



# Methodology for developing Life Cycle Inventory for Australian agricultural products

## Method Report for the LCAgMetrics Project

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Authors: Marguerite Renouf, Isobel Hume, Sandra Eady, Tim Grant



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# About the author

The LCAgMetrics project was conducted by Lifecycles. The authors of this report are:

Marguerite Renouf  
Isobel Hume  
Sandra Eady  
Tim Grant

Lifecycles is a sustainability consultancy based in Melbourne ([lifecycles.com.au](http://lifecycles.com.au)) specialising in environmental Life Cycle Assessment (LCA) and related services. This includes metrics for sustainability reporting, greenhouse gas (GHG) accounting, environmental product declarations (EPD), GHG emission reduction strategies and targets, among others. Lifecycles has been providing LCA services for more than 20 years for Australian and overseas clients, and is a pioneer of LCA data, training and tool development in Australia.

The authors have expertise in LCA of agricultural products and developed the original set of life cycle inventories (LCI) for Australian agricultural commodities (AusAgLCI) in 2014, led by the Rural Industries Research and Development Corporation (RIRDC). They have since contributed to many LCA projects related to Australian agricultural and biobased production. This has included guidelines for LCA and GHG accounting in agriculture, enabling access into market requiring sustainability credentials, and informing GHG reduction strategies. In this project, the authors were able to draw on this experience to update methods for agricultural LCI development in line with international best practice.

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# Acknowledgements

This document was developed as part of the LCAgMetrics project, a joint initiative of AgriFutures Australia and Lifecycles. It was funded by the Australian Government's Sustainability Reporting Uplift Grant Round, as part of the National Agriculture Traceability Grants Program.

AgriFutures Australia and Lifecycles acknowledge the First Nations people of Australia as the traditional custodians of the lands and waters on which we live, learn and work. We pay our respects to past, present and future Elders of these nations. In particular, we acknowledge the traditional custodians of the lands and waters where our offices are located.

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# Abbreviations

**ABS** – Australian Bureau of Statistics.

**ABARES** – Australian Bureau of Agricultural and Resource Economics.

**AF** – Acid factor.

**AER** – Agro-ecological regions.

**ALCAS** – Australian Life Cycle Assessment Society. Australia's peak professional organisation for professions involved in the use and development of LCA.

**APSIM** – Agricultural Production Systems Simulator.

**ARENA** – Australian Renewable Energy Agency.

**AusAgLCI** – the agricultural / agri-food dataset within the AusLCI database, originally developed in 2014 (Eady et al., 2014) and updated by this LCAgMetrics project.

**AusLCI** – Australian Life Cycle Inventory – national, publicly-accessible database with access to authoritative, comprehensive and transparent environmental information on a range of Australian products and services over their entire life cycle.

**Biogenic carbon** – carbon that originates from vegetation, animals and other organisms.

**BOD** – Biological oxygen demand, an indication of the amount organic matter in water.

**BOM** – Bureau of Meteorology.

**CH<sub>4</sub>** - methane

**CRDC** – Cotton Research and Development Corporation

**CSIRO** – Commonwealth Scientific and Industrial Research Organisation.

**DAP** – Diammonium Phosphate.

**DCCEEW** – Department of Climate Change, Energy, the Environment and Water.

**dLUC** – Direct land use change.

**Ecotoxicity** – the potential impact on an ecosystem from the release of toxic substances.

**EF** – emission factor.

**Elementary flows** – as defined in ISO4040 for LCA (International Organization for Standardization, 2019a) as “material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation”. They are flows between the process (in the technosphere) and the environment (biosphere, such as inputs of water, fuels and materials, and emissions of greenhouse gases, pesticides, nutrients, etc.).

**EPD** – Environmental product declarations are standardized (ISO 14025:2006) LCAs to communicate the environmental performance of a product or system.

**Eutrophication** – the enrichment of waterways with mineral and organic nutrients that promote a proliferation of plant life, especially algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms.

**GAF** – Greenhouse Accounting Framework - decision support framework tools for greenhouse accounting on Australian dairy, sheep, beef or grain farms.

**GHG** - Greenhouse gases are compounds that absorb infrared radiation, trap heat in the atmosphere, and contribute to global warming, the main ones being carbon dioxide from combustion of fossil fuels (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) and refrigerant gases.

**GIS** – Geographic Information System.

**GLAM** – Global Guidance for Life Cycle Impact Assessment (GLAM) method, an Initiative by the United Nations Environment Programme's Life Cycle Initiative.

**GRDC** – Grains Research and Development Corporation.

**Gross Margin Models** – analysis of inputs and outputs for product systems characterising inputs such as fertiliser, irrigation, pesticides and outputs such as yield of product.

**GWP** – Global warming potential.

**ILCD** – International Reference Life Cycle Data System, in the context of the ILCD impact assessment method.

**iLUC** – Indirect land use change.

**IPCC** – Intergovernmental Panel on Climate Change, an international body of the United Nation, which sets the methodology for estimating GHG emissions from industry sectors.

**KCl** – potassium chloride.

**kg CO<sub>2e</sub>** – kilograms of carbon dioxide equivalent.

**LCA** – Life Cycle Assessment is a technique to assess environmental impacts across all the stages of a product's life cycle from-cradle-to-grave (i.e., from raw material extraction to materials processing, manufacture, distribution, use, maintenance and disposal or recycling).

**LCI** – Life Cycle Inventory is data on elementary and material flows that is used for each process in the supply chain when undertaking a Life Cycle Assessment.

**LEAP** – Livestock Environmental Assessment and Performance Partnership – a partnership under the Food and Agriculture Organization that develops comprehensive guidelines and methodologies to assess the environmental performance of livestock supply chains.

**LUC** – Land use change.

**MAP** – Mono-ammonium phosphate.

**MLA** – Meat & livestock Australia.

**N** – Nitrogen.

**N<sub>2</sub>O** – Nitrous oxide

**NAAR** – Net annual acidification rate.

**NGER** – Australian Government National Greenhouse and Energy Reporting Scheme

**NIR** – National Inventory Report for Australia's Greenhouse Gas Accounts – annual reports prepared by the Australian Government to report national GHG emissions by sector (Commonwealth of Australia, 2025b, a).

**NMVOG** – Non-methane Volatile Organic Compounds.

**NO<sub>x</sub>** – Nitrogen oxides

**NRMR** – Natural Resource Management Region.

**NSW** – New South Wales.

**P** – Phosphorus.

**Parameter** – In the context of LCI, a parameter is a flexibly defined value used in the calculation of inventory flows from primary data variables (e.g. dry mass, heating value, etc.) and formulas instead of computed numbers.

**PCOP** - Photochemical ozone creation potential.

**PEF** – Product Environmental Footprint method of the European Commission.

**PestLCI** – a model developed by Technical University of Denmark for estimating crop pesticide emissions to air, surface water and ground water for use in life cycle inventory.

**QLD** – Queensland.

**ReCiPe** – an international Life Cycle Impact Assessment methodology.

**RUSLE** – Revised Universal Soil Loss Equation – a method for estimating soil losses to water via erosion.

**SA** – South Australia.

**SILO** – Scientific Information for Landowners.

**SOC**- Soil organic carbon

**TAS** – Tasmania.

**UNFCCC** – United Nations Framework Convention on Climate Change.

**Unit process** - a discrete production activity representing a step in a product supply chain.

**UseTOX** – a scientific consensus model of the United Nations Environment Programme's Life Cycle Initiative for characterising human and ecotoxicological impacts of chemicals.

**VIC** – Victoria.

**WA** – Western Australia.

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# Executive summary

This report describes the methods used to build LCI data for Australian agricultural and agri-food products as part of the LCAgMetrics project. The LCAgMetrics project was a joint initiative of AgriFutures Australia and Lifecycles to update and extend LCI for agriculture (AusAgLCI) contained in the Australian LCI (AusLCI) database. It was funded by the Federal Government's Sustainability Reporting Uplift Grant Round, as part of the National Agriculture Traceability Grants Program. It builds on an earlier investment from CSIRO, industry and the Australian Government.

This report will enable users of the AusAgLCI dataset to understand the methods and assumptions behind the data. It can also be used by future developers of agricultural LCI by providing guidance on building inventory consistent with AusLCI protocols. It describes the general method approaches used across all commodities and are based on similar guiding principles of earlier versions (Eady et al., 2014, Grant et al., 2014). Product-specific details on the methods can be found in the Appendices and within the inventory dataset itself.

The dataset covers many of the major agricultural commodities produced in Australia (beef, sheep, dairy, pigs, meat chickens, cereals, oilseeds, pulses, fodder, sugarcane, cotton, rice and some horticulture). It contains over 1,000 individual unit processes for on farm production at regional level as well as state and country averages. It also contains around 200 unit processes for post-farm primary processing and distribution at state or country averages, and a further 100 supporting processes (irrigation, machinery operations, infrastructure, feed mixes, etc). Therefore, the supply chain scope represented by the dataset extends from the farm to markets for primary processed agricultural products. The on farm and post-farm unit processes link to other energy, transport, fertiliser, chemical, and materials processes in background databases (AusLCI database and ecoinvent®) to enable cradle-to-farm gate, cradle-to-processor gate and cradle-to-market life cycle assessments.

The inventory data allows for the generation of a comprehensive range of environmental impact indicators relevant to agriculture, to enable its broadest possible use in LCA. Therefore, the methods estimate elementary flows related to:

- global warming (greenhouse gas emissions and carbon flows)
- water resource depletion and scarcity (regionalised water use)
- land resource depletion and ecosystem service (land occupation and transformation, soil organic carbon change, soil acidification and soil erosion)
- ecosystem health and human health impacts
  - o eutrophication (releases of nutrients to water and land)
  - o ecotoxicity (releases of pesticides and heavy metals to air, water and land)
  - o respiratory impacts (particulate matter, NMVOC)

All project outputs, including reports and data, are available from the Project webpage on the Lifecycles website ([www.lifecycles.com.au/lifecycle-assessment-project](http://www.lifecycles.com.au/lifecycle-assessment-project)).

AusLCI data is provided with no warranties as to its accuracy or correctness in all contexts. It is the responsibility of the user to determine if the data is appropriate and adequate for the application.

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# Introduction

Since the 2010s, Australian agriculture has recognised the critical importance of environmental Life Cycle Assessment (LCA) for generating sustainability metrics that holistically represent the environmental sustainability of a product over its life cycle. LCA-based sustainability metrics are increasingly required for doing business, reporting, business-to-business information sharing and communicating sustainability initiatives with customers, consumers and stakeholders. Undertaking LCA requires good quality Life Cycle Inventory (LCI) data, which are the building blocks representing the environmental inputs and outputs for individual processes that make up a product's life cycle.

The project updated and extended existing agricultural LCI data in the Australian Life Cycle Inventory (AusLCI) database, which is the national repository of LCI data used for environmental LCAs of products. The agricultural dataset within it is known as AusAgLCI and was first developed in 2014 (Eady et al., 2014, Grant et al., 2014).

Target readers are users of the AusAgLCI dataset, who want to understand the methods and assumptions behind the data. It can also be used by future developers of agricultural LCI as guidance for building LCI data consistent with AusLCI protocols.

Methods used to build earlier versions of the AusAgLCI dataset have been described previously (Grant et al., 2014, Grant et al., 2019). Many of the methods for the updated AusAgLCI dataset remain similar to earlier versions, and some have changed due to updated best practice modelling approaches or new data sources. This method document describes both unchanged and new methods, effectively replacing the earlier method documents (Grant et al., 2014, Grant et al., 2019).

Details of the methods and assumptions behind LCI data are important for ensuring the appropriateness and validity of the impact indicators / sustainability metrics that are derived from it. The scale of environmental impacts and benefits represented by impact indicators / sustainability metrics can vary due to method choices, such as the system boundary (inclusions and exclusions), data source, and factors for performing calculations (emission factor, allocation factors, etc.). Therefore, method descriptions allow users of the LCI data to confidently select and use the LCI data in a way that appropriately suits their purposes.

This Methodology Report describes the methods used to build the updated AusAgLCI data as part of the LCAgMetrics project. A separate Final Project Report records the activities and outcomes of LCAgMetrics project (Renouf et al., 2025). All project outputs, including reports and data, are available from the Project webpage on the Lifecycles website ([www.lifecycles.com.au/lifecycle-assessment-project](http://www.lifecycles.com.au/lifecycle-assessment-project)).

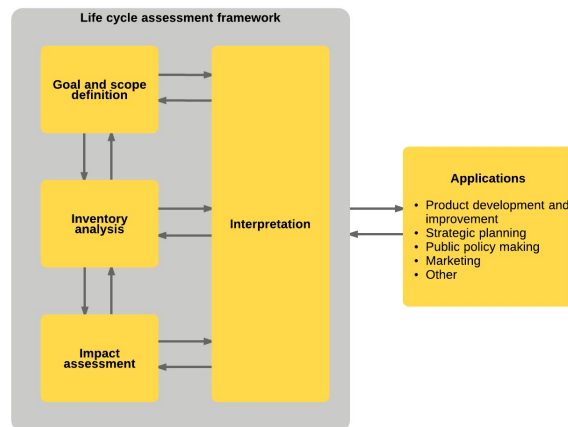
# Background to LCA and LCI

## Life cycle assessment (LCA)

LCA is a methodology for assessing the full 'cradle-to-grave' environmental impact of products by quantifying elementary flows at each stage of the life cycle. LCA aims to include all important environmental impacts for the product system being studied. In doing so, LCA seeks to avoid shifting impacts from one life cycle stage to another or from one environmental impact to another.

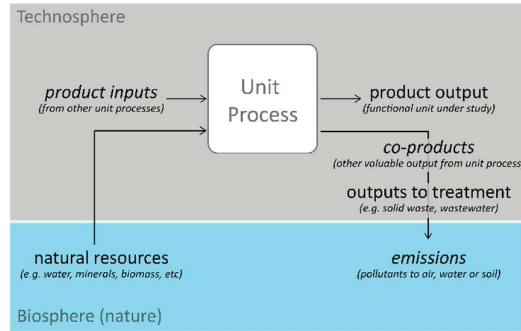
The framework and principles of LCA are described in the international standard ISO 14040 (International Organization for Standardization, 2019a). The general structure of the LCA framework is shown in Figure 1. Each stage of the LCA interacts with the other stages which makes LCA an iterative process. The specific requirements for LCA are defined by ISO 14044 (International Organization for Standardization, 2019b).

- The first stage (goal and scope) describes the reasons for the LCA, the system boundaries, the functional unit, the impact indicators to be assessed and various choices.
- The second stage (inventory analysis) builds a model of the product's life cycle, made up of many 'unit processes' and LCI data defining the amounts of inputs (resources) and outputs (emissions / releases) for each unit process.
- The third stage (impact assessment) converts the inventory data a set of environmental indicators using impact characterisation factors.
- The final stage (interpretation) analyses the impact assessment results and undertakes systematic checks of the assumptions and data to ensure robust results.



**Figure 1 Framework for LCA.**

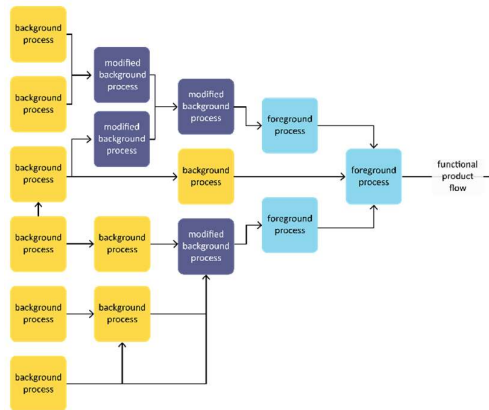
LCA quantifies exchanges between the natural world (the 'biosphere') and human activities (the 'technosphere') for a product system, ideally over the product's entire life cycle from cradle-to-grave (or sometimes part of the life cycle). Exchanges include the extraction of natural resources and emissions of pollutants to air, water and soil. The quantification of exchanges is done at the level of individual processes, referred to as gate-to-gate unit process. An example unit process is illustrated in Figure 2, showing inputs of resources and produced materials / energy, and outputs of wastes, emissions as well as products.



**Figure 2 Unit process inputs and outputs represented in LCI.**

## Life cycle inventory (LCI)

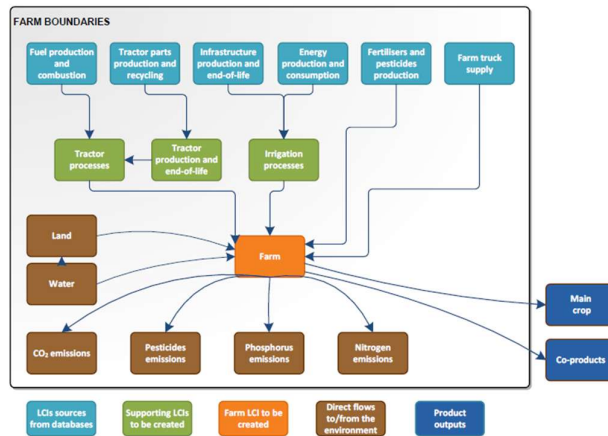
Gate-to-gate unit processes can be categorised as foreground processes and background processes (see Figure 3). Foreground processes are those closely related to the products being assessed, for which primary data or secondary data from literature are collected. The LCI development process described in this report relates to foreground processes in agricultural supply chains. Background processes, usually represent common inputs and services (electricity, fuels, transport, packaging materials, waste disposal). LCI for many common background processes in product supply chains are available in LCI databases, such as AusLCI.



**Figure 3 Linking unit processes in an LCA model.**

A typical unit process for an agricultural product is depicted in Figure 4, with the central on farm processes receiving inputs from many other unit processes, such as tractor processes and irrigation processes. There are also elementary flows from the on farm operation itself such as land use and emissions of pesticides, nitrate and nitrous oxide.

Development of LCIs involves identifying and quantifying the exchanges between the environment / biosphere and the technosphere for each gate-to-gate unit process. These exchanges are referred to as the 'elementary flows', which are the inputs from the environment (water, energy, and raw materials) and outputs to the environment (emissions to air, soil and water).



**Figure 4 Depiction of inventory flows (inputs and outputs) for an agricultural process.**

In an LCA study, LCI data for individual foreground and background processes are linked together into a model of a product's lifecycle. The elementary flows for all unit processes in the product life cycle are aggregated together and linked to the relevant environmental impact category to generate sustainability metrics. This is typically done in LCA software to handle the very large amounts of data.

## AusAgLCI dataset

The AusAgLCI dataset is a subset of agricultural and agri-food LCI within the AusLCI database (ALCAS, 2024). It contains over 1,200 individual processes for agri-food products, each containing inputs, outputs and elementary flow data, which are derived from primary data and mathematical relationships as shown in Figure 5.

The following product categories are represented in the AusAgLCI dataset:

- extensive livestock – beef, sheep, dairy
- intensive livestock – pigs and meat chickens
- broadacre crops - grains (cereals, oil seeds, pulses), hay, silage, fodder crops
- cotton
- sugarcane
- rice
- horticulture (limited set of crops and regions).

Products are represented at different points in their supply chain and at various scales:

- on farm agricultural products, at farm gate
  - o regional level
  - o state averages
  - o national averages
- post-farm agri-food products, at processor gate
  - o national averages
- post-farm agri-food products, at market (port or urban centre)
  - o state averages (for some products)
  - o national averages.

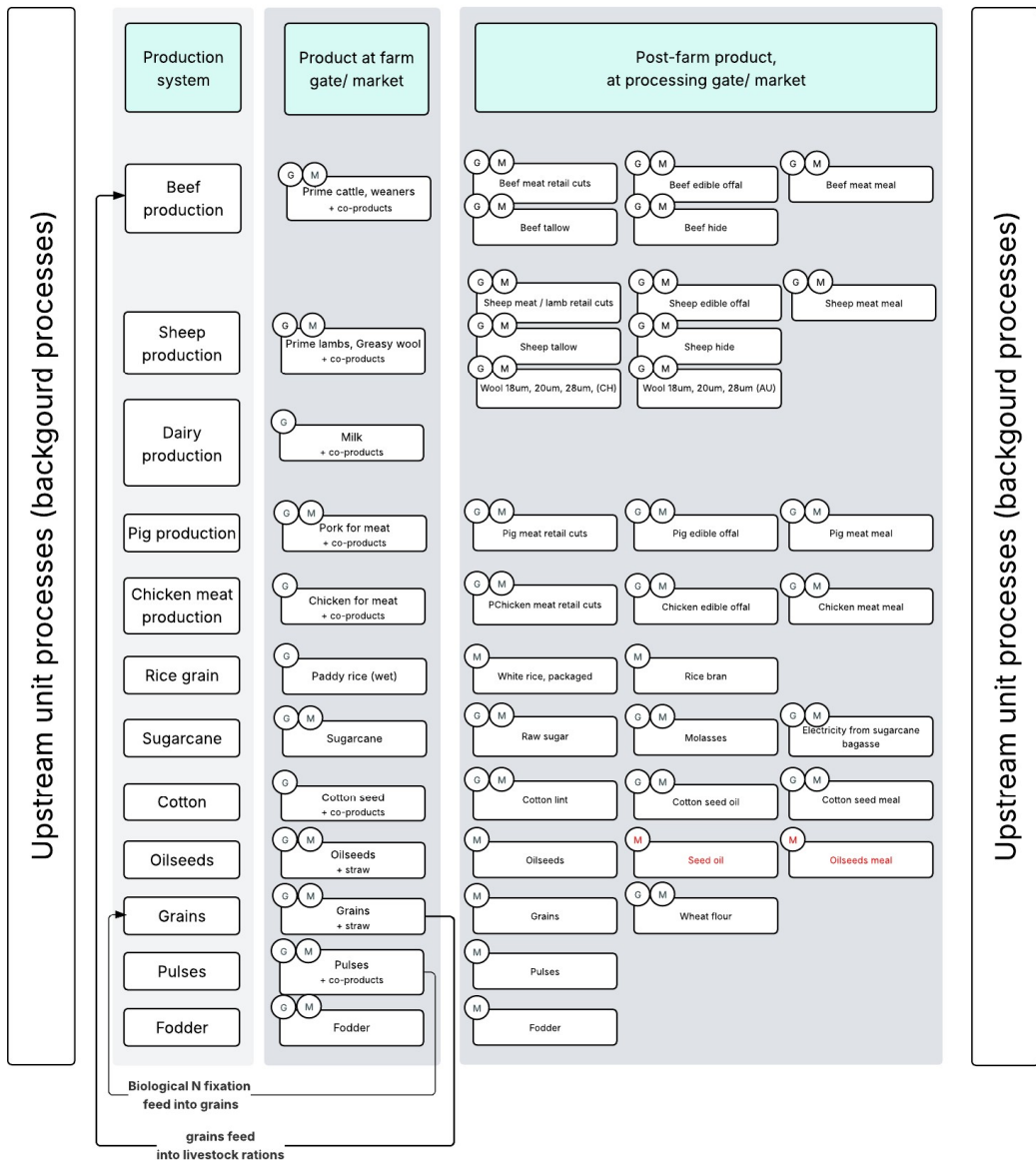


Figure 5 Scope of agricultural and agri-food products represented in AusAgLCI.

# Data development process

The development and update of LCI data in AusAgLCI followed the same principles as AusLCI:

- Based on an attributional LCA approach, which models the existing state. If applied using a consequential LCA approach, which models a change, the user may need to modify the LCIs to reflect marginal effects.
- LCIs are derived from publicly available data – most sourced from agricultural statistics (e.g. Australian Bureau of Statistics (ABS)), industry publications describing practices and inputs, gross margin documents developed by State Government agricultural departments, and survey data collected from a representative group.
- Differentiation of production systems where they are different enough to warrant separate inventories – inventories can represent individual regions or production system, which are also combined/aggregated to represent a production-weighted state or national average inventory.
- Simplicity by avoiding unnecessary disaggregation of the inventory. On farm agricultural processes are normally contained in one process.
- Parameterisation of calculations for estimating inputs, outputs and elementary flows.
- Modularity – common aspects such as farm machinery operations, irrigation infrastructure and feed formulations have been developed as supporting processes as inputs to a number of agricultural processes.

For most products represented in AusAgLCI, with a few exceptions, LCIs were developed from scratch using up-to-date activity data from a range of data sources. Exceptions were:

- For pigs and meat chickens was that inventories were derived from published LCA studies of Australian pig (Copley et al., 2024) and chicken (Copley and Wiedemann, 2023) production.
- For cotton, LCI data sets had previously been prepared as part of a Cotton Research and Development (CRDC) project (Sevenster et al., 2023a, Sevenster et al., 2023b), and were updated to be consistent with the updates applied across the AusAgLCI dataset.

The main data sources included:

- Australian Bureau of Statistics (ABS) for production statistics
- Australian Bureau of Agricultural and Resource Economics (ABARES), for land use categories
- Bureau of Meteorology (BOM) and Scientific Information for Land Owners (SILO) climate data
- Gross Margin information, for descriptions of production practices and inputs
- previously published LCA studies
- industry survey data, where available, such as the Dairy Farm Monitor Project
- expert input regarding inputs
- farm dam database (AusDams.org)
- National Inventory Report (NIR) for GHG emission estimation methods and factors.

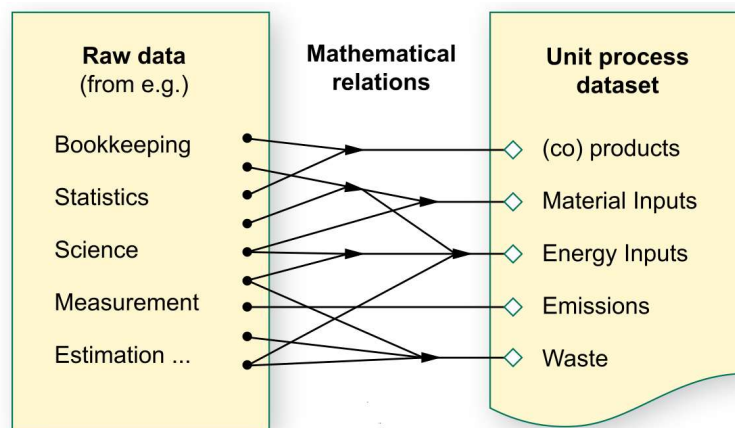
LCI for each on farm and post-farm process were compiled into a process model in SimaPro LCA software (V10.2). Activity data were entered into the process models as parameters

and the calculations of inputs, outputs and elementary flows were entered as algorithms based on mathematical relationships (Figure 6). This parameterised approach enables:

- transparency – all assumptions and calculations are transparent.
- updateability – changes to the datasets over time can be easier due to the ability to update parameters, which automatically propagate update to the entire inventory.
- configurability – allow users to adapt / customise unit process inventories to the user's local circumstances, for specific applications or for sensitivity analysis.

Inputs were linked to background processes from the AusLCI database (see Appendix C).

The overarching methods and calculation procedures are described broadly in the body of this Methodology Report, and product-specific details are provided in Appendix H. Full lists of the inventory data and calculations are transparently described in the data sets themselves, which can be downloaded as MS Excel spreadsheets from the AusLCI website ([auslci.com.au](http://auslci.com.au)).



**Figure 6 Approach for converting activity data into inputs, outputs and elementary flow data for unit processes (SETAC, 2011).**

## What's new

The following summarises the main updates to the AusAgLCI since the last version, further details of which can be found in subsequent sections:

- **Updated activity data**, since the last version of AusAgLCI, that more closely represents current practices, capturing the adoption of progressive practices such as low tillage systems, nitrogen use efficiency, changed pesticide active ingredients and accounting for upstream pumping by irrigation schemes.
- **Updated factors for estimating greenhouse gas (GHG) emissions** in line with the methods and factors in the most recent update of the NIR, which at the time of data development was for the year 2024 (Commonwealth of Australia, 2025a, b) for livestock enteric methane, and nitrous oxide from fertilisers and residues.
- **Updated factors for estimating N losses via leaching** (FracWet) in line with the above-mentioned latest NIR methods, which further enhanced regionalisation of the inventory in terms of N losses to water and also N<sub>2</sub>O emissions via leaching.

- **Updated approach for modelling the biological fixation of nitrogen (N)**, with soil N being a co-product of legume crops rather than being credited with avoided urea use as modelled previously.
- **Updated approach for modelling lime application for broadacre crops**, based on the lime required to counteract the annual acidification of the surface soil each year due to N fertiliser application. This approach differs to previous versions, where lime application was based on a standard, fixed application rate reported by industry.
- **Updated evaporative water loss from farm dams**, drawing on new data sources for calculating dam areas and using the estimation methods consistent with the latest NIR methods.
- **Added methane emissions from farm dams**, consistent with the latest NIR methods, which had not previously been included.
- **Added the relationship between soil organic carbon (SOC) change and N mineralisation** can be accounted for in the inventories of broadacre crops. When the relevant parameter for this function is switched on, changes in N mineralisation that occur with SOC change is accounted for in the N demand estimations. Given the uncertainty in modelling soil carbon loss, this switch parameter is off but can be switched on by the user.
- **Added electricity use for pumping water from irrigation scheme dams to farm** for sugarcane production. Since public data representing the energy and emissions intensity of scheme water became available since the last update via the National Greenhouse and Energy Reporting Scheme (NGERS), it was possible to include this additional upstream energy input.
- **Added all biogenic carbon flows** to enable (as far as possible) a carbon balance over a product's life cycle.

## Access to AusAgLCI

The AusAgLCI dataset is accessible in the following formats:

- **AusAgLCI data details.** Details of all the AusAgLCI unit processes can be downloaded from the AusLCI website ([auslci.com.au](http://auslci.com.au)) as MS Excel spreadsheets. This format allows the user to view the inventory details, parameters, calculations and data sources. However, it cannot be imported into LCA software for performing an LCA but could be used as a template for building LCIs in LCA software.
- **AusAgLCI dataset within the AusLCI database (parameterised).** The AusAgLCI dataset is available within the AusLCI database for importing into LCA software (EcoSpold format). The AusAgLCI data link to background processes in AusLCI and is parameterised allowing users to perform LCAs, but also to copy and adapt individual unit processes for customised analyses.
- **AusAgLCI dataset within the ecoinvent® database (not parameterised).** From 2026 the AusAgLCI database will also be available within the ecoinvent® database for importing into LCA software (EcoSpold format). The AusAgLCI data link to background processes in ecoinvent® rather than AusLCI and is not parameterised, which constrains the ability for customisation but gives broad access to international users.

