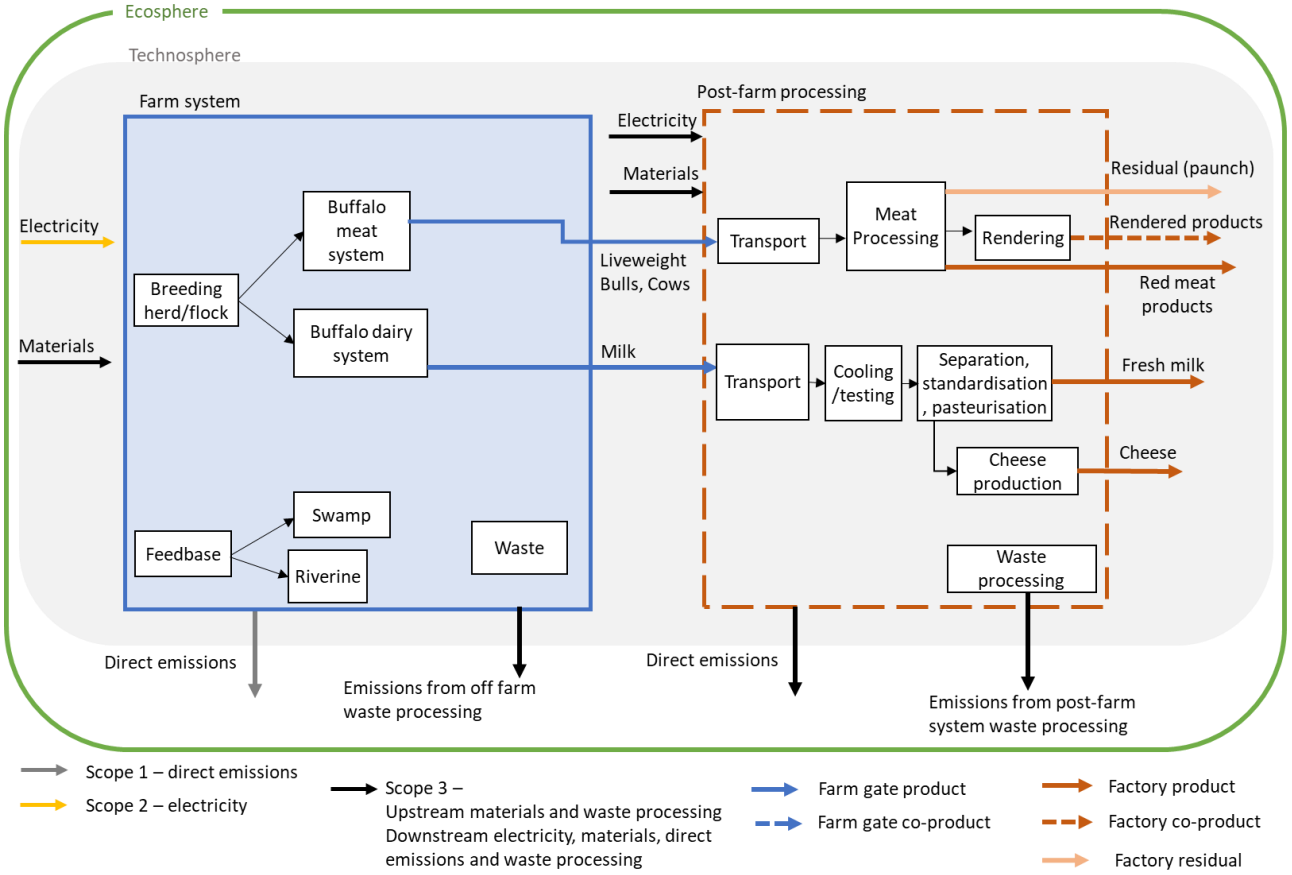

Figure 10 Indicative cradle-to-factory-gate system boundary of the buffalo sector in Australia (excluding harvest from wild populations).

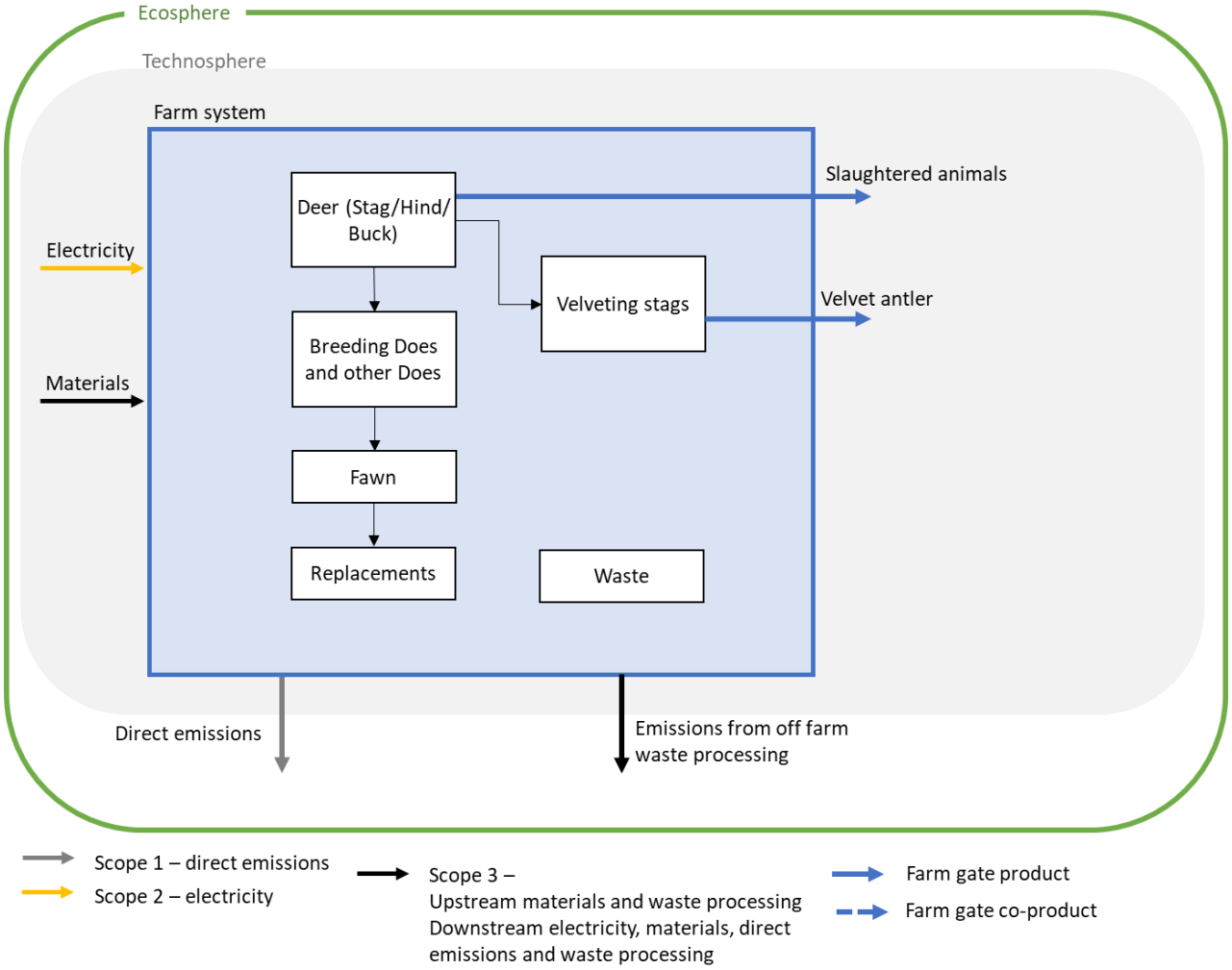

Figure 11 Indicative cradle-to-farm-gate system boundary of the deer sector in Australia (excluding harvest from wild populations).

Declared unit

For buffalo industry, the levy system is linked to animals exported or slaughtered (for human consumption). However, milk production is an integral part of the sector and shall not be treated as a co-product that leaves the sector system. The cradle-to-farm-gate GHG account shall include all emissions associated with dairy buffalo. The GHG report shall include number of head going to slaughter and to export, as well as mass of Fat-and Protein-Corrected Milk (FPCM; see (IDF, 2022)) produced in the reporting year, to reflect a dual declared unit. This is also in line with the guidance of the LEAP programme (FAO, 2016). In addition, total revenue at farm-gate associated with those physical outputs should be reported and used to report on GHG intensity. For a cradle-to-factory-gate GHG account, a dual declared unit of mass of carcass weight plus mass of FPCM processed should be used, along with factory-gate revenue. If separate accounts for processed buffalo meat and buffalo milk are desirable, allocation shall be applied in line with the guidance on multifunctional systems (see below).

For deer farming, the levy system is linked to slaughtered animals for human consumption, with the velvet levy and deer export levy set to zero in 2016. A similar logic applies as for buffalo. All deer production shall be included in the cradle-to-farm-gate GHG account, and the declared unit should be number of head slaughtered plus number of exported animals and mass of velvet antler

produced in the reporting year. In addition, total revenue at farm-gate associated with those physical outputs should be reported and used to report on GHG intensity.

Accounting for multifunctionality

Overarching guidance for dealing with multifunctional processes is described in Section 2.1.6.

It should be noted that the allocation to meat as a co-product of dairy systems (see 3.1.1) is not valid at the level of the buffalo sector, which includes both meat-production and dairy-production systems. Therefore, if separate GHG accounts for processed buffalo meat and buffalo milk are desirable, those systems shall be separated (subdivision according to the allocation principles outlined in 2.1.6) before applying a meat-dairy allocation (e.g., following (IDF, 2022)) to the dairy-production system.

Emission inventory

The emissions inventory for buffalo shall combine the relevant emission sources listed in the chart of accounts for red meat and for dairy, including post-farm processing depending on selected system boundary.

The emissions inventory for deer shall include the emission sources listed in the chart of accounts for red meat up to farm gate, adding any operations for velvet antler harvesting.

If harvesting of wild (feral) animals is included in the system boundary, an estimate of life-time emissions associated with animals harvested may be reported as supplementary information, as those emissions are not included in the NGGI (2.1.3).

Exclusions and cut-off criterion

To determine whether certain emission sources may be excluded, refer to 2.1.3 and 2.1.5. These sections provide guidance regarding the inclusion of capital goods and services, as well as the general cut-off criterion.

Activity data

The required on-farm activity data for buffalo and deer are the same as for red meat (Table 10) adding energy use relevant for milking and antler harvesting, respectively. The NGGI does not distinguish any sub-classes for these animals and Tier-1 emission factors are applied.

If post-farm processing is included for buffalo, relevant activity data as listed for red meat (3.1.3) as well as dairy (3.1.1) will be required.

Recommendations regarding data sources can be drawn from the activity data tables for red meat and dairy, but it should be noted that fewer data sources are available for buffalo and deer than for the beef and dairy cattle.

Table 10 Activity data required and suggested sources for buffalo and deer

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Animal Numbers by State Separate by system (meat/dairy/wild, venison/velvet antler/wild) if possible and appropriate	ABS, industry data, estimates
1.2	Production areas by State (irrigated/non-irrigated as applicable)	Industry data
1.3	Number of animals harvested, exported	ABS, industry data
1.4	Quantity of milk / velvet antler produced	Industry data
Agriculture (for each type and area defined under 1.1)		
2.1	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.2	Urea applied	As collected for 4.1
2.3	Lime, dolomite applied	As collected for 4.3
2.4	N mineralised	Derive from 3.1 and 3.2 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
2.5	Fraction of savannah burning (buffalo)	Expert consultation, ERF registry
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	Crop area (1.2) minus area determined under 3.3. Note that this emission source needs to be attributed/disaggregated between sectors, see 2.1.6 and 2.2.4.
3.2	Fraction of area that qualifies as “grassland remaining grassland”	Pasture area (1.2) minus area determined under 3.4. Note that this emission source needs to be attributed/disaggregated between sectors, see 2.1.6 and 2.2.4.
3.3	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of crop area (1.2) to NGGI total cropland area, or well documented sector-specific attribution
3.4	Fraction area that qualifies as “forest converted to grassland” or “wetlands converted to grassland”	Derive from NGGI relevant areas using ratio of grassland area (1.2) to NGGI total grassland area, or well documented sector-specific attribution
3.5	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.1	Feed sourced off farm	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data
4.2	Inorganic fertilisers applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS, Fertilizer Australia
4.3	Organic amendments applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.4	Other amendments applied (e.g. lime), quantity, frequency and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.5	Pesticides applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data
4.6	Fuel use requirements for operations, quantity and type	Farm surveys total fuel use if available, gross margin budgets
	Cultivation, sowing, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g. AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g. AusLCI)
	Irrigation pumping if applicable	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.7	Electricity use for irrigation pumping if applicable, quantity and type (e.g. grid, solar, wind)	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.8	Capital goods, type and lifetime	Expert consultation, reference LCI databases
4.9	Services, type and expenditure	Farm surveys, gross margin budgets
4.10	Waste flows	Expert consultation, reference LCI databases
Energy and materials, processing (buffalo only)		
5.1	Fuel use, quantity and type	Expert consultation, industry data/information
5.2	Electricity use, quantity and type	Expert consultation, industry data/information
5.3	Transport, distance and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

3.2 Annual crops

3.2.1 Grains

System definition

The grains sector in Australia encompasses 25 crops that are leviable by the Grains Research and Development Corporation (GRDC). The leviable crops are:

- Cereals:
    - Wheat, barley, oats, sorghum, (field) maize, triticale, millets/panicums, cereal rye, canary seed
- Pulses (or grain legumes):
    - lupins, field peas, chickpeas, faba beans, vetch, peanuts, mungbeans, navy beans, pigeonpeas, soybeans, cowpeas, lentils
- Oilseeds:
    - canola, sunflower, safflower, linseed.

These crops are largely grown in crop rotations that cycle between a set of cereals, pulses and oilseeds suited to specific soil type and climate. Wheat is the largest crop by volume (~55%) as well as by area (~50%). Grains are grown primarily in the so-called grain belt that is defined by the zone with average annual rainfall between 220mm (Nidumolu et al., 2012) and around 800mm, with the majority of the cropping taking place in the 300-600mm zone. A large fraction of the belt is in the dryland zone, where the ratio of evapotranspiration to precipitation is between 0.8 and 1.0 which means no leaching is expected (NGGI). Cultivation is primarily rainfed, with only about 1.5% of the area under irrigation. See Sevenster et al. (2022b).

Three regions are distinguished by GRDC: North (NSW, QLD), South (VIC, SA, TAS) and West (WA). Within those regions, 24 subregions are defined (GRDC, 2022). It should be noted that grain cropping also takes place in the Kimberley region (Ord Valley) and Cape York, well outside the grain belt and outside the three defined regions, but those areas are small relative to the total area under grains in Australia.

In Queensland (and northern WA), growing is dominated by summer crops (sorghum, sunflowers, maize, mungbeans, soybeans, and peanuts). Double cropping occurs in these areas, as well as in northern NSW, with a summer and a winter crop grown consecutively in some years. In the other areas, production is dominated by winter crops (wheat, barley, oats, chickpeas, triticale, faba beans, lupins, field peas, canola, millet/panicum, safflower, linseed).

System boundary

The system boundary shall be defined in line with the general guidance (Section 2.1.3). Because grain storage is an intrinsic step of the product chain, it shall be included in the assessment. As some storage takes place on farm and some off farm, in local shared facilities, the system boundary can be defined as “cradle-to-storage”. Beyond storage the value chains diverge considerably so this does provide a logical boundary for the grains sector. For separate cradle-to-farm-gate reporting (see 2.2.3) the baseline without storage may be used, or an estimate of the

fraction of on-farm storage may be applied. The contribution of storage and associated energy use for e.g. loading and aeration is small (Sevenster et al., 2022a).

The system boundary of grains production shall include raw material production (e.g. fertiliser, lime, pesticides, fuel), transportation of agricultural inputs to the farm, land preparation including any operations on pre-sowing fallow, sowing and planting, crop maintenance, harvesting, and post-harvest processes including on-farm or off-farm storage as shown in Figure 12 **Error! Reference source not found.**. Seed production should not be accounted separately because it is captured in the overall grain production activity data; a fraction of grain production is assumed to be directed to seed.