- **GHG Emission Factors (EF) derived from AusAgLCI data.** GHG emissions intensity results (carbon footprint – kg CO<sub>2</sub>e/kg product) have been generated from the AusAgLCI data, that links to a Lifecycles background database. The GHG EF dataset can be downloaded as a MS Excel spreadsheets from the AusLCI website ([auslci.com.au](http://auslci.com.au)). These factors are sought after for use in GHG reporting and GHG tools / calculators.

## Conditions of use

The data in AusLCI (of which AusAgLCI is a subset) is provided with no warranties as to its accuracy or correctness. Like all LCI data it is the responsibility of the user to determine if the data is appropriate and adequate for their situation. Data contained in AusLCI covers individual unit processes, or cradle-to-gate processes where indicated, but not full life cycle data.

Users should not make claims or comparisons based on partial life cycle data, in line with good practice LCA principles. The data provided in AusLCI should be used in compliance with the most recent ISO standards on LCA. Any comparisons or claims made using AusLCI data are solely the responsibility of the data user and they should not be seen or inferred to be endorsed by the developers or the suppliers of data in AusLCI. By using the data, you agree that distributor, the Australian Life Cycle Assessment Society (ALCAS), its members and/or the suppliers of data into AusLCI accept no liability for any claims, decisions, tools or labels based on AusLCI data.

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# Scope

This section describes the scope of unit processes represented in the AusAgLCI dataset. A unit process is a discrete production activity typically representing a step in a product supply chain (e.g. farming, food processing, distribution). The collection of unit processes in AusAgLCI includes foreground processes, supporting processes and the background processes. This report mostly relates to the development of foreground unit processes but refers to the background and supporting processes that they link to.

The AusAgLCI dataset contains unit processes for plant- and animal-based agricultural commodities (at farm gate) and primary processed agri-food products (at processor gate). Post-farm processing includes primary processing of bulk agricultural commodities and the transport of bulk products to markets. Secondary processing and packaging, retail, consumer use or end-of-life (after the use phase) are typically not covered.

## System boundary

The system boundary of each unit process in AusAgLCI is 'gate-to-gate', consistent with broader AusLCI database. Each unit process includes activities required to produce the end product from the receipt of production inputs and services to the output of the product (typically aligning with financial control of the enterprise including contracted services). Each 'gate-to-gate' process links to background processes (for the production of inputs) creating a full 'cradle-to-gate' system boundary.

## Exclusions / cut-off

The inventories are as comprehensive as possible. No inputs, outputs or elementary flows have been systematically excluded. In some cases, process inputs of very small quantities for which data or background processes were not readily available were excluded on the basis of their contribution to impacts was insignificant (i.e. <1%). This included antibiotics, micro additives in animal feed, personal protective equipment (PPE) consumables, tractor tyre and implement wear down, the processing of seed, farm buildings, fences and roads.

Best quality available data was used where possible, but in its absence, estimates were modelled or derived to ensure a value was recorded, albeit with lower data quality.

## Foreground processes

These are the core processes of interest for producing agricultural and agri-food products. The system boundaries and inclusions are summarised below. The processes are mostly agricultural in nature, but also industrial (primary processing of agricultural products).

On farm cropping unit processes:

- inclusions:
  - o land occupation and transformation
  - o fuel use for tractor operations (cultivation, planting, fertiliser applications, spraying etc.)
  - o fuel use for harvest / haul out operations
  - o fertiliser input (individual active ingredients)
  - o ameliorant input (lime, dolomite, gypsum, organic amendments)
  - o pesticide input (individual active ingredients)

- aerial spraying of pesticides (where relevant)
- water and electricity / fuel use for irrigation (on farm pumping and upstream supply of water)
- residue management (burning, baling, etc.)
- production of capital goods (tractors, implements, harvesters, irrigation systems)
- local transport of inputs to farm (transport for importation is captured in background market processes)
- exclusions:
  - seed input is not itemised as an input flow in the inventory, instead it is accounted for by subtracting the seed requirement from the yield.
  - product losses were not included as an elementary flow in the inventory, and are accounted for via the production output being represented as net, i.e. less losses.

On farm extensive livestock (beef cattle, sheep, dairy):

- inclusions:
  - land occupation and transformation
  - pasture production
  - breeding
  - grow-out
  - manure management (for dairy systems)
  - farm dam water storage
  - supplementary fed input
  - local transport of inputs to farm (transport for importation is captured in background market processes)
- exclusions:
  - feedlot processes for cattle
  - product losses were not included as an elementary flow in the inventory and are accounted for via the production output being represented as net, i.e. less losses.

On farm intensive livestock unit processes:

- inclusions:
  - breeding
  - grow-out
  - animal feed input
  - manure management
  - capital goods (farm buildings)
  - local transport of inputs to farm (transport for importation is captured in background market processes)
- exclusions:
  - product losses were not included as an elementary flow in the inventory and are accounted for via the production output being represented as net, i.e. less losses.

Post-farm unit processes (primary processing, storage, drying etc.)

- inclusions:
  - transport of farm product from farm to processing plant (transport of inputs are captured in the background market process)
  - energy input (fuel / heat / electricity)
  - water input
  - chemical and material inputs
  - co-product processing (where relevant)
  - waste management on-site
  - waste disposal off site (where relevant)

- capital goods (factory /plant, storage silos)
- exclusions:
  - packaging and packaging materials are not included since processes only cover primary processing of the bulk commodities.
  - product losses were not included as an elementary flow in the inventory and are accounted for via the production output being represented as net, i.e. less losses.

### Market processes

- inclusions:
  - storage (where relevant)
  - transport of processed product from farm / processor to urban centre / port
  - supply chain losses

### Supporting processes

Supporting processes are those associated with the foreground processes but modelled as separate unit processes. They typically represent common activities or inputs that feed into agricultural and agri-food foreground processes, for which good representative LCI data are not available as background data in LCI databases. The following were developed as part of earlier versions of AusAgLCI with some updates in the LCAgMetrics project:

- feed mixes for cattle, dairy cows and calves, pigs, chickens
- feed supplements
- cleaning chemicals (e.g. for dairies)
- agricultural machinery capital goods
- irrigation system capital goods
- irrigation pumping (for a range of pumping heads)
- activity-specific tractor operations (e.g. ploughing, planting, liming, spraying etc.)
- tractor operation (per litre of fuel combusted)
- aerial spraying
- land application of processing residues (e.g. mill mud, mill ash in sugarcane)
- combustion of residues for energy (e.g. in sugarcane mills).

Further details regarding the supporting processes relevant to each agricultural products are included in the product-specific method details in Appendix H.

### Background processes

Background unit processes link to the AusAgLCI foreground processes and are part of the broader AusLCI database. They relate to the energy, materials, transport and services that are inputs to AusAgLCI foreground processes, containing the inputs, outputs and elementary flows for the manufacture and supply of these inputs.

The background processes relevant to AusAgLCI data are:

- tractor and harvester operation
- production of tractors, harvesters and implements
- production of fertilisers, soil ameliorants (lime, gypsum, etc.)
- production of pesticides
- production of chemicals, refrigerant gases, etc.
- transport operations
- wastewater treatment (on farm and municipal).

The list of the linked AusLCI background processes is provided in Appendix C. The background processes were selected as the most appropriate or best available market mix for the input. An Australian (AU) market mix is selected where an input is known to be purchased from an Australian market specifically (e.g. lime, transport), and a global (GLO) market mix selected where an input is known to be purchased from the global market (e.g. fertilisers, pesticides). Where neither is available a rest of world (ROW) market mix is selected, which provides a general representation in the absence of region-specific data.

## Environmental impact categories

The inventory data must allow for the generation of a comprehensive range of environmental impact indicators relevant to agriculture, to enable its broadest possible use in LCA.

The inventories include elementary flows related to the following impact categories of importance for agriculture, and detailed in Table 1:

- climate change (GHG emissions)
- water resource depletion and scarcity (regionalised water use)
- land resource depletion (land occupation and transformation)
- ecosystem service impacts (SOC change, soil acidification, soil erosion, groundwater regeneration, mechanical filtration)
- ecosystem health and human health impacts
  - o eutrophication (releases of nutrients to water and land)
  - o ecotoxicity and human toxicity (releases of pesticides and heavy metals to air, water and land)
  - o terrestrial acidification (releases of acidic gases)
  - o particulate matter (releases to air)
  - o photo-oxidant formation (releases of air pollutants)
  - o ecosystem services (SOC, soil acidity, soil erosion, groundwater regeneration, mechanical filtration).

The inventory does not claim to be compatible with the inventory requirements for particular impact assessment method(s). Instead, it aims to be broadly compatible with most impact assessment methods. Users may find there to be some inventory items that need to be adjusted to be compatible with a specific impact assessment method. Examples are:

- Particulate matter emissions have been included as the PM10 fraction. Some methods may require the PM2.5 fraction, as required in the ILCD method.
- Energy values of products which are used to calculate energy allocation factors are based on the energy content of the material. Some methods may require energy expressed on a different basis, such as the PEF method.
- NH<sub>3</sub> does not have a characterisation factor for eutrophication in ReCiPe.

The sections that follow generally describe the elementary flows contributing to these impact categories that have been included in the inventories. Further details of the methods used for estimating the elementary flows are provided in the activity data sections.

**Table 1 Environmental impact categories and associated elementary flows in the foreground processes of agricultural systems.**

<b>Impact category</b>	<b>Elementary flows</b>
<b>Climate change</b>	<p>Emission from fuel combustion and electricity use (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) in the foreground systems are accounted for in the background inventories.</p> <p>Methane (CH<sub>4</sub>) enteric emissions from livestock</p> <p>Methane (CH<sub>4</sub>) emissions from burning crop residues</p> <p>Methane (CH<sub>4</sub>) emissions from dung and urine deposited on pasture</p> <p>Methane (CH<sub>4</sub>) emissions from manure management systems</p> <p>Methane (CH<sub>4</sub>) emissions from farm dams</p> <p>Nitrous oxide (N<sub>2</sub>O) direct emissions from nitrogen fertilisers, crop residues, burning crop residues, manure and urine</p> <p>Nitrous oxide (N<sub>2</sub>O) indirect emissions via leaching and run-off and deposited ammonia volatilisation, re-emitted as N<sub>2</sub>O.</p> <p>Carbon dioxide (CO<sub>2</sub>) emissions from carbonation of applied lime</p> <p>Carbon dioxide (CO<sub>2</sub>) emissions from conversion of applied urea</p> <p>Carbon dioxide (CO<sub>2</sub>) flux from SOC change <sup>Note 1</sup></p> <p>Carbon dioxide (CO<sub>2</sub>) flux from direct land use change (dLUC) <sup>Note 1</sup></p> <p>Carbon dioxide (biogenic CO<sub>2</sub>) from decomposition of crop residues</p> <p>Carbon dioxide (biogenic CO<sub>2</sub>) from burning crop residues</p> <p>Refrigerant gases</p> <p>(Emissions from peatland are not considered as not relevant for Australia)</p>
<b>Water resource depletion and scarcity</b>	<p>Natural water used by livestock, by catchment</p> <p>Natural water used for irrigation, by catchment</p> <p>Evaporative loss of water from farm dams, by catchment</p> <p>Tap water used in processing and cleaning.</p>
<b>Land use related impacts</b>	<p>Area of land occupied for the portion of the year that the product requires for a full production cycle, for crops covering land preparation to harvest. Also includes allocation of land use for fallow across rotation.</p> <p>Area of land transformed from and to a land use category.</p>
<b>Eutrophication</b>	<p>Nitrate (NO<sub>3</sub><sup>-</sup>) emissions to water (from fertilisers, urine, manure)</p> <p>Ammonia (NH<sub>3</sub>) emissions to air (from fertilisers)</p> <p>Nitrogen oxides (NO<sub>x</sub>) emissions to air (from fuel combustion)</p> <p>Phosphorus emissions to water, as soluble orthophosphates or particulate phosphorus adsorbed to soil</p> <p>Organic matter, measured as BOD emissions to water (from wastewaters).</p>
<b>Ecotoxicity / Human toxicity</b>	<p>Pesticide active ingredient releases to air, water and soil</p> <p>Heavy metals released from fertilisers to soil.</p>
<b>Terrestrial acidification</b>	<p>Ammonia (NH<sub>3</sub>) emissions to air (from fertilisers)</p> <p>Nitrogen oxide (NO<sub>x</sub>) and sulphur dioxide (SO<sub>2</sub>) emissions to air (from fuel combustion)</p> <p>Hydrogen ion (H<sup>+</sup>) emissions to soil (from N fertiliser application).</p>
<b>Particulate matter</b>	<p>PM&lt;2.5um, PM2.5um-10um, PM&gt;10um, ammonia, NO<sub>x</sub> emissions.</p>

Impact category	Elementary flows
Photo-oxidant formation potential	Nitrogen oxide (NOx) and non-methanic volatile organic compounds (NMVOC) emissions to air (from fuel combustion)  Methane (CH <sub>4</sub> ) emissions from livestock, farm dams, residue burning.
Ecosystem services	
SOC change	Change in SOC per year, decreases and increases  Land category defined for land occupation and/or transformation (used in the Global Life Cycle Impact Assessment Indicators and Methods (GLAM) method).
Soil acidity	Hydrogen ions to soil from the acidifying effects of nitrogen fertiliser and export of product (typically counteracted by addition of lime).
Soil erosion	Land category defined for land occupation and/or transformation (used in the GLAM method).
Groundwater regeneration	Land category defined for land occupation / transformation (used in the GLAM method).
Mechanical filtration	Land category defined for land occupation / transformation (used in the GLAM method).

Notes:

1. Data has been included for CO<sub>2</sub> flux from SOC change and dLUC, but have been switched off (see GHG emissions section for details),

## Climate change

Elementary flows that contribute to climate change are GHG emissions. Those of relevance for agriculture and included in the LCIs are listed in Table 1. They include not only emissions of fossil carbon dioxide (CO<sub>2</sub>) (from fuel combustion, emissions from urea / lime), but also methane emissions (enteric and from manure), and nitrous oxide emissions (from various origins, but in nitrogen fertiliser use in particular). The default approach for their estimation was to adopt the methods and factors described in the latest version of Australia's NIR, which at the time of writing was NIR 2024 (Commonwealth of Australia, 2025a, b).

Carbon fluxes also contribute to climate change. These are movements of carbon between CO<sub>2</sub> in the atmosphere and carbon in biomass (in vegetation and soil) when there are changes in SOC or changes in vegetation due to land use change (LUC). Carbon fluxes can result in net CO<sub>2</sub> emissions to atmosphere when SOC declines or LUC decreases vegetation, or net removals of CO<sub>2</sub> from atmosphere when SOC increases or LUC increases vegetation. Climate change impacts assessment models now facilitate the reporting carbon fluxes from SOC and LUC separate to GHG emissions, and line items for these elementary flows have been included in the inventories. However, due to no clear consensus on appropriate estimation methods in the Australian context at the time of writing, they are either not included, or available estimates are 'switched off'.

Biogenic carbon refers to carbon that is a part of organic compounds derived from living or recently living organisms. It is differentiated from fossil carbon, which is carbon that has been stored in geological formations for millions of years. Biogenic CO<sub>2</sub>, i.e. uptake of CO<sub>2</sub> into and release of CO<sub>2</sub> from plants / organisms / animals, has in the past not been considered in climate change impact models due to the neutrality approach and hence have not traditionally been included in inventories. More recently however, there are requirements to report biogenic CO<sub>2</sub> (separately), such as in GHG protocol, and in the ISO 14067 standard for carbon footprints. Climate change impacts assessment models now facilitate the reporting of biogenic CO<sub>2</sub> separate to GHG emissions. Therefore, biogenic CO<sub>2</sub> flows have been included in the inventories.

## Water scarcity

Water scarcity impacts are caused by anthropogenic demand for freshwater from surface and groundwater relative to the natural rate of replenishment. The problem is highly regionalised but is considered sufficiently widespread. The assessment of water use in LCA is guided by the international standard for water footprints (International Organization for Standardization, 2014), which defines water use broadly to include any human use of water.

The water scarcity impact category relates only to water abstracted and no longer available to other local users because it has been evaporated, incorporated into a product or released into a different drainage basin or the sea. Change in evaporation caused by land-use change is also considered water consumption as this can impact the local availability of surface and groundwater. However, the natural evapotranspiration of soil moisture derived from local precipitation (sometimes referred to as green water) is not considered water consumption. In summary, the inventory phase considers surface and groundwater consumption and changes in land use that impact surface and ground water resources.

The information required in the inventory to support water-related impact assessment methods (such as water footprints and water scarcity indicators) are the volume of consumptive water uses, and also the source of the water (catchment or region). For AusAgLCI data, consumptive uses include for irrigation, livestock drinking water and evaporative water losses from dams. Sources of water were those drawn from rivers, lakes, dams, or irrigation schemes and municipal water supplies. The definition of the catchment enables impact assessment methods to take into account the relative water stress in different supplying catchments.

## Land use

There are a number of impact characterisation methods associated with land use and LUC, which are relevant for agricultural production. The key ones are detailed in Table 2, along with the land use information required to perform impact assessment using these methods.

The land use information typically required in the inventory is land occupation and land transformation, including specification of the land classification / type. AusAgLCI inventories specify land types consistent with the land classifications required by the Global Guidance for Life Cycle Impact Assessment (GLAM) method (Koellner et al., 2013), so that they can be picked up by all methods listed in Table 2.

**Table 2 Impact assessment methods capturing land occupation and transformation impacts.**

Impact method	Basis for characterisation	Land use information required
Global Guidance for Life Cycle Impact Assessment (GLAM) method	GLAM uses defined land occupation / transformation flows to characterise a range of ecosystem service indicators.	Occupation by GLAM land type Land transformation to- by GLAM land type Land transformation from- by GLAM land type.
Product Environmental Footprint (PEF) method (Damiani et al., 2022)	PEF uses defined land occupation / transformation flows to characterise a range of ecosystem service indicators.	Occupation by GLAM land type Land transformation to- by GLAM land type Land transformation from- by GLAM land type.
<b>Change in SOC</b> (Brandão and Milà i Canals, 2013)	Impact of land occupation and transformation on SOC stock compared to potential natural vegetation reference.	Occupation by land type Land transformation to- by land type Land transformation from- by land type
<b>Impact World +</b> (Saad et al., 2011)	Impact of land occupation looking at the occupation type with some reference to previous state of land.	Occupation, land type, prior state of land being used

Impact method	Basis for characterisation	Land use information required
<b>ReCiPe Method</b> (Goedkoop et al., 2009)	Based on direct and indirect impacts land occupation of biodiversity through exclusion of re-establishment. Land transformation included as being an occupation until the time of re-establishment or 100 years whichever comes sooner.	Occupation by land type Land transformation to- by land type Land transformation from- by land type

## Eutrophication

Eutrophication is caused by the emission to water of macro-nutrients, which have the potential to increase biological activity. This can lead to excess algae production which can dramatically affect the water quality and deplete dissolved oxygen. The macro-nutrients typically accounted for are nitrogen (N) compounds, phosphorous (P) compounds, and organic compounds (measured as BOD). Example consequences of eutrophication can be fish kills, or a change changes in species composition, for example encouraging weeds. The aspects that contribute include:

- The release to water of N contained in applied fertilisers and manure / urine via the run-off and/or leaching, typically in the form of nitrate (NO<sub>3</sub>-)
- The release to water of P contained in applied fertilisers, either via run-off and/or leaching in a soluble form (orthophosphate) or as particulate phosphorus adsorbed to sediment
- Volatilisation to air of ammonia (NH<sub>3</sub>) from fertiliser and manure
- Discharge to water of food processing wastewaters with high organic load
- Fuel combustion processes (for electricity and transport), which release nitrogen compounds to air, i.e. nitrogen oxides (NO<sub>x</sub>).

## Ecotoxicity / Human toxicity

Ecotoxicity and human toxicity impacts in agricultural systems are mostly driven by releases of pesticides to the environment (air, water, soil) from pest and disease control activities. Losses are most significant for cropping systems and less so for livestock systems. Emissions of heavy metals also contribute toxicity impacts and originate from the minor heavy metal content in fertilisers. AusAgLCI inventories have accounted for lead (Pb), mercury (Hg) and Cadmium (Cd) contents and assume their fate to be agricultural soils.

The human toxicity impact category captures the adverse effects of chemicals on human health, including both carcinogenic and non-carcinogenic impacts. Ecotoxicity includes the effects of emissions on the environment in particular on individual species. For both, the impact of a chemical agent will vary significantly depending on impact pathway, fate and exposure to humans. The elementary flows required by impact assessment methods are the amounts of pesticide active ingredients emitted to air, water, soil.

## Terrestrial acidification

Acidification quantifies the acidifying impacts when acid precursor compounds are released to air and subsequently deposited on land or water. The substances typically accounted for are nitrogen oxides (NO<sub>x</sub>), ammonia (NH<sub>3</sub>), sulphur oxides (SO<sub>x</sub>) gases. When these are emitted to air, they react with moisture in the atmosphere to form acidic compounds (such as

nitric acid, sulphuric acid, etc.), which subsequently deposit on land (terrestrial acidification) making it acidic (reducing soil pH). Most impact methods focus on terrestrial acidification.

Agricultural systems contribute through ammonia (NH<sub>3</sub>) emissions from fertilisers and manure management, as well as nitrogen oxides (NO<sub>x</sub>) and sulphur dioxide (SO<sub>2</sub>) from farm machinery exhaust emissions (Huijbregts et al., 2017). These are the main elementary flows picked up by acidification impact assessment methods.

Cropping systems also acidify soils via the generation of hydrogen ions (H<sup>+</sup>) when ammonia (NH<sub>3</sub>) contained in N fertilisers converts to nitrate (NO<sub>3</sub><sup>-</sup>). However, H<sup>+</sup> is not accounted for in currently impact assessment methods. Emissions of hydrogen ions (H<sup>+</sup>) are estimated and included in the LCIs principally for the purpose of estimating lime requirements. However, they may be an elementary flow of interest for future impact assessment methods.

## Particulate matter

Particulate matter refers to fine particles is measured as particulate matter less than 2.5µm (PM<sub>2.5</sub>). Particulate matter has a significant effect on human health (Lim, Vos et al. 2012). Agriculture systems contribute through emission from burning residues, from machinery emissions and from ammonia emissions which are known as secondary particulates through the formation of aerosols. All three of these sources are quantified in the inventory data, with all emissions being placed in the low population sub-compartment of air emissions, due to them being released in the Australian context with low population density.

## Photo-oxidant formation

The inventory includes emissions effecting photochemical ozone creation potential (PCOP) including nitrogen oxides (NO<sub>x</sub>), non-methanic volatile organic carbon (NMVOC), and butadiene from burning of residues and combustion emissions from machinery operations. These are assigned to the low population sub-compartment, as their effect is likely to be small in the context of low population density in Australia.

## Ecosystem services

Ecosystem services are the benefits that humans derive from functioning ecosystems, including provisioning, regulating, and supporting services (World Resources Institute, 2005). Land use and land transformation affects multiple ecosystem services through changes to soil properties, vegetation cover and hydrological cycles. The following ecosystem service indicators can be quantified from land occupation and transformation flows in the inventory, with characterisation factors developed in GLAM (Bos et al., 2016):

- SOC change reflects the capacity of soils to sequester or release carbon through changes in land management, affecting both climate regulation and soil fertility maintenance.
- Soil erosion measures the ability of land systems to prevent soil loss, with impacts on long-term productivity and water quality through sediment loading.
- Groundwater regeneration quantifies the infiltration and recharge capacity of different land uses, affecting water availability for both ecosystems and human use.
- Mechanical filtration represents the soil's capacity to filter pollutants and retain nutrients, preventing contamination of groundwater and surface water bodies.

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# Representation

This section describes what the AusAgLCI dataset aims to represent, in terms of production systems, production coverage, temporal representation and functional unit.

## Production and production system coverage

The aim was to represent production systems as comprehensively as possible by covering:

- at least 90% of national production for each of the included products, and
- regional disaggregation where production systems were different enough to warrant separate inventories.

In most cases (beef, sheep, broadacre crops, sugarcane and cotton) sufficient regionally disaggregated production and activity data was available to build separate inventories for most producing regions, from which production-weighted state- and national average inventories could then be aggregated. This allowed for different regional production system to be represented and for the dataset to cover 90% of national production.

In the case of pigs and meat chickens, available production and activity data represented production as aggregated averages. This allowed for national production to be represented, and some different production systems, but not regionally disaggregated.

For rice, dairy and horticulture only data for particular regions were available or could be collected. In these cases, the inventories provide a partial representation of national production:

- For rice, only the Riverina region in southern New South Wales (NSW) is represented, but this is Australia's major producing region responsible for over 90% of national production.
- For dairy, only production regions in the state of Victoria are represented, based on publicly available data, which represents around 60% of national production.
- For horticulture, only a few crops in a small number of regions are represented due to insufficient publicly available data at present. LCA studies of Australian horticulture product are currently underway which will make data available in the future updates.

Production data were sourced from production statistics most relevant to the product, which included national agricultural statistics from the ABS, industry statistics or yields described in public reports. Product-specific details can be found in Appendix H.

## Product losses

For on farm and post-farm primary processes, product losses (food loss and waste) are reflected in the product output / yield being the net harvested / processed output (less losses). Losses are assumed to be retained on farm as harvest residue (in the case of on farm processes) or beneficially recovered in product streams (in the case of off farm processes). The opportunities for products recovery in the bulk commodity processes currently represented in the AusAgLCI dataset means that food loss and waste is not considered to be significant. Further enhancements of AusAgLCI to include LCIs for

products further downstream in food product supply chains, into secondary processes, distribution and retail, will require inclusion of product to loss pathways.

## Spatial definitions of regions

Where the available data enabled regional disaggregation, production regions were defined based on classification systems most applicable for the respective industry (see Table 3).

For the main broadacre crops, agro-ecological regions (AER) (Williams et al., 2002) were used to define areas where similar production systems operate. Within each AER, data on area of crop planted and production (yields) are available at the Statistical Area Level 2 (SA2) (Australian Bureau of Statistics, 2011). Broadacre cropping is not undertaken in all AERs.

For extensive livestock (beef and sheep), a combination of approaches was used to define areas where similar production systems operate.

- In Queensland, production areas were defined based on ABARES survey regions of northern Australia (Department of Agriculture and Water Resources, 2016).
- In New South Wales they were based on regions defined by NSW Department of Primary Industries (Phil Graham, NSW DPI, pers. comm.).
- In Victoria regions were based on the benchmark regions set up by Victorian Department of Primary Industries (Department of Primary Industries, 2014).
- In South Australian and Western Australia they were defined by rainfall (AgExcellence Alliance, 2024).
- In Tasmania livestock regions were matched to descriptions provided by Department of Primary Industries (Department of Primary Industries Parks Water and Environment, 2015).

For the dairy production, for which only Victorian regions were covered, regional definitions defined by the Dairy Farm Monitor Project (Agriculture Victoria, 2020, 2021, 2022, 2023, 2024) were used.

For the other represented crops, industry definitions of production regions were adopted for sugarcane (Topp et al., 2021), cotton (Sevenster et al., 2023b) and rice (NSW Government, 2025).

For intensive livestock (pigs and meat chickens), regional definitions were not relevant as the intensive nature of these production systems mean that regional climate and soil conditions do not influence elementary flows. Furthermore, the source data were only available aggregated to whole of national production, with no regional differentiation.

When defining elementary flows, it was necessary to use bio-physical factors that are defined against different spatial boundaries to those used for regional production. Therefore, it was necessary to align multiple set of spatial information. For example:

- Identification of the geographic origin of water inputs required the source catchments to be identified, which requiring concordance between production regions and water catchments (see Appendix A).
- Modelling of GHG EFs required the use of climate, soil and bio-physical factors defined by AERs, which required concordance between production regions and AERs. For

example, FracWet factors used to calculate the amount of applied nitrogen (N) potentially lost via leaching and run-off were match to the relevant AERs (see Appendix B).

**Table 3 Spatial definitions of regions.**

Category	Regional definition
Broadacre crops (cereals, oil seeds, pulses, hay)	Agro-ecological regions (Figure 7)
Beef	Livestock regions (see Figure 8)
Sheep	Livestock regions (see Figure 8)
Dairy	Livestock regions (see Figure 8)
Sugarcane	Sugarcane industry regions (see Figure 9)
Cotton	Cotton industry regions (see Figure 9)
Rice	Rice industry regions (see Figure 9)
Pigs	Not relevant
Chicken	Not relevant

## Temporal representation

The update of AusAgLCI aimed to represent current / recent production and production practices as far as possible. The other temporal consideration was interannual climate variation, which leads to variable production and practices. To even out the effects of climatic variability it is common for LCI data to be based on averages over multi-year timeframes. In the absence of a recommended timeframe, five-year averages were a practical compromise that allowed recent practices to be represented while considering interannual variation. Five-year averages are adopted in other agricultural LCI data (Blonk Consultants, 2022a, b).

Five-year averages do not adequately even out the impacts of drought, which can be extreme and prolonged in the context of Australia. Timeframes of around 30 years would be needed to enable that but would be impractical in terms of capturing contemporary practices and tracking production and practice changes over time. Selected five-year period may need to represent drought conditions.

The timeframe selected was product-specific and aimed to balance the following objectives:

- data availability
- representing typical climate conditions (i.e. not representing atypical periods affected by severe drought or natural disasters)
- representing contemporary practices.

For most commodities the LCI data represent production and practices around 2018-2022. Details of the timeframe represented for each product can be found in the product-specific method details (Appendix H). In comparison, the timeframe for the earlier version of AusAgLCI approximately represented production and practices for 2010-2014.

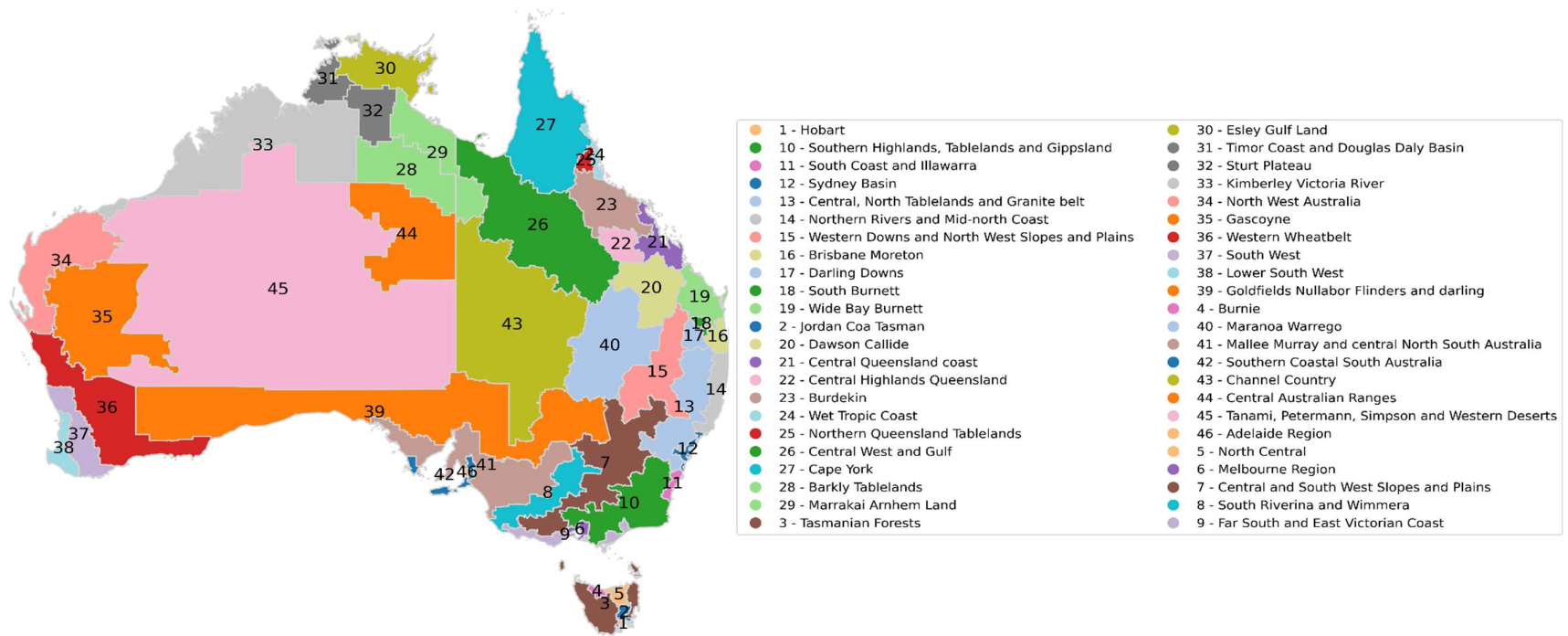
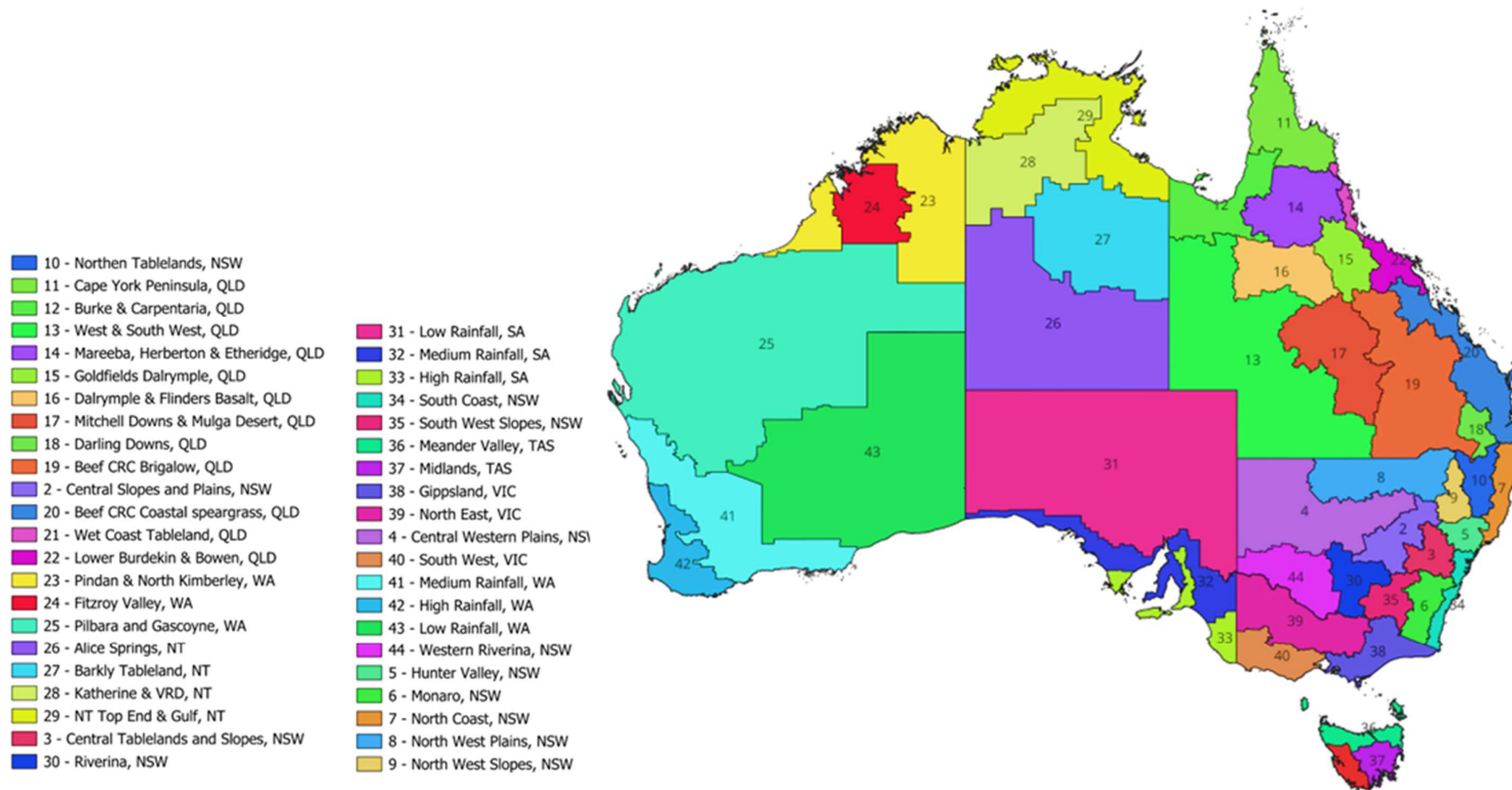


Figure 7 Agro-ecological regions (AER) Source: Williams et al. (2002).



**Figure 8 Livestock regions. Source: Holmes et al. (2011), DPI (2016), Bureau of Meteorology (2024) and Department of Primary Industries Parks Water and Environment (2015).**

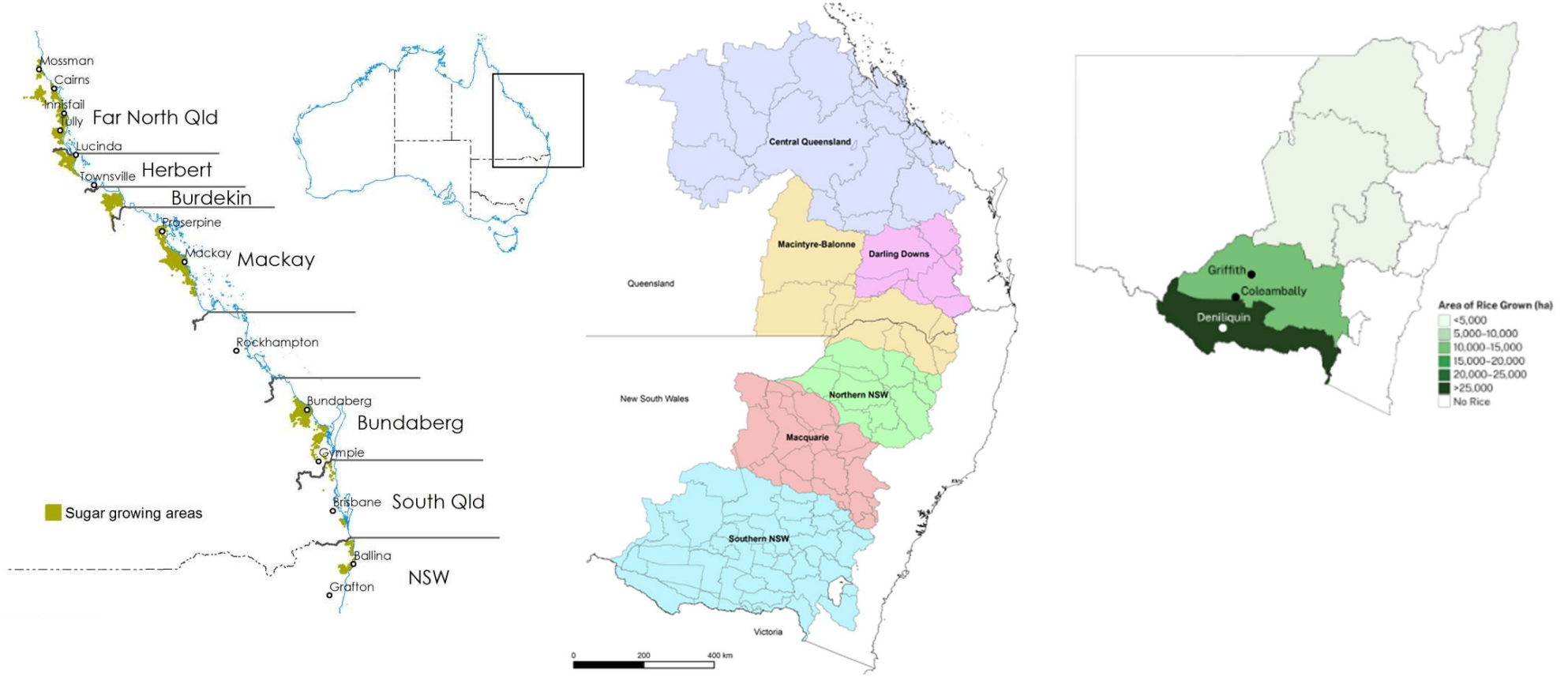


Figure 9 Industry regions for sugarcane (Topp et al., 2021), cotton (Sevenster et al., 2023b), rice (NSW Government, 2025).

## Functional unit and reference flow

The function unit for both on farm and post-farm processes is the production of the determining product. It is expressed as a mass of the product nominally per kilogram, at farm gate, processor gate or at market. The reference flow refers to the physical flows of products as traded, i.e., including moisture. Product specifications (production system, region) are noted in the process name and product properties (dry matter, energy content, etc.) are listed separately in the process name and/or comment fields. Parametrisation of the inventory allows for it to be rescaled by the user to a different functional unit if required, e.g. per hectare.

To model using different functional units, multiple properties of the reference flow are provided in the inventories. For example, the main reference flow for crop cultivation is 1 kg of crop, but the dry matter and energy content are given as additional properties. The general principle used in Agri-footprint is that the reference flow varies depending on the source of the data. For crops at farm gate, the reference flow may be a hectare of production when the data source provides activity data per hectare per year to deliver an estimated yield. For livestock processes the reference flow may be annual production for a herd of 1,000 head of cattle. For post-farm processing, the reference flow may be 100 tonnes of input commodity, or a year of plant operation, etc.

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## Allocation

Many of the on farm and post-farm agricultural processes in AusAgLCI produce multiple co-products, residues and wastes, requiring consideration of how the inventory is assigned to these different categories of outputs.

Products / co-products are outputs from the process that have economic value. Some outputs typically considered residues were determined to be a co-product due to them having some value. Examples of this are rendering material from meat processing, straw from broadacre crops, and chicken manure / litter.

Residues and waste are defined and handled based on guidance provided in the LEAP Guidelines (FAO, 2016):

- Residues do not contribute revenue to the generator, they may be value-added in other separate processes, but do not impact the activities of the generating process. Residues do not receive any allocated impacts and are considered 'cut-off' from the process. An example is sugarcane trash
- Wastes incur a cost for treatment, management and disposal, the impacts of which are included in the inventory and assigned to the product / co-products. Examples are cattle and sheep manure, dairy cattle manure, pig manure, rice paddy straw, sugar mill mud / ash, cotton gin trash, wool processing residues and meat processing wastewater.

The definitions of co-products, residues and waste for each AusAgLCI product system can be found in the product-specific details in Appendix H.

For multiple products and co-products, LCI databases typically rely on allocation rules to attribute the impacts of a system to products and co-products. The AusLCI guidelines

(AusLCI Committee, 2014) recommends that where allocation cannot be avoided, it should reflect the underlying physical relationships between products and co-products. Table 4 summarises how the AusLCI guidelines have been applied in different situations.

The intent is for the AusAgLCI data to be agnostic of allocation, by providing parameters and allocation switches within the inventory to enable the user to apply an allocation approach that best suits their application. For example, the Australian Renewable Energy Agency (ARENA) guidelines for LCA of bioenergy require an energy-based allocation.

The LCI data includes parameters that allows allocation on the basis of mass, energy content, economic value, or protein content (in some cases). There is also enough information in the datasets to allow the user to apply consequential modelling to avoid allocation.

By default, the parameters in the allocation fields have been set to economic allocation, as in practice this is the most common approach in LCI databases.

**Table 4 Approaches to applying allocation in AusAgLCI.**

Situation	Approach	Comments
<b>Co-production of products with economic value</b>	Allocation – economic allocation by default, but parameters available to switch to an alternative basis of allocation (mass, energy, protein).	<p>Allocation is applied to on farm processes producing multiple products:</p> <ul style="list-style-type: none"> <li>- sheep meat and wool</li> <li>- beef prime cattle with weaners and culled breeders</li> <li>- dairy beef and milk</li> <li>- grains and straw</li> <li>- legume grains and fixed N.</li> </ul> <p>Allocation is also applied post-farm where primary processing generates multiple products and co-products:</p> <ul style="list-style-type: none"> <li>- raw sugar and molasses and surplus electricity</li> <li>- cotton lint and seed</li> <li>- almonds kernels and almond hulls and husks</li> <li>- canola meal and oil</li> <li>- rice grain and rice bran and husk</li> <li>- scoured wool and wool grease.</li> </ul>
<b>Mixed farming</b>	Sub-systems have been separated to model the impact of each crop independently.	When the inventory data is to be used to investigate the benefits of crop rotations and interaction with livestock, these interactions will need to be modelled separately.
<b>Fixed nitrogen (N) co-produced from legume crops</b>	Allocation - N fixed by the legume crops is assumed to be a co-product from the crop, with allocation applied accordingly.	The fixed N co-product can be an input to a production system aiming to utilise the residual fixed N, in which case some impacts of the legume crops will flow through to the follow-on crop.
<b>Fallow period within crop rotations</b>	Allocated across all crops in the rotation in which the fallow is included.	Where there is a fallow period in the cropping rotation, impacts are allocated to all crops in the rotation based on the fraction of time each crop typically occupies in the rotation.

# Activity data

Activity data refers to the quantities of inputs to and outputs from a unit process, including those related to land, energy, chemicals, materials, infrastructure (capital goods), transport and service etc. For many products, it was possible to derive much of the required activity data from Gross Margin publications prepared by State Government agricultural department or industry extension services.

Gross Margins are agricultural extension publications which inform growers of how to produce a particular agricultural product (both crops and livestock) in their region, with the purpose of quantifying the costs and profit margin for an agricultural activity. They are a suitable source of activity data because they include estimates for most inputs (cost centres) for a representative farming operation, they are reliable (prepared by knowledgeable extension advisers), the number available is growing and they are updated from time to time. Gross Margin documents can vary in format and some interpretation is required to convert the contained data into activity data for an inventory. An example is provided in Figure 10. Product-specific details of the gross margin sources of activity data can be found in Appendix H.

Used to find the agroecological zone and access to climate parameters

Used to calculate the quantity of active ingredient applied

Used to estimate the leaching/runoff of pesticides in accordance with climate influencing factors (rain, temperature...)

Used to derive the number of tractor operations

**DRYLAND GRAIN SORGHUM (No-fill)**  
**Farm Enterprise Budget Series (North-East NSW)**  
**Summer 2011-2012**

Operation	Month	Machinery		Inputs		Total		
		hrs /ha	\$/hour	Cost \$/ha	Total \$/ha	Rate/ha	Cost \$/ha	Total \$/ha
Herbicide - ground spray, glyphosate CT	Jan	0.05	54.60	2.73	1.5 L	4.42	6.63	9.36
Wetter - non-ionic surfactant	Jan	with above			0.2 L	6.45	1.29	1.29
Herbicide - paraquat + diquat	Jan	0.05	54.60	2.73	2.0 L	10.28	20.56	23.29
Herbicide - ground spray, glyphosate CT	Apr	0.05	54.60	2.73	1.5 L	4.42	5.30	8.03
Herbicide - 2,4-D i.p.a. 300 g/L	Apr	with above			0.8 L	4.20	3.30	3.30
Wetter - non-ionic surfactant	Apr	with above			0.2 L	6.45	1.29	1.29
Herbicide - ground spray, glyphosate CT	Jun	0.05	54.60	2.73	1.2 L	4.42	5.30	8.03
Wetter - non-ionic surfactant	Jun	with above			0.2 L	6.45	1.29	1.29
Herbicide - ground spray, glyphosate CT	Sep	0.05	54.60	2.73	1.2 L	4.42	5.30	8.03
Wetter - non-ionic surfactant	Sep	with above			0.2 L	6.45	1.29	1.29
Seed - thiamethoxam - Concep II treated	Oct	0.18	74.08	13.33	2.6 kg	12.38	32.19	45.52
Fertiliser - Granulock SuPreme Z	Oct	with above			10.0 kg	7.08	43.20	43.20
Fertiliser - Urea (bulk)	Oct	with above			150 kg	0.70	105.00	105.00
Herbicide - ground, PSPE	Oct	0.05	54.60	2.73				2.73
Herbicide - S-metolachlor+atrazine	Oct	with above			3.2 L	14.09	45.09	45.09
Herbicide - fluoxypyr 333g/L	Nov	0.05	54.60	2.73	0.3 L	28.10	8.43	11.16
Wetter - non-ionic surfactant	Nov	with above			0.1 L	6.45	0.65	0.65
Insecticide - ground spray (contract)	Jan			16.00				16.00
Nuclear polyhedrosis virus (NPV)	Jan	with above			0.375 L	48.33	18.12	18.12
Crop insurance *	Jan			4.21%				34.10
Desiccant - aerial spray, glyphosate CT	Feb/Mar			20.00	1.6 L	4.42	7.07	27.07
Wetter - non-ionic surfactant	Feb/Mar	with above			0.2 L	6.45	1.29	1.29
Harvest #	Mar/Apr	contract		86.20	per ha incl fuel			86.20
Grains Research Levy		1.020%	of farm gate value				8.26	8.26
GrainCorp Levy \$/t				\$1.50	per tonne			6.75

Figure 10 Example gross margin for deriving activity data.

# Inputs

This section describes how activity data was converted into the inputs, outputs and elementary flows in the inventories. Not all inputs relate to all processes, some are relevant only to crops and some are relevant only to livestock, as indicated. Parameterisation of the inventories means it is possible to see how the gross margin data was converted into inputs, outputs and elementary flows in the individual inventories. Therefore, more details of the calculations performed can be found within the inventories themselves.

## Land use

Land, as an input is relevant to all processes in AusAgLCI, is represented in the inventories as land occupied and land transformed.

Land occupied is the area of land used to produce the reference flow multiplied by the time occupied, as hectare annum (ha.a). For on farm agricultural processes the area of land for a reference flow of 1 tonne product is the inverse of the crop yield (t/ha). For post-farm industrial processes, the area of land occupied for the production plant and infrastructure is amortised over the production output for the life span of the plant.

For crop systems, the guidance of Koellner et al. (2013) is applied, which recommend including the full production cycle from the end of the previous crop to the end of the crop under study. For annual cropping systems, this is usually one year being allocated to the crop production. For sugarcane, which is a perennial crop, the inventories for the multiple plant and ratoon crops are annualised so that the inventory can be prepared as an annual crop. Where there is a fallow period as part of a crop rotation, the fallow period is allocated (shared) across all crops in the rotation.

Land transformation describes the original use of the land (land transformation from) and the new use of the land (land transformation to). Where no LUC has occurred, the values for both will be equivalent. Where LUC has occurred, the values will be different reflecting a net transformation of land. For all the products represented in AusAgLCI it is assumed that no LUC has occurred over the 20 years prior due to there currently being no agreed and verifiable source of data to draw on at the time of update. See discussion in the Carbon fluxes section from direct LUC section for further details. Note that the carbon flux consequences of land occupation and transformation are covered in the GHG emissions section.

For both land occupation and land transformation, the selection of land classification in the inventory is important to make the data globally applicable but also locally relevant. To be consistent with emerging impact assessment methods (see Environmental Impact Categories section) care was taken to select land use categories that are picked up by the GLAM methods.

## Water use

In line with the latest consensus method for water scarcity impact assessment the water uses accounted for in the LCI are those abstracted and no longer available to other local users because they have been evaporated, incorporated into a product or released into a different drainage basin or the sea. This includes:

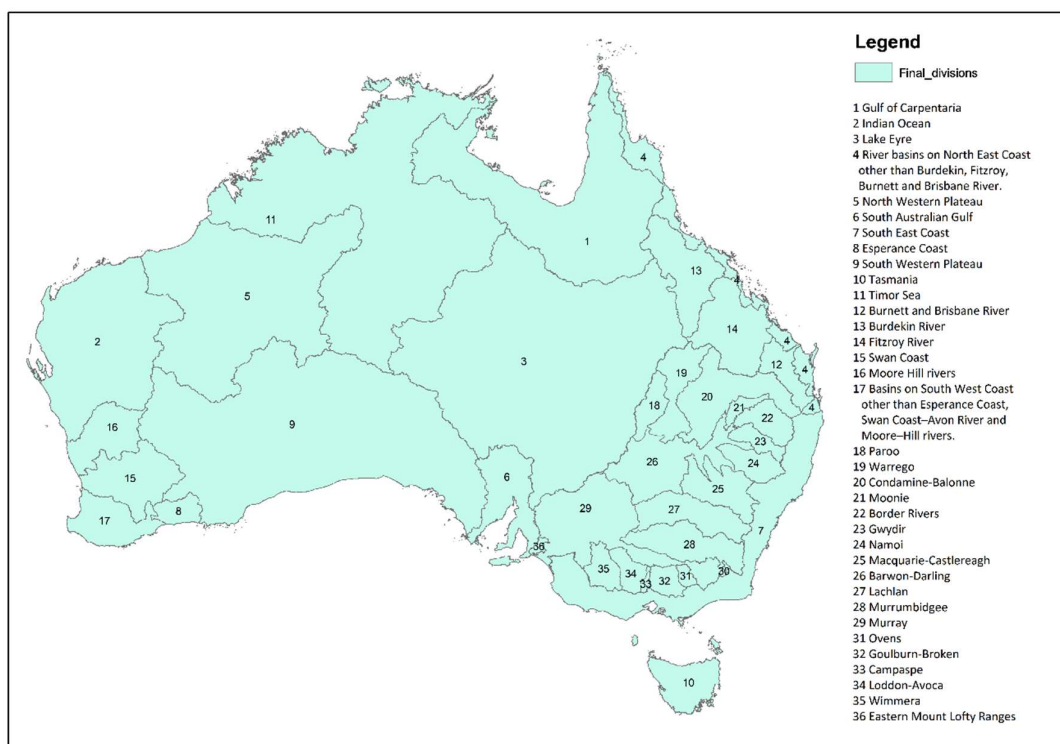
- water abstracted and irrigated onto crops / pastures, which is subsequently either incorporated into a product, evaporated or drains back to the original catchment.

- evaporative losses from farm dams holding water for the purpose of irrigation / stock watering.

## Irrigation water

Input of water for irrigation is relevant for on farm production of sugarcane, cotton and rice. A few broadacre grain and hay crops represented in AusAgLCI are irrigated, but the majority are dryland. Quantities of water were derived from the relevant gross margin documents, typically as ML/ha.

The sources of the irrigation water were defined using the catchment definitions for Australia, developed for AusLCI (Renouf et al., 2016) (see Figure 11). These are regional catchments derived from a mix of drainage divisions (of which there are 11) and aggregated sub-catchments (of which there are 11), to provide an appropriate level of resolution. The concordance of water catchments against production areas (AERs, livestock regions) is provided in Appendix A.



**Figure 11** Water catchment definitions developed for AusLCI (Renouf et al., 2016).

## Evaporative losses from farm dams

Evaporative losses from farm dams are relevant for extensive livestock processes of beef cattle, sheep and dairy production. It was estimated based on dam surface area and pan evaporation on grazing lands.

Annual farm dam evaporative loss is driven by the dam water surface area and the evaporation rate per unit area. The surface area of farm dam within grazing land was derived from the modelling of Malerba et al. (2021), which aligns with the latest NIR (Commonwealth of Australia, 2025a, b), and the area of grazing land (ABARES, 2016). Pan evaporation values were derived from Bureau of Meteorology (2024).

## Drinking water for livestock

Drinking water is relevant for extensive livestock processes of beef cattle, sheep and dairy production.

For beef cattle and sheep, it was estimated based the relationship defined by Sun et al. (2014):

$$W \text{ total intake} = \text{DMI} \times 1.445 \times \exp(0.055T) + \text{Milkprod}$$

Where:

- W total intake = total water intake by beef cattle and sheep
- DMI= dry matter intake (kg)
- T = mean ambient temperature (°C)
- Milkprod = 20% increase in water intake for lactating females (L).

DMI was estimated using the NIR equations for feed intake used for the estimation of enteric methane production. The increase in water requirements for lactating females was calculated based on the proportion of DMI consumed by that class of stock. For example, if 25% of the DMI for the herd/flock was consumed by lactating females, the adjustment made to overall water intake for the herd/flock was a factor of 1.05.

For dairy cows, water intake was based on estimates from industry publications (Agriculture Victoria, 2024).

## Seed

Seeding rates were derived from the relevant gross margin documents. Seed inputs are not itemised as an input flow in the inventory. Instead, seed requirements are subtracted from the yield, effectively accounting for the production of the seed (or seed cane in the case of sugarcane). For the crops currently represented in AusAgLCI, the impacts of seed processing are insignificant and do not justify the development of seed-specific inventories. For future updates of AusAgLCI, development of seed-specific inventories would be warranted for horticulture.

## Livestock feed and supplements

Inputs of livestock feed, such as dairy concentrate, grain, hay, and mineral supplements were derived from the relevant gross margin documents (see Activity Data Section). Where the type of feed supplement for sheep was not specified, the assumption was that the fodder comprised 50% hay and 50% wheat. Milk for rearing dairy calves is accounted for by subtracting the milk required from total milk production.

## Energy

### On farm machinery operations

The details of machinery operations or the fuel used for machinery operations (tractors, harvesters, haul out trucks etc.) were derived directly from the relevant gross margin documents. Depending on how the data is provided in the original source, the input of machinery operations or fuel use (assumed to be diesel) will be entered either as:

- supporting processes for the activity-specific tractor operations (ploughing, planting, mechanical weeding, liming, spraying etc.) reported as hectares (ha) of operation, which has the fuel use in the background, or

- supporting process for tractor operations reported as an aggregated amount of diesel fuel use (per litre of fuel combusted in tractors).

For broadacre grain crops, the degree of tillage is taken into account when estimating fuel use, by including parameters for the extent of minimal and zero tillage adopted. Cultivation practices are largely no or low-till for dryland grain cropping in Australia. The assumed rates of no or low-till adoption for broadacre cropping land in Australia, based on the Land Management and Farming in Australia Survey (Australian Bureau of Statistics, 2018), where zero cultivation (other than sowing) is considered no-till, one additional cultivation event is considered low-till, and multiple cultivation events are considered multi-till. A weighted average of the cultivation practice for each AER was based on the proportion of the AER in each Natural Resource Management Region (NRMR).

### **On farm irrigation**

Electricity and fuel (diesel) use on farm for irrigation is most relevant for of sugarcane, cotton and rice growing. Electricity is the most common source of energy for water pumping and assumed to be from the relevant state grid electricity.

The details of on farm irrigation requirements were derived directly from the relevant gross margin documents. Depending on how the data is provided in the original source, the inputs for irrigation are entered either as the relevant irrigation process for a particular pumping head (per ML applied) which calculates energy input in the background, or the known electricity or fuel input for the pumping.

For sugarcane, where irrigation water is supplied from irrigation schemes, the upstream electricity for pumping water from the scheme dam to the farm is also included, in addition to the on farm pumping. Electricity demand for scheme pumping was derived from the irrigation scheme's scope 2 emissions (electricity) reported to NGERs (Clean Energy Regulator, 2025). Energy for scheme water delivery has not been included for cotton and rice in this update.

### **On farm livestock production**

Electricity and fuel (diesel) use for beef cattle and sheep was calculated from economic data from farm gross margins and from average price per unit. Economic data were reported in farm surveys from ABARES for 2018-2022 (ABERS, 2025).

For dairy cows, electricity and fuel use was calculated from economic data reported in farm benchmarking (Agriculture Victoria, 2020, 2021, 2022, 2023, 2024).