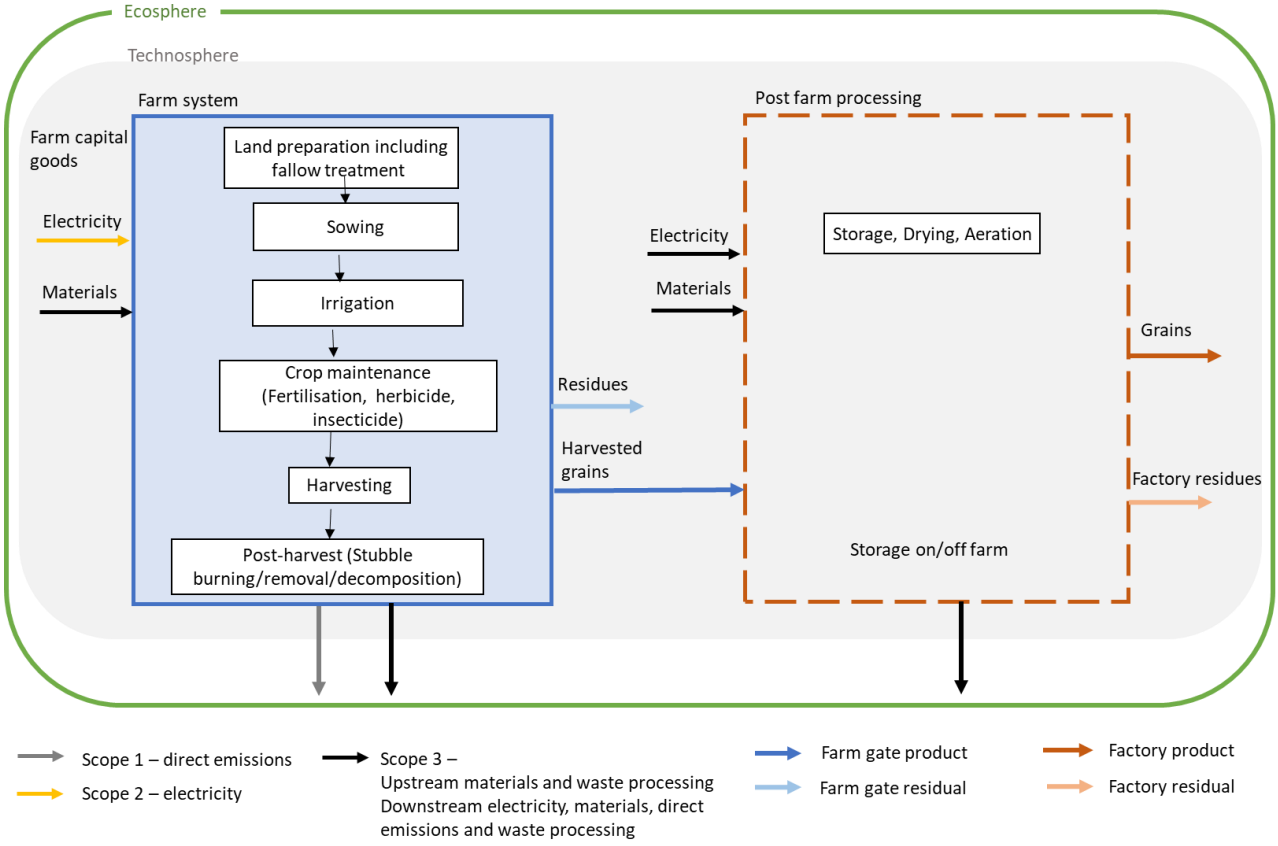

Figure 12 Cradle-to-storage system boundary of grain production in Australia.

Declared unit

The grains sector is diverse, with cereals, pulses and oilseeds having different functions both nutritionally and in terms of use as food, feed or fuel. However, as a measure of productivity of the sector that can be used to define an overall GHG intensity, total mass of grains produced in the assessment year is an appropriate metric. In addition, financial output could be used as a metric.

In the 2022 grains baseline assessment (Sevenster et al., 2022a), no significant differences were found in preferred mitigation scenarios selected based on metrics of total mass, total value, total protein or total energy produced by grains. In other words, the potential to reduce GHG intensity was found to be the same, regardless of the exact declared unit adopted in the definition of intensity. This is to be expected when shifts in rotation toward higher or lower proportion of pulses and oilseeds are only minor. If major shifts in those proportions were to occur, the average

amount of protein and/or energy per unit grains mass might change enough to warrant additional declared units.

Accounting for multifunctionality

Allocation in case of multifunctional processes shall follow the guidance provided in 2.1.6.

The grain sector shares farming systems with several other sectors, especially with livestock grazing and cotton. As stated in 2.1.6, this shall be dealt with via a subdivision approach, applying a strict cut-off between growing seasons. All inputs applied in the lead up or during the growing season for a crop are allocated to that crop. Emissions calculated using that crop's activity data are allocated to that crop. Only infrequently applied products shall be equally divided between growing seasons that take place between applications (see 2.1.6).

For inputs that are generated in upstream multifunctional processes, such as manure, the guidance in 2.1.6 shall be applied.

The grains sector is multifunctional in itself, as it encompasses 25 crops. For the sector GHG assessment there is no need to divide the system, but this need may arise when other sectors use outputs of the grain sector as inputs, such as livestock feed. The activity data for the livestock sector involved (See 3.1) is likely to include specific crops as inputs, such as barley, sorghum, wheat or oilseed meals. To facilitate consistent accounting for those material flows between sectors, and correcting for double counting if at any point sector-level GHG accounts are to be combined to give an all-of-agriculture baseline, crop-level accounts could be generated. In line with the guidance (2.1.6) this would be achieved by applying the same subdivision approach to the shared farming systems, i.e., grain-grain rotations. Any post-farm processing such as milling of oilseeds is outside the boundary of the grains sector. The allocation for multiple outputs of that process has to be applied by the receiving (i.e., livestock) sector.

Emission inventory

The chart of accounts (Table 11) lists all the emissions that shall be investigated in the emission inventory for grains. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

For all calculations using NGGI equations, grains fall in the category "Non-irrigated crop(s)" except for a small fraction of "Irrigated crop(s)". For calculations using NGGI simulated values, grains fall in the category "cropland" (cropland remaining cropland or land converted to cropland).

Disaggregation of elements of the emission calculation, compared to the calculations in the NGGI, may be applied when not inconsistent with the methods underlying NGGI calculations (see 2.2.1). Specifically, this could be relevant to:

- The EF for nitrous oxide for Inorganic fertilisers (Source Category Agricultural Soils). Rather than using the national average EF, a sector-specific evaluation of the fraction of area in high-rainfall zone (P>600mm) could be used.
- The value of FracWET used to calculate emissions from Leaching and runoff (Source Category Agricultural Soils). FracWET reflects the fraction of nitrogen that is available for leaching, i.e., applied outside the dryland zone which is defined by $0.8 < Et/P < 1.0$. The NGGI provides values

for FracWET by state. More disaggregated values could be derived by analysing the relevant spatial data for the sector-specific area.

- The value of emissions or removals in the Source Category Cropland remaining cropland. This category includes all crops including perennial crops and temporary pastures in mixed farming rotations. Disaggregation by region as well as sector could be achieved by running targeted simulations using FullCAM or equivalent (see 2.2.1 and 2.2.4).

Table 11 Chart of accounts for GHG emissions for grains production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Agricultural soils (direct)	N_2O emissions– fertiliser (inorganic, organic) applied to crop	1	NGGI
			N_2O emissions – crop residue	1	NGGI
			N_2O emissions from cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions -Mineralisation due to loss of soil organic carbon (excl LUC)	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition	1	NGGI
			N_2O emissions – Leaching and run off	1	NGGI
		Residue burning	CH_4 and N_2O emissions from field burning of stubble	1	NGGI
		Application of lime and urea	CO_2 emissions-lime and urea application	1	NGGI
	Energy and Materials	Inputs for agriculture processes	CO_2-equivalent emissions on farm fuel use for land preparation, planting & sowing, crop maintenance, and harvesting (for tractors, agricultural aircraft, harvester, etc.)	1	NGA
			CO_2-equivalent emissions grid-supplied electricity	2	NGA
			CO_2-equivalent emissions grid-supplied electricity (pre-combustion)	3	NGA
			CO_2-equivalent emissions embedded in farm inputs (fertiliser, pesticides, fuel, etc.)	3	LCI, NGA
			CO_2-equivalent emissions transport of fuel, fertilisers, pesticides, and other inputs to farm (if not included in above)	3	LCI
			CO_2-equivalent emissions-services (insurance, consultants, etc.)	3	See 2.1.3
	Land use, land use change, forestry	Forest converted to cropland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland	1	NGGI_s
		Cropland remaining cropland	CO_2 emission due to change in soil carbon	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission other Constructed Water Bodies (dams)	1	NGGI
	Energy and Materials	Grain storage	CO_2-equivalent emissions fuel use on farm (loading, drying, etc)	1	NGA
			CO_2-equivalent emissions electricity use on farm (drying, aeration, etc)	2	NGA
			CO_2-equivalent emissions fuel use off farm (loading, drying, etc)	3	NGA
			CO_2-equivalent emissions electricity use off farm (drying, aeration, etc)	3	NGA
			CO_2-equivalent emissions embedded in fuel used (on farm and off farm)	3	NGA
			CO_2-equivalent emissions embedded in electricity supply chain (on farm and off farm)	3	NGA
			CO_2-equivalent emissions transport from farm to off farm storage	3	LCI
	Capital goods		CO_2-equivalent emissions-capital goods on farm and off-farm storage (equipment, tractor, sheds, harvester, etc.)	3	LCI
			CO_2-equivalent emissions-capital goods on manufacturing stages (equipment, sheds, chiller, etc.)	3	LCI
	Waste treatment		CO_2-equivalent emissions from all off-farm solid waste disposal (transport, composting, landfill)	3	LCI, NGA
			CO_2-equivalent emissions from all on-farm solid waste disposal (transport, spreading, composting)	1	LCI, NGA
			CO_2-equivalent emissions from all wastewater disposal and treatment during manufacturing	3	LCI, NGA
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in live biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Cropland remaining cropland	CO_2 removal due to change in soil organic carbon	1	NGGI_s
Sub-total removals					

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Net-GHG emission					

Exclusions and cut-off criterion

To determine whether certain emission sources may be excluded, refer to 2.1.3 and 2.1.5. These sections provide guidance regarding the inclusion of capital goods and services, as well as the general cut-off criterion.

Activity data

Table 12 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 12 Activity data required and suggested sources, for grains sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Production areas and harvested quantities (yields)	ABS, industry data
	*by crop and/or region as needed**	ABS, industry data
	by system type (irrigated/rainfed, tillage type, etcetera)	Farm surveys, ABARES land use data (ALUM)
	by climate zone (low/high rainfall and dryland/non dryland)	Use NGGI default values or derive using spatial data
Agriculture (for each production area defined under 1.1)		
2.1	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.2	Nitrogen and carbon content of crop residue	Derive from 1.1 using NGGI equations (Agricultural Soils, Crop Residues)
2.3	Fraction of residue burnt, removed, or left in field	Farm survey data
2.4	Urea applied	As collected for 4.1
2.5	Lime, dolomite applied	As collected for 4.3
2.6	N mineralised	Derive from 3.1 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	System area (1.1) minus area determined under 3.2. Note that this emission source needs to be allocated between sectors, see 2.1.6
3.2	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of system area (1.1) to NGGI total cropland area, or well documented sector-specific attribution
3.3	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Inorganic fertilisers applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.2	Organic amendments applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime), quantity, frequency and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.4	Pesticides applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys total fuel use if available
	Cultivation, sowing, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Irrigation pumping if applicable	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.6	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.7	Capital goods, type, and lifetime	Expert consultation, reference LCI databases
4.8	Services, type, and expenditure	Farm surveys, gross margin budgets
4.9	Waste flows	Expert consultation, reference LCI databases
Energy and materials, storage		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Transport, for storage off farm, distance, and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

* This is dictated by the objectives in terms of regionalised or crop (type) level reporting, but also by practicability of data collection. While it is possible to collect activity data and apply inventory calculations for “grains” as an aggregated group, in practice it is may be preferred to do this at crop (type) level as many data sources are at that level

3.2.2 Cotton

System definition

Approximately 680,000 tonnes of raw cotton fibre are produced on average by the Australian cotton industry. It contributes 3-5% of global production and is the fourth largest cotton exporter in the world. Almost all the national production is exported contributing more than $1.8 billion in export revenue to the national economy each year (CRDC, 2022). Cotton is mostly grown in Queensland (Qld) and New South Wales (NSW). The major production areas in NSW cover adjacent areas of Macintyre, Barwon, Darling, Lachlan, and Murrumbidgee River, and Gwydir, Namoi, and Macquarie valleys. Bourke, Moree, Walgett, Wee Waa, Narrabri, Boggabri, Gunnedah, Warren, Trangie, Narromine, Hillston, Condobolin, Hay, Griffith, Jerilderie, and Narrandera is the major cotton growing area in NSW. In QLD, cotton is mostly grown in Darling Downs, St George, Dirranbandi, Macintyre, Clermont, Emerald, Biloela, Theodore, Dalby, Toowoomba, St George, Cecil Plains, Dirranbandi, Goondiwindi, and Mungindi (CA, 2020). The grower surveys often group these areas into six larger cotton growing regions (Figure 13). Cotton production has also started in parts of WA, NT, and northern QLD at small scale in recent years.

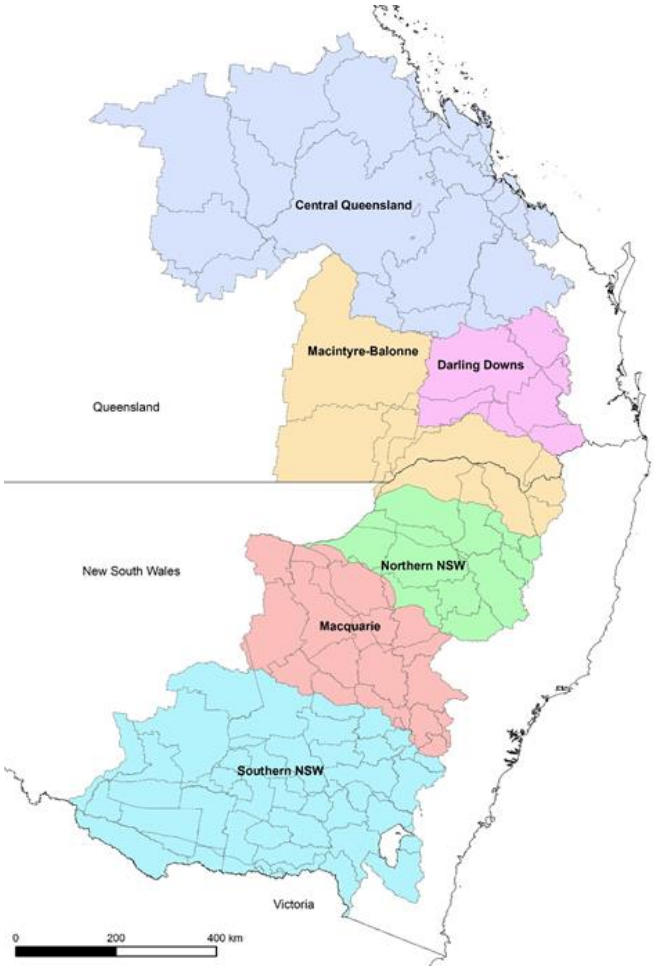

Figure 13 Cotton growing regions in New South Wales and Queensland. Source: CSIRO

Around 74% of the Australian cotton is fully irrigated, followed by rain grown/dryland (15%) and partially irrigated (11%); however, this varies between years depending on rainfall. Furrow is the

dominant irrigation system (85%), and the remaining (15%) is pressurized systems including overhead and drip system (CRDC, 2021). The growing season lasts approximately six months, covering different time-period in different growing regions (Table 13Table 13).

Table 13 Cotton growing calendar of Australia

GROWING REGION	LAND PREPARATION	PLANTING	GROWING SEASON	PICKING (HARVESTING)
Northern Australia	November-February	January-March	February-June	June-August
Emerald/Dawson Valley	April-July	August-December	September-May	January- July
All other regions	July-September	October-November	November-March	March-June

Source: Cotton Australia

There are two types of cultivation systems, one is a continuous (back-to-back) system, and another one is a cotton-break crop system. For the latter case, cotton cultivation is rotated either into another crop or fallowed. The rotation crops are usually wheat, faba beans, chickpeas, and maize, which ultimately help to build and maintain healthy soils and moisture levels, as well as to minimize pests and diseases.

Soil preparation cover bed forming, weed removal, fertiliser application, and irrigation based on the requirement, followed by planting. Cotton stubble is usually kept in the field to add nutrients to the soils. Nitrogen fertilisers are usually applied during soil preparation through top-dressing (broadcast or water-run N fertiliser). Plant protection products (e.g., pesticides) are also used during the growing phase. The initial irrigation for irrigated cultivation system is followed by several irrigations at intervals of 2-3 weeks based on soil and weather conditions covering mid-December to late February. Such irrigation practice varies in different growing regions, based on temperatures and soil type. Defoliation of matured cotton occurs when the crop is ready for picking. The cotton is harvested mechanically and placed into large round, wrapped modules, which are then loaded onto trucks and transported from the field to the cotton gin. The lint is separated from the seeds during the ginning process, which is then pressed into rectangular bales of 227 kg. The seeds constitute around 52% of the cotton weight, followed by lint (42%), and trash (10%) (CA, 2021). After that, most of the bales are shipped overseas to be spun, dyed, knitted, and woven into fabrics.

System boundary

The estimation of life cycle GHG emissions of cotton shall follow the general system boundary guideline (Section 2.1.3) covering the on-farm stage (e.g., soil preparation, fuel use for farming practices) and the post-farm stage (e.g., cotton ginning). Cradle-to-gin gate system boundary shall include production and transport of raw materials (seed for sowing, fertiliser, pesticides, electricity for irrigation), land preparation, sowing and planting, crop maintenance, harvesting, and post-harvest processing up to the gin gate as shown in Figure 14.

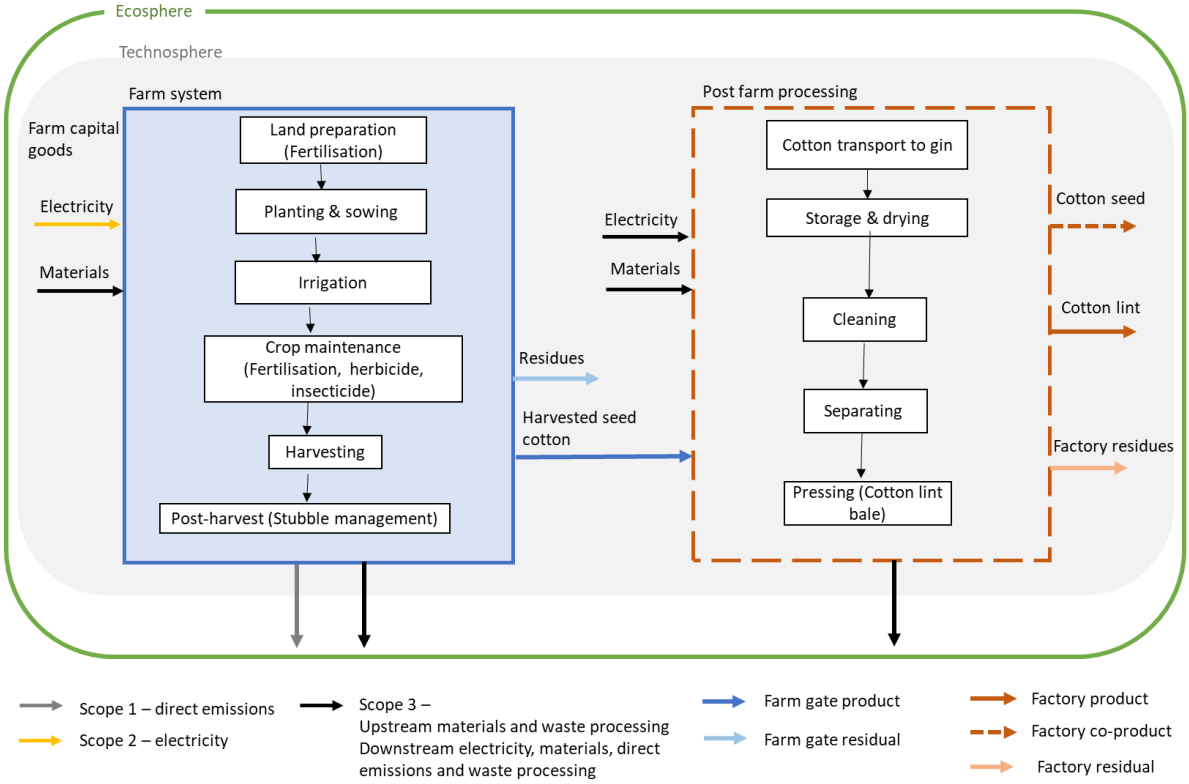

Figure 14 Cradle-to-gin-gate system boundary of cotton production in Australia

Declared unit

The declared unit shall be mass of seed cotton for the cradle-to-farm-gate GHG account and mass of cotton lint for the cradle-to gin-gate system boundary.

Accounting for multifunctionality

The allocation principles suggested in section 2.1.6 shall be followed for allocating the emissions of co-products. Economic allocation is recommended for the allocation between cotton lint and seed, with relative prices determined as 5-year averages.

Emission inventory

The emissions inventory for cotton shall include those emissions listed in the chart of accounts (Table 14). The chart of accounts lists all the emission sources that shall be investigated in the emission inventory for cotton. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations including the textbox "Example: N_2O emissions, cotton" in that section.

Table 14 Chart of accounts for GHG emissions for cotton production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Agricultural soils (direct)	N_2O emissions– fertiliser (inorganic, organic) applied to crop	1	NGGI
			N_2O emissions – crop residue/ manure/sewage sludge applied to crop	1	NGGI
			N_2O emissions from cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions-Mineralisation due to loss of soil organic carbon	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition	1	NGGI
			N_2O emissions – Leaching and run off	1	NGGI
		Residue burning (if any)	CH_4 and N_2O emissions from field burning of stubble	1	NGGI
		Application of lime and urea	CO_2 emissions-lime and urea application	1	NGGI
	Energy and Materials	Inputs for agriculture processes	CO_2-equivalent emissions on farm fuel use for land preparation, planting & sowing, crop maintenance, and harvesting (for tractors, agricultural aircraft, harvester, etc.)	1	NGA
			CO_2-equivalent emissions grid-supplied electricity	2	NGA
			CO_2-equivalent emissions grid-supplied electricity (pre-combustion)	3	NGA
			CO_2-equivalent emissions embedded in farm inputs (seed, fertiliser, pesticides, fuel, etc.)	3	LCI, NGA
			CO_2-equivalent emissions transport of fuel, fertilisers, pesticides, and other inputs to farm (if not included in above)	3	LCI
			CO_2-equivalent emissions-services (insurance, consultants, etc.)	3	See section 2.1.3
	Land use, land use change, forestry	Forestland converted to cropland (deforestation)	CO_2 emission due to change in soil carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic matter	1	NGGI
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Cropland remaining cropland	CO_2 emissions due to change in soil carbon	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission other Constructed Water Bodies (dams)	1	NGGI
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland	1	NGGI_s
	Energy and Materials inputs for processing	Cotton gins	CO_2 emissions-on-factory fuel use	1	NGA
			CO_2 emissions-grid-supplied electricity	2	NGA
			CO_2 emissions-factory inputs (water, packaging materials, etc.)	3	NGA
			CO_2 emissions from transport of inputs (packaging materials, etc.)	3	NGA
			CO_2 emissions-capital goods (equipment, storage sheds, etc.)	3	NGA
			CO_2 emissions-services used	3	NGA
	Capital goods		CO_2-equivalent emissions-capital goods on farm and off-farm storage (equipment, tractor, sheds, harvester, etc.)	3	LCI
			CO_2-equivalent emissions-capital goods on manufacturing stages (equipment, sheds, chiller, etc.)	3	LCI
	Waste treatment		CO_2-equivalent emissions from all off-farm waste disposal (transport, composting, landfill)	3	LCI, NGA
			CO_2-equivalent emissions from all on-farm waste disposal (transport, spreading, composting)	1	LCI, NGA
			CO_2-equivalent emissions from all wastewater disposal and treatment during manufacturing.	3	LCI, NGA
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in the live biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Cropland remaining cropland	CO_2 removal due to change in soil carbon	1	NGGI_s

Exclusions and cut-off criterion

To determine whether certain emission sources may be excluded, refer to 2.1.3 and 2.1.5. These sections provide guidance regarding the inclusion of capital goods and services, as well as the general cut-off criterion.

Activity data

Table 15 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 15 Activity data required and suggested sources for the cotton sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Production areas and harvested quantities (yields)	ABS, industry data
	*by crop and/or region as needed**	ABS, industry data
	by system type (irrigated/rainfed, tillage type, etcetera)	Farm surveys, ABARES land use data (ALUM)
	by climate zone (low/high rainfall and dryland/non dryland)	Use NGGI default values or derive using spatial data
Agriculture (for each production area defined under 1.1)		
2.1	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.2	Nitrogen and carbon content of crop residue	Derive from 1.1 using NGGI equations (Agricultural Soils, Crop Residues)
2.3	Fraction of residue burnt, removed, or left in field	Farm survey data
2.4	Urea applied	As collected for 4.1
2.5	Lime, dolomite applied	As collected for 4.3
2.6	N mineralised	Derive from 3.1 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	System area (1.1) minus area determined under 3.2. Note that this emission source needs to be allocated between sectors, see 2.1.6
3.2	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of system area (1.1) to NGGI total cropland area, or well documented sector-specific attribution
3.3	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Inorganic fertilisers applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.2	Organic amendments applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime), quantity, frequency and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.4	Pesticides applied, quantity and type	Farm surveys, gross margin, expert consultation, commercial benchmark data
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys total fuel use if available
	Cultivation, sowing, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Irrigation pumping if applicable	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.6	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.7	Capital goods, type, and lifetime	Expert consultation, reference LCI databases
4.8	Services, type, and expenditure	Farm surveys, gross margin budgets
4.9	Waste flows	Expert consultation, reference LCI databases
Energy and materials, storage		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Transport, distance, and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

3.2.3 Sugarcane

System definition

The sugarcane sector grows sugarcane (cane) and processes it into raw sugar. The Australian sugarcane sector produces around 30 million tonnes of harvested cane annually from around 4,500 farms, which is crushed and processed in 22 sugar mills to produce 4.3 million tonnes of raw sugar annually (Canegrowers, 2022). Raw sugar is the main traded commodity from the sector, with 85% exported from six bulk shipping ports (Canegrowers, 2022). The sector also produces and sells milling co-products: molasses (to animal feed and ethanol production) and electricity from combustion of remaining bagasse (to the national power network). Parts of the sector sell crop residues (cane trash) to garden mulch producers, but not at a scale big enough for it to be accounted for in an emissions inventory at this stage.

The burgeoning use of biomass for bio-based production will increase demand for cane trash as feedstock in the future. At some point it may be considered a co-product from the sector, at which time the recovery / removal of cane trash may need to be a sector activity considered in an emissions inventory. At this stage, it is not considered as such.

Sugarcane is grown along a 2,000 km stretch of Australia's east coast from north Queensland to northern New South Wales (Canegrowers, 2022). Due to the large geographic spread over multiple climate zones, the regional variation in production systems needs to be considered for this sector, in terms of extent of irrigation, burnt versus green cane harvesting, crop length (1 year versus 2 years), nitrogen use efficiency.

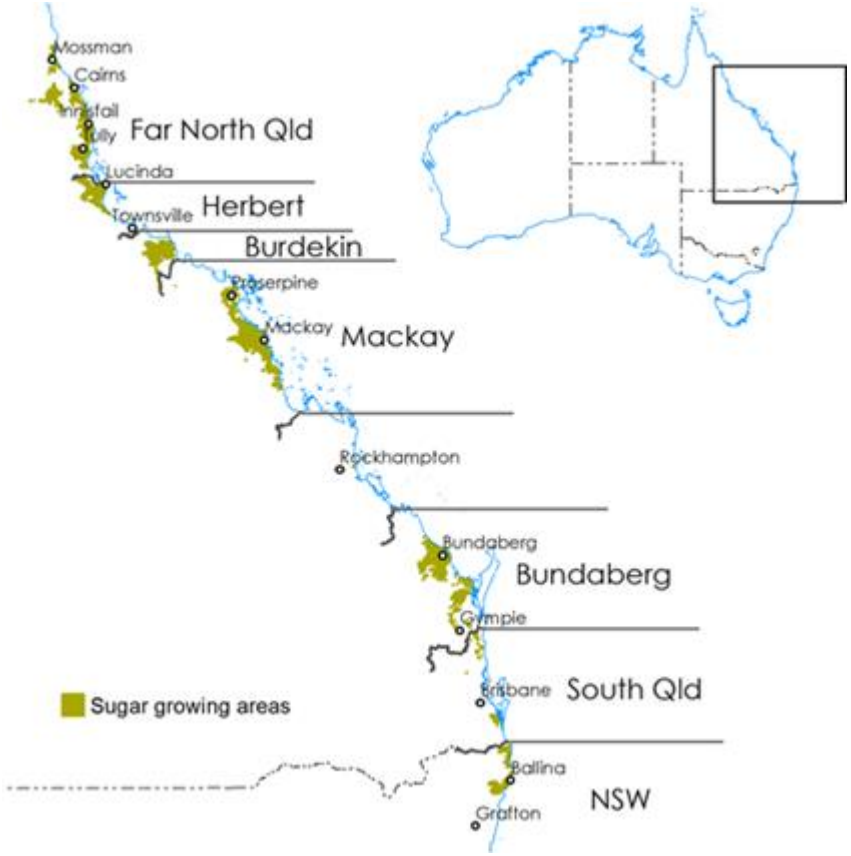

Figure 15 Locations of sugarcane growing in Australia.

Source ABARES, 2021

The cane growing system is best defined as a multi-year crop cycle (5 to 6 years), with around one fifth of a given cane growing area under plant cane, three fifths under ratoon cane, and one fifth under fallow. Plant and ratoon crops are harvested annually, except in NSW where 2-year crops are common. In the fallow year a break crop (typically legumes) may be grown, and either turned-in as green manure (to provide nitrogen) or harvested as a cash crop. The emissions inventory for a regional cane growing system is the area-weighted average from the 5 to 6 phases of the crop cycle (including activities in the fallow period).

Regional variations in cane growing, harvesting and cane transport practices, and soil and climate conditions (influencing N_2O emissions) leads to significant regional variation in GHG emissions. The sector inventory needs to reflect the constituent regional production systems, categorised using the industry's established breakdown of cane growing regions (Figure 15). The emissions inventory for the cane growing sector is a production-weighted aggregation of the constituent regional cane growing systems.

The cane growing sector has been progressively adopting best management practices (BMP) since 2010 to improve soil health, maintain productivity and reduce water quality impacts (in Reef catchments). This has included a transition to reduced tillage, controlled traffic, precision application of fertilisers and herbicides, green cane harvesting with associated retention of harvest residues (trash). This means there may be cane production sub-systems present in each region (for example A,B,C,D class practices in Queensland growing regions), which may need to be reflected in the inventory for a given year. There is some organic cane production, but too small to be included as a production sub-system. For the baseline inventory (2005) the more homogenous regional production systems in place before BMP adoption can be represented.

Harvested sugarcane is transported to sugar mills mostly by dedicated cane rail, and to a lesser extent by road trucks. At sugar mills cane is crushed to generate cane juice, from which the raw sugar is crystallized, leaving molasses as a residue. The separated cane fibre (bagasse) is all combusted in mill boilers to produce steam and electricity for mill operations, and bagasse surplus to mill requirements is also combusted to generate export electricity. The sugar milling process and emission profile is homogenous across regions and static over time, except for differences in the amount of electricity co-produced. Therefore, a single raw sugar processing system can be reflected in the inventory.

System boundary

As raw sugar is the traded commodity the default system boundary shall be up to the sugar mill gate, including sugarcane growing, harvesting, cane transport and milling of cane into raw sugar. While some raw sugar is processed into refined sugars in Australia it is not included in the sector inventory (Figure 16).

The system boundary up to farm gate shall include all activities associated with the growing and harvesting of cane (including that produced as seed cane): production and supply of material and energy inputs (synthetic and organic fertilisers, lime, gypsum, pesticide products, water, fuels, electricity), tractor and harvester operations, irrigation, and any pre- or post-harvest cane burning. Seed cane production (cane billets) should not be accounted separately because it is captured in the overall sugarcane production data. Activity data for post-farm processing (milling) should deduct cane that is used as seed cane. Where mill mud and boiler ash generated from sugar mills,

and/or dunder (vinasse) generated from separate fermentation processes are applied to cane land, emissions associated with their production, processing, transport, and spreading are assigned to the process generating them, being regarded as waste management. Therefore, the processing, transport and spreading of mill mud and boiler ash are included in a factory gate system boundary (as the sugar mill is the generating process), but not in a farm gate system boundary. Processing, transport and spreading of applied dunder is not included in either system boundary as it is generated from downstream ethanol fermentation activities that are outside the sector system boundary. Emissions arising from mill mud, boiler ash and dunder applied to cane soils are included.