### **Post-farm processing**

The information on energy use for post-farm primary processing was obtained from the relevant industry publication, and the type of energy use varies depending on the commodity. For grains, the energy for post-farm drying and ventilating was assumed to be from a combination of electricity from the relevant state grid and natural gas. For livestock (beef cattle, sheep, pigs and chickens), the energy for post-farm processes was assumed to be a combination of from the relevant state grid electricity and natural gas of biogas for boiler operations. For sugarcane, the energy for milling was on-site bagasse combustion which meets all the energy needs of the mill with no input of purchased energy. For cotton and rice, energy for ginning and milling was assumed to be electricity from the relevant state grid.

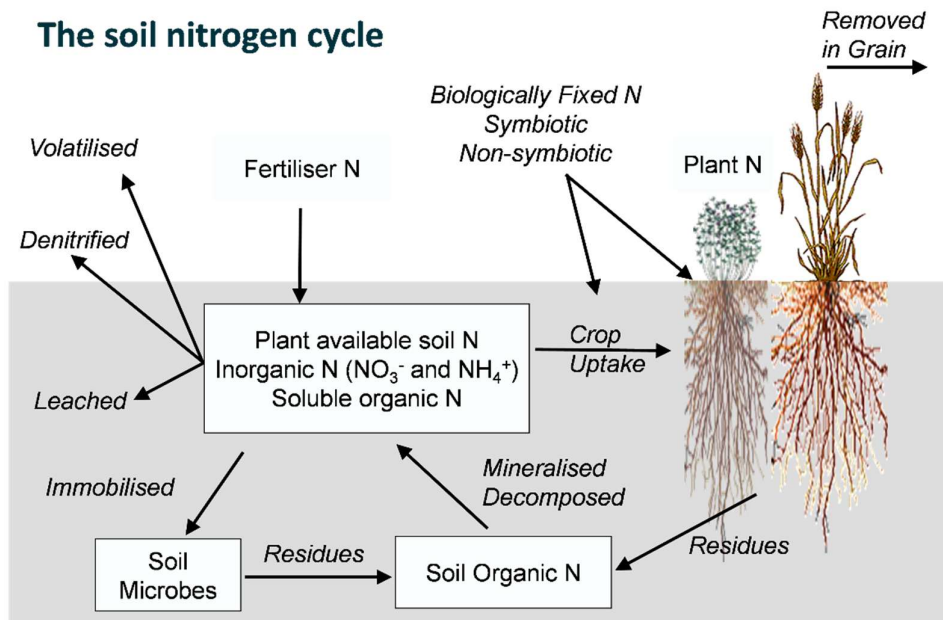
## Fertilisers

### Fertiliser application rates

The default approach for determining types and amounts of fertilisers applied is to draw on information contained in relevant gross margin documents, which represent estimates of typical application regimes and rates. This was the case for sugarcane, cotton and rice. It was a straightforward process to identify the fertiliser products or blends (brand name) and constituent fertiliser ingredients (urea, DAP, MAP, KCl etc.) and to convert the fertiliser product application rates into quantities of constituent fertiliser ingredients.

For broadacre grain and hay crops, a different approach was taken due to the extremely large number of individual inventories (per crop type and per region), which necessitates the automated and consistent derivation of application rates from first principles:

- The type of fertilisers applied for broadacre grains and hay crops was based on statistics for fertiliser use (Australian Bureau of Statistics, 2013). The dominant fertilisers used are urea and mono-ammonium phosphate (MAP) in eastern Australia (including South Australian and Tasmania), and urea ammonium nitrate (UAN) in Western Australia. The mix of fertiliser use in Eastern and Western Australia was calculated by first determining how much MAP was needed to deliver the P requirements, then the additional N required for the crop was assumed to be supplied from urea in eastern Australia and a 50:50 mix of urea and UAN in Western Australia.
- Phosphorus (P) requirements were based on average assumed replacement rate of 9.4 kg per ha for P removed in grain for dryland crops (Department of Agriculture and Fisheries Queensland Government, 2012).
- N requirements were estimated using a Nitrogen Balance Tool developed in the original AusAgLCI project based on equations in the Generic Yield and Nitrogen Calculator developed by (Baldock et al., 2009) (Figure 12). The equations used in the Nitrogen Balance Tool were adjusted so that they calculate the net N requirement to grow the harvested crop, considering lost N from leaching, volatilisation and denitrification. The estimated N requirements were then converted into quantities of N fertiliser application for the inventory. This approach enabled a consistent method, which generally aligns with regional N fertiliser application rates reported in gross margin documents.
- Unlike the original Generic Yield and Nitrogen Calculator, the AusAgLCI Nitrogen Balance Tool does not account for residual soil N at the beginning or end of the cropping cycle. It assumes that the residual N pools in the soil (from crop residues, mineralisation, and fixation by a prior legume crop) are stable and that all of the fertiliser N required ends up in the harvested product or is lost through leaching and volatilisation (i.e. N in the soil organic matter pools on farm are stable and the system is in a steady state).



**Figure 12 Crop nitrogen cycle (Baldock et al., 2019).**

For all crops, the heavy metal contents of fertilisers were accounted for, to the extent that data was available. It was possible to account for the cadmium (Cd), lead (Pb) and mercury (Hg) contents of urea, diammonium phosphate (DAP) and MAP, based on analysis of fertilisers used in Australia (VIC DPI, 2010). It was assumed that the fate of all of the heavy metal content was to agricultural soil.

### Nitrogen fixation by legume crops

For pulses produced from legume crops, the biological fixation of nitrogen (N) in soil was considered to be a co-product, with allocation applied accordingly. This was a change to how N fixation was previously modelled in earlier versions of AusAgLCl. Previously, the co-production of biological N was accounted for using system expansion, with a credit for avoided urea application being applied. In this update this was changed to allocation.

The amount of soil N produced, (i.e. the amount of N fixation in the soil and surplus to the legume crop's requirements) was estimated for each producing region using the biological N fixation model of Herridge et al. (2022), which corrects for the percentage of crop N that is derived from atmospheric nitrogen. The share of crop N demand met by soil N in each growing region is detailed in Table 5. It was found that on average 11% of N demand is met from biological N fixation, but this ranges regionally from 1% to 35%.

The soil N co-product can be an input to a production system (for example a cereal crop) modelled to utilise soil N, in which case some impacts of the legume crops will flow through to the follow-on crop. The changed approach to accounting for soil N is described in Figure 13.

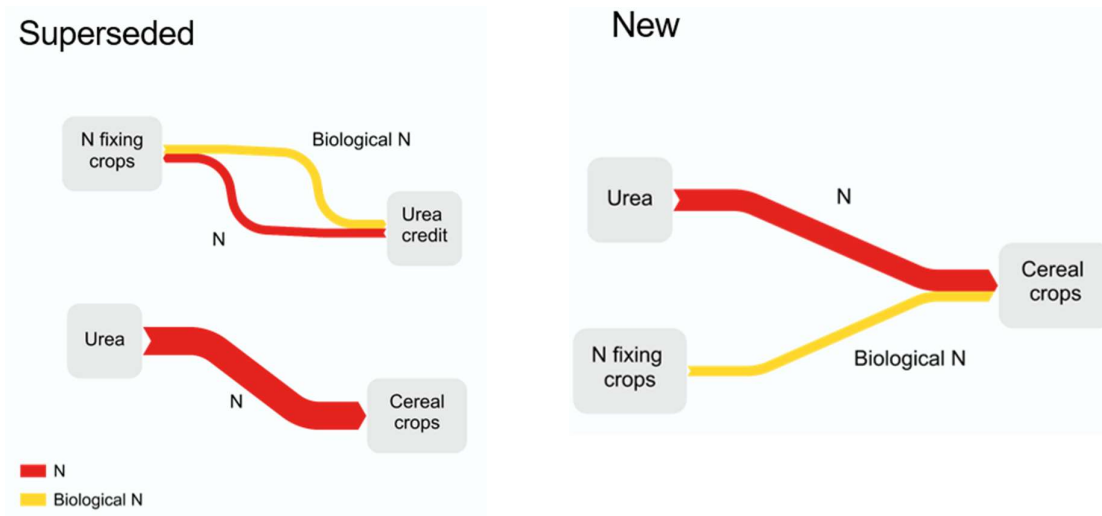


Figure 13 Approaches to modelling soil N fixed by legume crops.

Table 5 Average biological nitrogen (N) fixation (kg N/ha) from legume crops in specific regions and the estimated proportion of N demand of non-fixing crops supplied by soil N derived from fixation.

AER no.	AER name (short)	N fixed (kg N / ha)	% N demand met by fixation	
7	Central Plains	56	5%	
8	Riverina	65	19%	
9	SE VIC Coast	78	2%	
10	S Highland and Gippsland	66	1%	
13	Granite Belt	48	12%	
15	W Downs	41	17%	
16	Brisbane	55	7%	
17	Darling D	39	17%	
18	Burnett	43	53%	*Use 11%
19	WB Burnett	48	2%	
20	Dawson	38	32%	
21	C QLD Coast	37	1%	
22	C Highlands	32	57%	*Use 11%
23	Burdekin	44	0%	
36	W Wheatbelt	45	11%	
37	South West	56	5%	
39	Goldfields	23	2%	
40	Maranoa	29	10%	
41	Mallee	43	24%	
42	S Coast	60	20%	
45	Desserts	26	8%	
Aus Average		46	11%	

Note: \* These outlier values were replaced with Australian average value of 11%,

## **N mineralisation associated with SOC change**

For broadacre crops the relationship between SOC loss and N mineralisation can also be accounted for in the inventories. The mass of N applied is adjusted to account for N either made available or immobilised due to long term SOC changes. This adjustment allows fertiliser application rates to reflect the impact of SOC dynamics on N availability. SOC change is currently assumed to be zero, with the option for users to enable SOC change via a switch built into the dataset. When activated, the switch enables the direct GHG emissions from changes to mineralised N to be estimated. Although there is currently a high level of uncertainty in SOC change estimates, the update allows SOC-related dynamics to be appropriately handled as SOC change models continue to evolve.

## **Urea background processes**

The input of urea fertiliser to agricultural systems is an important source of GHG emissions, originating from both the production and use of urea. When urea is an input to an agricultural process the AusAgLCI inventories include the production of urea as input, which is linked to a background process for urea production. It is important to understand how the background processes account for the flow of carbon (C) and carbon dioxide (CO<sub>2</sub>) in the urea product life cycle to ensure that CO<sub>2</sub> emissions are properly accounted for when the AusAgLCI inventories are used.

The following describes how urea production processes are currently represented in both AusLCI and ecoinvent® inventories in terms of carbon and CO<sub>2</sub> flows:

- The first step in urea production is ammonia production, in which natural gas is converted into ammonia. In this process the fossil C in the natural gas is converted to CO<sub>2</sub>, which is assumed to be released to air. Therefore, in the LCI of ammonia, there is an emission of fossil CO<sub>2</sub>.
- The second step is urea production combines ammonia with carbon dioxide (CO<sub>2</sub>) gas. The input of CO<sub>2</sub>, effectively removes CO<sub>2</sub> from the atmosphere (a negative emission). Hence the LCI of urea will have an uptake of CO<sub>2</sub>, countering the fossil CO<sub>2</sub> emission that occurred in the background ammonia production. The original fossil C contained in the natural gas when the ammonia was made is effectively held in the resulting urea.
- When the urea is applied in the field, urea hydrolysis occurs, releasing the C contained in the urea as CO<sub>2</sub>. Therefore, the LCI of the agricultural process will have an emission of fossil CO<sub>2</sub>, since the fossil C first emitted in the ammonia process and effectively re-captured in the urea process, needs to be accounted for as a re-release of fossil C.
- This approach is consistent with how C flows are accounted for in national inventories.
- The processes for producing ammonia and urea are kept independent so that the LCI for ammonia can be used in applications other than urea production.
- 

Therefore, when current urea LCI data from AusLCI or ecoinvent® databases are used, inventories for on-farm processes that apply urea in the field need to include an emission of fossil CO<sub>2</sub> needs to be included when urea is an input.

In the past, background processes for urea production accounted for both the uptake and the subsequent on farm release within the urea production process, and emissions of fossil CO<sub>2</sub> from urea hydrolysis on application did not need to be included in on-farm processes.

However, due to changes in the background processes for urea since then, the ultimate release of fossil CO<sub>2</sub> needs to be accounted for in the field.

## Lime

The application of lime, and in some cases other soil ameliorants (gypsum, dolomite) is relevant to the crop processes, and the approach taken was different for the different crops.

For sugarcane, cotton and rice, details of lime application and other ameliorants (amounts and types) was available in the relevant gross margin documents. Therefore, it was based on industry estimates of actual use.

For broadacre grain and hay crops, lime application was based on the amount of lime required to counteract the acidification of the surface soil layer. This is equivalent to the amount of lime required to offset Net Annual Acidification Rate (NAAR), also referred to as the maintenance lime requirement (Slattery et al., 2009, Baldock et al., 2019). See the Soil Acidity section for further details.

The updated NAAR-based method assumes that, regardless of current liming practices, ongoing acidification will eventually require remediation. It is attributed to the crops contributing to the acidification over the time period between applications. This approach differs to previous versions, where fixed industry estimates of lime application rates were used. The fixed value may slightly over, or underestimate the actual lime required to address acidification occurring within the modelled system. The responsibility for this burden is attributed to the crops contributing to the acidification today.

Lime requirement for broadacre crops were calculated as follows:

$$\text{Total lime requirement (kg CaCO}_3\text{ / ha)} = \text{NAAR} / (\text{Lime AF} / \text{Lime purity}).$$

Where:

- NAAR (kMol/kg N) for fertilisers applied (Table 6)
  - o The NAAR values take into account of the fraction of N being leached and H<sup>+</sup> added due to removal of crops. Leaching fraction is based on the regional FracWet (Appendix B) and FracNLeach value of 0.24 (Commonwealth of Australia, 2025a, b).
- Lime Acid Factor (AF), which is -0.02 kMol/ kg lime (Commonwealth of Australia, 2025a, b).
- Lime purity, which is 0.9 (Commonwealth of Australia, 2025a, b).

**Table 6 The AF of fertilisers applied in kMol/ kg N as per (Harding and Masters, 2016).**

	<b>0% leaching</b>	<b>100% leaching</b>
<b>MAP</b>	<b>0.036</b>	<b>0.072</b>
<b>Urea</b>	<b>0</b>	<b>0.036</b>
<b>UAN</b>	<b>0</b>	<b>0.036</b>

## Pesticides

Pesticide application is relevant to the crop and livestock processes.

For all crop processes, the amounts and types of pesticides applied were derived directly from details in the relevant gross margin documents. Each commercial pesticide/crop protection product was matched to its active ingredient(s) and active ingredient concentration using product fact sheets and pesticide repositories. This enabled conversion of pesticide application rates (typically reported as the commercial product) into quantities of active ingredients applied. Where background processes could be found for the specific active ingredient, these were used, otherwise a generic pesticide inventory was substituted, but with the active ingredient specified. The full list of pesticides can be found in Appendix E.

For livestock processes internal and external parasite treatments are included in the inventory for beef cattle, sheep and dairy cows. For each livestock species, a suite of pesticides was selected that reflects current usage of different drug families (Love and Hutchinson, 2007, Love, 2011, Joshua and Turnbull, 2012). The use of different active ingredients is common in the industry to avoid drug resistance in the parasites. Pesticides inputs were modelled as an overall amount, with each treatment event assumed to use the available drugs in equal proportion. While this does not reflect practice (in that only one drug is given at any one time), it allows the full spectrum of drugs to be modelled in the absence of good data on drug rotations. Frequency of both pesticide and vaccine treatment for cattle is based on the gross margin data (see Activity Data Section). Based on this information, vaccines were simplified to one annual vaccine for cows mated and one vaccine for calves weaned across all regions. Pesticide treatments ranged from 0-2 per year for weaners and cows mated, the frequency depending on the severity of parasite challenge. Dairy cows were assumed to receive two internal parasite treatment per year and young cattle received three. Where background processes could be found for the specific active ingredient, these were used, otherwise a generic pesticide inventory was substituted, but with the active ingredient noted. Vaccines are modelled using an unspecific organic chemical process as a proxy.

## Infrastructure and capital goods

For on farm processes, farm machinery (tractors, harvesters, implements) and irrigation infrastructure (piping, pumps) were included. Other infrastructure and capital goods, such as farm buildings, fences, roads, were noted included being insignificant (<1% of impacts).

For post-farm processes, infrastructure items determined to be significant were included. For example, storage silos for grain storage and drying.

### **Farm machinery**

Farm machinery infrastructure is relevant to all on farm crop and livestock processes.

Depending on how the data is provided in the original source, the production of farm machinery capital goods is accounted for either as:

- Supporting processes for the Australian tractor operations (ploughing, planting, liming, spraying etc.) reported as hectares (ha) of operation, which has the production and maintenance of machinery in the background, or
- Background process for global market production of tractors and agricultural machinery, reported as kg of machinery, which includes production and maintenance of tractors amortised over the production output for the life span of the machinery.

## **Irrigation infrastructure**

Infrastructure for irrigation systems is relevant for on farm production of sugarcane, cotton and rice. A few broadacre grain and hay crops represented in AusAgLCI are irrigated, but the majority are dryland.

The production of irrigation system infrastructure is included in the supporting processes for the specific type of system (flood, travelling gun, centre pivot etc.) reported as hectares (ha) of infrastructure, which has the production of irrigation infrastructure in the background.

## **Emissions**

This section describes how activity data was converted into the elementary emissions to the environment in the inventories. Some emissions are relevant only to crops and some are relevant only to livestock, as indicated. Parameterisation of the inventories means it is possible to see how the emissions were estimated in the individual inventories, making it possible to find more details within the inventories themselves.

### **Greenhouse gas (GHG) emissions**

Australia has undertaken a large body of research on agricultural GHG emissions from cropping land and livestock systems and employs Tier 2 methods in the latest version of the NIR (Commonwealth of Australia, 2025a, b), for the estimation of emissions from the use of synthetic fertiliser, decomposition of crop residues, burning of crop residues, indirect N<sub>2</sub>O emissions from leaching and volatilisation, and enteric methane and methane from manure management. Method descriptions are published by the Australian Government's Department of Climate Change Energy Environment and Water (DCCEEW) in the NIR, which are accepted as a Tier 2 accounting method for Kyoto Protocol and United Nations Framework Convention on Climate Change (UNFCCC) GHG reporting.

The estimation of on farm GHG emissions in AusAgLCI were based on the Tier 2 methods employed in the latest version of the NIR (Commonwealth of Australia, 2025a, b). The NIR calculation equations and factors applied are not reproduced in this report. Instead, the reader is referred to the NIR reports, and details of the calculations are transparent in the parameterised inventories themselves. Only aspects that diverge from the NIR approach or that require use of a specific data source are discussed in the sections that follow.

EFs used in the NIR methods may not necessarily reflect the best available science. AusAgLCI adopts the current published NIR factors even where factors based on best available science have been published and accepted. This is to allow for GHG emissions estimated from AusAgLCI to not be inconsistent with NIR estimates, which are used in may reporting applications. AusAgLCI is updated annually to reflect updated NIR factors.

### **Nitrous oxide (N<sub>2</sub>O) emissions**

Estimation of direct nitrous oxide (N<sub>2</sub>O) emissions using the NIR methods is based on the amount of N applied (in applied fertilisers and in residues) and N<sub>2</sub>O emission factors (EF).

The estimation of indirect N<sub>2</sub>O emissions from N leaching and run-off required additional data for land areas subject to leaching, i.e. in <600 mm/year rainfall zone. This climate data was sourced from the Australian BOM Climate Data Services (<http://www.bom.gov.au/climate/data-services>).

## Enteric methane (CH<sub>4</sub>) emissions

For livestock, the Greenhouse Accounting Framework (GAF) tools for beef, sheep and dairy (Eckard, 2012b, c, a) were used to estimate GHG emissions. The GAF Tools apply the NIR equations to calculate livestock emissions for a given herd size and structure, animal growth rate and reproduction rate. They were populated with activity data on livestock numbers, live weight, live weight gain and proportion of females lactating to estimate total GHG emissions for each livestock region from cattle and sheep as detailed in the section above on herd and flock structure.

## Methane emissions (CH<sub>4</sub>) from farm dams

Annual methane emissions from farm dams (kg CH<sub>4</sub> / year) were estimated using the same approach as used in the NIR (Commonwealth of Australia, 2025a, 2025b), which employs a temperature dependant approach described by (Malerba et al., 2024; Malerba et al., 2022). Farm dam emissions were assigned to inventories based on the density of farm dam surface area (Malerba et al., 2021).

The NIR approach recognises that farm dams on non-grazing land emit significantly less methane than those on grazing land, likely due to lower manure input. Therefore, total methane emissions are separated into a “manure component” (60% of total) and a “base component” (40% of total). Emissions from manure are reported elsewhere in the inventory, so only the base component is reported as methane emissions from farm dams.

The Boltzmann-Arrhenius equation adapted by Malerba et al. (2022) and used to estimate methane emissions in the inventories is:

$$\text{Base EF}_t = 0.4 \times (\exp(\ln \text{EF}_{15} + (E_m \times (1/kBT_{15} - 1/kBT)))$$

Where:

Base EF<sub>t</sub> = base methane emission factor at temperature T (in Kelvin), in t CH<sub>4</sub> ha<sup>-1</sup> yr<sup>-1</sup>

EF<sub>15</sub> = baseline emission factor at 15°C

T<sub>15</sub> = 288.15 Kelvin

E<sub>m</sub> = temperature sensitivity coefficient (0.43)

kB = Boltzmann constant (8.617 × 10<sup>-5</sup> eV/K)

T = temperature in Kelvin

The average temperatures in each AER were calculated from the monthly minimum and maximum values that occur on grazing land over a 30-year period (1993-2023). Dam surface area was calculated from ausdams.org filtered for dams occurring on grazing land using ABERs land use classification.

## Burning of agricultural residues (CH<sub>4</sub>, N<sub>2</sub>O)

Emissions to air from the burning of agricultural residues were included in the inventories for sugarcane growing in the Burdekin region, the only Queensland region where pre-harvest burning of sugarcane occurs. The emissions were calculated using the NIR methods and factors, which are based on the fraction of the cane crop that is residue, the fraction of residue burnt, the dry matter, carbon and nitrogen contents of cane residues, a burning

efficiency factor and emission factors for each of the combustion gases of interest (CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub> and NMVOC).

## Carbon fluxes (CO<sub>2</sub> emissions / removals)

### Soil organic carbon (SOC) change

Carbon fluxes due to changes in SOC were included as an elementary flow of CO<sub>2</sub> in all the on farm inventories. However, whether a value has been entered depended on the availability of data for the commodity and confidence in the available data. Clear and consistent consensus methods for estimating SOC change were not available across all agricultural commodities at the time of writing, and so the approach varied between commodities.

For broadacre grain crops, APSIM modelling (Agricultural Production Systems Simulator) had been conducted previously (Luo et al., 2019) to estimate SOC changes and the resulting CO<sub>2</sub> emissions for the crops, under assumed crop rotations (see Appendix D). The simulated CO<sub>2</sub> emissions have been included as an elementary flow in the inventory but have been 'switched off' (via an on/off parameter switch). This was due to uncertainty in the value being adequately representative of most situations. Users of the inventory data can elect to 'switch' the flow on if it is considered representative of their assessment context.

For some commodities, there was evidence to suggest that SOC has been relatively stable with CO<sub>2</sub> from SOC recorded to be zero. This was the case for sugarcane, rice, pigs, chickens.

For the remaining commodities (beef, sheep, dairy, cotton), there was no available data or information to draw on and hence CO<sub>2</sub> from SOC was also recorded to be zero.

### Direct land use change (dLUC)

There is considerable interest globally in the climate change impacts from dLUC, due to carbon fluxes and associated releases or removals of carbon dioxide (CO<sub>2</sub>). In the previous version of AusAgLCI, available estimates of dLUC emissions for inclusion in the inventory were investigated. At that time, a method developed by (Blonk Consultants, 2017) (the Blonk Tool) was available, and dLUC emission estimates derived from it were included in the inventory, but 'switched off' due to them not being fully verified as appropriate. The Blonk Tool draws on estimates of LUC that has occurred over a 20-year period within national borders, which is then allocated to specific crops-based on the expansion or contraction of area planted for that crop. Since then, work was undertaken to better adapt the Blonk Tool to the Australian context (Bontinck et al., 2020). This adapted data was considered for inclusion in the updated AusAgLCI dataset, but would have required further updating to be current.

In the meantime, a new estimation approach has evolved, referred to as Orbae, developed by AdAdstra Sustainability. The ecoinvent® international database proposes to adopt Orbae for dLUC estimation (pers. comm with ecoinvent® personnel, May 2025). Given that compliance with, and submission to, the ecoinvent® database was identified as an important data pathway for AusAgLCI data, adoption of Orbae in AusAgLCI would seem the best approach.

The Orbae method employs satellite imagery and spatial data to identify land conversion over the past 20 years based on Intergovernmental Panel on Climate Change (IPCC) land classifications and the land conversion definition from the draft Greenhouse Gas Protocol Land Sector and Removals Guidance (WBCSD, 2022). From this, carbon fluxes are modelled, including carbon stock losses from biomass loss, loss of SOC and peat oxidation.

Carbon fluxes (emissions or removals) are then assigned to specific crops-based on observed changes in vegetation cover from the satellite imagery.

Subsequent consultations with Orbae representatives found that there is insufficient transparency in the Orbae modelling to adequately sense-check the estimates for Australia. While Orbae includes dLUC emission estimates for barley, beef, cocoa, coffee, corn, cotton, palm, peanuts, canola, soy, sugarcane and wheat in its database, values in the Australian context, are only available for canola, wheat, barley and cotton, leaving significant data gaps for the full range of commodities now represented in AusAgLCI. Therefore, the project team were not confident of the rigour of the Orbae model at present to include its dLUC emission estimates in the AusAgLCI update.

Line items for CO<sub>2</sub> emissions / removals due to dLUC have been included in the LCI data for all relevant products. However, the value is set to zero due to there being no clear, verifiable source of data at the time of update. Once Orbae estimates are verified for Australia, dLUC emission values can be added. It is anticipated that this could occur when the AusAgLCI inventories are submitted to the ecoinvent® international database in 2026. Using the existing Blonk Tool values, adapted by (Bontinck et al., 2020), in the interim was not considered feasible due to do resources required to update the adapted values.

### **Indirect land use change (iLUC)**

iLUC is a change in the use or management of land as a consequence of dLUC, but which occurs outside the product system being assessed (International Organization for Standardization, 2013). Due to a lack of consensus on methods for evaluation of indirect effects and uncertainties in modelling and attribution, quantitative assessment of GHG effects of iLUC is subject to significant uncertainty and with no clear agreement on calculation methods. For these reasons iLUC impacts are not included in the inventory at this point.

### **Biogenic carbon flows**

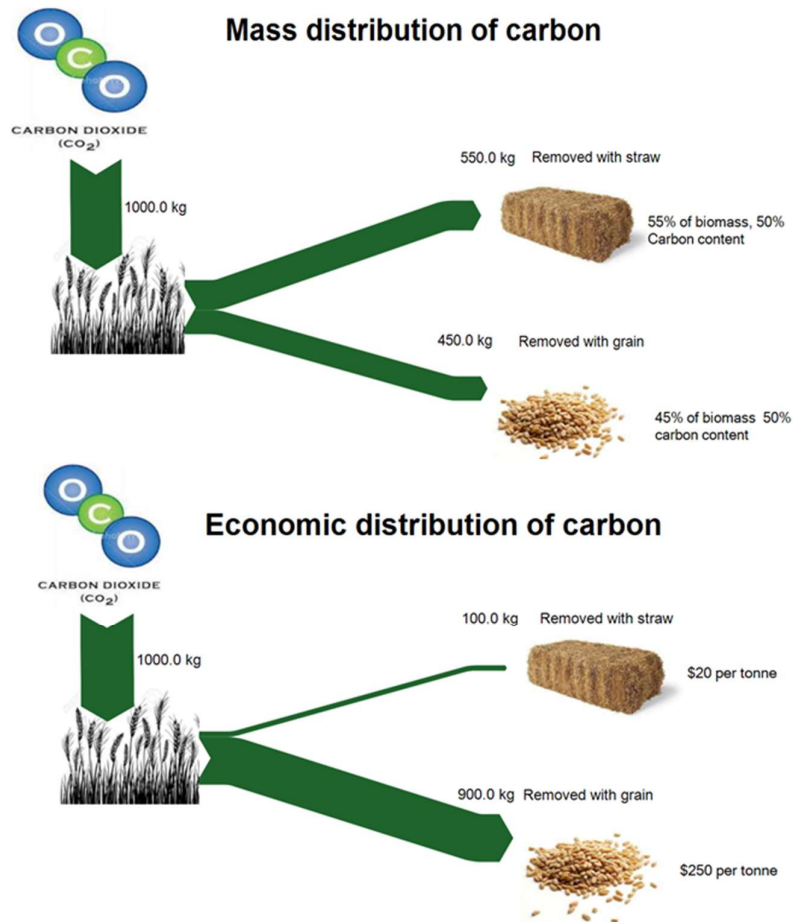
Biogenic carbon is carbon that originates from vegetation, animals and other organisms. Increasingly, reporting schemes are requiring separate itemisation of biogenic carbon flows, (such GHG protocol, the ISO 14067 standard for carbon foot printing and climate related financial disclosures). To meet the requirements a concerted effort was made to account for all biogenic carbon flows in AusAgLCI, and to enable (as far as possible) a carbon balance over a product's life cycle.

For the gate-to-gate on farm agricultural and post-farm processing inventories, this includes:

- input of CO<sub>2</sub> from air for the growth of plant / animal biomass
- emissions of CO<sub>2</sub> (biogenic) to air from any degradation or burning of biomass (e.g. crop residues)
- emissions of methane (CH<sub>4</sub>) from enteric fermentation or manure management, recorded as 'methane, biogenic'.

Where there are multiple products and co-products produced from a system (e.g. wool and meat from sheep), the adoption of allocation approaches other than mass allocation is problematic for accurately achieving a mass balance for biogenic carbon. When impacts are assigned based on economic or energy allocation, the mass balance of the co-producing model (including the biogenic carbon content) no longer reflects the actual physical flows.

To ensure that biogenic carbon flows are accurately tracked throughout the inventories a biogenic carbon correction factor was introduced, as described in Figure 14. This correction is applied after the initial co-product allocation to restore the accurate carbon mass flow in the model. The carbon correction to the determining product is applied in the main process, and the carbon correction for the other co-products is applied in a separate co-product process.



**Figure 14 Process for correcting carbon balance after co-product allocation.**

Carbon storage is not included as this carbon is part of the short-term carbon cycle. However, the carbon content of material inputs and all outputs are recorded as parameters to enable a carbon balance to be checked.

## Pesticides

For pesticides applied to crops, the flows of pesticide active ingredients to the environment were estimated by multiplying the amount of active ingredient by the fraction released to each compartment.

The estimation of pesticide AI losses from cropping to the environment is highly dependent of local site factors, timing and method of application. The best practice approach for estimating losses is to use the PestLCI model (Dijkman et al., 2012), which simulates those conditions to predict the fractions of applied pesticide AIs that are emitted to various compartments of the environment (air, soil, water).

As part of the original development of the AusAgLCI data, crop archetypes were modelled using the PestLCI consensus-based model (Dijkman et al., 2012) based on Australian conditions to generate a set of typical partitioning fractions, i.e. the fraction of applied AI assumed to end up in each of the environmental compartments (Grant et al., 2014). These partitioning fractions were applied in the updated cropping inventories.

Furthermore, based on the recommendation of Fantke et al. (2016), only the instantaneous (primary) partitioning of AIs between air, agriculture soil and drift off farm be accounted for, and off farm drift should also be further partitioned between soil and freshwater depending on the land cover type expected to be adjacent to the farm. Off farm drift is further partitioned between freshwater, natural land and agriculture land using an analysis of cropland boundary land cover in Australia. (Latham et al., 2014) (see Table 7).

The PestLCI model was run for typical crop archetypes (crop architecture, climate conditions, application methods, timing of application) to generate partitioning factors that were used in the inventories (see Appendix E).

**Table 7 Pesticide active ingredient (AI) partitioning fractions.**

Partitioning fraction	Estimation approach
Fraction of AI deposited on soil on the field of application	Default value calculated with PestLCI 2.0 (Dijkman et al., 2012) based on primary partitioning.
Fraction of AI released into air assumed to then be emitted to soil off farm	Default value calculated with PestLCI 2.0 (Dijkman et al., 2012) based on primary partitioning.
Fraction of AI deposited on crop	Default value calculated with PestLCI 2.0 (Dijkman et al., 2012) based on primary partitioning.
Fraction of AI released into surface water	Default value calculated with PestLCI 2.0 (Dijkman et al., 2012).
Fraction of AI deposited into surface water	Default value calculated with PestLCI 2.0 (Dijkman et al., 2012) and multiplied by % of land next to the field that is fresh waste for the region - source: based on Global Land Cover GIS layer (Latham et al., 2014).
Fraction of AI deposited into natural land offsite	Default value calculated with PestLCI 2.0 (Dijkman et al., 2012) and multiplied by % of land next to the field that is natural land for the region – based on Global Land Cover GIS layer (Latham et al., 2014).
Fraction of AI deposited into agricultural land offsite	Default value calculated with PestLCI 2.0 (Dijkman et al., 2012) and multiplied by % of land next to the field that is agricultural land for the region - based on Global Land Cover GIS layer (Latham et al., 2014).

For pesticides administered to livestock, there is evidence that veterinary pesticides pass through animals largely untransformed, killing the parasites enroute, and are excreted by the animals in faeces and urine (Boxall and Long, 2005, Strong, 1993, FAO, 2004). Treatment of sheep for external parasites with backline and jetting products results in small quantities (approximately 5 mg/kg greasy wool) of pesticide residues in wool (Savage, 1998) that is subsequently exported from the farm. Hence, all the AI in the pesticides administered to sheep (less the amount exported in wool) is treated as an emission to soil. Vaccines are modelled with no resulting emissions to the environment.

## Nitrogen losses

Emissions of N compounds from agricultural systems to water (nitrate - NO<sub>3</sub><sup>-</sup>) were estimated using the methods of the NIR (Commonwealth of Australia, 2025a, b). These are based on the amount of fertiliser applied, the N content of the fertilisers, spatial land classification data (ABARES, 2016) to determine fractions of N that are prone to leaching and run-off, and NIR fractions assumed to be lost.

Emissions of ammonia (NH<sub>3</sub>) and nitrogen oxide (NO<sub>x</sub>) to air were also modelled in line with the NIR methodology and EF (Commonwealth of Australia, 2025a, b), and assigned to the low population sub-compartment, as they occur in rural agricultural regions.

## Phosphorus losses

Losses of P compounds to water via leaching and run-off include both soluble orthophosphates and particulate phosphorous adsorbed to sediment and lost via soil erosion.

Losses of soluble orthophosphates are estimated using the method developed for the ecoinvent® database (Nemecek and Schnetzer, 2011), which uses average P loss factors based on the type of land use (arable land, intensive or extensive permanent pastures).

Losses of particulate phosphorous is based on the estimated sediments losses (described in the next section) and the P-content of eroded soil. The P-content of soil was calculated for 0-10 cm soil layer based on data from the Soil and Landscape Grid of Australia (Terrestrial Ecosystem Research Network, 2016) and the intersection with the 2010 land use layer (ABARES, 2016) for the land class corresponding to each agricultural sector. The 0-10 cm layer was created by taking a weighted average of the two published layers for 0-5 cm and 5-15 cm.

## Soil (sediment) losses

Estimates of soil (sediment) erosion are used to calculate P losses transported by soil erosion for eutrophication impacts.

The Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991) was identified as appropriate method for estimates soil losses to water via erosion (Vidal Legaz et al., 2016), since it is open and available for use, can be applied at the appropriate geo-spatial scale, and also enables uncertainty estimates to be generated.

Inventory in AusAgLCI are parametrised to implement RUSLE based on Geographic Information System (GIS) data for each component of the equation (Teng et al., 2016), and enables changes in sediment loss due to management interventions to be observed:

- adjustments to slope length and steepness through actions such as contour banks
- soil cover management such as cover crops and stubble retention
- soil erosion control practices such as contour ploughing.

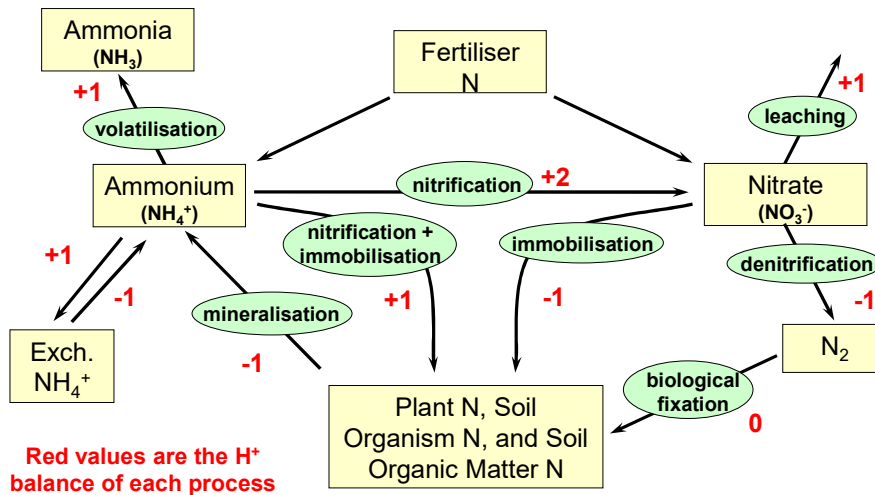
## Soil acidity

Soil acidification is a natural process accelerated by agriculture. Soil acidifies because the concentration of hydrogen ions in the soil increases when nitrogen fertilisers (mainly ammonia-based fertilisers) are applied, combined with the export of alkalinity in produce. Figure 15 shows the flows of H<sup>+</sup> leading to net acid addition from nitrogen inputs into agricultural systems. Ammonia is readily converted to nitrate with a loss of hydrogen ions to the soil. If nitrate is not taken up by plants, it can leach away from the root zone leaving behind hydrogen ions thereby increasing soil acidity. In addition, most plant material is slightly alkaline and removal by grazing or harvest leaves residual hydrogen ions in the soil. Over time, as this process is repeated, the soil becomes acidic, but this trend can be ameliorated by the application of soil conditioners such as lime.

The approach taken to estimate change in soil acidity is based on the underlying chemistry leading to a net acid addition. The NAAR can be expressed as cation flow into and out of the technosphere. Hydrogen ions accumulate with the addition of N fertiliser to the soil, the

acidifying effect being dependent on the type of N fertiliser (greater for ammonium-based fertilisers) and the amount of nitrate leached out of the root zone. This is countered by the addition of soil conditioners such as lime. The ash alkalinity of exported products also increases acidity. These chemical relationships have been modelled in AusAgLCI data based on inputs of fertiliser and outputs of crop product to estimate the hydrogen ion flow. The elementary flow included in the inventory is hydrogen ions emitted to soil.

The acidifying rate for fertilisers is based on the type of fertiliser and the level of leaching of nitrate in the soil profile (Baldock et al., 2019). When leaching occurs the fraction of N leached is assumed to 30%, consistent with the NIR method for indirect N<sub>2</sub>O loss from leaching. The areas where leaching is likely to occur were identified by comparing the annual precipitation with the sum of evapotranspiration and soil water holding capacity. ( $\Sigma(\text{rain}) > \Sigma(\text{ET0}) + \text{soil water holding capacity}$ ) (Commonwealth of Australia, 2025a, b). The proportion of a cropping or grazing region where leaching occurs was determined using spatial layers provided by DCCEEW in line with the NIR 2023 methodology (Commonwealth of Australia, 2025a, b), and land use data (ABARES, 2016).



**Figure 15 Production and consumption of acidity associated with transformations of soil N (Baldock et al., 2019).**

NAAR is responsive to management interventions and the type of investigations that the NAAR method enables are:

- The relative acidifying effect of different N sources.
- The impact of product removal on NAAR.
- The effect of soil conditioners such as lime on NAAR.
- The presence or absence of leaching on NAAR.

The NAAR method has been implemented for all crop types grown in each AER and for grazing systems producing beef, sheep and dairy products in each livestock region.

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# Data quality and uncertainty

## Data quality measures

The following data quality measures were taken as part of the data development process:

- Data was drawn from official statistics, and reputable industry reports.
- Industry review of data sources and key assumption about the product systems by industry technical experts, details of which can be found in the Product-Specific Method Details in Appendix H.
- Consistent data development processes were employed across the datasets, where appropriate, to enable robust methods are duplicated and to easily detect anomalies.
- Mass balance checks were undertaken for key flows along the product life cycles (carbon and nitrogen) to test for omission and double counting errors.
- Results generated from the updated AusAgLCI dataset were sense-checked by comparing with results generated from the following, details of which can be found in the Product-Specific Method Details in Appendix H.
  - o the earlier version of AusAgLCI,
  - o comparable LCI data in other databases, and
  - o other published LCA results.
- External peer-review of data development methods (see next section).

## External peer-review

This data development methods, as described in this Method Report, were reviewed by external reviewers with LCA expertise. The criteria for review were based on the LCI analysis components of the international standard for LCA, ISO14044 (International Organization for Standardization, 2019b). Reviews were conducted by agriculture LCA researchers from AgResearch New Zealand, CSIRO and NSW Department of Primary Industries. The reviewers identified areas requiring improvement or greater clarification, which were addressed.

## Data quality ratings

The AusAgLCI datasets contain data quality indicators, which can be used for propagating uncertainty estimates when used in LCA software. These are based on the 'pedigree matrix' in the ecoinvent® data quality guidelines version 3 (Weidema et al., 2023). This is a best practice approach for representing data quality and prepares the dataset for later submission to the ecoinvent® database. The uncertainty parameters combine a basic uncertainty (specific to the type of input or flow) along with a five data quality pedigree scores that rates the reliability, completeness and temporal, geographic and technology correlation of the input, output or elementary flow.

Some reporting schemes have slightly compliance requirements for representing data quality, for example:

- The Greenhouse Gas (GHG) Protocol suggests data quality scoring system that is based on and consistent with the ecoinvent® guidance. Therefore, the AusAgLCI data quality scoring will be consistent for GHG Protocol applications.
- The European Union's PEF method requires uncertainty parameters generated from a seven data quality pedigree scores. The aspect that influences the ability of the AusAgLCI data to be compliant with this is capacity of the LCA software, in which the LCI data will be used, to process seven data pedigree items rather than five. Since SimaPro LCA software was used to build the inventory, it was not possible to be compatible with the seven pedigree scores required by PEF at this stage.

Due to the AusAgLCI dataset being parameterised, the data quality scores are entered with the parameter fields rather than the input/output fields. When AusAgLCI is submitted to the ecoinvent® database, parameterisation will be removed (due to ecoinvent® not allowing parameterisation) and the uncertainty scores attached to them will also be lost. The dataset has been set up in a way that will retain the data quality scores in the meta information.

## Uncertainty

The aspects of the AusAgLCI data with the greatest uncertainty are the estimations of carbon fluxes (CO<sub>2</sub> emissions or removals) from SOC changes and dLUC. These are either not included or included but 'switched off' in the LCI datasets due to lack of data or high uncertainty in the available data. The implications of this are that climate change impact results generated from the data may not represent the complete impacts due to the omission. They could under- or over-represent the impacts depending on whether CO<sub>2</sub> emissions or removals are occurring due to SOC change or LUC. Users need to be aware of the omission and check if this conforms with their required use of the results. Users are also encouraged to source relevant estimates of CO<sub>2</sub> emissions or removals from any SOC changes or LUC occurring for the system being assessed. The parameterised inventories allow for user to customise the inventory for their purposes by copying it and modifying the relevant parameters.

For the market processes involving storage and transport to market, losses are accounted for using values from the National Food Loss and Waste Baseline (Arcadis, 2019).

# Appendix A – Water catchments

**Table 8 Water catchments assigned to agro-ecological regions (AER) for broadacre crops.**

Agro-ecological region	Catchment name	Fraction
Hobart	Tasmania_TAS	1.000
Jordan Coal Tasman	Tasmania_TAS	1.000
Tasmanian Forests	Tasmania_TAS	1.000
Burnie	Tasmania_TAS	1.000
North Central	Tasmania_TAS	1.000
Melbourne Region	South_East_Coast_NSW_VIC_and_SA	0.997
Central and South West Slopes and Plains	South_East_Coast_NSW_VIC_and_SA	0.107
	Namoi_NSW	0.022
	Macquarie_Castlereagh_NSW	0.223
	Barwon_Darling_NSW	0.017
	Lachlan_NSW	0.246
	Murrumbidgee_NSW	0.216
	Murray_NSW_VIC_and_SA	0.049
	Ovens_VIC	0.015
	Goulburn_Broken_VIC	0.048
	Campaspe_VIC	0.006
	Loddon_Avoca_VIC	0.044
	Wimmera_VIC	0.007
South Riverina and Wimmera	South_East_Coast_NSW_VIC_and_SA	0.243
	Lachlan_NSW	0.038
	Murrumbidgee_NSW	0.253
	Murray_NSW_VIC_and_SA	0.163
	Loddon_Avoca_VIC	0.115
	Wimmera_VIC	0.187
Far South and East Victorian Coast	South_East_Coast_NSW_VIC_and_SA	1.000
Southern Highlands, Tablelands and Gippsland	South_East_Coast_NSW_VIC_and_SA	0.446
	Lachlan_NSW	0.064
	Murrumbidgee_NSW	0.192
	Murray_NSW_VIC_and_SA	0.113
	MiddaMidda_VIC	0.017
	Ovens_VIC	0.038
	Goulburn_Broken_VIC	0.098
	Campaspe_VIC	0.021
	Loddon_Avoca_VIC	0.013
South Coast and Illawarra	South_East_Coast_NSW_VIC_and_SA	1.000
Sydney Basin	South_East_Coast_NSW_VIC_and_SA	1.000
Central, North Tablelands and Granite belt	South_East_Coast_NSW_VIC_and_SA	0.447
	Condamine_Balonne_NSW_and_QLD	0.030
	Border_Rivers_NSW_and_QLD	0.176
	Gwydir_NSW	0.082
	Namoi_NSW	0.089
	Macquarie_Castlereagh_NSW	0.128
	Lachlan_NSW	0.049
Northern Rivers and Mid-north Coast	South_East_Coast_NSW_VIC_and_SA	1.000
Western Downs and North West Slopes and Plains	South_East_Coast_NSW_VIC_and_SA	0.007
	Burnett_and_Brisbane_River_QLD	0.022
	Condamine_Balonne_NSW_and_QLD	0.154
	Moonie_QLD	0.059
	Border_Rivers_NSW_and_QLD	0.149
	Gwydir_NSW	0.115

Agro-ecological region	Catchment name	Fraction
	Namoi NSW	0.190
	Macquarie Castlereagh NSW	0.092
	Barwon Darling NSW	0.212
Brisbane Moreton	NE Coast other than Burd Fitz QLD	0.491
	South East Coast NSW VIC and SA	0.008
	Burnett and Brisbane River QLD	0.501
Darling Downs	Burnett and Brisbane River QLD	0.045
	Condamine Balonne NSW and QLD	0.805
	Border Rivers NSW and QLD	0.150
South Burnett	Burnett and Brisbane River QLD	0.952
	Condamine Balonne NSW and QLD	0.048
Wide Bay Burnett	NE Coast other than Burd Fitz QLD	0.488
	Burnett and Brisbane River QLD	0.483
	Fitzroy River QLD	0.025
Dawson Callide	Fitzroy River QLD	0.897
	Condamine Balonne NSW and QLD	0.102
Central Queensland coast	NE Coast other than Burd Fitz QLD	0.375
	Burdekin River QLD	0.038
	Fitzroy River QLD	0.587
Central Highlands Queensland	Burdekin River QLD	0.655
	Fitzroy River QLD	0.341
Burdekin	GuloCarpentaria NT and QLD	0.009
	Lake Eyre NSW QLD NT and SA	0.038
	NE Coast other than Burd Fitz QLD	0.098
	Burdekin River QLD	0.792
	Fitzroy River QLD	0.062
Wet Tropic Coast	NE Coast other than Burd Fitz QLD	0.991
	Burdekin River QLD	0.008
Northern Queensland Tablelands	GuloCarpentaria NT and QLD	0.017
	NE Coast other than Burd Fitz QLD	0.785
	Burdekin River QLD	0.199
Central West and Gulf	GuloCarpentaria NT and QLD	0.466
	Lake Eyre NSW QLD NT and SA	0.483
	Burdekin River QLD	0.038
	Warrego NSW and QLD	0.013
Cape York	GuloCarpentaria NT and QLD	0.843
	NE Coast other than Burd Fitz QLD	0.155
Barkly Tablelands	GuloCarpentaria NT and QLD	0.067
	Lake Eyre NSW QLD NT and SA	0.133
	Timor Sea NT and WA	0.800
Marrakai Arnhem Land	GuloCarpentaria NT and QLD	0.837
	Lake Eyre NSW QLD NT and SA	0.149
	Timor Sea NT and WA	0.014
Esley Gulf Land	GuloCarpentaria NT and QLD	0.268
	Timor Sea NT and WA	0.732
Timor Coast and Douglas Daly Basin	Timor Sea NT and WA	1.000
Sturt Plateau	GuloCarpentaria NT and QLD	0.663
GuloCarpentaria NT and QLD	Timor Sea NT and WA	0.337
Kimberley Victoria River	Indian Ocean WA	0.014
	North Western Plateau WA and NT	0.137
	Timor Sea NT and WA	0.849
North West Australia	Indian Ocean WA	0.999
Gascoyne	Indian Ocean WA	0.651
	North Western Plateau WA and NT	0.046
	South Western Plateau WA	0.179
	Moore Hill rivers WA	0.123
Western Wheatbelt	Indian Ocean WA	0.156
	Esperance Coast WA	0.099
	South Western Plateau WA	0.098
	Swan Coast WA	0.400
	Moore Hill rivers WA	0.156
	SW Coast other than Esp Avon WA	0.091
South West	Swan Coast WA	0.199

Agro-ecological region	Catchment name	Fraction
	Moore Hill rivers WA	0.217
	SW Coast other than Esp Avon WA	0.584
Lower South West	Swan Coast WA	0.146
	SW Coast other than Esp Avon WA	0.853
Goldfields Nullabor Flinders and darling	Lake Eyre NSW QLD NT and SA	0.113
	Southstralian GulSA	0.103
	Esperance Coast WA	0.010
	South Western Plateau WA	0.522
	Swan Coast WA	0.017
	Barwon Darling NSW	0.099
	Lachlan NSW	0.024
	Murray NSW VIC and SA	0.111
	Paroo NSW and QLD	0.082
Maranoa Warrego	Warrego NSW and QLD	0.308
	Condamine Balonne NSW and QLD	0.387
	Moonie QLD	0.031
	Macquarie Castlereagh NSW	0.008
	Barwon Darling NSW	0.183
Mallee Murray and central North South Australia	Lake Eyre NSW QLD NT and SA	0.019
	Southstralian GulSA	0.177
	South East Coast NSW VIC and SA	0.098
	South Western Plateau WA	0.148
	Lachlan NSW	0.023
	Murrumbidgee NSW	0.006
	Murray NSW VIC and SA	0.397
	Loddon Avoca VIC	0.031
	Wimmera VIC	0.079
	Eastern Mount Lofty Ranges SA	0.020
	Southern Coastal South Australia	Southstralian GulSA
South Western Plateau WA		0.121
Murray NSW VIC and SA		0.007
Eastern Mount Lofty Ranges SA		0.058
Channel Country	Lake Eyre NSW QLD NT and SA	0.917
	Paroo NSW and QLD	0.029
	Barwon Darling NSW	0.011
	Murray NSW VIC and SA	0.040
Central Australian Ranges	Lake Eyre NSW QLD NT and SA	0.613
	Timor Sea NT and WA	0.387
Tanami, Petermann, Simpson and Western Deserts	Indian Ocean WA	0.017
	Lake Eyre NSW QLD NT and SA	0.151
	North Western Plateau WA and NT	0.319
	South Western Plateau WA	0.323
	Timor Sea NT and WA	0.186
Adelaide Region	Southstralian GulSA	1.000

**Table 9 Water catchments assigned to livestock regions for extensive livestock production.**

Livestock region	Catchment name	Fraction
R322 - Beef CRC Brigalow	Lake Eyre NSW QLD NT and SA	0.001
	NE Coast other than Burd Fitz QLD	0.00004
	Burnett and Brisbane River QLD	0.035
	Burdekin River QLD	0.293
	Fitzroy River QLD	0.124
	Warrego NSW and QLD	0.013
	Condamine Balonne NSW and QLD	0.105
	Moonie QLD	0.172
	Border Rivers NSW and QLD	0.220

Livestock region	Catchment name	Fraction
	Barwon_Darling_NSW	0.036
Western Australia-over 450mm	Swan_Coast_WA	0.158
	Moore_Hill_rivers_WA	0.113
	SW_Coast_other_than_Esp_Avon_WA	0.729
Central Slopes and Plains	Namoi_NSW	0.073
	Macquarie_Castlereagh_NSW	0.534
	Barwon_Darling_NSW	0.015
	Lachlan_NSW	0.379
Central Tablelands	South_East_Coast_NSW_VIC_and_SA	0.289
	Macquarie_Castlereagh_NSW	0.479
	Lachlan_NSW	0.233
Central Western Plains	Paroo_NSW_and_QLD	0.012
	Lake_Eyre_NSW_QLD_NT_and_SA	0.277
	Namoi_NSW	0.001
	Macquarie_Castlereagh_NSW	0.103
	Barwon_Darling_NSW	0.359
	Lachlan_NSW	0.071
	Murray_NSW_VIC_and_SA	0.178
Monaro NSW	South_East_Coast_NSW_VIC_and_SA	0.446
	Lachlan_NSW	0.150
	Murrumbidgee_NSW	0.351
	Murray_NSW_VIC_and_SA	0.00032
	MiddaMidda_VIC	0.054
North Coast NSW	NE_Coast_other_than_Burd_Fitz_QLD	0.00018
	South_East_Coast_NSW_VIC_and_SA	1.000
North West Slopes NSW	Border_Rivers_NSW_and_QLD	0.052
	Gwydir_NSW	0.244
	South_East_Coast_NSW_VIC_and_SA	0.009
	Namoi_NSW	0.695
	Macquarie_Castlereagh_NSW	0.00001
Northern Tablelands NSW	Condamine_Balonne_NSW_and_QLD	0.00003
	NE_Coast_other_than_Burd_Fitz_QLD	0.00003
	Border_Rivers_NSW_and_QLD	0.334
	Gwydir_NSW	0.130
	South_East_Coast_NSW_VIC_and_SA	0.493
	Namoi_NSW	0.043
R311a	GuloCarpentaria_NT_and_QLD	0.667
	NE_Coast_other_than_Burd_Fitz_QLD	0.333
Western Riverina NSW	Lachlan_NSW	0.117
	Murrumbidgee_NSW	0.230
	Murray_NSW_VIC_and_SA	0.653
	Goulburn_Broken_VIC	0.00000
	Campaspe_VIC	0.00001

Livestock region	Catchment name	Fraction
	Loddon_Avoca_VIC	0.00001
R313e - Dalrymple	GuloCarpentaria_NT_and_QLD	0.768
	Lake_Eyre_NSW_QLD_NT_and_SA	0.226
	Burdekin_River_QLD	0.006
R311b - Burke	GuloCarpentaria_NT_and_QLD	1.000
R314 - Mitchell	Paroo_NSW_and_QLD	0.030
	Warrego_NSW_and_QLD	0.560
	Condamine_Balonne_NSW_and_QLD	0.072
	Lake_Eyre_NSW_QLD_NT_and_SA	0.133
	Burdekin_River_QLD	0.196
	Fitzroy_River_QLD	0.009
Riverina NSW	Lachlan_NSW	0.355
	Murrumbidgee_NSW	0.581
	Murray_NSW_VIC_and_SA	0.063
	Ovens_VIC	0.00008
South Coast NSW	South_East_Coast_NSW_VIC_and_SA	1.000
	Murrumbidgee_NSW	0.00001
South West Slopes NSW	South_East_Coast_NSW_VIC_and_SA	0.00007
	Lachlan_NSW	0.152
	Murrumbidgee_NSW	0.692
	Murray_NSW_VIC_and_SA	0.155
	MiddaMidda_VIC	0.00018
Tasmania - Midlands	Tasmania_TAS	1.000
R511a - Pindan & North	North_Western_Plateau_WA_and_NT	0.362
	Timor_Sea_NT_and_WA	0.638
South Australia-less than 250mm	Lake_Eyre_NSW_QLD_NT_and_SA	0.456
	Southstralian_GulSA	0.086
	South_Western_Plateau_WA	0.419
	Timor_Sea_NT_and_WA	0.002
	Murray_NSW_VIC_and_SA	0.038
R313b - EMareeba	GuloCarpentaria_NT_and_QLD	0.513
	NE_Coast_other_than_Burd_Fitz_QLD	0.363
	Burdekin_River_QLD	0.124
R313c - Goldfields Dalrymple	GuloCarpentaria_NT_and_QLD	0.012
	Lake_Eyre_NSW_QLD_NT_and_SA	0.066
	NE_Coast_other_than_Burd_Fitz_QLD	0.015
	Burdekin_River_QLD	0.907
R321 - Darling	Condamine_Balonne_NSW_and_QLD	0.708
	Moonie_QLD	0.001
	NE_Coast_other_than_Burd_Fitz_QLD	0.00001
	Border_Rivers_NSW_and_QLD	0.209
	South_East_Coast_NSW_VIC_and_SA	0.00023
	Burnett_and_Brisbane_River_QLD	0.082

Livestock region	Catchment name	Fraction
R331 - Beef CRC Coastal	NE_Coast_other_than_Burd_Fitz_QLD	0.377
	South_East_Coast_NSW_VIC_and_SA	0.00008
	Burnett_and_Brisbane_River_QLD	0.332
	Burdekin_River_QLD	0.020
	Fitzroy_River_QLD	0.269
	Condamine_Balonne_NSW_and_QLD	0.002
R312 - W&SW Qld	GuloCarpentaria_NT_and_QLD	0.300
	Lake_Eyre_NSW_QLD_NT_and_SA	0.279
	Paroo_NSW_and_QLD	0.196
	Warrego_NSW_and_QLD	0.154
	Condamine_Balonne_NSW_and_QLD	0.071
R332a - Wet Coast Tableland	GuloCarpentaria_NT_and_QLD	0.001
	NE_Coast_other_than_Burd_Fitz_QLD	0.992
	Burdekin_River_QLD	0.008
R511b - Fitzroy Valley	North_Western_Plateau_WA_and_NT	0.527
	Timor_Sea_NT_and_WA	0.473
R512 - Pilbara and Gascoyne	Indian_Ocean_WA	0.207
	North_Western_Plateau_WA_and_NT	0.224
	South_Western_Plateau_WA	0.269
	Timor_Sea_NT_and_WA	0.113
	Moore_Hill_rivers_WA	0.188
R711 - Alice Springs	Lake_Eyre_NSW_QLD_NT_and_SA	0.444
	North_Western_Plateau_WA_and_NT	0.025
	South_Western_Plateau_WA	0.018
	Timor_Sea_NT_and_WA	0.514
R712 - Barkly Tableland	GuloCarpentaria_NT_and_QLD	0.070
	Lake_Eyre_NSW_QLD_NT_and_SA	0.179
	Timor_Sea_NT_and_WA	0.751
Tasmania - Meander Valley	South_East_Coast_NSW_VIC_and_SA	0.001
	Tasmania_TAS	0.999
South Australia-250mm to 450mm	Lake_Eyre_NSW_QLD_NT_and_SA	0.027
	Southstralian_GulSA	0.245
	South_East_Coast_NSW_VIC_and_SA	0.048
	South_Western_Plateau_WA	0.380
	Murray_NSW_VIC_and_SA	0.279
	MiddaMidda_VIC	0.001
	Eastern_Mount_Lofty_Ranges_SA	0.021
R713 - Katherine & VRD	GuloCarpentaria_NT_and_QLD	0.239
	North_Western_Plateau_WA_and_NT	0.044
	Timor_Sea_NT_and_WA	0.716
North West Plains NSW	Paroo_NSW_and_QLD	0.007
	Warrego_NSW_and_QLD	0.089
	Condamine_Balonne_NSW_and_QLD	0.110