The system boundary up to factory gate includes, in addition to activities up to farm gate, the production of milling inputs (fuel oil for boiler start-up, flocculants, lime, phosphoric acid, lubricants), bagasse combustion, and mill mud and boiler ash processing, transport and spreading (waste management processes).

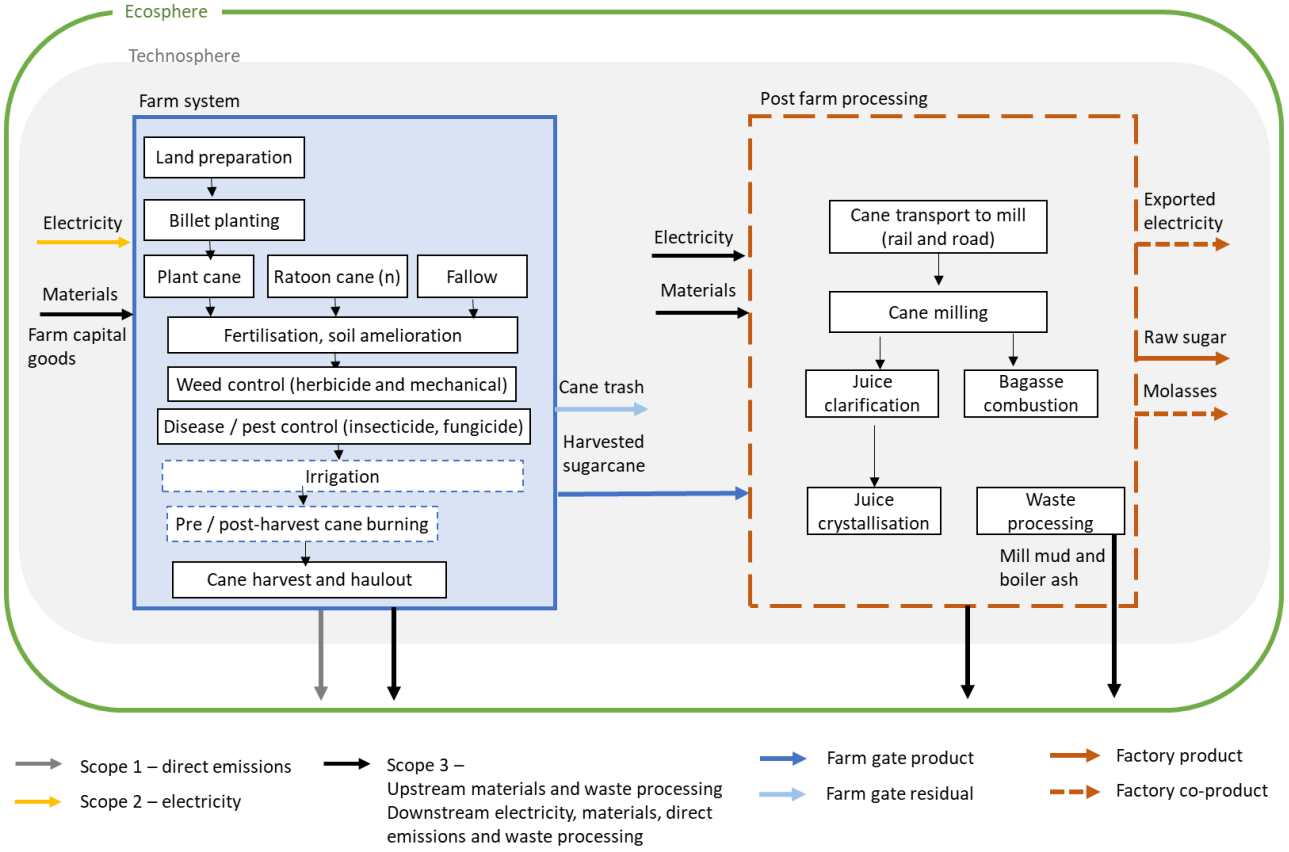

Figure 16 Cradle-to-factory-gate system boundary of sugarcane/raw sugar production

Declared unit

The determining product from the sugarcane sector is raw sugar, a food commodity. Therefore, an appropriate declared unit for a sector inventory is the mass of raw sugar produced (for factory gate scope), or the mass of harvested sugarcane delivered to mills (for farm gate scope) in the reference year. The declared unit may be total sector production or regional production of raw sugar or harvested cane.

If future demand for sugarcane as feedstock for bio-based products beyond sugar significantly influences the above, the declared unit shall be reconsidered. Other parameters may become more appropriate to capture sector productivity, such as carbon or energy content.

Accounting for multifunctionality

For most sugarcane growing systems, multifunctionality does not need to be considered since cane growing does not share any farming systems with other sectors, and there are typically no products other than harvested sugarcane. An exception is in cane growing systems where break crops are grown in the fallow year in rotation with the cane crop. However, for the baseline reference year (2005) legume break crops were rare and so multifunctionality is insignificant enough to be excluded. However, if it is significant, the following approach shall be taken. Where the break crop is grown for the sole benefit of the cane crop (typically a legume crop grown as green manure to fix nitrogen in the soil for the following plant cane crop), then all emissions from growing the break crop are assigned to cane. Where the break crop is harvested and sold (for example, legume grain), subdivision shall be applied which means all activities for growing the break crop are attributed to the break crop (see 2.1.6).

For sugarcane milling, multiple products need to be considered, as molasses and exported electricity from bagasse fibre are co-products. Subdivision is not possible and so economic allocation shall be used (as per guidance in 2.1.6) to assign emissions to raw sugar, molasses, and any exported electricity. As molasses is an ingredient of cattle feed, the allocation of molasses outputs from the sugar sector shall be consistent with the allocation of molasses input to the red meat sector.

Mill mud and boiler ash are considered wastes, whose emissions due to their transport and spreading onto cane land are included within the factory gate system boundary.

Emission inventory

The chart of accounts (Table 16) lists the emissions that shall be included in the emission inventory for harvested sugarcane and raw sugar. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations. The guidance in 2.2.1 states that the inventory calculations shall be not inconsistent with NGGI for Agriculture emissions such as direct denitrification N_2O emissions from N in applied fertilisers. Unless there are alternatives to the NGGI Tier 2 emission factors (1.99% of applied N) that meet the requirements of the exemption described in that section, the NGGI emission factor shall be applied. This does not recognise significant regional variation. It is recommended to include a sensitivity assessment as indicated in 2.2.1.

The emissions inventory for the cane growing sector is the production-weighted aggregation of emissions from constituent regional cane growing production systems, plus the aggregation of emissions from all sugar mills. The emissions inventory for each regional cane growing system is an area-weighted average over the 5 to 6 phases of the rotation, including any break crops.

Table 16 Chart of accounts for GHG emissions for sugarcane/raw sugar production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Agricultural soils (direct)	N_2O emissions from applied synthetic fertilisers	1	NGGI
			N_2O emissions from applied organic fertilisers (mill mud, dunder)	1	NGGI
			N_2O emissions from retained crop residues (cane trash)	1	NGGI
			N_2O emissions from cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions from mineralisation due to loss of soil organic carbon (SOC) (excl LUC)	1	NGGI
		Agricultural soils (indirect)	N_2O emissions from ammonia deposition	1	NGGI
			N_2O emissions from nitrogen leaching and run off	1	NGGI
		Crop residue burning	CH_4, and N_2O emissions from any pre-harvest of post-harvest burning of cane	1	NGGI
		Application of lime and urea	CO_2 emissions from application of agricultural lime and/or urea application	1	NGGI
	Energy and material inputs for growing	Inputs for sugarcane growing	CO_2-equivalent emissions from on-farm combustion of fuel in tractors, harvesters, pumps etc. (for cultivation, billet planting / break crop seed sowing, application of fertilisers, lime, gypsum and pest control products, irrigation and harvest and haul out)	1	NGA
			CO_2-equivalent emissions from grid-supplied electricity	2	NGA
			CO_2-equivalent emissions from grid-supplied electricity	3	NGA
			CO_2-equivalent emissions for production of farm inputs (fuels, synthetic fertilisers, organic fertilisers, agricultural lime, gypsum, agrochemicals, etc.)	3	LCI, NGA
			CO_2-equivalent emissions for transport of farm inputs (fuels, synthetic fertilisers, organic fertilisers, lime, gypsum, agrochemicals)	3	LCI
			CO_2-equivalent emissions for services used on farm (insurance, consultants, extension services etc.)	3	See section 2.1.3
	Land use, land use change, forestry	Forest converted to cropland (deforestation)	CO_2 emission due to change in soil organic carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic carbon	1	NGGI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Cropland remaining cropland	CO_2 emission due to change in soil organic carbon	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission other Constructed Water Bodies (dams)	1	NGGI
	Energy and material inputs for processing	Inputs for sugar milling	CO_2-equivalent emissions from transport (by rail and/or truck) of harvested cane to mills	1	LCI
			CO_2-equivalent direct emissions from fuel (oil, coal etc.) combustion during mill boiler start-up	1	NGA
			CH_4, and N_2O emissions from bagasse combustion in mill boiler	1	NGGI
			CO_2-equivalent emissions for production of milling inputs (fuel for boiler start-up, flocculants, calcined lime, phosphoric acid, lubricants)	3	LCI
			CO_2-equivalent emissions for services used on at the mill (insurance, consultants, laboratory services etc.)	3	LCI
	Capital goods		CO_2-equivalent emissions for production and maintenance of on-farm capital goods (tractor, implements, sheds, harvester, etc.) and cane rail (tracks, rolling stock)	3	LCI
			Production and maintenance of sugar mill capital goods are not included as they contribute less than the cut-off threshold		
	Waste treatment	Mill mud and boiler ash application to cane land	CO_2-equivalent emissions from transport (by truck) to deliver mill mud / ash to cane land	3	LCI
			CO_2-equivalent emissions from all wastewater treatment and disposal at the sugar mill.	3	LCI, NGA
			CO_2-equivalent direct emissions from on-farm combustion of fuel in tractors / trucks for spreading mill mud and ash to cane land	1	NGA
			CO_2-equivalent emissions for the production of fuel used for spreading mill mud /ash to cane land	3	LCI, NGA
Removals	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in live biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Cropland remaining cropland	CO_2 removal due to change in soil organic carbon	1	NGGI_s

Exclusions and cut-off criterion

Capital goods production for on-farm items (tractors, harvesters, sheds) and the cane rail system (tracks, rolling stock) shall be included (amortised by the production they contribute to over their lifespans), as they have been found to contribute emissions above the cut-off threshold (defined in 2.1.6) (Renouf et al., 2010).

Production and maintenance of the sugar mill are not included as they are insignificant due to the long lifespan of mill infrastructure (Renouf et al., 2011).

Activity data

Table 17 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 17 Activity data required and suggested sources for the sugarcane/raw sugar production sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Sugarcane production areas and harvested quantities delivered to mill (yields):	ABS, ASMC mill data
	- *by crop class (I.e., plant, ratoon, fallow)*	ABS, industry ASMC mill data
	- *by system type (irrigated/rainfed, tillage type, green cane harvesting / burnt cane harvesting etc.)*	Canegrowers, ABARES land use data (ALUM)
	- *by soil type and / or climate zone (low/high rainfall and dryland/non dryland)*	
1.2	Sugar mill products (raw sugar, molasses, exported electricity) quantities (used in mill product allocation)	ASMC mill data
Agriculture (for each production area defined under 1.1)		
2.1	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.2	Nitrogen and carbon content of crop residue	Derive from 1.1 using NGGI equations (Agricultural Soils, Crop Residues)
2.3	Fraction of residue burnt, removed, or left in field	Canegrowers, ABS
2.4	Urea applied	As collected for 4.1
2.5	Lime, dolomite applied	As collected for 4.3
2.6	N mineralised	Derive from 3.1 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	System area (1.1) minus area determined under 3.2.2.1.6
3.2	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of system area (1.1) to NGGI total cropland area
3.3	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Inorganic fertilisers applied, quantity and type	Reef regulation records, farm gross margin budgets, extension advisors, commercial benchmark data, ABS

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.2	Organic amendments applied (e.g., mill mud, dunder), quantity and type	Reef regulation records, farm gross margin budgets, extension advisors, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime, gypsum), quantity, frequency, and type	Farm surveys, farm gross margin budgets, extension advisors, ABS
4.4	Pesticides applied, quantity and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys of total fuel use if available
	- *Cultivation, sowing, fertiliser spreading, harvesting, etcetera*	Farm gross margins budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	- *Aerial spraying if applicable*	Extension advisors, combined with estimates of specific fuel use per operation (e.g., AusLCI)
	- *Irrigation pumping if applicable*	ABS for water use, combined with estimates of specific fuel use for pumping based on irrigation type (in 4.6).
4.6	*Irrigation type (drip, flood, high pressure gun, low pressure gun) if applicable*	Canegrowers
4.6	Electricity use for irrigation pumping, quantity, and type (e.g., grid, solar, wind)	ABS for water use combined with estimates of specific electricity use for pumping based on irrigation type.
4.7	Capital goods, type, and lifetime	Expert consultation, reference LCI databases, academic literature
4.8	Services, type, and expenditure	Extension advisors
Energy and materials and other inputs, milling		
5.1	Fuel use in mills (for boiler start-up), quantity and type	Individual sugar mills
5.2	Electricity use, quantity, and type	ASMC mill data
5.3	Material use in mills (lubricants, flocculants	Individual sugar mills
5.4	Cane transport (rail and road), distance and mode	ASMC mill data, combined with specific fuel use for cane rail and road transport
5.5	Capital goods, type and lifetime	ASMC and individual sugar mills
5.6	Bagasse combusted, quantity	ASMC mill data
5.7	Mill mud land application, quantity, distance transported	ASMC mill data

3.2.4 Rice

System definition

Australian rice production is concentrated in the temperate climatic zone of NSW (the Murrumbidgee Valley) and Victoria (the Murray Valley). Geographical (availability of large flat land and water, suitable clay-based soils), and infrastructural factors (storage and milling facility) are the key reasons for such a localized rice production. A smaller proportion of rice is also grown in the sub-tropical Northern Rivers of NSW, and tropical zones of Far North Queensland. Leeton, Griffith, Deniliquin, Coleambally, Hay, Finley, Barham, Wakool, and Moulamein in NSW; Kerang and Tongala in Victoria; and Ingham, Tully, and Gordonvale in Queensland are the rice-producing areas of Australia (Bull and Rose, 2018).

Flooded rice cultivation is the prevailing agriculture practice in Australia, and hence rice production is highly influenced by water availability and irrigation. Urea fertiliser is used for cultivation instead of manure application, and rice stubble is usually burnt after harvesting. Hence, rice cultivation in Australia has fewer inputs of organic matter (DoISER, 2022).

Rice is grown between October and April in Australia. Farmers start preparing the rice field in July and August by laser-leveling the paddock, pulling up banks, and applying fertiliser. Rice growers sow the crops from October to early November. Many farmers used agricultural aircraft and satellite-guided technology to sow the rice seed evenly into the irrigated paddock. Rice is also sown using a combined seeding machine in dry paddock, and in this case, after sowing the fields are flushed with water, and drained a couple of times before permanent water is applied around December. Farmers keep permanent water on their rice crops for almost all the growing season. During January and February panicle initiation and flowering occur. Due to high evapotranspiration, farmers closely monitor the water levels during this time. As the grain starts to mature, no more irrigation is provided, and existing water in the paddock is used to finish growing.

The crop is ready to harvest when the moisture content of the rice is 22%. The common herbicides used during the cultivation process to control weeds, insects, and diseases are Gramoxone, Saturn, Ordram, Magister, Stomp, Barnstorm, Aura, and Stam (Troldahl and Stevens, 2020). Rice is harvested from March to May using a combined harvester. The harvesting machine separates the grains from the straw (threshing). After the rice is being cut and threshed it is stored in a bin of the harvester. When the bin is full, the harvester transferred the rice to another larger bin being pulled by a tractor (often known as the chaser bin). The tractor unloads the rice from the chaser bin into trucks on the edge of the paddock. Trucks transferred the harvested rice to a storage shed for drying and storing until the moisture content is reduced to 14%. It is stored until the rice is transferred to the rice mill.

At the rice milling facility, the outer layer (husk) is removed from the grains (hulling), and rice husks from this process are used in pet foods production (packed and branded under the CopRice). After hulling the rice grains are milled, polished, and sorted for packing. The bulk of Australian rice is milled, packed, and branded in the Riverina by SunRice which is the sole exporter of Australian rice products. It supplies more than 60 major international destinations (RGA, 2019).

System boundary

The estimation of life cycle GHG emissions of rice shall follow the general system boundary guideline (Section 2.1.3). The cradle-to-farm gate system boundary of rice production shall include raw material production (e.g. fertiliser, pesticides, irrigation electricity use), transportation of agricultural inputs to the farm, land preparation, sowing and planting, crop maintenance, harvesting, and post-harvest processes at the farm gate (residue burning) as shown in Figure 17. Cradle-to-factory-gate system boundary should include transport and milling processes as shown in Figure 17. Rice produced for seed should not be accounted separately because it is captured in the overall rice production activity data, a fraction of which is assumed to be directed to seed. Activity data for post-farm processing (hulling) should deduct the amount of rice grains is used as seed.

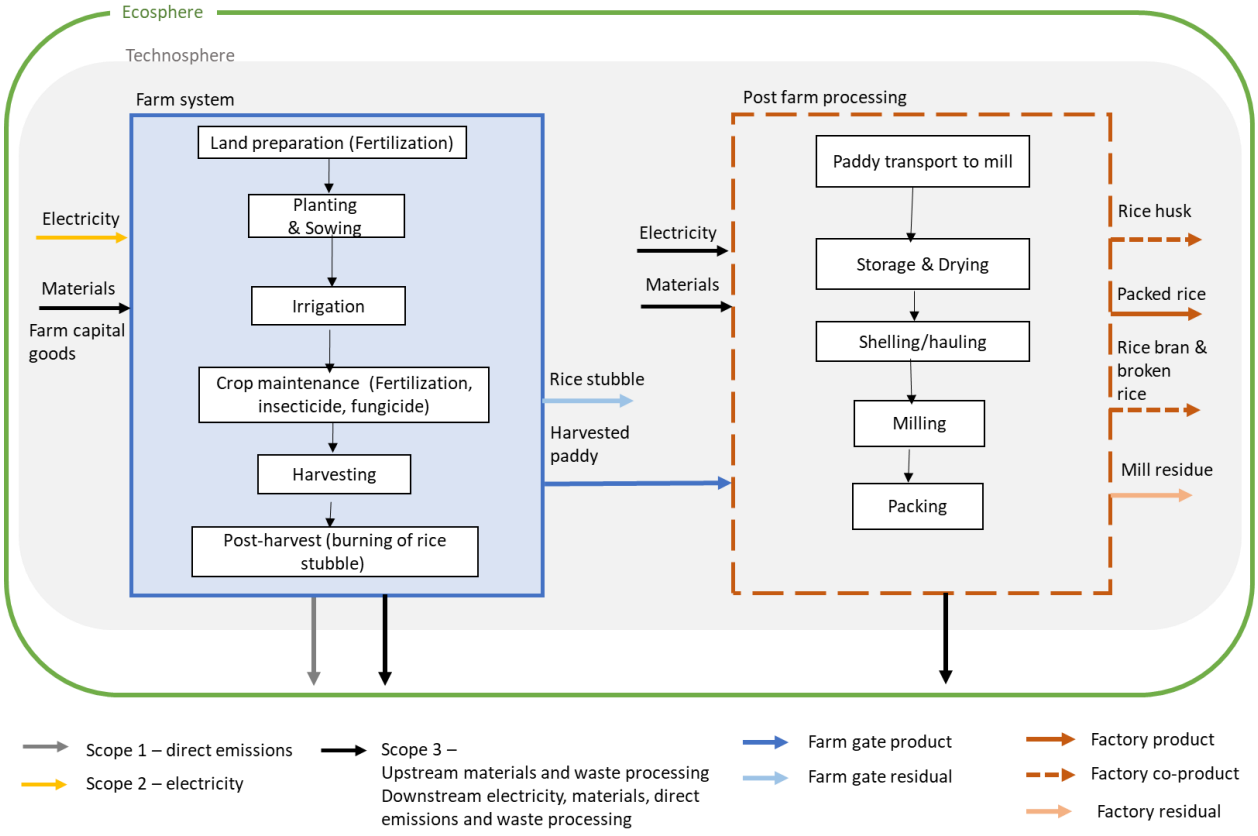

Figure 17 Cradle-to-factory-gate system boundary of rice production in Australia

Declared unit

The declared unit should be mass of paddy rice at the farmgate considering the cradle-to-farm-gate system boundary. If the system boundary is extended to the factory gate, the declared unit should be mass of rice milled and packed at the factory gate.

Accounting for multifunctionality

Overarching guidance for dealing with multifunctional processes is described in Section 2.1.6. For post-farm processing involving multiple genuine co-products such as rice husk, rice bran and broken rice, economic allocation is recommended.

Emission inventory

The emissions inventory for rice shall use the chart of accounts (Table 18). The chart of accounts lists all the emission sources that shall be investigated in the emission inventory for rice. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

For all calculations using NGGI equations, rice falls in the category “Rice” or “Irrigated crop(s)”. For calculations using NGGI simulated values, rice falls in the category “cropland” (cropland remaining cropland or land converted to cropland).

Table 18 Chart of accounts for GHG emissions for rice production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Agricultural soils (direct)	N_2O emissions– fertiliser (inorganic, organic) applied to crop	1	NGGI
			N_2O emissions – crop residue	1	NGGI
			N_2O emissions from cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions-Mineralisation due to loss of soil organic carbon (excl LUC)	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition	1	NGGI
			N_2O emissions – Leaching and run off	1	NGGI
		Rice Cultivation	CH_4 emissions-rice cultivation	1	NGGI
		Residue burning	CH_4, and N_2O emissions from field burning of stubble	1	NGGI
		Application of lime and urea	CO_2 emissions-lime and urea application	1	NGGI
	Energy and Materials	Inputs for agriculture processes	CO_2-equivalent emissions on farm fuel use for land preparation, planting & sowing, crop maintenance, and harvesting (for tractors, agricultural aircraft, harvester, etc.)	1	NGA
			CO_2-equivalent emissions grid-supplied electricity	2	NGA
			CO_2-equivalent emissions grid-supplied electricity (pre-combustion)	3	NGA
			CO_2-equivalent emissions embedded in farm inputs (fertiliser, pesticides, fuel, etc.)	3	LCI, NGA
			CO_2-equivalent emissions transport of fuel, fertilisers, pesticides, and other inputs to farm (if not included in above)	3	LCI
			CO_2-equivalent emissions of services used on farm (insurance, consultancy, etc)	3	See section 2.1.3
	Land use, land use change, forestry	Forest converted to cropland (deforestation)	CO_2 emission due to change in soil organic carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic carbon	1	NGGI
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland	1	NGGI_s
		Cropland remaining cropland	CO_2 emission due to change in soil organic carbon	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission other Constructed Water Bodies (dams)	1	NGGI
	Energy and Materials	Milling and processing	CO_2-equivalent emissions fuel use in factory	3	NGA
			CO_2-equivalent emissions electricity use in factory	3	NGA
			CO_2-equivalent emissions embedded in inputs (water, packaging materials, etc.)	3	LCI
			CO_2-equivalent emissions -services (insurance, consultants, etc.)	3	See section 2.1.3
	Capital goods		CO_2-equivalent emissions -capital goods on farm and off-farm storage (equipment, etc.)	3	LCI
			CO_2-equivalent emissions -capital goods on manufacturing stages (equipment, sheds, etc.)	3	LCI
	Waste treatment		CO_2-equivalent emissions from all off-farm waste disposal (transport, composting, landfill)	3	LCI, NGA
			CO_2-equivalent emissions from all on-farm waste disposal (transport, spreading, composting)	1	LCI, NGA
			CO_2-equivalent emissions from all wastewater disposal and treatment during manufacturing.	3	LCI, NGA
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in live biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Cropland remaining cropland	CO_2 removal due to change in soil organic carbon	1	NGGI_s
Sub-total removals					
Net-GHG emission					

Exclusions and cut-off criterion

To determine whether certain emission sources may be excluded, refer to 2.1.3 and 2.1.5. These sections provide guidance regarding the inclusion of capital goods and services, as well as the general cut-off criterion.

Activity data

Table 19 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 19 Activity data required and suggested sources for the rice sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Production areas and harvested quantities (yields)	ABS, industry data
	*by crop and/or region as needed**	ABS, industry data
	by system type (irrigated/rainfed, tillage type, etcetera)	Farm surveys, ABARES land use data (ALUM)
	by climate zone (low/high rainfall and dryland/non dryland)	Use NGGI default values or derive using spatial data
Agriculture (for each production area defined under 1.1)		
2.1	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.2	Nitrogen and carbon content of crop residue	Derive from 1.1 using NGGI equations (Agricultural Soils, Crop Residues)
2.3	Fraction of residue burnt, removed, or left in field	Farm survey data
2.4	Urea applied	As collected for 4.1
2.5	Lime, dolomite applied	As collected for 4.3
2.6	N mineralised	Derive from 3.1 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	System area (1.1) minus area determined under 3.2. Note that this emission source needs to be allocated between sectors, see 2.1.6
3.2	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of system area (1.1) to NGGI total cropland area, or well documented sector-specific attribution
3.3	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Inorganic fertilisers applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.2	Organic amendments applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime), quantity, frequency, and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.4	Pesticides applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys total fuel use if available
	Cultivation, sowing, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Irrigation pumping if applicable	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.6	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.7	Capital goods, type, and lifetime	Expert consultation, reference LCI databases
4.8	Services, type, and expenditure	Farm surveys, gross margin budgets
4.9	Waste flows	Expert consultation, reference LCI databases
Energy and materials, storage		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Transport, distance, and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

3.3 Horticulture

Horticulture is the third largest agricultural industry in Australia. For the year ending June 2021, 3.8 million tonnes of products were produced and valued at $4,913 million (HIA, 2022). In terms of production, 58% of the sectors products are vegetables, 38% are fruits, and 4% are nuts (HIA, 2022). The wide range of horticultural crops as shown in Table 20 have been categorised according to a commonality in production aspects that influence how GHG inventories are calculated, as follows:

- row crops (mostly vegetables), which are annual crops
- tree crops (mostly fruits and nuts), which are long-term or perennial
- vine crops (mostly grapes), which are long-term and require some form of infrastructure.

Viticulture (of wine grapes) is a separate industry sector to horticulture but has been included under the umbrella of horticulture to also capture production of eating grapes and other vine fruits such as kiwi fruit and passionfruit. Flower, nursery, and turf production are not specifically covered, but could follow guidance for row crops if appropriate.

Annual statistics provided by ABS, such as “Agricultural Commodities” and “Water use on Australian Farms” distinguish the following categories:

- vegetables
- fruit trees, nut trees, plantation, or berry fruits (fruit and nuts)
- grapevines (fruit and nuts)
- nurseries, cut flowers and cultivated turf

Table 20 Overview of the horticulture crops in Australia. Percentage values in brackets indicate the fraction sent to processing. Remaining product consumed as fresh produce (HIA, 2022). FAO crop classification is based on FAO (2020).

CLASSIFICATION	PRODUCTS	FAO CROP CLASSIFICATION	ABS COMMODITIES	ABS WATER USE
Row crops	Potatoes (67%)	Root, bulb, or tuberous	Vegetables	Vegetables
	Carrots (6%)	Root, bulb, or tuberous	Vegetables	Vegetables
	Onions (9%)	Root, bulb, or tuberous	Vegetables	Vegetables
	Sweet potatoes (9%)	Root, bulb, or tuberous	Vegetables	Vegetables
	Beetroot (60%)	Root, bulb, or tuberous	Vegetables	Vegetables
	Garlic (5%)	Root, bulb, or tuberous	Vegetables	Vegetables
	Ginger (47%)	Root, bulb, or tuberous	Vegetables	Vegetables
	Parsnips (3%)	Root, bulb, or tuberous	Vegetables	Vegetables
	Sweet Corn (54%)	Vegetables (maize, green)	Vegetables	Vegetables
	Beans (French, Runner)	Vegetables (beans, green)	Vegetables	Vegetables
	Peas (78%)	Vegetables (peas, green)	Vegetables	Vegetables
	Broccoli (5%)	Brassica	Vegetables	Vegetables
	Brussels Sprouts (18%)	Brassica	Vegetables	Vegetables
	Cabbage (15%)	Brassica	Vegetables	Vegetables
	Cauliflower (8%)	Brassica	Vegetables	Vegetables
	Cucumbers	Fruit-bearing	Vegetables	Vegetables
	Eggplant (6%)	Fruit-bearing	Vegetables	Vegetables
	Tomatoes (49%)	Fruit-bearing	Vegetables	Vegetables
	Capsicums (5%)	Fruit-bearing	Vegetables	Vegetables
	Chillies (23%)	Fruit-bearing	Vegetables	Vegetables
	Zucchini (2%)	Fruit-bearing	Vegetables	Vegetables
	Pumpkins (3%)	Fruit-bearing	Vegetables	Vegetables
	Blueberries	Fruit-bearing	Fruit and nuts - Berry fruit	Fruit trees, nut trees, plantation or berry fruits

CLASSIFICATION	PRODUCTS	FAO CROP CLASSIFICATION	ABS COMMODITIES	ABS WATER USE
	Rubus Berries (raspberries, blackberries)	Fruit-bearing	Fruit and nuts - Berry fruit	Fruit trees, nut trees, plantation or berry fruits
	Strawberries (7%)	Fruit-bearing	Fruit and nuts - Berry fruit	Fruit trees, nut trees, plantation or berry fruits
	Muskmelons	Fruit-bearing	Vegetables	Vegetables
	Watermelons	Fruit-bearing	Vegetables	Vegetables
	Spinach / Silver beet / Kale (7%)	Leafy or stem	Vegetables	Vegetables
	Herbs (4%)	Leafy or stem	Vegetables	Vegetables
	Leafy Asian Vegetables	Leafy or stem	Vegetables	Vegetables
	Leafy Salad Vegetables	Leafy or stem	Vegetables	Vegetables
	Leeks	Leafy or stem	Vegetables	Vegetables
	Lettuce	Leafy or stem	Vegetables	Vegetables
	Artichokes	Leafy or stem	Vegetables	Vegetables
	Asparagus	Leafy or stem	Vegetables	Vegetables
	Celery (1%)	Leafy or stem	Vegetables	Vegetables
	Fennel (3%)	Leafy or stem	Vegetables	Vegetables
	Mushrooms (3%)		Vegetables	Vegetables
Tree crops	Custard Apples	Tropical and subtropical fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
	Lychees	Tropical and subtropical fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
	Mangoes	Tropical and subtropical fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
	Papaya/Pawpaw	Tropical and subtropical fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
	Avocados	Tropical and subtropical fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
	Bananas	Tropical and subtropical fruits	Fruit and nuts - Plantation fruit	Fruit trees, nut trees, plantation or berry fruits
	Pineapples (34%)	Tropical and subtropical fruits	Fruit and nuts - Plantation fruit	Fruit trees, nut trees, plantation or berry fruits
	Apples (29%)	Pome fruits and stone fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
	Cherries (11%)	Pome fruits and stone fruits	Fruit and nuts - Stone fruit	Fruit trees, nut trees, plantation or berry fruits
	Nashi	Pome fruits and stone fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits

CLASSIFICATION	PRODUCTS	FAO CROP CLASSIFICATION	ABS COMMODITIES	ABS WATER USE
	Persimmons	Pome fruits and stone fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
	Pears (43%)	Pome fruits and stone fruits	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
	Apricots (18%)	Pome fruits and stone fruits	Fruit and nuts - Stone fruit	Fruit trees, nut trees, plantation or berry fruits
	Nectarines/Peaches (16%)	Pome fruits and stone fruits	Fruit and nuts - Stone fruit	Fruit trees, nut trees, plantation or berry fruits
	Plums (17%)	Pome fruits and stone fruits	Fruit and nuts - Stone fruit	Fruit trees, nut trees, plantation or berry fruits
	Grapefruit (4%)	Citrus fruits	Fruit and nuts - Citrus fruit	Fruit trees, nut trees, plantation or berry fruits
	Lemons/Limes (10%)	Citrus fruits	Fruit and nuts - Citrus fruit	Fruit trees, nut trees, plantation or berry fruits
	Mandarins (2%)	Citrus fruits	Fruit and nuts - Citrus fruit	Fruit trees, nut trees, plantation or berry fruits
	Oranges (39%)	Citrus fruits	Fruit and nuts - Citrus fruit	Fruit trees, nut trees, plantation or berry fruits
	Almonds	Nuts	Fruit and nuts - Nuts	Fruit trees, nut trees, plantation or berry fruits
	Chestnuts	Nuts	Fruit and nuts - Nuts	Fruit trees, nut trees, plantation or berry fruits
	Hazelnuts	Nuts	Fruit and nuts - Nuts	Fruit trees, nut trees, plantation or berry fruits
	Macadamias	Nuts	Fruit and nuts - Nuts	Fruit trees, nut trees, plantation or berry fruits
	Pecans	Nuts	Fruit and nuts - Nuts	Fruit trees, nut trees, plantation or berry fruits
	Pistachios	Nuts	Fruit and nuts - Nuts	Fruit trees, nut trees, plantation or berry fruits
	Walnuts	Nuts	Fruit and nuts - Nuts	Fruit trees, nut trees, plantation or berry fruits
	Olives	Oil crops	Fruit and nuts - Other orchard fruit	Fruit trees, nut trees, plantation or berry fruits
Vine crops	Wine grapes	Grapes	Fruit and nuts - Grapes for wine production	Grapevines
	Eating grapes (10%)	Grapes	Fruit and nuts - Grapes for all other uses	Grapevines
	Kiwifruit	Berries	Fruit and nuts - Other fruit	Fruit trees, nut trees, plantation or berry fruits
	Passionfruit	Tropical and subtropical fruits	Fruit and nuts - Other fruit	Fruit trees, nut trees, plantation or berry fruits

3.3.1 Vegetables (row crops)

System definition

This sub-sector produces annual crops grown primarily in outdoor operations in rows wide enough to be tended with agricultural machinery (row crops). These crops are mostly vegetables but also include berries, melons, and herbs. There is minimal processing of Australian-grown vegetables, due to the low cost of imported processed products (HIA, 2022). Therefore, the traded commodities for the sector are largely unprocessed fresh vegetables, although for some products there is more substantial processing (potatoes, sweet corn, ginger, chillies, tomatoes, peas, beetroot). The nature of processing is too variable for it to be considered an intrinsic part of the (agricultural) sector's activities.