Livestock region	Catchment name	Fraction
	Moonie_QLD	0.002
	Border_Rivers_NSW_and_QLD	0.047
	Gwydir_NSW	0.112
	Namoi_NSW	0.121
	Macquarie_Castlereagh_NSW	0.014
	Barwon_Darling_NSW	0.498
Hunter Valley NSW	South_East_Coast_NSW_VIC_and_SA	0.997
	Namoi_NSW	0.00029
	Macquarie_Castlereagh_NSW	0.003
Victoria - North East	Wimmera_VIC	0.215
	South_East_Coast_NSW_VIC_and_SA	0.056
	Murrumbidgee_NSW	0.0000045
	Murray_NSW_VIC_and_SA	0.244
	MiddaMidda_VIC	0.0002
	Ovens_VIC	0.049
	Goulburn_Broken_VIC	0.191
	Campaspe_VIC	0.034
	Loddon_Avoca_VIC	0.211
R714 - NT Top End & Gulf	GuloCarpentaria_NT_and_QLD	0.444
	Timor_Sea_NT_and_WA	0.556
South Australia-more than 450mm	Lake_Eyre_NSW_QLD_NT_and_SA	0.008
	Southstralian_GulSA	0.409
	South_East_Coast_NSW_VIC_and_SA	0.472
	South_Western_Plateau_WA	0.053
	Murray_NSW_VIC_and_SA	0.011
	MiddaMidda_VIC	0.0001
	Eastern_Mount_Lofty_Ranges_SA	0.046
Victoria - Gippsland	South_East_Coast_NSW_VIC_and_SA	0.765
	Murray_NSW_VIC_and_SA	0.199
	MiddaMidda_VIC	0.0002
	Ovens_VIC	0.034
	Goulburn_Broken_VIC	0.001
R332b - Lower Burdekin & Bowen	NE_Coast_other_than_Burd_Fitz_QLD	0.419
	Burdekin_River_QLD	0.569
	Fitzroy_River_QLD	0.012
Victoria - South West	Wimmera_VIC	0.100
	South_East_Coast_NSW_VIC_and_SA	0.898
	Campaspe_VIC	0.0000004
	Loddon_Avoca_VIC	0.002
Western Australia-250mm-450mm	Indian_Ocean_WA	0.066
	Esperance_Coast_WA	0.063
	South_Western_Plateau_WA	0.504
	Swan_Coast_WA	0.228

Livestock region	Catchment name	Fraction
	Moore_Hill_rivers_WA	0.085
	SW_Coast_other_than_Esp_Avon_WA	0.053
Western Australia-under 250mm	North_Western_Plateau_WA_and_NT	0.580
	South_Western_Plateau_WA	0.293
	Timor_Sea_NT_and_WA	0.113
	Swan_Coast_WA	0.005
	Moore_Hill_rivers_WA	0.009

**Table 10 Water catchments assigned to production regions for cotton, sugarcane, rice\*.**

Production region	Catchment name
Cotton – Central QLD	Fitzroy River*
Cotton – Darling Downs	Condamine Balonne*
Cotton – Macintyre Balonne	Border Rivers*
Cotton - Macquarie	Macquarie-Castlereagh*
Cotton – Southern NSW	Lachlan*
Cotton – Northern NSW	Barwon Darling*
Sugarcane – Tully, South Johnstone, Herbert regions	NE Coast other than Burdekin and Fitzroy
Sugarcane – Burdekin Delta and BRIA	Burdekin River
Sugarcane – Mackay (representing Central region)	Fitzroy River
Sugarcane – Bundaberg (representing Southern region)	Burnett and Brisbane River
Rice - Riverina	Murray River

*\*100% assigned to dominate catchment*

# Appendix B – FracWet factors

Table 11 FracWet factors assigned to agro-ecological regions (AER) for broadacre crops.

AER number	AER name	FracWet factor
1	Hobart	0.188
2	Jordan Coal Tasman	0.425
3	Tasmanian Forests	0.632
4	Burnie	0.885
5	North Central	0.588
6	Melbourne Region	0.378
7	Central and South West Slopes and Plains	0.061
8	South Riverina and Wimmera	0.053
9	Far South and East Victorian Coast	0.318
10	Southern Highlands, Tablelands and Gippsland	0.356
11	South Coast and Illawarra	0.802
12	Sydney Basin	0.990
13	Central, North Tablelands and Granite belt	0.527
14	Northern Rivers and Mid-north Coast	0.995
15	Western Downs and North West Slopes and Plains	0.075
16	Brisbane	0.802
17	Darling Downs	0.062
18	South Burnett	0.033
19	Wide Bay Burnett	0.089
20	Dawson Callide	0.002
21	Central Queensland coast	0.526
22	Central Highlands Queensland	0.052
23	Burdekin	0.222
24	Wet Tropic Coast	0.983
25	Northern Queensland Tablelands	0.814

26	Central West and Gulf	0.029
27	Cape York	0.770
28	Barkly Tablelands	0.000
29	Arnhem Land	0.083
30	Esley Gulf Land	1.000
31	Timor Coast and Douglas Daly Basin	0.995
32	Sturt Plateau	0.995
33	Kimberley	0.942
34	North West Australia	0.000
35	Gascoyne	0.000
36	Western Wheatbelt	0.057
37	South West	0.006
38	Lower South West	0.587
39	Goldfields Nullabor Flinders and darling	0.006
40	Maranoa Warrego	0.015
41	Mallee Murray and central North South Australia	0.014
42	Southern Coastal South Australia	0.083
43	Channel Country	0.006
44	Central Australian Ranges	0.000
45	Tanami, Petermann, Simpson and Western Deserts	0.909
46	Adelaide Region	0.254

# Appendix C – Background processes

**Table 12 AusLCI background unit processes linked to AusAgLCI unit processes.**

Process name
Fertilisers, production, per kg, AU market mixes - urea, DAP, MAP, SSP, KCl, GranAM,
Pesticides, production, per kg, AU market mixes -generic pesticides or specific chemical where available – listed in Appendix E.
Agricultural lime (limestone), production, per kg, AU market mix
Gypsum, production, per kg, AU market mix
Chemicals, production, per kg, GLO market mix - generic organic, generic inorganic, detergents, soap, aluminium sulphate, sodium bicarbonate, sodium chloride,
Cleaners, production, per kg, GLO market mix -acid cleaner, alkaline cleaner, acid sanitiser
Road freight transport, per tkm, AU, fleet averages - truck, 60t, 40t, 16-28t, 3.5-16t
Rail freight transport, per tkm. AU, AU market
Electricity, low voltage, per kWh, state or AU market mixes* - AU, QLD, NSW, VIC, TAS, SA, WA, TAS
Tap water, per kg, state or AU market mixes -AU, QLD, NSW, VIC, TAS, SA, WA, TAS
Diesel burned in machine (pump), per MJ, GLO market mix
LPG (propane) burned in machine, per MJ, GLO market mix
Natural gas burned in boiler, per MJ, AU market mix
Other fuels burned in boiler, per MJ (coal, wood, fuel oil, propane), ROW market mix
Plastic materials, production, per kg, ROW market mix -LDPE, polyurethane
Building materials (for farm infrastructure), GLO market mixes -steel, concrete
Wastewater treatment
Tractor engine operation, on farm, per litre of diesel consumed
Tractor, production, per kg
Harvester, production, per kg
Agricultural machinery, general, production, per kg

*\*All background electricity processes use regional (state or national, depending on process applicability) low voltage market mixes based on AusLCI 2024 release at the time of writing. Grid mix data is updated annually. The market mix reflects average consumption data available from national energy statistics (NGER).*

# Appendix D – Grain crop rotations

**Table 13 Representative grain crop rotations for each agro-ecological region (AER) including fallow periods and pasture in rotation with crops.**

<sup>a</sup> w - winter crop, s - summer crop, F – fallow, xyPasture where x = continuous years of pasture

AER	Crop rotation <sup>a</sup>
5	wBarley-sF-wWheat-sF-wFababean-sF-wOats-sF-wBarley-sF-wWheat-2yPasture
6	wBarley-sF-wWheat-sF-wCanola-sF-wBarley-sF-wFieldpea-sF-wWheat-2yPasture
7	wWheat-sF-wWheat-sF-wCanola-sF-wBarley-sF-wLupin-sF-wWheat-sF-wCanola-3yPasture
8	wWheat-sF-wFieldpea-sF-wWheat-sF-wF-sF-wCanola-sF-wBarley-2yPasture
9	wWheat-sF-wWheat-sF-wCanola-sF-wBarley-sF-wHay-2yPasture
10	wWheat-sF-wWheat-sF-wCanola-sF-wWheat-sF-wWheat-sF-wCanola-sF-wTriticale-sF-wOats-3yPasture
13	wWheat-sF-wWheat-sF-wCanola-sF-wBarley-sF-wWheat-sF-wF-sF-wChickpea-sF-wOats-sF-wBarley-sF-wF-sSorghum-wF-sF
15	wWheat-sF-wBarley-sF-wChickpea-sF-wF-sSorghum-wF-sF-wWheat-sF-wWheat-sF-wChickpea-sF-wWheat-sF-wWheat-sF-wF-sF-wWheat-sF
17	wWheat-sF-wBarley-sF-wChickpea-sF-wF-sSorghum-wF-sF-wWheat-sF-wF-sSorghum-wF-sMaize-wF-sSorghum-wF-sSorghum-wF-sF
19	wWheat-sF-wBarley-sF-wF-sPeanut-wF-sSorghum-wWheat-sF-wF-sMungbean-wF-sMaize-wF-sMungbean-wF-sF-wWheat-sF-wF-sSoybean-wF-sSorghum-wF-sF
20	wWheat-sF-wChickpea-sF-wF-sSorghum-wF-sF-wWheat-sF-wF-sSorghum-wF-sF-wWheat-sMungbean
21	wWheat-sF-wChickpea-sF-wF-sSorghum-wF-sMungbean-wF-sSorghum-wF-sF-wChickpea-sSorghum-wF-sSorghum-wF-sF
22	wWheat-sF-wChickpea-sF-wWheat-sF-wF-sSorghum-wF-sF-wWheat-sF-wChickpea-sF-wF-sSorghum-wF-sSorghum-wF-sF
23	wF-sMaize-wF-sMaize-wF-sMaize-wF-sPeanut-wF-sMaize-wF-sMaize-wF-sF
25	wF-sMaize-wF-sMaize-wF-sMaize-wF-sPeanut-wF-sMaize-wF-sMaize-wF-sF



# Appendix E – Pesticides

The pesticide active ingredients included in AusAgLCI inventories are listed in Table 14, including AusLCI background processes representing their production. The fractions of active ingredients assumed to be released to air, soil and water are summarised in Table 15.

**Table 14 Pesticide active ingredients included in AusAgLCI inventories.**

Pesticide active ingredient	AusLCI background process selected
Enamectin benzoate	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Azoxystrobin	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Atrazine	Atrazine (GLO)  market for atrazine
Prothioconazole	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Isoxaflutole	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Bifenthrin	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Prosulfocarb	Prosulfocarb (GLO)  market for prosulfocarb
Flumetsulam	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Bromoxynil	Bromoxynil (GLO)  market for bromoxynil
Carbendazim	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Carfentrazone-ethyl	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Chlorothalonil	Chlorothalonil (GLO)  market for chlorothalonil
Chlorpyrifos	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Clethodim	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Clopyralid	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Diflufenican	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Dimethoate	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Diuron	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Epoxiconazole	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Butoxydim	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Flutriafol	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Glyphosate	Glyphosate (GLO)  market for glyphosate
Haloxypop	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Imazamox	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Lambda-cyhalothrin	Pesticide, unspecified (GLO)  market for pesticide, unspecified
MCPA dimethylamine salt	Pesticide, unspecified (GLO)  market for pesticide, unspecified
MCPA dimethylamine salt	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Mancozeb	Mancozeb (GLO)  market for mancozeb
metsulfuron	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Metsulfuron-methyl	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Florasulam	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Paraquat	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Procymidone	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Propiconazole	Pesticide, unspecified (GLO)  market for pesticide, unspecified
2,6-Dichlorobenzamide	Pesticide, unspecified (GLO)  market for pesticide, unspecified
S-metolachlor	Metolachlor (GLO)  market for metolachlor

Pesticide active ingredient	AusLCI background process selected
Pyrooxasulfone	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Simazine	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Tebuconazole	Tebuconazole (GLO)  market for tebuconazole
Clodinafop-propargyl	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Sulfoxaflor	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Triallate	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Trifluralin	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Cyhalothrin, gamma-	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Tralkoxydim	Pesticide, unspecified (GLO)  market for pesticide, unspecified
2,4-D, dimethylamine salt	Dimethylamine (GLO)  market for
terbutylazine	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Oxyfluorfen	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Imazethapyr	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Pinoxaden	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Bentazone	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Tribenuron-methyl	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Fluroxypyr	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Pendimethalin	Pendimethalin (GLO)  market for pendimethalin
Simazine	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Triclopyr	Triclopyr (GLO)  market for triclopyr
Alpha-cypermethrin	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Chlorantraniliprole	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Deltamethrin	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Emamectin benzoate	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Fipronil	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Indoxacarb	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Thiodicarb	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Pirimicarb	Pesticide, unspecified (GLO)  market for pesticide, unspecified
MCPA dimethylamine salt	Pesticide, unspecified (GLO)  market for pesticide, unspecified
diquat	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Primicarb	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Halosulfuron-Methyl	Pesticide, unspecified (GLO)  market for pesticide, unspecified
Bixafen	Pesticide, unspecified (GLO)  market for pesticide, unspecified

**Table 15 Partitioning fraction for pesticide active ingredients emitted to air, soil and water.**

Compartment	Sub-compartment	Parameter name	Partitioning fraction
Air	Low. Pop.	FracAir	0.01
Soil	Agriculture	FracSoil	0.83
	Agriculture	FracOF_AgSoil	0.092
	Forestry	FracOF_NatSoil	0.067
Water	River	FracOF_FW	0.001
Crop	Crop	FracCrop	0

# Appendix F – Grain crop tillage adoption

**Table 16 Assumed tillage practices for broadacre grain crops by AER.**

AER No	AER name	Cultivation practices		
		Zero/No-Till (0 to 30% soil disturbance)	Minimum tillage	Multiple tillage
5	North Central	10%	33%	58%
6	Melbourne Region	75%	16%	9%
7	Central and South West Slopes and Pla	80%	13%	7%
8	South Riverina and Wimmera	81%	10%	9%
9	Far South and East Victorian Coast	75%	16%	9%
10	Southern Highlands, Tablelands and Gi	80%	13%	7%
11	South Coast and Illawarra	80%	13%	7%
12	Sydney Basin	76%	10%	14%
13	Central, North Tablelands and Granite	76%	10%	14%
14	Northern Rivers and Mid-north Coast	76%	10%	14%
15	Western Downs and North West Slopes a	76%	10%	14%
16	Brisbane_Moreton	76%	10%	14%
17	Darling Downs	76%	10%	14%
18	South Burnett	76%	10%	14%
19	Wide Bay _ Burnett	76%	10%	14%
20	Dawson_Callide	77%	6%	16%
21	Central Queensland coast	77%	6%	16%
22	Central Highlands Queensland	77%	6%	16%
25	Northern Queensland Tablelands	77%	6%	16%
36	Western Wheatbelt	96%	3%	1%
37	South West	96%	3%	1%
38	Lower South West	96%	3%	1%

39	Goldfields_Nullabor_Flinders	72%	19%	9%
40	Maranoa_Warrego	85%	6%	9%

# Appendix G – Uncertainty

The approach for estimating uncertainty in AusAgLCI inventories is based on the ecoinvent® approach (Weidema et al., 2023), which is made up of two elements. The first is the basic uncertainty of the flow and the second is the data quality characteristics which are used to modify this basic uncertainty.

Basic uncertainty factors are specified for different kinds of input and output. It is assumed that, for instance, CO<sub>2</sub> emissions show in general a much lower uncertainty as compared to CO emissions. While the former can be calculated from fuel input, the latter is much more dependent on boiler characteristics, engine maintenance, load factors etc.

**Figure 16 Basic uncertainty values (Weidema et al., 2023).**

input / output group	c	p	a	input / output group	c	p	a
<b>demand of:</b>				<b>pollutants emitted to air:</b>			
thermal energy, electricity, semi-finished products, working material, waste treatment services	1.05	1.05	1.05	CO <sub>2</sub>	1.05	1.05	
transport services (tkm)	2.00	2.00	2.00	SO <sub>2</sub>	1.05		
Infrastructure	3.00	3.00	3.00	NMVOC total	1.50		
<b>resources:</b>				NO <sub>x</sub> , N <sub>2</sub> O	1.50		1.40
primary energy carriers, metals, salts	1.05	1.05	1.05	CH <sub>4</sub> , NH <sub>3</sub>	1.50		1.20
land use, occupation	1.50	1.50	1.10	individual hydrocarbons	1.50	2.00	
land use, transformation	2.00	2.00	1.20	PM>10	1.50	1.50	
<b>pollutants emitted to water:</b>				PM10	2.00	2.00	
BOD, COD, DOC, TOC, inorganic compounds (NH <sub>4</sub> , PO <sub>4</sub> , NO <sub>3</sub> , Cl, Na etc.)		1.50		PM2.5	3.00	3.00	
individual hydrocarbons, PAH		3.00		polycyclic aromatic hydrocarbons (PAH)	3.00		
heavy metals		5.00	1.80	CO, heavy metals	5.00		
pesticides			1.50	inorganic emissions, others		1.50	
NO <sub>3</sub> , PO <sub>4</sub>			1.50	radionuclides (e.g., Radon-222)		3.00	
<b>pollutants emitted to soil:</b>							
oil, hydrocarbon total		1.50					
heavy metals		1.50	1.50				
pesticides			1.20				

Note c: combustion emissions; p: process emissions; a: agricultural emissions

Data sources are then assessed according to the five characteristics in the Pedigree Matrix "reliability", "completeness", "temporal correlation", "geographic correlation" and "further technological correlation". Each characteristic is divided into five quality levels with a score between 1 and 5. Accordingly, a set of five indicator scores is attributed to each individual input and output flow (excluding the reference product) reported in a data source. An uncertainty factor (expressed as a contribution to the square of the geometric standard deviation) is attributed to each of the score of the five characteristics.

**Figure 17 Pedigree Matrix (Weidema et al., 2023).**

Indicator score	1	2	3	4	5 (default)
<b>Reliability</b>	Verified <sup>3</sup> data based on measurements <sup>4</sup>	Verified data partly based on assumptions <i>or</i> non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
<b>Completeness</b>	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered <i>or</i> >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered <i>or</i> some sites but from shorter periods	Representativeness unknown or data from a small number of sites <i>and</i> from shorter periods
<b>Temporal correlation</b>	Less than 3 years of difference to 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	Less than 15 years of difference to the time period of the dataset	Age of data unknown or more than 15 years of difference to the time period of the dataset
<b>Geographical correlation</b>	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 <i>or</i> distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
<b>Further technological correlation</b>	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 but from different technology	Data on related processes or materials	Data on related processes on laboratory scale <i>or</i> from different technology

# Appendix H – Product-specific method details

## Beef

### On farm beef production

LCI data for on farm beef production had previously been available in the original AusAgLCI dataset (Eady et al., 2014). It was updated in the LCAgMetrics project, to include more recent data on livestock numbers, co-product prices, area of grazing land use, area of farm dams and climate parameters. Emissions of CH<sub>4</sub> from farm dams was added.

<p><b>Production systems represented</b></p>	<p>The data represents the production of live beef cattle in Australia at the farm gate, including breeding operations, grazing operations, supplementary feeding, etc..</p> <p>Multiple production systems in each of 40 livestock regions in NSW, QLD, SA, WA VIC and TAS are represented. Within each of these livestock regions, the following range of unique regional beef cattle systems are represented. Not all systems will be present in each livestock zone.</p> <ul style="list-style-type: none"> <li>- Northern beef</li> <li>- Southern beef</li> <li>- Southern beef (feeder steers)</li> <li>- Southern beef (heavy grassfed)</li> <li>- Southern beef (inland weaners)</li> <li>- Southern beef (coastal weaners)</li> </ul> <p>For each production system a herd structure was defined (proportion of different ages of animals), with the inventory representing the inputs, outputs and elementary flows for the herd as a whole. As such breeding of calves would not be an input to the process, instead an element of the herd.</p>
<p><b>Products represented</b></p>	<p>The following products / co-products are represented:</p> <ul style="list-style-type: none"> <li>- cattle, prime beef, live weight, on farm</li> <li>- cattle, manufacturing beef, live weight, live weight, on farm</li> <li>- weaned cattle, live weight, on farm</li> </ul> <p>Beef cattle manure is considered a waste, with the impacts (methane emissions) included in the inventory and assigned to the associated product / co-products.</p> <p>Inventory is provided at three scales:</p> <ul style="list-style-type: none"> <li>- each producing region</li> <li>- aggregated average of the state herd (production-weighted) for each producing state (NSW, QLD, SA, WA, VIC, TAS)</li> <li>- aggregated average of the national herd (production-weighted) for Australia.</li> </ul>
<p><b>Supporting processes</b></p>	<p>Cattle, internal parasite control, AU</p> <p>Dry season mix, 30% urea, 5.5% P, at production</p> <p>Wet Season Mix, 0% N 14% P, at regional store.</p>
<p><b>Regional coverage</b></p>	<p>All major beef production regions are represented.</p>
<p><b>Production coverage</b></p>	<p>The data represent around 95% Australian beef production.</p>
<p><b>Time period</b></p>	<p>The available data sources enabled a temporal representation of the 5-year reference period from FY 2017/18 to 2021/22.</p>

<b>Functional unit</b>	kg liveweight for prime cattle, weaners, culled breeders, at farm gate.
<b>Reference flow</b>	Annual production of all beef classes (prime cattle, weaners, culled breeders) for a herd of 1,000 cows for northern beef systems and 100 cows for southern beef systems.
<b>Allocation</b>	The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products from beef production (economic, mass, energy, protein). The default allocation is economic allocation based on economic values for the time period.
<b>Sources of production data</b>	<p>Production of live cattle classes was based on Breedcow Beef Co-operative Research Centre (CRC) Brigalow templates (Holmes et al., 2011) and farm gross margins (DPI, 2023) (AgExcellence Alliance, 2024). Production of live cattle classes was based on Breedcow Beef CRC templates (Holmes et al., 2011) and farm gross margins (DPI, 2023) (AgExcellence Alliance, 2024).</p> <p>Stocking rate was estimated using 2010 Land Use Map (Australian Bureau of Agricultural and Resource Economics and Sciences, 2016) grazing native vegetation and grazing modified pastures combined with ABS statistics on total livestock numbers (adjusted for DSE) (ABS, 2019, 2020, 2021, 2022, 2023).</p> <p>Herd structure, reproduction and growth rates, classes and number of animals sold, live weight of cattle sold, and prices for all livestock products were drawn from a series of State Government Department of agriculture publications and market statistics for the 5 year period 2019-2023.</p> <p>For northern cattle production, the data representing herd structure, reproduction rate, growth rate, turn-off weights and profitability were drawn from the Beef CRC Gross Margin Templates in the herd modelling program Breedcow and Dynama (Holmes et al., 2011, Department of Agriculture and Fisheries, 2011). The Breedcow templates were scaled to 1,000 breeders.</p> <p>For southern cattle production, data from Gross Margin publications (Department of Primary Industries, 2012, Department of Primary Industries Parks Water and Environment, 2015, (AgExcellence Alliance, 2024) and farm benchmarking programs (Department of Primary Industries, 2014a) were used to construct Breedcow templates that reflected herds in each livestock region. The Breedcow templates were scaled to 100 breeders.</p> <p>Where States did not have current publications the best matching Gross Margin from a neighbouring s was used.</p>
<b>Sources of activity data (inputs)</b>	<p>Farming inputs were mostly derived from available and current farm gross margin data. For cattle, data were drawn from templates (Holmes et al., 2011) and farm gross margin (DPI, 2023, AgExcellence Alliance, 2024) Farming inputs were mostly derived from available and current farm gross margin data. For cattle, data were drawn from templates (Holmes et al., 2011) and farm gross margins (DPI, 2023, AgExcellence Alliance, 2024)</p> <p>Fertiliser inputs were derived from Incitec Pivot Fertilisers (2021).</p>
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	<p>The GAF Tool for Beef (Eckard, 2012a) was used to estimate GHG emissions. The GAF Tools applies the NIR equations and factors (Commonwealth of Australia, 2025a, b) to calculate livestock emissions (enteric methane, manure methane, nitrous oxide, etc.) for a given herd size and structure, animal growth rate and reproduction rate. It was populated with seasonal data on livestock numbers, live weight, live weight gain and proportion of females lactating to estimate total GHG emissions for each livestock region.</p> <p>Annual total methane emissions from farm dams (kg CH<sub>4</sub> year<sup>-1</sup> ha<sup>-1</sup>) were estimated using temperate depended algorithm outlined in (Malerba et al., 2024), and allocated to farm dams following the approach of the NIR Report (Commonwealth of Australia, 2025a, b).</p> <p>Evaporative water losses from dams (ML/ha/yr) is derived from the modelling of Malerba et al. (2021), which aligns with the latest NIR report (Commonwealth of Australia, 2025a, b).</p> <p>Nitrogen releases to air (ammonia) and water (nitrate) were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025a, b) (as precursors of nitrous oxide).</p> <p>Maintenance lime requirement was calculated from product additions and removals, with direct emissions from lime application calculated using NIR emissions factors (Commonwealth of Australia, 2025a, b).</p>

<b>Industry review</b>	Compiled production and activity data and assumptions was reviewed by representatives from WA DPIRD and NSW DPI.
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with results previously published by Wiedemann et al. (2016) for QLD and NSW beef and Wiedemann et al. (2023) for WA beef.