Some crops are closely linked to crops that are covered in the grains sector (3.2.1), namely sweet corn, green peas, and green beans. The grain crops are distinguished by production system as well as end uses. The horticulture crops reach the consumer as fresh or as fresh-tinned/frozen vegetables and are grown primarily in high-rainfall or irrigated systems, which aligns with the higher emissions factors for horticulture in the NGGI.

There are 38 individual vegetable commodities grown in Australia. Around 84% of production is from outdoor row cropping operations (as a 2017-18), but there is also greenhouse production (capsicums, cucumber, eggplant, herbs), and hydroponic production (ABARES, 2019). Mushroom production occurs within indoor facilities and involves significant production of the compost substrate. A sector inventory needs to reflect the production systems present for the reference year, which would mostly be outdoor row crops and mushroom production systems, but potentially greenhouse, and hydroponics systems. The emissions inventory for the sector will be a production-weighted aggregation of the constituent systems. For the baseline reference year (2005) most production could be assumed to be outdoor row crops plus mushroom production.

This sub-sector has a wide geographic spread across Australia including in peri-urban areas around major capital cite as well as rural agricultural areas. Main areas are in NSW (Greater Sydney, the Murrumbidgee Irrigation Area, Far North Coast), VIC (Greater Melbourne, Gippsland, Murray River irrigation areas), QLD (Darling Downs, Bundaberg, Bowen, Burdekin delta), SA (Mallee, Riverland, Adelaide Plains), WA (Perth, Busselton, Pemberton, Geraldton, Carnarvon), TAS (northern coastal fringe and midlands).

Around 14% of farms have large production areas of 70 hectares or more, accounting for 67% of total vegetable production and 59% of the value. At the other end of the scale, 31% of farms are less than 5 hectares, producing intensive, high value crops, accounting for only 2% of production amount by 12% of the value. The remaining 55% of farms are between 5 and 70 hectares, accounting for around 30% in terms of both production volume and value (ABARES, 2019).

System boundary

As described above, processing shall not be included in the system boundary. As vegetable storage is an intrinsic step of the product chain, it shall be included in the system boundary. With some storage taking place on-farm at packing sheds and some off-farm at centralised distribution centres, the system boundary can be defined as "cradle-to-storage". Beyond storage, the value

chains diverge considerably so this does provide a logical boundary for the vegetable sector (Figure 18).

For row crop production systems, the system boundary shall include all activities associated with annual growing and harvesting (vegetables and berries and melons) - production and supply of material and energy inputs (synthetic and organic fertilisers, seeds or seedlings, lime, gypsum, pesticide products, water, fuels, electricity, mulch, plastics, irrigation components), tractor and harvester operations (for land preparation, seed planting, fertiliser application, organic fertiliser spreading, weed and pest control spraying, harvesting), and irrigation. Storage shall include packaging as relevant. Due to the high amount of manual labour employed at harvest time, the transport of contracted labour to and from the fields is also included. Activities associated with any management of wastes (plastic collection and disposal) and on-farm management of harvest residues (collection, on-site composting, spreading) shall be included.

For mushroom, greenhouse, hydroponic or production systems the system boundary will also include production of the greenhouse and building structures, production, and supply of growing substrates (compost in the case of mushrooms), electricity or fuel for temperature control.

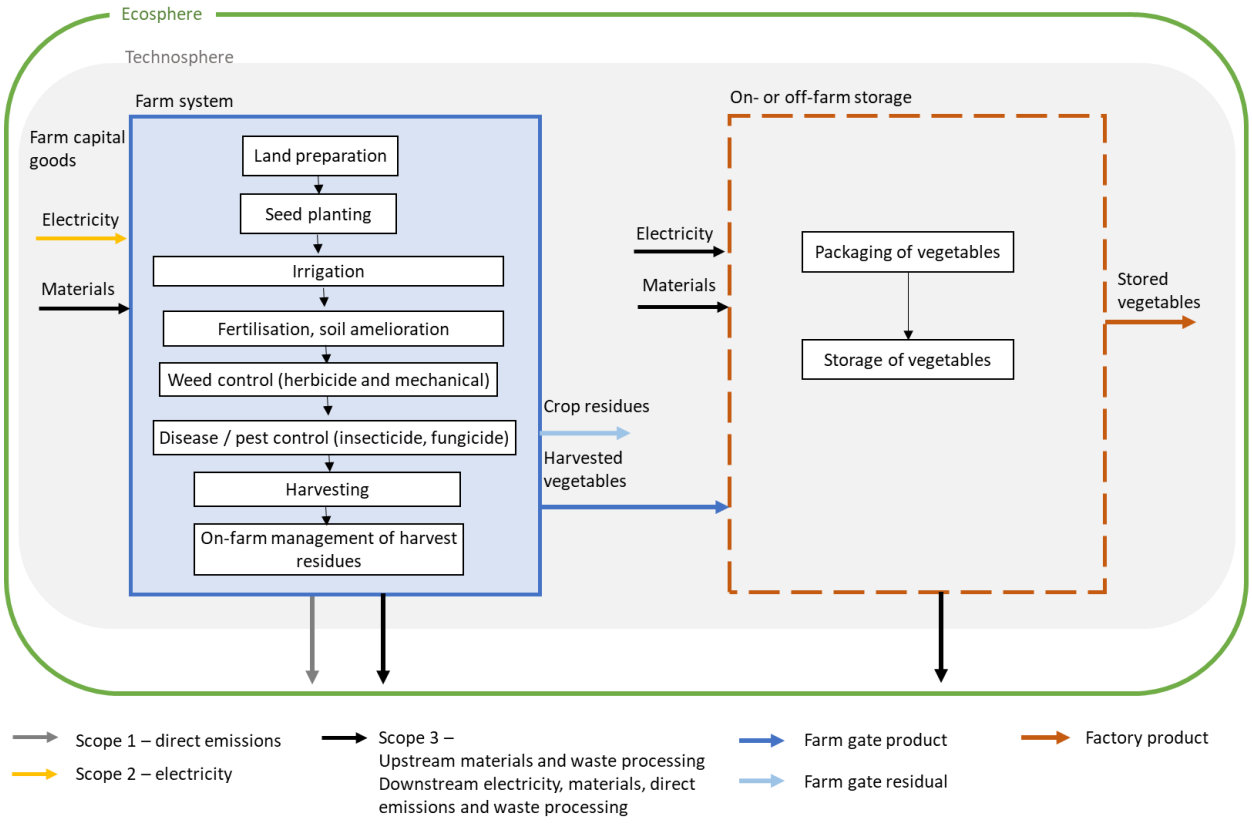

Figure 18 Cradle-to-factory-gate system boundary of vegetable production in Australia

Declared unit

Appropriate declared units for the inventory of this horticulture sub-sector are the mass of all produce and total revenue generated. Reporting on emissions intensity for both declared units is encouraged, as this would capture two important ways to reflect efficiency of the system.

The number of different products in the horticulture sector means that revenue can be the best 'proxy' for production, where usually physical units are preferred. For inventories of parts of the

sector that are more homogeneous, mass only could be used. In all cases, the associated mix of final products or product groups may be reported for additional information and transparency, with contributions by mass.

Accounting for multifunctionality

The multifunctionality that needs to be considered for vegetable row crops is that different vegetable crops may be grown in rotation and break crops may also be included in a rotation. If rotation involves crops that are not considered part of the sector, or livestock, this shall be dealt with via a subdivision approach, applying a strict cut-off between the sectors (see 2.1.6). If rotation involves horticulture crops only, e.g., green beans, sweet corn and broccoli in a rolling rotation, apply a cut-off between crops if reporting at product (group) level is aimed for. All inputs applied in the lead up or during the growing for one crop are allocated to that crop. Emissions calculated using that crop's activity data are allocated to that crop. Only infrequently applied products shall be equally divided between growing seasons that take place between crops (see 2.1.6).

There is typically no co-production of multiple products from vegetable growing. Harvest residues from vegetable production (surplus or product not within specification) may be provided to livestock farmers to supplement animal feed. Unless these have significant economic value (see 2.1.6), these shall be regarded as residual products and carry no embedded impacts post farm gate.

Emission inventory

The emissions inventory for vegetables (and berries, melons, mushrooms) shall include those emissions listed in the chart of accounts (Table 21). The chart of accounts lists all the emission sources that shall be investigated in the emission inventory. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

Table 21 Chart of accounts for GHG emissions for vegetable (row crop) production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Agricultural soils (direct)	N_2O emission - fertiliser (synthetic, organic) applied to crop	1	NGGI
			N_2O emissions - crop residue (if relevant)	1	NGGI
			N_2O emissions from cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions - mineralisation due to loss of soil organic carbon (excl LUC)	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition	1	NGGI
			N_2O emissions – Leaching and run off	1	NGGI
		Residue burning	CH_4, and N_2O emissions from any harvest residue burning	1	NGGI
		Application of lime and urea	CO_2 emissions- agricultural lime and urea application	1	NGGI
	Energy, material and service inputs	Inputs for agricultural processes	CO_2-equivalent emissions from combustion of fuel in tractors / harvesters / pumps (for cultivation, seed sowing, application of fertilisers, lime, gypsum and weed and pest control products, irrigation, and harvest)	1	NGA
			CO_2-equivalent emissions from grid-supplied electricity	2	NGA
			CO_2-equivalent emissions grid-supplied electricity	3	NGA
			CO_2-equivalent emissions embedded in farm inputs (fuels, fertilisers, agricultural lime, gypsum, pest control products, etc.)	3	LCI, NGA
			CO_2-equivalent emissions for transport to supply fuels, fertilisers (synthetic, organic), lime, gypsum, pest control products	3	LCI
			CO_2-equivalent emissions for transport of farm labourers	3	NGA
			CO_2-equivalent emissions-services (insurance, consultants, etc.)	3	See 2.1.3
	Land use, land use change, forestry	Forest converted to cropland (deforestation)	CO_2 emission due to change in soil organic carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic matter	1	NGGI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Cropland remaining cropland	CO_2 emission due to change in soil organic carbon	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission other Constructed Water Bodies (dams)	1	NGGI
	Energy and material inputs	Packaging and storage	CO_2-equivalent emissions embedded in fuel used (on farm and off farm)	3	NGA
			CO_2-equivalent emissions embedded in electricity supply chain (on farm and off farm)	3	NGA
			CO_2-equivalent emissions embedded in packaging materials	3	NGA
			CO_2-equivalent emissions transport from farm to off farm storage	3	LCI
	Capital goods	On-farm production	CO_2-equivalent emissions for production and maintenance of on-farm capital goods (tractor, implements, sheds, harvester, etc.)	3	LCI
		Greenhouse, hydroponic, mushroom production	CO_2-equivalent emissions for production and maintenance of building infrastructure	3	LCI
		Vegetable storage	Production and maintenance of storage facilities not included as they contribute less than the cut-off threshold	3	LCI
	Waste treatment		CO_2-equivalent emissions from all off-farm solid waste disposal (transport, composting, landfill)	3	LCI, NGA
			CO_2-equivalent direct emissions from combustion of fuel in tractors / trucks for spreading harvest residues on-farm	1	NGA
			CO_2-equivalent emissions embedded in fuel for spreading harvest residues on-farm	3	NGA
			CO_2-equivalent emissions from all wastewater disposal and treatment during manufacturing.	3	LCI, NGA
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil carbon	1	NGGI_s
			CO_2 removal due to change in live biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Cropland remaining cropland	CO_2 removal due to change in soil carbon	1	NGGI_s
Sub-total removals					
Net-GHG emission					

Exclusions and cut-off criteria

Guidance on exclusions and cut-off of smaller emission sources is provided in 2.1.5. On-farm capital goods (tractors, harvesters, sheds) shall be included (2.1.3) as they are likely to contribute emissions above the cut-off threshold in horticulture. Similarly, for mushroom, greenhouse and hydroponic systems, production of the greenhouse and building structures shall be included.

Activity data

Table 22 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 22 Activity data required and suggested sources for the vegetable (row crop) sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Production areas and harvested quantities (yields)	ABS, industry data
	*by crop and/or region as needed**	ABS, industry data
	by system type (irrigated/rainfed, tillage type, etcetera)	Farm surveys, ABARES land use data (ALUM)
	by climate zone (low/high rainfall and dryland/non dryland)	Use NGGI default values or derive using spatial data
Agriculture (for each production area defined under 1.1)		
2.1	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.2	Nitrogen and carbon content of crop residue	Derive from 1.1 using NGGI equations (Agricultural Soils, Crop Residues)
2.3	Fraction of residue burnt, removed or left in field	Farm survey data
2.4	Urea applied	As collected for 4.1
2.5	Lime, dolomite applied	As collected for 4.3
2.6	N mineralised	Derive from 3.1 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	System area (1.1) minus area determined under 3.2. Note that this emission source needs to be allocated between sectors, see 2.1.6
3.2	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of system area (1.1) to NGGI total cropland area, or well documented sector-specific attribution
3.3	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Inorganic fertilisers applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.2	Organic amendments applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime), quantity, frequency, and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data, ABS

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.4	Pesticides applied, quantity and type	Farm surveys, gross margin budgets, expert consultation, commercial benchmark data
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys total fuel use if available
	Cultivation, sowing, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Irrigation pumping if applicable	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.6	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, expert consultation. ABS for water use combined with calculation of pumping energy required
4.7	Transport of farm labourers, distance and mode	Expert consultation, estimates.
4.8	Capital goods, type, and lifetime	Expert consultation, reference LCI databases
4.9	Services, type, and expenditure	Farm surveys, gross margin budgets
4.10	Waste flows	Expert consultation, reference LCI databases
Energy and materials, storage		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Transport, distance, and mode	Expert consultation, industry data/information, transport logistics tools
5.4	Capital goods, type and lifetime	Expert consultation, industry data/information
5.5	Product losses	Expert consultation, industry data/information

3.3.2 Fruits and nuts (tree crops)

System definition

This sub-sector produces fruits and nuts from tree crops. Tree crops are characterised as having production cycles that are longer than a few years and commonly involve longer-term tree establishment. As well as requiring the typical annual crop management practices, tree crops also involve a non-production establishment phase, and crop biomass is in place for many years.

For Australian produced fruits there is limited processing (HIA, 2022). Therefore, the traded commodity is considered to be the unprocessed fresh fruit. While around 10%-30% of some fruits are processed (stone fruit, pear, oranges, pineapples, grapes, plums), the nature of processing is too variable for it to be included in sector's default activities. This sub-sector has a very wide geographic spread across Australia with significant fruit production in every state in both coastal and inland environments.

For nuts (walnuts, pistachio, hazelnut, chestnut, almonds, pecan, macadamia), the nuts in shell are most commonly cracked or processed before being sold. Therefore, the traded commodity is considered to be processed nuts. The geographic spread of this sub-sector is confined to SE Queensland and Northern NSW (for macadamia and pecan) and Southern NSW and northern VIC for all others.

There are 19 individual fruit commodities and 7 individual nut commodities grown in Australia. Production systems for fruit and nuts trees are fairly homogeneous, with practices differing mostly in terms of amount of irrigation requirements, and pest and disease control measures.

The emissions inventory for the sector will be a production-weighted aggregation of the constituent systems. For the baseline reference year (2005) most production could be assumed to be outdoor row crops plus mushroom production.

System boundary

For tree crops producing fruit, the system boundary shall be up to the farm gate. As fruit storage is an intrinsic step of the product chain, it shall be included in the system boundary. As some storage takes place on-farm at packing sheds and some off-farm at centralised distribution centres, the system boundary should be defined as "cradle-to-storage". Beyond storage the value chains diverge considerably so this does provide a logical boundary for the fruit sector.

For tree crops producing nuts, the system boundary shall extend beyond the farm gate to include post-farm processing.

For both fruits and nuts, the on-farm system boundary shall include all activities associated with annual activities - production and supply of material and energy inputs (synthetic and organic fertilisers, lime, gypsum, pesticide products, water, fuels, electricity, mulch, plastics, irrigation components), tractor and harvester operations (soil cultivation, fertiliser application, organic fertiliser spreading, weed and pest control spraying, harvesting), and irrigation. Due to the high amount of manual labour employed at harvesting, transport of contracted labour to and from the fields is also included. Activities associated with any management of wastes (plastic collection and disposal) and on-farm management of harvest residues (collection, on-site composting, spreading) shall also be included.

The system boundary shall also include the establishment phase as well as the productive phase. This includes from the production of seedlings (commonly graphed stock), the planting of seedling, and the phase of non-productive growth up until the trees become production.

For nuts, the post-farm processing system shall include the transport of nuts to the cracking plant, production and supply of materials and energy inputs to the cracking process (electricity, packaging materials), and storage.

For fruits, the post-farm processing system shall only include storage and associated transport (Figure 19).

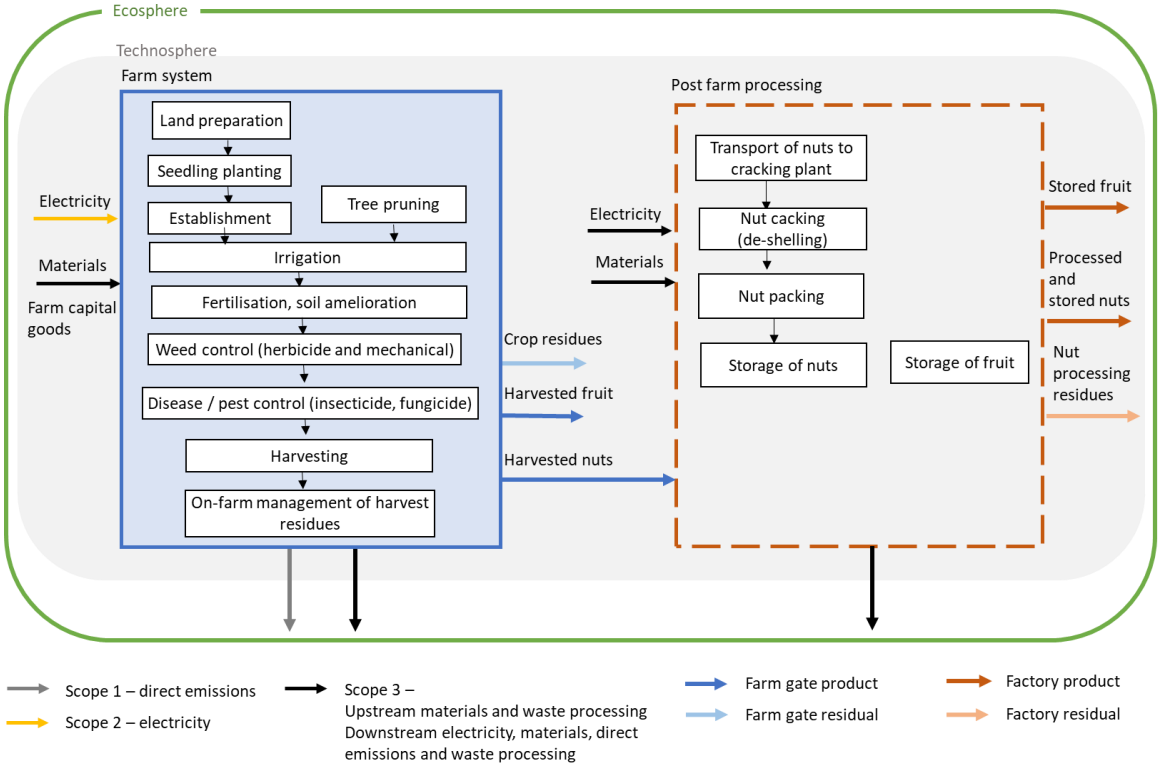

Figure 19 Cradle-to-factory gate system boundary of fruit and nut (tree crop) production in Australia

Declared unit

Appropriate declared units for the inventory of this horticulture sub-sector are the mass of all produce and total revenue generated. Reporting on emissions intensity for both declared units is encouraged, as this would capture two important ways to reflect efficiency of the system.

The number of different products in the horticulture sector means that revenue can be the best 'proxy' for production, where usually physical units are preferred. For inventories of parts of the sector that are more homogeneous, mass only could be used. In all cases, the associated mix of final products or product groups may be reported for additional information and transparency, with contributions by mass.

Accounting for multifunctionality

There is typically no multifunctionality or co-production of multiple products for the on-farm growing of fruit and nuts. Harvest residues (surplus or product not within specification) may be provided to livestock farms to supplement animal feed. These are regarded as residual products

and carry no embedded impacts post farm gate. The post-farm cracking of nuts generates shells, which are regarded as residual products and carry no embedded impact when beneficially utilised.

When not utilised, those residues shall be treated as waste.

Emission inventory

The emissions inventory for tree crop production of fruits and nuts shall include those emissions listed in the chart of accounts (Table 23). The chart of accounts lists all the emission sources that shall be investigated in the emission inventory. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

Burning of prunings is not included in the sector-level chart of accounts as it is not reported in NGGI. It should be noted that for farm-level or product-level accounting (i.e., outside the scope of this guidance) a different choice may be more appropriate.

Carbon sequestration in fruit and nut tree biomass may be counted if the tree biomass is fixed in harvested wood products and contribute to an increase in the carbon pool in the market in line with the NGGI (see 2.2.4). However, this rarely occurs and so is unlikely to be significant in a sector inventory.

Table 23 Chart of accounts for GHG emissions for fruit and nut (tree crop) production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Agricultural soils (direct)	N_2O emissions from applied synthetic fertilisers	1	NGGI
			N_2O emissions from applied organic fertilisers (manure, biosolids)	1	NGGI
			N_2O emissions from cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions from, mineralisation due to loss of soil organic carbon (SOC) (excl LUC)	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition	1	NGGI
			N_2O emissions – Leaching and run off	1	NGGI
		Application of lime and urea	CO_2 emissions from application of agricultural lime and/or urea application	1	NGGI
	Energy and material inputs for farming operations	Inputs for agricultural processes	CO_2-equivalent emissions from on-farm combustion of fuel in tractors, sprayers, harvesters, pumps etc. (for cultivation, seed sowing, application of fertilisers, lime, gypsum and weed and pest control products, irrigation, and harvest)	1	NGA
			CO_2-equivalent emissions for grid-supplied electricity	2	NGA
			CO_2-equivalent emissions for grid-supplied electricity	3	NGA
			CO_2-equivalent emissions for the production of farm inputs (fuels, synthetic fertilisers, organic fertilisers, agricultural lime, gypsum, agrochemicals, etc.)	3	LCI
			CO_2-equivalent emissions for transport of farm inputs (fuels, synthetic fertilisers, organic fertilisers), lime, gypsum, agrochemicals etc.)	3	LCI, NGA
			CO_2-equivalent emissions for transport of farm labourers	3	NGA
			CO_2-equivalent emissions for services used on farm (insurance, consultants, extension services, etc.)	3	See section 2.1.3
	Land use, land use change, forestry	Forest converted to cropland (deforestation)	CO_2 emission due to change in soil organic carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic matter	1	NGGI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Cropland remaining cropland	CO_2 emission due to change in soil organic carbon	1	NGGI_s
			CO_2 emission due to change in area of perennial woody crops	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission other Constructed Water Bodies (dams)	1	NGGI
	Energy and material inputs for storage	Inputs for fruit / nut storage	CO_2-equivalent emissions embedded in fuel used (on farm and off farm)	3	NGA
			CO_2-equivalent emissions embedded in electricity used (on farm and off farm)	3	NGA
			CO_2-equivalent emissions transport from farm to off farm storage	3	LCI
	Capital goods	On-farm production	CO_2-equivalent emissions for production and maintenance of on-farm capital goods (tractor, implements, sheds, harvester, etc.)	3	LCI
		Nut cracking	*Production and maintenance of nut cracking plants not included as they contribute less than the cut-off threshold*		
		Fruit and nut storage	*Production and maintenance of storage facilities not included as they contribute less than the cut-off threshold*		
	Waste treatment	Harvest residues	CO_2-equivalent emissions from transport to deliver harvest residues to off-farm disposal	3	LCI
			CO_2-equivalent direct emissions from on-farm combustion of fuel in tractors / trucks for spreading harvest residues on-farm	3	NGA
			CO_2-equivalent emissions for the production of fuel used for spreading harvest residues on-farm	3	LCI, NGA
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in live biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
		Cropland remaining cropland	CO_2 removal due to change in soil organic carbon	1	NGGI_s
		Perennial woody crops	CO_2 removal due to change in area of perennial woody crops	1	NGGI_s
Sub-total removals					
Net-GHG emission					

Exclusions and cut-off criteria

For the on-farm system, production for on-farm capital goods (tractors, harvesters, sheds) shall be included (amortised by the production they contribute to over their lifespans), as they have been found to contribute emissions above the cut-off threshold (defined in 2.1.5).

For post-farm storage of fruit and nuts and processing of nuts, production, and maintenance of capital goods (storage facilities, nut cracking plants, etc.) For post-farm storage of fruit and nuts and processing of nuts, production and maintenance of capital goods (storage facilities, nut cracking plants, etc.) are not included as they contribute less than the cut-off threshold (defined in 2.1.5).

Activity data

Table 24 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 24 Activity data required and suggested sources for the fruit and nut (tree crop) sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Fruit / nut production areas and harvested quantities (yields)	ABS, industry data
	- *by region / variety as needed and by crop stage (establishment versus in production)*	ABS, industry data
	- *by system type (irrigated/rainfed, etc.)*	Farm surveys, industry data, ABARES land use data (ALUM)
	- *by soil type and/or climate zone (low/high rainfall and dryland/non dryland)*	Use NGGI default values or derive using spatial data
Agriculture (for each production area defined under 1.1)		
2.1	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.2	Urea applied	As collected for 4.1
2.3	Lime, dolomite applied	As collected for 4.3
2.4	N mineralised	Derive from 3.1 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	System area (1.1) minus area determined under 3.2.
3.2	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of system area (1.1) to NGGI total cropland area, or well documented sector-specific attribution
3.3	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Inorganic fertilisers applied, quantity and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data, ABS
4.2	Organic amendments applied, quantity and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime), quantity, frequency, and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data, ABS
4.4	Pesticides applied, quantity and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys of total fuel use if available
	Orchard preparation, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Irrigation pumping if applicable	Farm surveys, extension advisors. ABS for water use combined with calculation of pumping energy required
4.6	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, extension advisors. ABS for water use combined with calculation of pumping energy required
4.7	Transport of farm labourers, distance and mode	Expert consultation, estimates.
4.8	Capital goods, type, and lifetime	Extension advisors, reference LCI databases
4.9	Services, type, and expenditure	Farm surveys, gross margin budgets
4.10	Solid waste generated	Extension advisors, reference LCI databases
Energy and materials, fruit, and nut storage		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Packaging use (if applicable), quantity and type	Expert consultation, industry data/information
5.4	Transport, for storage off farm, distance, and mode	Expert consultation, industry data/information
5.5	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.6	Product losses	Expert consultation, industry data/information

3.3.3 Viticulture and other vine crops

System definition

This section relates to vine crops that produce grapes for wine (viticulture), eating grapes, kiwifruit, and passionfruit. This section relates to vine crops that produce grapes for wine (viticulture), table grapes, kiwifruit, and passionfruit. The aspect these all have in common is that the crop grows on a trellis structure and the plant is in production for a long period.

Grape growing for winemaking in Australia extends from the Granite Belt in southern Queensland to Tasmania in the south and Margaret River in the west, with the state of South Australia the largest producer by volume. There is a big range of climates, soil types and varietal mixes making Australia's wine offering very diverse. Australia has around 4 per cent of world wine production and is the world's fifth largest wine exporter globally. It is made up of 65 wine regions, approximately 2500 wineries and over 6000 grape growers, contributing over $40 billion annually to the Australian economy (WA, 2022).

Grape growing for eating grapes occurs in all states, but Victoria is the major producing state. Kiwifruit production occurs predominantly in the southern states. Passionfruit production occurs in sub-tropical and tropic regions of Queensland.

The production system for vine crops commences with the construction of trellis infrastructure and then the establishment of the vine. After an establishment phase of a few years, the productive phase of vine crops can extend for many years (up to 50 years or more for wine grapes, 20 years for eating grapes, 50 years for kiwifruit and 3 years for passionfruit).

For wine grapes, production is managed for quality rather than quantity. After a period of dormancy overwinter vines are pruned. In early spring, bud break and flowering of the vines commences, and the vines are carefully managed to ensure no impacts from the environment impede upon product growth. Fruit set begins and again the vineyards are carefully managed to avoid pest or disease events, with veraison the indicator for grapes showing signs of ripening and development of sugars. When the product reaches is point of ripening (late-January to late April), harvest begins, and fruit begins its journey to the wineries for crushing, fermentation and other processing stages prior to packaging. Winery operations are seasonal, in general, taking place during 3 months of the year, with emission activity over this period actively contributing to the winery's GHG. For the vineyard, following harvest, dormancy begins again, and the cycle commences.

System boundary

A generalised system boundary diagram for vine fruit production is given in Figure 20. For wine grape production, the wine produced from the grapes is the traded commodity, hence a 'cradle-to-factory gate' system boundary shall be applied, including wine grape growing, harvesting, and transport to the winery, and production of wine at the winery. For other vine fruits (eating grapes, kiwifruit, passionfruit), the traded commodity is the produced fruit (as per tree crops in 3.3.2). As fruit storage is an intrinsic part of the product chain, storage should be included in the system boundary, and so a 'cradle-to-storage' system boundary shall be applied. Some storage takes place on-farm at packing sheds and some off-farm at centralised distribution centres.

The ‘cradle-to-storage’ system boundary (Figure 20) shall include all annual activities and associated inputs, including fuel (for spraying, slashing, spreading, pruning, seeding cover crops, irrigating, and harvesting), electricity, irrigation water, fertilisers and pesticides, production and transport of all inputs, and soil emissions from fertiliser use. It also includes the establishment phase, which involves the production of seedlings (commonly graphed stock), the planting of seedlings, and the phase of non-productive growth up until the trees become production. The production of trellis and irrigation infrastructure is included if significant and amortised to production over the productive life. Changes in soil carbon from direct land use change are also within the system boundary.

The ‘cradle-to-factory gate’ system boundary shall also include winemaking processes of crushing, fermentation, fining, stabilising, filtering, aging, and packaging, as well as tank cleaning and wastewater treatmen.t It includes the production and supply of inputs to winemaking, including electricity, fuels, additives, oak, filter aids, packaging materials. and any onsite treatment of wastewater treatment. Grape marc is a processing residue from the winery which can be stockpiled and then applied to vineyard soils, in which case any associated inputs and emissions are included in the grape growing stage.