**Table 17 Beef production systems and products represented in AusAgLCI**

<b>Livestock region</b>	<b>Production system</b>	<b>Products</b>
NSW Central Slopes & Plains	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Heavy Grassfed)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Inland Weaners)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Heavy Grassfed)	Prime Cattle, Culled Breeders
NSW Central Slopes & Plains	Southern beef (Inland Weaners)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
NSW Central Slopes & Plains	Southern beef (Coastal Weaners)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
NSW North Coast	Southern beef (Inland Weaners)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Coastal Weaners)	Prime Cattle, Culled Breeders, Weaners
NSW North West Plains	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Heavy Grassfed)	Prime Cattle, Culled Breeders
	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Heavy Grassfed)	Prime Cattle, Culled Breeders
NSW Northern Tablelands	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Heavy Grassfed)	Prime Cattle, Culled Breeders
	Southern beef (Inland Weaners)	Prime Cattle, Culled Breeders, Weaners
NSW Riverina	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Heavy Grassfed)	Prime Cattle, Culled Breeders
	Southern beef (Inland Weaners)	Prime Cattle, Culled Breeders, Weaners
NSW South Coast	Southern beef (Coastal Weaners)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
NSW Southwest Slopes	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Heavy Grassfed)	Prime Cattle, Culled Breeders
	Southern beef (Inland Weaners)	Prime Cattle, Culled Breeders, Weaners
NSW Western Riverina	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
NT Alice Springs	Northern Beef	Prime Cattle, Culled Breeders
NT Barkly Tableland	Northern Beef	Prime Cattle, Culled Breeders, Weaners
NT Katherine & VRD	Northern Beef	Prime Cattle, Culled Breeders, Weaners
NT Top End & Gulf	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD Brigalow	Northern Beef	Prime Cattle, Culled Breeders
QLD Burke	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD Cape Yorke	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD Coastal Speargrass	Northern Beef	Prime Cattle, Culled Breeders
QLD Dalrymple & Flinders	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD Darling Downs	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD Mareeba	Northern Beef	Prime Cattle, Culled Breeders
QLD Goldfields Dalrymple	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD Lower Burdekin & Bowen	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD Mitchell Downs & Mulga	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD West & Southwest	Northern Beef	Prime Cattle, Culled Breeders, Weaners
QLD Wet Coast Tableland	Northern Beef	Prime Cattle, Culled Breeders
SA Cereal Zone	Northern Beef	Prime Cattle, Culled Breeders, Weaners
SA High Rainfall	Northern Beef	Prime Cattle, Culled Breeders, Weaners
SA Pastoral Zone	Northern Beef	Prime Cattle, Culled Breeders
TAS Meander Valley	Southern beef (Coastal Weaners)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
TAS Midlands	Southern beef (Coastal Weaners)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
VIC Gippsland	Southern beef (Coastal Weaners)	Prime Cattle, Culled Breeders, Weaners

Livestock region	Production system	Products
VIC Northeast	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Feeder Steers)	Prime Cattle, Culled Breeders, Weaners
	Southern beef (Heavy Grassfed)	Prime Cattle, Culled Breeders
	Southern beef (Inland Weaners)	Prime Cattle, Culled Breeders, Weaners
VIC Southwest	Southern Beef	Prime Cattle, Culled Breeders, Weaners
WA Cereal Zone	Southern Beef	Prime Cattle, Culled Breeders, Weaners
WA Fitzroy Valley	Northern Beef	Prime Cattle, Culled Breeders, Weaners
WA High Rainfall	Southern Beef	Prime Cattle, Culled Breeders, Weaners
WA Pastoral Zone	Southern Beef	Prime Cattle, Culled Breeders
WA Pilbara and Gascoyne	Northern Beef	Prime Cattle, Culled Breeders, Weaners
WA Pindan & North	Northern Beef	Prime Cattle, Culled Breeders, Weaners

**Table 18 Mix of Beef Enterprise Types in Livestock Zones.**

System	State	Livestock region	sub-system	% split	Co-Products	Mature weight of cows (kg)	Calves weaned	Weaner/ Steer turn-off weight (kg)
Southern	NSW	Central Slopes & Plains	Feeder Steers	37	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Heavy Grassfed	36	Prime Cattle, Culled Breeders, Weaners	500	92%	560
			Inland Weaners	27	Prime Cattle, Culled Breeders, Weaners	540	86%	245
Southern	NSW	Central Western Plains	Feeder Steers	37	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Heavy Grassfed	36	Prime Cattle, Culled Breeders	500	92%	560
			Inland Weaners	27	Prime Cattle, Culled Breeders, Weaners	540	86%	245
Southern	NSW	Hunter Valley	Feeder Steers	50	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Coastal Weaners	50	Prime Cattle, Culled Breeders, Weaners	500	86%	245
Southern	NSW	Monaro	Feeder Steers	50	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Inland Weaners	50	Prime Cattle, Culled Breeders, Weaners	540	86%	245
Southern	NSW	North Coast	Coastal Weaners	100	Prime Cattle, Culled Breeders, Weaners	500	86%	245
Southern	NSW	North West Plains	Feeder Steers	64	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Heavy Grassfed	36	Prime Cattle, Culled Breeders	500	92%	560
Southern	NSW	North West Slopes	Feeder Steers	64	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Heavy Grassfed	36	Prime Cattle, Culled Breeders, Weaners	500	92%	560
Southern	NSW	Northern Tablelands	Feeder Steers	34	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Heavy Grassfed	33	Prime Cattle, Culled Breeders	500	92%	560
			Inland Weaners	33	Prime Cattle, Culled Breeders, Weaners	540	86%	245
Southern	NSW	Riverina	Feeder Steers	37	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Heavy Grassfed	36	Prime Cattle, Culled Breeders	500	92%	560
			Inland Weaners	27	Prime Cattle, Culled Breeders, Weaners	540	86%	245

System	State	Livestock region	sub-system	% split	Co-Products	Mature weight of cows (kg)	Calves weaned	Weaner/ Steer turn-off weight (kg)
Southern	NSW	South Coast	Coastal Weaners	50	Prime Cattle, Culled Breeders, Weaners	500	86%	245
			Feeder Steers	50	Prime Cattle, Culled Breeders, Weaners	500	86%	450
Southern	NSW	South West Slopes	Feeder Steers	37	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Heavy Grassfed	36	Prime Cattle, Culled Breeders	500	92%	560
			Inland Weaners	27	Prime Cattle, Culled Breeders, Weaners	540	86%	245
Southern	NSW	Western Riverina	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	500	86%	450
Northern	NT	Alice Springs	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	450	60%	445
	NT	Barkly Tableland	Weaners	100	Prime Cattle, Culled Breeders, Weaners	460	61%	311
	NT	Katherine & VRD	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	425	60%	296
	NT	Top End & Gulf	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	410	53%	300
Northern	QLD	Brigalow	Heavy Grassfed	100	Prime Cattle, Culled Breeders, Weaners	540	90%	620
Northern	QLD	Burke	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	420	67%	435
Northern	QLD	Cape Yorke	Heavy Grassfed	100	Prime Cattle, Culled Breeders, Weaners	400	43%	350
Northern	QLD	Coastal Speargrass	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	520	72%	320
Northern	QLD	Dalrymple & Flinders	Heavy Grassfed	100	Prime Cattle, Culled Breeders, Weaners	480	89%	620
Northern	QLD	Darling Downs	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	520	85%	540
Northern	QLD	EMareeba	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	450	58%	400
Northern	QLD	Goldfields Dalrymple	Heavy Grassfed	100	Prime Cattle, Culled Breeders, Weaners	470	73%	595
Northern	QLD	Lower Burdekin & Bowen	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	420	73%	400
Northern	QLD	Mitchell Downs & Mulga Desert	Heavy Grassfed	100	Prime Cattle, Culled Breeders, Weaners	480	81%	670
Northern	QLD	West & South West	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	460	79%	310
Northern	QLD	Wet Coast Tableland	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	520	85%	540
Southern	SA	Cereal Zone	Weaners+Heifers	100	Prime Cattle, Culled Breeders, Weaners	550	90%	280
Southern	SA	High Rainfall	Weaners	100	Prime Cattle, Culled Breeders, Weaners	550	89%	280
Southern	SA	Pastoral Zone	Heavy Grassfed	100	Prime Cattle, Culled Breeders, Weaners	550	80%	500
Southern	TAS	Meander Valley	Coastal Weaners	47	Prime Cattle, Culled Breeders, Weaners	500	86%	245
			Feeder Steers	53	Prime Cattle, Culled Breeders, Weaners	500	86%	450
Southern	TAS	Midlands	Inland Weaners	47	Prime Cattle, Culled Breeders, Weaners	540	86%	245
			Feeder Steers	53	Prime Cattle, Culled Breeders, Weaners	500	86%	450
Southern	VIC	Gippsland	Coastal Weaners	50	Prime Cattle, Culled Breeders, Weaners	500	86%	245

System	State	Livestock region	sub-system	% split	Co-Products	Mature weight of cows (kg)	Calves weaned	Weaner/ Steer turn-off weight (kg)
			Feeder Steers	50	Prime Cattle, Culled Breeders, Weaners	500	86%	450
Southern	VIC	North East	Feeder Steers	37	Prime Cattle, Culled Breeders, Weaners	500	86%	450
			Heavy Grassfed	36	Prime Cattle, Culled Breeders	500	92%	560
			Inland Weaners	27	Prime Cattle, Culled Breeders, Weaners	540	86%	245
Southern	VIC	South West	Weaners	100	Prime Cattle, Culled Breeders, Weaners	550	89%	415
Southern	WA	Cereal Zone	Weaners + Heifers	100	Prime Cattle, Culled Breeders, Weaners	550	90%	280
Northern	WA	Fitzroy Valley	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	420	59%	290
Southern	WA	High Rainfall	Weaners	100	Prime Cattle, Culled Breeders, Weaners	550	89%	280
Southern	WA	Pastoral Zone	Heavy Grassfed	100	Prime Cattle, Culled Breeders, Weaners	550	80%	500
Northern	WA	Pilbara and Gascoyne	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	392	66%	290
Northern	WA	Pindan & North	Feeder Steers	100	Prime Cattle, Culled Breeders, Weaners	350	42%	330

## Post-farm red meat processing

Note: This is relevant not only to beef meat processing but also for sheep meat processing.

<b>Production systems represented</b>	<p>The data represents the slaughter and processing of beef cattle in Australia into retail-ready beef meat.</p> <p>The inventory for processed beef at the abattoir gate includes primary processing (to carcass) and secondary processing (boned and portioned) at the abattoir, wastewater treatment and disposal by irrigation, and primary packaging. It represents typical beef abattoir operations as described in documentation from Australian Meat Processor Corporation (Ridoutt, 2025). It assumes a single-species abattoir processing beef only but would be broadly representative of an abattoir processing mostly beef but also other species. Therefore, it could be used to represent sheep meat processing as well.</p> <p>Inventories processed beef products / co-products at market add transport to an appropriate location approximating a port destination for export markets or a major urban centre for domestic markets.</p>
<b>Products represented</b>	<p>Beef meat products and co-products produced from the aggregated (production-weighted) Australian average supply of prime cattle, culled breeders and spent dairy cows:</p> <p>Products / co-production at processor gate are:</p> <ul style="list-style-type: none"> <li>- Beef retail cuts, at plant</li> <li>- Beef edible offal, at plant</li> <li>- Beef raw hide, at plant</li> <li>- Beef pet food, at plant</li> <li>- Beef processing waste, at plant (rendering material).</li> </ul> <p>Wastewater from abattoir processes is considered a waste, with the impacts included in the inventory and assigned to the associated product / co-products.</p> <p>Products at market are:</p> <ul style="list-style-type: none"> <li>- Beef retail cuts, at market</li> <li>- Beef edible offal, at market</li> <li>- Beef raw hide, at market</li> <li>- Beef pet food, at market</li> <li>- Animal processing waste, at market (rendering material from pork, beef and sheep combined).</li> </ul>
<b>Supporting processes</b>	Rendering process
<b>Regional coverage</b>	A single dataset representing typical Australian red meat abattoir operations as described by Ridoutt (2025). No regional differentiation.
<b>Production coverage</b>	The dataset can be considered representative of 68% Australian red meat production (beef, lamb and sheep).
<b>Time period</b>	The available data sources enabled a temporal representation of the year 2022.
<b>Functional unit</b>	kg of beef meat retail cuts, and relative proportions of co-products
<b>Reference flow</b>	1 kilogram Hot Standard Carcase Weight processed
<b>Allocation</b>	The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products (economic, mass, energy, protein). The default allocation is economic allocation based on economic values reported by Meat & Livestock Australia (MLA), and representative of calendar year 2024 (Meat & Livestock Australia, 2025a, b).
<b>Sources of production data</b>	Yield of determining product and co-products per tonne of Hot Standard Carcase Weight was sourced from Meat & Livestock Australia's co-product compendium (Meat & Livestock Australia, 2009).
<b>Sources of activity data (inputs)</b>	<p>Transport distances for delivering live cattle to abattoirs was derived from the CSIRO TraNSIT model (<a href="https://benchmark.transit.csiro.au/">https://benchmark.transit.csiro.au/</a>).</p> <p>Inputs to abattoir operations, as well as detail of wastewater treatment and disposal and general waste production were sourced from survey data reported by the Australian Meat Processor Corporation (Ridoutt, 2025).</p>

	Transport of processed products to market was estimated from the distance between Australian abattoirs and the closest urban centre. The distance was average based on annual red meat production from ABS of each state (ABS, 2023) to provide a national average.
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	GHG emissions from wastewater treatment at abattoirs (methane) were sourced from reported by the Australian Meat Processor Corporation, as reported by Ridoutt (2025).
<b>Industry review</b>	Representatives from the Australian Meat Processors Corporation (AMPC) were consulted with as part of the inventory development process.
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with results previously published by (Wiedemann et al., 2015) in relation to the post-farm processing.

# Sheep

## On farm sheep production

<b>Production systems represented</b>	<p>Production of live sheep in Australia at the farm gate, including breeding operations, grazing operations, supplementary feeding and shearing. Rotations with cropping systems was not considered.</p> <p>Multiple production systems in each of 29 livestock regions in NSW, QLD, SA, WA VIC and TAS are represented. Within each of these livestock regions, the following range of unique regional sheep systems are represented. Not all systems will be present in each livestock zone.</p> <p>For each production system a herd structure was defined (proportion of different ages of animals), with the inventory representing the inputs, outputs and environmental elementary flows for the herd as a whole. As such breeding of lambs is not an input to the process, but instead an element of the herd.</p>
<b>Products represented</b>	<p>The following products /co-products are represented:</p> <ul style="list-style-type: none"> <li>- wool 18um, baled on farm</li> <li>- wool 20um, baled on farm</li> <li>- wool 28um, baled on farm</li> <li>- prime lamb, liveweight, on farm</li> <li>- lambs, wether weaners, liveweight, on farm</li> <li>- sheep, mutton, liveweight, on farm</li> <li>- sheep, breeding stock, liveweight, on farm</li> </ul> <p>Sheep manure is considered a waste, with the impacts (methane emissions) included in the inventory and assigned to the associated product / co-products.</p> <p>Inventory is provided at three scales:</p> <ul style="list-style-type: none"> <li>- each producing livestock region</li> <li>- aggregated average of the state herd (production-weighted) for each producing state (NSW, QLD, SA, WA, VIC, TAS)</li> <li>- aggregated average of the national herd (production-weighted) for Australia.</li> </ul>
<b>Supporting processes</b>	<p>Sheep, internal parasite control</p> <p>Sheep, external parasite control.</p>
<b>Regional coverage</b>	All major sheep production regions are represented.
<b>Production coverage</b>	The data represent around 95% Australian sheep production.
<b>Time period</b>	The available data sources enabled a temporal representation of the 5-year reference period from FY 2017/18 to 2021/22.
<b>Functional unit</b>	<p>Per kg liveweight for lambs, weaners, culled breeders, breeding stock, at farm gate</p> <p>Per kg of greasy fleece for wool, at farm gate.</p>
<b>Reference flow</b>	Annual production of all sheep classes (prime lambs, wool, breeding stock, culled breeders) for a flock size of 1,000 breeding ewes.
<b>Allocation</b>	<p>The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products from sheep production (economic, mass, energy, protein). The default allocation is economic allocation based on economic values for the time.</p> <p>Economic values (for allocation) for live sheep were derived from Meat and Livestock Australia market reports 2019-2023 (MLA, 2023) and those for wool prices from Australian Wool Innovations market reports 2019-2023 (AWI, 2024).</p>
<b>Sources of production data</b>	<p>Stocking rates were estimated using 2010 Land Use Map (Australian Bureau of Agricultural and Resource Economics and Sciences, 2016) for natural and sown pastures combined with ABS statistics on total livestock numbers (adjusted for DSE) (ABS, 2023, 2022, 2021, 2020, 2019).</p> <p>Information to describe flock structure, reproduction and growth rates, classes and number of animals sold, live weight of sheep and quantity of wool sold, and prices for all livestock products were drawn from a series of State Government Department of agriculture publications and market statistics for 2019-2023. Production data were drawn from</p>

	(AgExcellence Alliance, 2024, DPI, 2022) Average prices for National Trade Indicator (\$/kg live weight sold) were drawn from MLA ( <a href="https://www.mla.com/prices-markets/statistics/">https://www.mla.com/prices-markets/statistics/</a> ) for 5 year period 2019 - 2024.
<b>Sources of activity data (inputs)</b>	<p>Farming inputs (feed, vehicle operations) were mostly derived from on farm GM publications for each region (or nearest to the region). GM data was available for NSW for 2022, which was applied to Eastern Australian regions (DPI, 2022), and for SA for 2022, which applied to SA and WA regions) (Rural Solutions SA, 2022).</p> <p>Fertiliser inputs were derived from Incitec Pivot Fertilisers (Incitec Pivot Fertilisers, 2021).</p>
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	<p>The GAF Tool for (Eckard, 2012c) was used to estimate GHG emissions. The GAF Tools applies the NIR equations and factors (Commonwealth of Australia, 2025a, b) to calculate livestock emissions (enteric methane, manure methane, nitrous oxide, etc.) for a given herd size and structure, animal growth rate and reproduction rate. It was populated with seasonal data on livestock numbers, live weight, live weight gain and proportion of females lactating to estimate total GHG emissions for each livestock region.</p> <p>Annual total methane emissions from farm dams (kg CH<sub>4</sub> year<sup>-1</sup> ha<sup>-1</sup>) were estimated using temperate depended algorithm outlined in (Malerba et al., 2024), and allocated to farm dams following the approach of the NIR (Commonwealth of Australia, 2025a, b)</p> <p>Evaporative water losses from dams (ML/ha/yr) is derived from the modelling of Malerba et al. (2021), which aligns with the latest NIR report (Commonwealth of Australia, 2025a, b).</p> <p>Nitrogen releases to air (ammonia) and water (nitrate) were calculated using methods and factors from the NIR report (Commonwealth of Australia, 2025a, b) (as precursors of nitrous oxide).</p> <p>Maintenance lime requirement was calculated from product additions and removals, with direct emissions from lime application calculated using NIR factors (Commonwealth of Australia, 2025a, b).</p>
<b>Industry review</b>	Compiled production and activity data and assumptions was reviewed by representatives from Australian Wool Innovation (AWI), WA DPRID and NSW DPI.
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the AusLCI data with results previously published by Wiedeman et al. (2016).

**Table 19 Sheep production systems and products represented in AusAgLCI.**

<b>Regions (Livestock zone)</b>	<b>Production System</b>	<b>Products</b>
NSW Central Slopes & Plains	Maternal BL x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW Central Tablelands & Slope	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	BL x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW Central Western Plains	Maternal BL x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW Hunter Valley	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Meat	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW Monaro	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW North Coast	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Meat	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW North West Plains	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW Northern Tablelands	Maternal BL x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW Riverina - MIA	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW South Coast	Meat x Meat	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW South West Slopes	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
NSW Western Riverina	Meat x Meat	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
QLD Brigalow	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
QLD Dalrymple & Flinders	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
QLD Darling Downs	Maternal BL x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
QLD Mitchell & Mulga	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
QLD South West	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
SA Medium Rainfall	Meat x Merino 20um	Culled Breeders, Prime Lamb, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Cleanskin x Cleanskin	Culled Breeders, Prime Lamb, Breeding Stock
SA High Rainfall	Maternal BL x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x 1st X	Culled Breeders, Prime Lamb, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Meat	Culled Breeders, Prime Lamb, Breeding Stock, Wool
SA Low Rainfall	Meat x Merino 20um	Culled Breeders, Prime Lamb, Wool

	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Cleanskin x Cleanskin	Culled Breeders, Prime Lamb, Breeding Stock
TAS	Maternal BL x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Meat	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
VIC Gippsland	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Meat	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
VIC North East	Maternal BL x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
VIC South West	Meat x 1st X	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 18um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
WA Medium Rainfall	Meat x Merino 20um	Culled Breeders, Prime Lamb, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Cleanskin x Cleanskin	Culled Breeders, Prime Lamb, Breeding Stock
WA High Rainfall	Meat x Merino 20um	Culled Breeders, Prime Lamb, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Meat x Meat	Culled Breeders, Prime Lamb, Breeding Stock, Wool
WA Low Rainfall	Meat x Merino 20um	Culled Breeders, Prime Lamb, Wool
	Merino x Merino 20um	Culled Breeders, Prime Lamb, Breeding Stock, Wool
	Cleanskin x Cleanskin	Culled Breeders, Prime Lamb, Breeding Stock

## Post-farm sheep wool processing

Note: Sheep meat processing is covered by a common red meat processing unit operation, which is described in the beef section.

<b>Production systems represented</b>	<p>Processing of Australian greasy wool into processed wool of different grades - 18<math>\mu</math>m (for soft-handling fabrics and knitting yarns), 20<math>\mu</math>m (for woven apparel, knitting yarns and soft furnishings), and 28<math>\mu</math>m (for carpets and upholstery). As most Australian wool is scoured in China, the inventory for post-farm processing aims to represent Chinese scouring operation up to scoured and baled wool at the gate of a Chinese processor.</p> <p>The inventory includes the following processes, as described by Wiedemann et al. (2019) and (Wiedemann et al., 2020) - sea transport of greasy wool from an Australian wool port to a scouring plant in China, scouring, combing and baling and treatment and disposal of co-products and residues.</p>
<b>Products represented</b>	<p>Wool products and co-products produced from the aggregated (production-weighted) Australian average supply of the respective greasy wool:</p> <ul style="list-style-type: none"> <li>- Wool 18<math>\mu</math>m, scoured and baled, at Chinese plant</li> <li>- Wool 20<math>\mu</math>m, scoured and baled, at Chinese plant</li> <li>- Wool 28<math>\mu</math>m, scoured and baled, at Chinese plant</li> <li>- Wool grease, at Chinese plant.</li> </ul> <p>Processing residues are considered a waste, with the impacts (landfill disposal) included in the inventory and assigned to the associated product / co-products.</p>
<b>Supporting processes</b>	Not relevant
<b>Regional coverage</b>	A single dataset representing typical Chinese wool scouring operations as described by Wiedemann et al. (2019). No regional differentiation.
<b>Production coverage</b>	The dataset can be considered representative of approximately 80% of wool products from Australian greasy wool.
<b>Time period</b>	The available data sources enabled a temporal representation of the period 2016-2017.
<b>Functional unit</b>	1 kg of scoured, combed and baled wool and relative proportions of co-products
<b>Allocation</b>	The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products (economic, mass, energy). The default allocation is economic allocation based on economic values for the time period.
<b>Sources of production data</b>	<p>Inputs and yields of wool scouring were sourced from Wiedemann et al. (2019).</p> <p>The data from the Wiedemann et al. (2019) paper (and some data from the Wiedemann et al. (2020) paper) were directly translated into an LCI model using SimaPro software. The data from the paper provided the foreground data for wool scouring, combing and baling. These processes were then linked to LCI for background input processes from the AusLCI database (electricity, fuels, detergents etc.) to build a full LCA model of processed wool.</p>
<b>Sources of activity data (inputs)</b>	<p>Shipping distances for transport of greasy wool from Australian port to China scouring plant was derived from Google Maps and Sea-distances.org</p> <p>Inputs to Chinese wool scour plants were sourced from Wiedemann et al. (2019).</p> <p>Details of residue treatment and disposal were based on Wiedemann et al. (2019).</p>
<b>Industry review</b>	Activity data and assumptions was reviewed by representatives from Australian Wool Innovation (AWI). Reviewer comments were recorded and addressed.
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with results reported in Wiedemann et al. (2019) (from the primary data source). The Wiedemann et al. (2019) paper did not report results specifically for the scouring process. However, results from the developed LCI data were consistent with the Wiedemann et al. (2019) paper in terms of showing the scouring process to make a very small relative to the total impacts of scoured wool – with the majority of impacts associated with sheep production.

# Dairy

## On farm production

<b>Production systems represented</b>	The data represents typical dairy farming operations in Victoria, which is the main dairy producing state of Australia. It does not represent Victoria's entire dairy farm population since the underlying data source is derived from a small sample. The processes included are breeding operations, grazing operations and supplementary feeding.
<b>Products represented</b>	<p>The following products / co-products are represented:</p> <ul style="list-style-type: none"><li>- milk, at farm gate</li><li>- dairy livestock, at farm gate (as a co-product).</li></ul> <p>Dairy cattle manure is considered a waste, with the impacts (methane emissions) included in the inventory and assigned to the associated product / co-products.</p> <p>Inventory is provided at three scales:</p> <ul style="list-style-type: none"><li>- each producing regions within VIC (Gippsland, Northern VIC, South-West Victoria)</li><li>- aggregated as a typical representation for the state of VIC.</li></ul>
<b>Supporting processes</b>	<p>Dairy calf feed mix, concentrate meal, southern Australia</p> <p>Dairy cow feed, concentrate meal, southern Australia</p> <p>Wet season mix</p> <p>Acid cleaner for lines and vat for dairy</p> <p>Acid sanitiser for milk lines and vat for dairy</p> <p>Alkaline cleaner for lines for dairy</p> <p>Alkaline sanitiser for milk vat for dairy</p>
<b>Regional coverage</b>	Three Victorian dairy regions are represented.
<b>Production coverage</b>	The modelled Victorian regions produce around 60% of Australia's dairy production.
<b>Time period</b>	The available data sources enabled a temporal representation of the 5-year reference period from FY 2019/20 to 2023/24.
<b>Functional unit</b>	<p>kg of Fat and Protein Corrected Milk (FPCM)</p> <p>kg of liveweight dairy livestock sold for meat.</p>
<b>Reference flow</b>	Annual production of dairy and dairy livestock sold for meat for a herd size.
<b>Allocation</b>	The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products from the farm (economic, mass, energy, protein). The allocation is set to economic allocation as a default, based on economic values for the time period.
<b>Sources of production data</b>	<p>Stocking rates, milk and liveweight production were derived from the Dairy Farm Monitor Project 2019/20 to 2023/24 relevant to the region (Agriculture Victoria, 2020, 2021, 2022, 2023, 2024).</p> <p>Herd structure, pregnancy rate, perinatal loss, cow replacement rates, were derived from Axford et al. (2024), and Haile-Mariam Haile-Mariam et al. (2023).</p> <p>Market pathways for calves born (heifer replacements, dairy beef, bobby calf market, euthanised), was based on Gresham (2023).</p> <p>Economic values (for allocation) for cattle and milk solids were derived from the Dairy Farm Monitor Project 2019/20 to 2023/24 relevant to the region (Agriculture Victoria, 2020, 2021, 2022, 2023, 2024).</p>

<b>Sources of activity data (inputs)</b>	<p>Inputs to dairy production were derived from the Dairy Farm Monitor Project 2019/20 to 2023/24 relevant to the region, which include gross margin information (Agriculture Victoria, 2020, 2021, 2022, 2023, 2024).</p> <p>Calf milk and pelleted feed intake estimates were taken from Dairy Australia (2022).</p> <p>Drinking water intake was based on Agriculture Victoria (2024), drinking water access and quality.</p> <p>Data for size and frequency of solar photo-voltaic installations came from Dairy Australia (2023).</p> <p>Dosing frequency for internal parasites was sourced from both New South Wales Department of Primary Industries (2023) and AgExcellence Alliance (2024). Dosing frequency for internal parasites was sourced from both New South Wales Department of Primary Industries (2023) and AgExcellence Alliance (2024).</p> <p>Irrigation volume per hectare was from RM Consulting Group (2021).</p> <p>Methods of machinery cleaning were sourced from Dairy Australia (2020), and volume of water used in cleaning was sourced from Department of Primary Industries (2009).</p>
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	<p>GHG EFs were taken from the GAF Tool for dairy (Eckard, 2012b) and the NIR (Commonwealth of Australia, 2025a, b) (for leached to N<sub>2</sub>O)</p> <p>Carbon foot printing standards were aligned with International Dairy Federation (IDF, 2022).</p> <p>GHG emissions for foreground systems (enteric methane, manure methane, nitrous oxide, etc.) were calculated using methods and factors from the latest National Inventory Report (NIR) (Commonwealth of Australia, 2025a, b), and the Dairy Greenhouse Accounting Framework (D-GAF) tool (Eckard, 2012b).</p> <p>Annual total methane emissions from farm dams (kg CH<sub>4</sub> / year) were estimated using temperate depended algorithm outlined in (Malerba et al., 2024), and allocated to farm dams following the approach of the NIR (Commonwealth of Australia, 2025a, b).</p> <p>Evaporative water losses from dams (ML/ha/yr) is derived from the modelling of Malerba et al. (2021), which aligns with the latest NIR report (Commonwealth of Australia, 2025b, a). Evaporative water losses from dams (ML/ha/yr) is derived from the modelling of Malerba et al. (2021), which aligns with the latest NIR report (Commonwealth of Australia, 2025b, a).</p> <p>Nitrogen releases to air (ammonia) and water (nitrate) were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025b, a) (as precursors of nitrous oxide).</p> <p>Maintenance lime requirement was calculated from product additions and removals, with direct emissions from lime application calculated using NIR emissions factors (Commonwealth of Australia, 2025b, a).</p>
<b>Industry review</b>	<p>Compiled production and activity data and assumptions was reviewed by representatives from Agriculture Victoria.</p>
<b>Sense-checking of results generated by inventory</b>	<p>The LCI data were sense-checked by comparing the impact assessment results generated from the AusLCI data with figures in industry benchmarking reports (Agriculture Victoria, 2020, 2021, 2022, 2023, 2024).</p>

# Pigs

## On farm pig production

<b>Production systems represented</b>	<p>The data represents production of live pigs in Australia at the farm gate, including upstream production of feed, feed milling, breeding, grow-out operations and manure management. It is based on average Australian pig production, as described in Copley et al. (2024), and is made up of the four main production and manure management systems:</p> <ul style="list-style-type: none"> <li>- conventional system with no covered anaerobic ponds</li> <li>- conventional system with fully covered anaerobic ponds</li> <li>- deep litter production system</li> <li>- outdoor production system.</li> </ul>
<b>Products represented</b>	<p>The products / co-products represented at farm gate are:</p> <ul style="list-style-type: none"> <li>- pig, live weight, outdoor production system</li> <li>- pig, live weight, deep litter production system</li> <li>- pig, live weight, conventional system, uncovered manure management pond</li> <li>- pig, live weight, conventional system, covered manure management pond</li> <li>- electricity from biogas, pig production (covered manure pond system only).</li> </ul> <p>Pig manure is considered a waste, with the impacts (from manure management system) included in the inventory and assigned to the associated product / co-products.</p> <p>Inventory is provided at two scales:</p> <ul style="list-style-type: none"> <li>- each production system</li> <li>- aggregated average of the national Australian herd (production-weighted average of the four production systems).</li> </ul>
<b>Supporting processes</b>	Pig feed mix, average.
<b>Regional coverage</b>	A single dataset representing typical Australian pig production as described by Copley et al. (2024). No regional differentiation was available.
<b>Production coverage</b>	The industry sample represented by the Copley et al. (2024) study represents ~70% of pigs produced in Australia, across the 42 operations that made up the data sample.
<b>Time period</b>	The available data sources of (Copley et al., 2024) enabled a temporal representation of the 2021-2022 financial year.
<b>Functional unit</b>	kilogram liveweight for pigs, at farm gate.
<b>Reference flow</b>	Annual production of the Australian herd made up of all pig classes (sows, weaners, progeny).
<b>Allocation</b>	No allocation was required.
<b>Sources of production data</b>	Details of product yields were based on those reported in the Copley et al. (2024) paper.
<b>Sources of activity data</b>	Energy, water and feed inputs are sourced from Copley et al. (2024), supplemented with data from the NIR (Commonwealth of Australia, 2025b, a).
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	Direct emissions associated with enteric fermentation (methane) and manure management systems (methane and dinitrogen monoxide) were modelled based on parameters and formulas reported in the NIR (Commonwealth of Australia, 2025b, a).
<b>Industry review</b>	The translation of the Copley et al. (2024) study parameters was reviewed by representatives from Australian Pork Limited (APL).
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with the results reported in the source document (Copley et al., 2024).