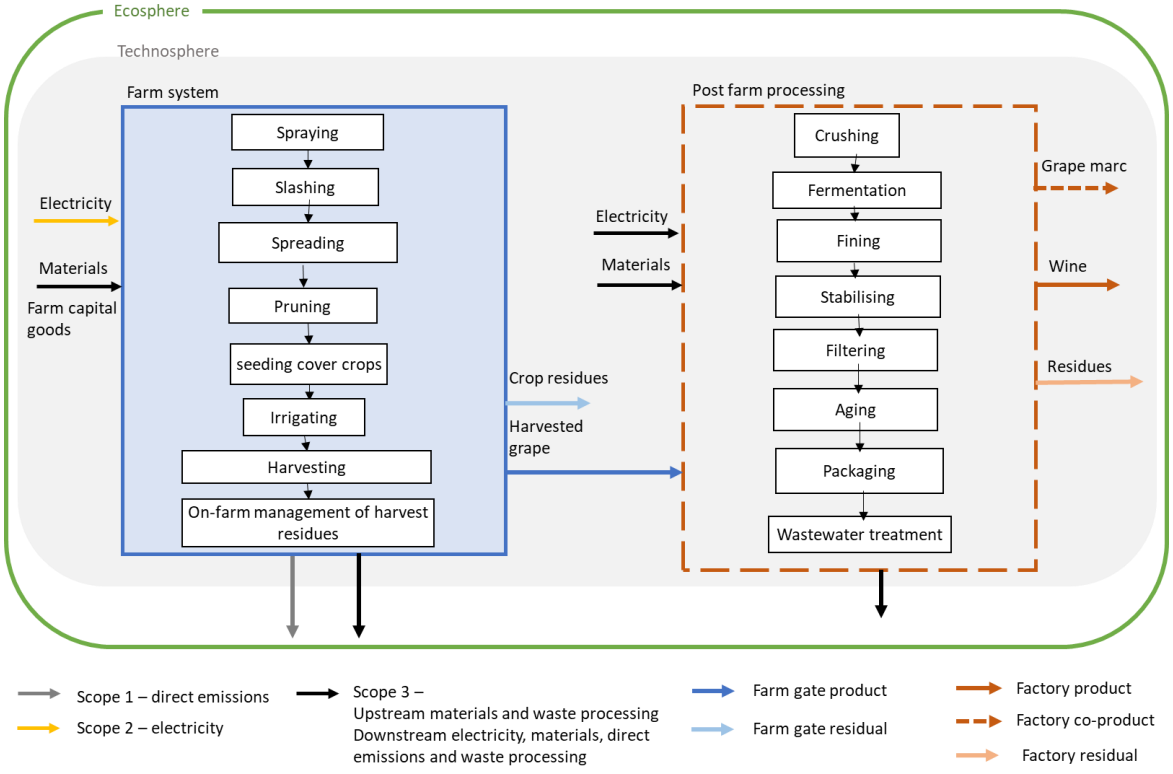

Figure 20 Cradle-to-farm-gate system boundary for vine fruit and cradle-to-factory-gate system boundary for wine production in Australia Post farm processing is included for wine grapes, but not other vine crops.

Declared unit

The declared unit shall be defined as total volume (ML) of wine produced and packaged.

In the case of other vine crop production (table grapes, kiwifruit, passionfruit) the declared unit shall be mass of all produce and total revenue generated, following the recommendations for row crops (3.3.1).

Accounting for multifunctionality

For most viticulture and vine crop systems, multifunctionality does not need to be considered since they do not share any farming systems with other sectors, and there are typically no products other than harvested fruit. If livestock grazing occurs in vineyards over winter, please refer to 2.1.6.

Grape marc produced from wineries is considered a waste if it is stored and applied back to viticulture soils. In this case, emissions associated with stockpiling, transport and spreading are included in the grape growing system. If grape marc is used as a feedstock in the production of a value-added product (e.g., tartaric acid) it is considered residual product, which has no economic value at the winery but has a subsequent use. Subdivision shall be applied in line with the guidance in 2.1.6.

Emission inventory

The emissions inventory shall use the chart of accounts (Table 25). The chart of accounts lists all the emission sources that shall be investigated in the emission inventory. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data. The calculation types are explained in 2.2.1, along with general guidance for inventory calculations.

Burning of prunings is not included in the sector-level chart of accounts as it is not reported in NGGI. It should be noted that for farm-level or product-level accounting (i.e., outside the scope of this guidance) a different choice may be more appropriate.

Production and maintenance of winery capital goods are not included as they contribute less than the cut-off threshold.

Table 25 Chart of accounts for GHG emissions for vine fruit crops including vineyard and wine production. The last column identifies the type of calculation required to calculate the value of the inventory items from the collected activity data (see 2.2.1 for details)

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
Emissions	Agriculture	Agricultural soils (direct)	N_2O emissions from applied synthetic fertilisers	1	NGGI
			N_2O emissions from applied organic fertilisers (manure, biosolids)	1	NGGI
			N_2O emissions from cultivation of histosols (if relevant)	1	NGGI
			N_2O emissions from, mineralisation due to loss of soil organic carbon (SOC) (excl LUC)	1	NGGI
		Agricultural soils (indirect)	N_2O emissions – Deposition	1	NGGI
			N_2O emissions – Leaching and run off	1	NGGI
		Application of lime and urea	CO_2 emissions from application of agricultural lime and/or urea application	1	NGGI
	Energy and material inputs for farming operations	Inputs for agricultural processes	CO_2 -equivalent emissions from on-farm combustion of fuel in tractors, sprayers, harvester, pumps etc. (for land preparation, vine maintenance, and fruit harvesting)	1	NGA
			CO_2-equivalent emissions for grid-supplied electricity	2	NGA
			CO_2-equivalent emissions for grid-supplied electricity	3	NGA
			CO_2-equivalent emissions for the production of farm inputs (fuels, synthetic fertilisers, organic fertilisers, agricultural lime, gypsum, agrochemicals, etc.)	3	LCI, NGA
			CO_2-equivalent emissions for transport of farm inputs (fuels, synthetic fertilisers, organic fertilisers), lime, gypsum, agrochemicals etc.)	3	LCI, NGA
			CO_2-equivalent emissions for transport of farm labourers	3	NGA
			CO_2-equivalent emissions for services used on farm (insurance, consultants, extension services, etc.)	3	See section 2.1.3
	Land use, land use change, forestry	Forest converted to cropland (deforestation)	CO_2 emission due to change in soil organic carbon	1	NGGI_s
			CO_2 emission due to change in live biomass	1	NGGI_s
			CO_2 emission due to change in DOM	1	NGGI_s
			CO_2-equivalent emissions due to controlled burning	1	NGGI_s
			N_2O emissions from N mineralisation associated with a change in soil organic matter	1	NGGI

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			N_2O emissions from Leaching and run-off from mineralised N	1	NGGI
		Wetlands converted to cropland	CO_2-equivalent emissions wetlands converted to cropland (crops and temporary pasture)	1	NGGI_s
		Cropland remaining cropland	CO_2 emission due to change in soil organic carbon	1	NGGI_s
			CO_2 emission due to change in area of perennial woody crops	1	NGGI_s
		Wetlands remaining wetlands	CH_4 emission other Constructed Water Bodies (dams)	1	NGGI
	Energy and material inputs for processing	Inputs for winery (for wine grape production)	CO_2 -equivalent direct emissions from onsite fuel combustion at the winery	1	NGA
			CO_2-equivalent emissions for grid-supplied electricity	3	NGA
			CO_2 -equivalent emissions-from production of winery inputs (water, chemical, packaging materials, etc.)	3	LCI
			CO_2 -equivalent emissions from transport of grapes and other inputs (packaging materials, etc.)	3	LCI
			CO_2 -equivalent emissions –from services used at the winery (insurance, consultants, laboratory services etc.)	3	See 2.1.3
		Inputs for fruit storage (for other vine fruit production)	CO_2 -equivalent emissions from on-farm combustion of fuel	1	NGA
			CO_2-equivalent emissions for the production of fuel	3	NGA
			CO_2 -equivalent emissions from off-farm combustion of fuel	3	NGA
			CO_2-equivalent emissions for grid-supplied electricity (on farm)	2	NGA
			CO_2-equivalent emissions for grid-supplied electricity (off farm and embedded)	3	NGA
			CO_2 -equivalent emissions transport from farm to off farm storage	3	LCI, NGA
	Capital goods	On-farm production	CO_2-equivalent emissions for production and maintenance of capital goods on-farm and for off-farm storage (equipment, tractor, sheds, harvester, etc.)	3	LCI
	Waste treatment	Harvest residues	CO_2-equivalent emissions from transport to deliver harvest residues to off-farm disposal	3	LCI
			CO_2-equivalent direct emissions from on-farm combustion of fuel in tractors / trucks for spreading harvest residues on-farm	3	NGA

GHG FLUX	CATEGORY	SOURCE CATEGORY	ITEM	SCOPE	CALCULATION TYPE
			CO_2-equivalent emissions for the production of fuel used for spreading harvest residues on-farm	3	LCI, NGA
Sub-total emissions					
Removals	Land use, land use change, forestry	Cropland converted to forestland (on-farm afforestation, reforestation, if attributable)	CO_2 removal due to change in soil organic carbon	1	NGGI_s
			CO_2 removal due to change in live biomass	1	NGGI_s
			CO_2 removal due to change in DOM	1	NGGI_s
		Cropland remaining cropland	CO_2 removal due to change in soil organic carbon	1	NGGI_s
		Perennial woody crops	CO_2 removal due to change in area of perennial woody crops	1	NGGI_s
Sub-total removals					
Net-GHG emission					

Exclusions and cut-off criteria

Guidance on exclusions and cut-off of smaller emission sources is provided in 2.1.5. On-farm capital goods (tractors, harvesters, sheds, trellising) shall be included (2.1.3) as they are likely to contribute emissions above the cut-off threshold in vine crops and viticulture. For post-farm storage of vine fruits and processing of wine grapes into wine, production, and maintenance of capital goods (storage facilities, winery, etc.) are not included as they contribute less than the cut-off threshold (defined in 2.1.5).

Activity data

Table 26 lists typical activity data needed for emission estimation, as well as the suggested sources available based on authors' knowledge. The suggestions in the table are not recommendations and new data sources may become available. Therefore, at any time for actual emissions estimation available activity data should be evaluated against the data quality assessment framework provided in 2.2.2. Farm survey data, if available, are likely to be preferred due to representative coverage and repeatability.

Table 26 Activity data required and suggested sources for the vineyard management and wine production sector

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
General system		
1.1	Vine crop production areas and harvested quantities (yields)	ABS, industry data
	- *by region / variety as needed, and by crop stage (establishment versus in production)*	ABS, industry data
	- *by system type (irrigated/rainfed, trellis type, etc.)*	Farm surveys, industry data, ABARES land use data (ALUM)
	- *by soil type and/or climate zone (low/high rainfall and dryland/non dryland)*	Use NGGI default values or derive using spatial data
Agriculture (for each production area defined under 1.1)		
2.1	Nitrogen applied	Derive from 4.1 and 4.2 by nitrogen content (chemical composition, product data)
2.2	Urea applied	As collected for 4.1
2.3	Lime, dolomite applied	As collected for 4.3
2.4	N mineralised	Derive from 3.1 using NGGI equations (Agricultural Soils, Mineralisation due to loss of soil carbon)
Land use, land use change and forestry		
3.1	Fraction of area that qualifies as "cropland remaining cropland"	System area (1.1) minus area determined under 3.2.
3.2	Fraction of area that qualifies as "forest converted to cropland" or "wetlands converted to cropland"	Derive from NGGI relevant areas using ratio of system area (1.1) to NGGI total cropland area, or well documented sector-specific attribution
3.3	Sector attributable reforestation	Farm surveys, carbon market data, expert consultation. Note that this emission source needs to be allocated between sectors, see 2.1.6
Energy, materials and other inputs, farm		
4.1	Inorganic fertilisers applied, quantity and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data, ABS
4.2	Organic amendments applied, quantity and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data, ABS
4.3	Other amendments applied (e.g., lime), quantity, frequency and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data, ABS

CATEGORY	DATA POINT	SUGGESTED SOURCE OR APPROACH
4.4	Pesticides applied, quantity and type	Farm surveys, farm gross margin budgets, extension advisors, commercial benchmark data
4.5	Fuel use requirements for operations, quantity, and type	Farm surveys of total fuel use if available
	Establishment, fertiliser spreading, harvesting, etcetera	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Aerial spraying if applicable	Gross margin budgets combined with estimates of fuel use per operation (e.g., AusLCI)
	Irrigation pumping if applicable	Farm surveys, extension advisors. ABS for water use combined with calculation of pumping energy required
4.6	Electricity use for irrigation pumping if applicable, quantity and type (e.g., grid, solar, wind)	Farm surveys, extension advisors. ABS for water use combined with calculation of pumping energy required
4.7	Transport of farm labourers, distance and mode	Expert consultation, estimates.
4.8	Capital goods, type and lifetime	Extension advisors, reference LCI databases
4.9	Services, type, and expenditure	Farm surveys, gross margin budgets
4.10	Solid waste generated	Extension advisors, reference LCI databases
Energy and materials, wine production (for wine grapes) and fruit storage (for other vine fruits)		
5.1	Fuel use, quantity, and type	Expert consultation, industry data/information
5.2	Electricity use, quantity, and type	Expert consultation, industry data/information
5.3	Packaging use (if applicable), quantity and type	Expert consultation, industry data/information
5.4	Transport, for storage off farm, distance, and mode	Expert consultation, industry data/information
5.5	Capital goods, type, and lifetime	Expert consultation, industry data/information
5.6	Product losses	Expert consultation, industry data/information

Glossary

Co-product	Any of two or more products coming from the same unit process or product system (ISO, 2006). In this guidance, a co-product is specifically a product that has economic value but is not the primary leviable product of the sector.
DOM	Dead organic matter
Downstream	Occurring along a product supply chain (value chain) after the point of referral (farming system in this guidance). Product Environmental Footprint (PEF) Guide(EU, 2021).
Economic value	Average market value of a product at the point of production, for example over a 5-year time frame (FAO, 2016)
ERF	Emission Reduction Fund
FCMP	Full Cream Milk Powder
FPCM	Fat and Protein Corrected Milk
GHG-P	Greenhouse Gas Protocol (see ghgprotocol.org)
LCI	Life Cycle Inventory – inputs and outputs of material flows to a system
LMC	Land management change. Emissions from land management change are those resulting from a considerable change in the way land is managed, within a land use type, for example a shift in average rotation to more cropping and less temporary grazing
LU	Land use. Emissions from land use are those resulting from ongoing land use without LMC or LUC.
LUC	Land use change. Emissions from land use change are those resulting from conversion of one land use type to another, with types being forestland, grassland, cropland, wetlands, settlements (and other). A distinction is made between direct LUC (dLUC) and indirect LUC (iLUC).
LULUCF	The combined emissions category of land use, land use change and forestry (as used in NGGI)
NGA	National Greenhouse Gas Accounts
NGGI	National Greenhouse Gas Inventory as implemented in the most recent National Inventory Report
PEF	Product Environmental Footprint
Residual product	Adopted from FAO (2016). A residual product is a substance that is not the end product(s) that a [multifunctional] production process

	directly seeks to produce. More specifically, a residue is any material without economic value leaving the product system in the condition as it [was] created in the process, but which has a subsequent use. There may be value-added steps beyond the system boundary, but these activities do not impact the product system calculations. Note 1: Materials with economic value are considered products. Note 2: Materials whose economic value is both negligible relative to the annual turnover of the organization and is also entirely determined by the production costs necessary not to turn such materials [into] waste streams are to be considered as residual products from an environmental accounting perspective. Note 3: Those materials whose relative economic value volatility is high in the range of positive and negative value, and whose average value is negative are residual products from an environmental accounting perspective. Materials economic value volatility is possibly calculated over a 5-year time frame at the regional level.
SMP	Skim Milk Powder
Supplementary information	Supplementary information is information relevant to the GHG performance of the sector that is outside the scope defined by this guidance. It is reported but not included in the GHG baseline or account. Rules regarding supplementary information are defined in 2.2.3
Tier	'A tier represents a level of methodological complexity. Usually, three tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher tier methods and are generally considered to be more accurate' (IPCC, 2019)
Upstream	Occurring along the supply chain of purchased goods/services prior to entering the system boundary. - Product Environmental Footprint (PEF) Guide (European Commission, 2013) – adopted by FAO LEAP (2016).
Waste	Substances or objects that the holder intends or is required to dispose of (ISO, 2006).

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