## Post-farm pig meat processing and delivery to market

<b>Production systems represented</b>	The data represents the slaughter and processing of pigs and culled sows into retail-ready pork meat. It includes primary and secondary processing at the abattoir, and wastewater treatment and disposal by irrigation. It represents average Australian processing as described in Copley et al. (2024). It assumed a single-species abattoir processing pigs only.
<b>Products represented</b>	<p>Pork products and co-products produced from the aggregated average of the national Australian herd.</p> <p>Products / co-products at the processor gate are:</p> <ul style="list-style-type: none"> <li>- pork, retail cuts, at plant</li> <li>- pork edible offal, at plant</li> <li>- pork, pet food, at plant</li> <li>- pork processing waste, at plant.</li> </ul> <p>Wastewater from abattoir processes is considered a waste, with the impacts included in the inventory and assigned to the associated product / co-products.</p> <p>Products / co-products at market are:</p> <ul style="list-style-type: none"> <li>- pork, retail cuts, at market</li> <li>- pork, edible offal, at market</li> <li>- pork, pet food, at market</li> <li>- animal processing waste, at market (grouping pork, beef and sheep processing waste).</li> </ul>
<b>Supporting processes</b>	Rendering process
<b>Regional coverage</b>	A single dataset representing typical Australian pig abattoir operations as described by Copley et al. (2024). No regional differentiation.
<b>Production coverage</b>	The dataset can be considered representative of around 70% Australian pork meat abattoirs (Copley et al., 2024).
<b>Time period</b>	The available data sources of Copley et al. (2024) enabled a temporal representation of the 2021-2022 financial year.
<b>Functional unit</b>	kg of pork meat retail cuts, and relative proportions of co-products
<b>Reference flow</b>	1 kilogram of Hot Standard Carcase Weight
<b>Allocation</b>	The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products (economic, mass, energy, protein). The default allocation is economic allocation based on economic values for the time period.
<b>Sources of production data</b>	<p>Production data is sourced primarily from Wiedemann and Yan (2014).</p> <p>Transport distances for delivering live pigs to abattoirs was derived from the CSIRO TraNSIT model (<a href="https://benchmark.transit.csiro.au/">https://benchmark.transit.csiro.au/</a>).</p>
<b>Sources of activity data (inputs)</b>	<p>Transport distances for delivering processed meat to market were estimated from the approximate distance from Google Maps.</p> <p>A production-weighted average distance was derived based on annual production in each state (ABS, 2023).</p>
<b>Models for estimating emissions / releases to the environment (outputs)</b>	GHG emissions from wastewater treatment at abattoirs (methane) were calculated using methods and factors from the latest NIR (Commonwealth of Australia, 2025b, a)
<b>Industry review</b>	The translation of the Copley et al. (2024) study parameters was reviewed by a representative from Australian Pork Limited (APL).
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with results previously published by (Copley et al., 2024).

# Chickens

## On farm meat chicken production

<b>Production systems represented</b>	<p>The data represents Australian average live weight chicken production, as described in Copley and Wiedemann (2023). It included feed milling, chicken breeding and hatching, grow-out of chickens and manure management.</p> <p>The average picture of Australian growing represented in the Copley and Wiedemann paper was based on “data collected from a representative cross-section of vertically integrated chicken meat producers”.</p>
<b>Products represented</b>	<p>The products / co-product represented at farm gate are:</p> <ul style="list-style-type: none"> <li>- chickens for slaughter, live weight</li> <li>- chicken manure / litter</li> </ul> <p>Inventory is provided at one scale:</p> <ul style="list-style-type: none"> <li>- average for Australia.</li> </ul>
<b>Supporting processes</b>	Chicken feed mix, meat chickens, average.
<b>Regional coverage</b>	A single dataset representing average Australian meat chicken production as described in the LCA study conducted by Copley and Wiedemann (2023). No regional differentiation was available.
<b>Production coverage</b>	The industry sample represented by the Copley and Wiedemann study represents “50% of supply chains in all major regions”.
<b>Time period</b>	The available data source of Copley and Wiedemann (2023) enabled a temporal representation of the period 2008 – 2009.
<b>Functional unit</b>	kilogram liveweight meat chickens, at farm gate.
<b>Reference flow</b>	Annual production of meat chickens.
<b>Allocation</b>	The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products (economic, mass, energy, protein). The default allocation is economic allocation based on economic values for the time period.
<b>Sources of production data</b>	Details of product yields were based on those reported in the Copley and Wiedemann (2023) paper.
<b>Sources of activity data</b>	Energy, water and feed inputs and waste production were sourced from the Copley and Wiedemann (2023) paper.
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	Direct emissions associated with manure management (methane and dinitrogen monoxide) were modelled based on parameters and formulas reported in the NIR (Commonwealth of Australia, 2025b, a).
<b>Industry review</b>	The translation of the Copley and Wiedemann study parameters was reviewed by representatives from the Australian Chicken Meat Federation (ACMF).
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with the results reported in the source document (Copley and Wiedemann, 2023).

## Post-farm meat chicken processing and delivery to market

<b>Production systems represented</b>	<p>The data represents the slaughter and primary processing of meat chickens in Australia as described in Copley and Wiedemann (2023) to produce a mix of minimally processed chicken meat products - 51% whole birds, 16% bone-in pieces and 33% boneless portions, up to the point of on-site cold storage. It includes primary processing operations at the plant and treatment and disposal by irrigation of wastewater. It does not include secondary processing into retail cuts.</p> <p>The average picture of Australian processing represented in the Copley and Wiedemann paper was based on “data collected from a representative cross-section of vertically integrated chicken meat producers”.</p>
<b>Products represented</b>	<p>The products represented are:</p> <ul style="list-style-type: none"> <li>- Chicken meat, minimally processed, at plant</li> <li>- Chicken offal, at plant</li> </ul> <p>Chicken meat meal, at plant</p>
<b>Supporting processes</b>	Rendering process
<b>Regional coverage</b>	A single dataset representing average Australian meat chicken production as described by Copley and Wiedemann (2023). No regional differentiation was available.
<b>Production coverage</b>	The industry sample represented by the Copley and Wiedemann study represents “50% of supply chains in all major regions”.
<b>Time period</b>	The available data source of Copley and Wiedemann (2023) enabled a temporal representation of the period 2008 – 2009.
<b>Functional unit</b>	kg of chicken meat primary processed, and relative proportions of co-products
<b>Reference flow</b>	kilogram of minimally processed chicken meat
<b>Allocation</b>	The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products (economic, mass, energy, protein). The default allocation is economic allocation based on economic value split reported in the Copley and Wiedemann paper.
<b>Sources of activity data (inputs)</b>	<p>Inputs to the processing operation were sourced from the Copley and Wiedemann (2023) paper. Details of wastewater treatment and disposal were based on Copley et al. (2024).</p> <p>Transport distances for delivering processed meat to market were estimated from the approximate distance from Google Maps.</p>
<b>Industry review</b>	The translation of the Copley and Wiedemann study parameters was reviewed by representatives from the Australian Chicken Meat Federation (ACMF). Reviewer comments were recorded and addressed.
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with the results reported in the source document (Copley and Wiedemann, 2023).

# Broadacre Crops – grains (cereals, oil seeds, pulses / legumes) and fodder (hay, silage)

## On farm production

The development of on farm LCI for grains (cereals, oil seeds and pulses / legumes) was delivered under two projects in parallel:

- The Grains Research and Development Corporation (GRDC) / CSIRO Project CSP201-013RTX updated the LCI dataset for 14 grain crops (cereals, oil seeds and pulses) across 19 agro-ecological zones (24 agro-ecological regions) in 2024-2025, in terms of representing current practices using recent activity data, applying greenhouse gas emissions estimation methods and factors consistent with the latest NIR (Commonwealth of Australia, 2025a, b), and in a format suitable for submission to ecoinvent® (and by extension PEF compliance).
- The AgriFutures Project PRO-017538 (LCAgMetrics) updated the LCI dataset for grains (as part of a broad set of agricultural commodities) in terms of data formats that enable interoperability with a range of end uses beyond ecoinvent® and PEF, and also developed LCI data for post-farm processing and market processes.

Data development for hay and silage products on farm was delivered by the LCAgMetrics project.

All the grains (cereals, oil seeds, pulses) and fodder (hay, silage) were developed using the same approach, so have been described collectively here.

<b>Production systems represented</b>	<p>The data represents the production of broadacre grains (cereals, oil seeds, pulses), hay and silage in Australia at the farm gate, including land preparation, sowing, fertilising, pest control and weed management, harvesting, baling (where relevant). Most production systems are dryland production, and only 17 irrigated production systems are included, for lucerne hay and maize silage</p> <p>Most producing regions are represented based on Agro-ecological Regions (AER).</p>
<b>Products represented</b>	<p>The following products / co-products are represented. Straw was considered to be a co-product from each crop. Fixed nitrogen (N) was also considered a co-product for legume crops producing pulses.</p> <p>Grains</p> <ul style="list-style-type: none"> <li>- barley grain, and barley straw, on farm</li> <li>- maize grain, and maize straw, on farm</li> <li>- oat grain, and oat straw, on farm</li> <li>- sorghum grain, and sorghum straw, on farm</li> <li>- wheat grain, and wheat straw, on farm.</li> </ul> <p>Oil seeds</p> <ul style="list-style-type: none"> <li>- canola seed, and canola straw, on farm</li> <li>- sunflower seed, and sunflower straw, on farm.</li> </ul> <p>Pulses (from legume crops)</p> <ul style="list-style-type: none"> <li>- chickpea, chickpea straw and soil N on farm</li> <li>- lentils, lentil straw and soil N on farm</li> <li>- lupins, lupin straw and soil N on farm</li> <li>- Mung beans, and mung bean straw and soil N on farm</li> <li>- Faba bean, and faba bean straw and soil N on farm</li> <li>- field beans, and field bean straw and soil N on farm</li> <li>- field peas, and field pea straw and soil N on farm.</li> </ul> <p>Hay, silage, forage</p> <ul style="list-style-type: none"> <li>- oaten hay, on farm and at market</li> </ul>

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- cereal hay, on farm and at market
  - cereal silage, on farm and at market
  - lucern hay, on farm and at market
  - pasture hay, on farm and at market
  - sorghum-forage, on farm and at market
  - maize silage, on farm and at market.

Inventory for each is provided at three scales:

- each Agro-Ecological Region (AER)
- aggregated production-weighted average for each state (NSW, QLD, SA, WA, VIC, TAS)
- aggregated production-weighted average for Australia.

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**Supporting processes**

Cultivating, broadacre crop  
 Disc ploughing, broadacre crop  
 Fertilising, broadacre crop, pre and post-emergence  
 Grader operation, broadacre crop, medium load factor  
 Grain collection, broadacre, in-field with tractor+bin  
 Harvesting, broadacre crop, combine <200kW  
 Liming, broadacre crop, pre and post-emergence  
 Planting, broadacre crop, soil clay content >20%  
 Planting, broadacre crop, soil clay content 0-10%  
 Planting, broadacre crop, soil clay content 10-20%  
 Scarifying, broadacre crop  
 Spraying, aerial, broadacre crop  
 Spraying, broadacre crop, pre and post-emergence  
 Windrowing, broadacre crop  
 Hay mowing, broadacre crop  
 Hay raking, broadacre crop  
 Hay baling, large square bales, broadacre crop  
 Hay baling, round bales, broadacre crop  
 Hay baling, small square bales, broadacre crop  
 Cultivating, broadacre crop, controlled traffic  
 Disc ploughing, broadacre crop, controlled traffic  
 Fertilising, broadacre crop, pre and post-emergence, controlled traffic  
 Grader operation, broadacre crop, medium load factor, controlled traffic  
 Grain collection, broadacre, in-field with tractor and bin, controlled traffic  
 Harvesting, broadacre crop, combine less than 200kw, controlled traffic  
 Hay baling, large square bales, broadacre crop, controlled traffic  
 Hay baling, round bales, broadacre crop, controlled traffic  
 Hay baling, small square bales, broadacre crop, controlled traffic  
 Hay mowing, broadacre crop, controlled traffic  
 Hay raking, broadacre crop, controlled traffic  
 Liming, broadacre crop, pre and post-emergence, controlled traffic  
 Planting, broadacre crop, soil clay content 0 to 10%, controlled traffic  
 Planting, broadacre crop, soil clay content 10 to 20%, controlled traffic  
 Planting, broadacre crop, soil clay content greater than 20%, controlled traffic

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	Scarifying, broadacre crop, controlled traffic Spraying, broadacre crop, pre and post-emergence, controlled traffic Windrowing, broadacre crop, controlled traffic
<b>Regional coverage</b>	All regions where crops are grown (i.e. 32 AERs over six States).
<b>Production coverage</b>	Represent around 95% Australian production.
<b>Time period</b>	The available data sources enabled a temporal representation of the 5-year reference period from FY 2017/18 to 2021/22.
<b>Functional unit</b>	Per 1 tonne harvested product (grain, seed, pulse, hay), at farm gate.
<b>Reference flow</b>	Production of specified crop on 1 ha of land during a single production year.
<b>Allocation</b>	Hay and silage outputs, when produced in conjunction with grain production, are considered a co-product, to which elementary flows are allocated accordingly. The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products from production (economic, mass, energy). The default allocation is economic allocation based on economic values for the time period.
<b>Sources of production data</b>	Production area and yields were derived from production statistics reported in ABS data for the 2017/18 - 2021/22 reference period to generate a 5-yr averages (ABS, 2019, 2020, 2021, 2022, 2023, Australian Bureau of Agricultural and Resource Economics and Sciences, 2016).
<b>Sources of activity data (inputs)</b>	Farming inputs were mostly derived from farm gross margin data. GM data was available for QLD from 2021 (Queensland Government, 2021) and applied to AERs located primarily in QLD, for SA from 2022 (South Australian Grains Industry Trust, 2024) and applied to AERs in southern Australia (SA, VIC, Southern WA and Tas), and for NSW from 2011- 2013 and applied to AERs located primarily in NSW (NSW DPI, 2012a, e, b, d, c).
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	GHG emissions for on farm production were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025b, a). This includes (but is not limited to): all nitrous oxide emissions associated with the application of N fertiliser, and direct CO <sub>2</sub> emissions from ameliorant (lime).  Nitrogen releases to air (ammonia) and water (nitrate) were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025b, a) (as precursors of nitrous oxide).  Maintenance lime requirement was calculated from product additions and removals (Harding and Masters, 2016), with direct emissions from lime application calculated using NIR (Commonwealth of Australia, 2025b, a).  Losses of pesticides to air, water and soil were estimated using partitioning fractions derived from the PestLCI tool (Dijkman et al., 2012).
<b>Industry review</b>	Compiled production and activity data and assumptions for grain crops were reviewed by representative from CSIRO on behalf of the Grains Research and Development Corporation (GRDC). For hay crops, they were reviewed by a representative from the Hay Exporters Committee of the Australian Exporters Company (AEXCO).
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with results reported in the 2022 Australian Grains GHG Baseline (Sevenster et al., 2022), and with results generated from grains LCI data in the ecoinvent and Agribalyse databases.

**Table 20 Grains (cereals, oilseed, pulse) production systems and products in AusAgLCI.**

State	Agro-Ecological Region	Crop
NSW	Central and South West Slopes and Plains	Barley, Canola, Chickpea, (Pulses), Lentils, Lupins, Maize, Oats, Sorghum, Sunflower, Wheat
	Central, North Tablelands and Granite belt	Barley, Canola, Chickpea, (Pulses), Lentils, Lupins, Maize, (Pulses), Oats, Sorghum, Sunflower, Wheat
	Northern Rivers and Mid-north Coast	Oats, Sunflower, Wheat
	Southern Highlands, Tablelands and Gippsland	Barley, Canola, (Pulses), Lupins, Oats, Sorghum, Wheat
	Western Downs and North West Slopes and Plains	Barley, Canola, Chickpea, (Pulses), Lentils, Lupins, Maize, Oats, Sorghum, Sunflower, Wheat
QLD	Brisbane Moreton	Barley, Chickpeas, Lentils, Maize, Sorghum, Wheat, (Pulse)
	Burdekin	Chickpeas, Sunflower, (Pulses), Sorghum
	Cape York	Sorghum for grain
	Central Highlands Queensland	Barley, Chickpeas, (Pulse), Sorghum, Wheat
	Central Queensland coast	Chickpeas, Sunflower, (Pulses), Sorghum, Wheat
	Channel Country	Oats, Wheat
	Darling Downs	Barley, Chickpeas, Lupins, Maize, Oats, Sunflower, (Pulse), Sorghum, Wheat
	Dawson Callide	Barley, Chickpeas, Lupins, Maize, Oats, Sunflower, (Pulse), Sorghum, Wheat
	Maranoa Warrego	Barley, Chickpeas, Oats, (Pulses), Sorghum, Wheat
	South Burnett	Chickpeas, Maize, (Pulses), Sorghum, Wheat, Barley
SA	Goldfields Nullabor Flinders and darling	Barley, Canola, Chickpeas, Lentils, Lupins, Maize, Oats, (Pulses), Wheat
	Mallee Murray Central North SA	Barley, Canola, Chickpeas, Lentils, Lupins, Oats, (Pulses), Wheat
	Southern Coastal SA	Barley, Canola, Chickpeas, Lentils, Lupins, Oats, (Pulses), Wheat
	Tanami, Petermann, Simpson and Western Deserts	Barley, Canola, Chickpeas, (Pulses), Wheat
TAS	North Central	Barley, Canola, Oats, Wheat
	Tasmanian Forests	Wheat
VIC	Far South and East Victorian Coast	Barley, Canola, Lupins, Oats, (Pulses), Wheat
	Melbourne Region	Barley, Canola, Wheat
	South Riverina and Wimmera	Barley, Canola, Chickpeas, Lentils, Lupins, Maize, Oats, Sunflower, (Pulses), Sorghum, Wheat
WA	Gascoyne	Wheat
	Kimberley Victoria River	Maize
	Lower South West	Barley, Oats, Wheat
	South West	Barley, Canola, Chickpeas, Lentils, Lupins, Oats, (Pulses), Wheat
	Western Wheatbelt	Barley, Canola, Chickpeas, Lentils, Lupins, Oats, (Pulses), Wheat

**Table 21 Hay and silage production systems and products in AusAgLCI.**

<b>State</b>	<b>Ecological Region</b>	<b>Crop</b>
<b>NSW</b>	Central and South West Slopes and Plains	Cereal hay, Cereal silage, Oaten hay for export, Pasture hay, maize silage
	Central, North Tablelands and Granite belt	Cereal hay, Lucerne hay, Oaten hay for export, maize silage
	Northern Rivers and Mid-north Coast	Pasture hay, maize silage
	Southern Highlands, Tablelands and Gippsland	Cereal hay, Cereal silage, Oaten hay for export, Pasture hay, maize silage
	Sydney Basin	Lucerne hay, Pasture hay
	Western Downs and North West Slopes and Plains	Cereal hay, Oaten hay for export, maize silage
<b>QLD</b>	Brisbane Moreton	Cereal hay, Lucerne hay
	Darling Downs	Cereal hay, forage sorghum, maize silage
	Dawson Callide	Cereal hay, Cereal silage, Pasture hay, maize silage
	Maranoa Warrego	Cereal hay, Pasture hay, forage sorghum
	Wide Bay Burnett	Cereal hay, Cereal silage, Lucerne hay, maize silage
<b>SA</b>	Goldfields Nullabor Flinders and darling	Cereal hay, Oaten hay for export
	Mallee Murray and central North South Australia	Cereal hay, Oaten hay for export
	Southern Coastal South Australia	Cereal hay, Oaten hay for export
<b>TAS</b>	North Central	Cereal hay, Lucerne hay, Pasture hay
	Tasmanian Forests	Cereal hay, Cereal silage, Pasture hay
<b>VIC</b>	Far South and East Victorian Coast	Cereal hay, Cereal silage, Lucerne hay, Oaten hay for export, Pasture hay
	Melbourne Region	Cereal hay, Cereal silage, Lucerne hay, Oaten hay for export, Pasture hay
	South Riverina and Wimmera	Cereal hay, Cereal silage, Lucerne hay, Oaten hay for export, Pasture hay, forage sorghum, maize silage
<b>WA</b>	Lower South West	Cereal hay, Oaten hay for export, Pasture hay
	South West	Cereal hay, Oaten hay for export, Pasture hay
	Western Wheatbelt	Cereal hay, Oaten hay for export

## Post-farm storage and drying of grains

There is no post-farm processing for fodder products (hay, silage) as they are baled as part of the on farm process.

<b>Production systems represented</b>	<p>Storage, drying and transport of grains to market</p> <ul style="list-style-type: none"> <li>- Grains are assumed to be stored for 9 months on average, at some point between farm and market, either at on farm storage or at a regional bulk handling facility.</li> <li>- Only grains from regions with high rainfall (southern states) are assumed to be dried to reduce moisture content from 15% to 13% on average.</li> <li>- All grains are assumed to be ventilated for a period of time while in storage to i) reduce moisture content from 13% to 12% and ii) fumigated for fungal control.</li> <li>- The transport is calculated by taking the distance of the centre point of each AER to their respective ports.</li> <li>- Transport assumed to be either via train or road (B-double trucks) depending on the region.</li> </ul>
<b>Products represented</b>	<p>The following products are represented:</p> <p>Grains</p> <ul style="list-style-type: none"> <li>- barley grain, at market</li> <li>- maize grain, at market</li> <li>- oat grain, at market</li> <li>- sorghum grain, at market</li> <li>- wheat grain, at market.</li> </ul> <p>Seeds</p> <ul style="list-style-type: none"> <li>- canola seed, at market</li> <li>- sunflower seed, at market.</li> </ul> <p>Pulses</p> <ul style="list-style-type: none"> <li>- chickpea, at market</li> <li>- lentils, at market</li> <li>- lupins, at market</li> <li>- Mung beans, at market</li> <li>- Faba bean, at market</li> <li>- field beans, at market</li> <li>- field peas, at market.</li> </ul> <p>Inventory is provided at two scales for each:</p> <ul style="list-style-type: none"> <li>- aggregated average (production-weighted) for each producing state (NSW, QLD, SA, WA, VIC, TAS)</li> <li>- aggregated average (production-weighted) for Australia.</li> </ul>
<b>Supporting processes</b>	<p>Building for storage</p> <p>Canola storage</p> <p>Grain storage</p> <p>Pulses storage</p> <p>Drying of canola</p> <p>Drying of grain</p> <p>Drying of pulses</p>
<b>Regional coverage</b>	All regions where crops are grown
<b>Production coverage</b>	Represent around 95% Australian production.
<b>Time period</b>	The available data sources were not specific about the temporal representation, but is considered to represent current practices (early 2020s).

<b>Functional unit</b>	Per 1 tonne processed grain, seed, pulse, at market
<b>Reference flow</b>	Aggregated national production
<b>Allocation</b>	Not relevant
<b>Sources of production data</b>	As for on farm production
<b>Sources of activity data (inputs)</b>	<p>Energy for storage, ventilation and drying of grains, seed, pulses were derived from first principles and validated by industry experts.</p> <p>Transport distances for delivering grains to market were derived from the Australian Bureau of Statistics, AER data, google maps and personal communication with grain expert.</p> <p>Information on phosphine dosage was taken from Grains Research &amp; Development corporation (Warrick, 2011).</p>
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	Not relevant
<b>Industry review</b>	Activity data and assumptions was reviewed by a representative from Grains and Research and Development Corporation (GRDC). Reviewer comments were recorded and addressed.
<b>Sense-checking of results generated by inventory</b>	Estimates for energy for ventilation was sense-checked against literature data (Carlescu et al., 2022).

# Sugarcane

## On farm sugarcane production

<b>Production systems represented</b>	<p>The data represents regional sugarcane growing production systems in Queensland, Australia, producing harvested cane up to farm gate. The scope of activities included in the inventory are land preparation, soil cultivation, planting of cane billets, fertilising, pest control and weed management, irrigation (where relevant), pre-harvest burning of cane (where relevant), cane harvest and haul out. It does not consider application of mill by-products on field or the growing of legume break crops in the fallow year. For regions where irrigation occurs, it includes electricity input for both on farm pumping and for the upstream supply from irrigation scheme to farm) and on farm irrigation infrastructure (amortised).</p> <p>Cane production is represented as the annualised average of the average 5-6 year cane growing cycle (1 yr plant cane, 3-4 yr ratoon cane, 1 yr fallow).</p>
<b>Products represented</b>	<p>The following products is represented</p> <ul style="list-style-type: none"> <li>- sugarcane, harvested, at farm</li> </ul> <p>Sugarcane harvest residue (cane trash) is considered a residue, which do not receive any allocated impacts and are considered 'cut-off' from the process.</p> <p>Inventory is provided at two scales:</p> <ul style="list-style-type: none"> <li>- each Queensland (QLD) sugarcane region</li> <li>- aggregated production-weighted average for QLD, the main producing state</li> </ul>
<b>Supporting processes</b>	<p>Irrigation, flood or furrow irrigation system</p> <p>Irrigation, travel spray boom irrigation system</p> <p>Irrigation, travelling gun irrigation system</p> <p>Irrigation, centre pivot system</p>
<b>Regional coverage</b>	<p>Queensland regions and sub-regions are represented:</p> <ul style="list-style-type: none"> <li>- Tully, South Johnstone, and Herbert (representative of North QLD production)</li> <li>- Burdekin River Irrigation Area (BRIA)</li> <li>- Burdekin Delta</li> <li>- Mackay (representative of Central QLD production)</li> <li>- Bundaberg (representative of Southern QLD production)</li> </ul> <p>At the time of data collation, comprehensive data for of Northern New South Wales (NSW) production systems (which typically have a 2-year growing period rather than 1-year in QLD) was not available. However, publicly available data for Northern NSW recently compiled by Sugar Research Australia may be available for future updates (Clarke and Wiedemann, 2026).</p>
<b>Production coverage</b>	<p>The production in Queensland represents 95% of Australian production.</p>
<b>Time period</b>	<p>The available data sources enabled a temporal representation of FY 2017/18 to 2021/22</p>
<b>Functional unit</b>	<p>Per 1 tonne harvested sugarcane at farm transport siding</p>
<b>Allocation</b>	<p>Not relevant</p>
<b>Sources of production data</b>	<p>Where possible, yields defined for each region by Thompson et al. (2024) were prioritised, as they were based on current N application rates (recommended by the Six Easy Steps program). When not available in Thompson et al. (2024), yields were derived from the FEAT Online Base Files (featonline.com.au), which are gross margins for the sugar industry.</p> <p>Regional production quantities were obtained from industry statistics published by Australian Sugar Manufacturers (<a href="https://sugarmanufacturers.org/">https://sugarmanufacturers.org/</a>)</p>
<b>Sources of activity data (inputs)</b>	<p>Practices and farming inputs were derived from gross margin data compiled for each region in Thompson, Poggio et al. (2024). This source provides the most current and most widely consulted source of cane growing practices and inputs. Where details were not available in Thompson, Poggio et al., they were sourced from the gross margin data relevant to the region from the Base Files within the FEAT Online web portal (featonline.com.au).</p>

	<p>A separate set of activity data was developed for each component of the multi-year sugarcane crop cycle (1 plant cane crop, followed by 3-4 ratoon crops and a fallow year). The activity data was then annualised in the CaneLCA tool V1.05 (Renouf et al., 2013). It thereby represents the annual inventory as a production-weighted average over the entire multi-year (5-6 years) crop cycle. The inventory does not consider application of milling by-products (mill mud, mill ash, vinasse) or the growing of a legume fallow.</p> <p>For irrigated cane growing regions, the electricity use on farm for pumping water was derived from the above-mentioned farm activity data. Electricity use for irrigation scheme supply of water to the farm was derived from Sunwater scope 2 emissions (electricity) reported to NGERS and total volume supplied from Sunwater Annual Report, and calculated as a 10 yr average (2015-2024) 105.93 tCO<sub>2</sub>/ML. For the inventory, this was converted to 129.80 kWh/ML based on electricity intensity for Qld market for electricity of 0.8161 kg CO<sub>2</sub>/kWh. This approach was used for all Burdekin River Irrigation Area, Mackay and Bundaberg. For the Burdekin Delta irrigation water is pumped from underlying groundwater. Electricity use reported by the Burdekin Haughton Distribution Service was used to represent the pumping by Lower Burdekin Water to recharge river water into the groundwater table.</p>
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	<p>GHG emissions for foreground systems (nitrous oxide, cane burning emissions, emission from residues etc.) were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025b, a). GHG emissions in foreground systems (nitrous oxide, cane burning emissions, emission from residues etc.) were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025b, a).</p> <p>Nitrogen releases to air (ammonia) and water (nitrate) were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025b, a) (as precursors of nitrous oxide).</p> <p>Losses of pesticides to air, water and soil were estimated using partitioning fractions derived from the PestLCI tool (Dijkman et al., 2012).</p>
<b>Industry review</b>	<p>Compiled production and activity data and assumptions were reviewed by personnel from Sugar Research Australia (SRA). Reviewer comments were recorded and addressed.</p>
<b>Sense-checking of results generated by inventory</b>	<p>Underlying assumptions were cross-checked against those being applied in a parallel LCA study commissioned by Sugar Research Australia (SRA) (Clarke and Wiedemann, 2026). Some adjustments were made to the LCI to ensure that the underlying assumptions was mostly consistent with the SRA LCA study. The two pieces of work have different purposes, drawing on slightly different data sources. The AusLCI dataset aimed to represent 'typical' regional production systems, compared with the SRA LCA study which aimed to represent 'statistically representative' production systems.</p> <p>Sence-checking was also conducted by comparing the GHG results generated from the new AusLCI data with results generated from LCI available for other international cane growing regions in other databases (ecoinvent® and World Food LCA databases).</p>

## Post-farm sugarcane milling

<b>Production systems represented</b>	Milling of sugarcane at Queensland sugar mills, including transport of harvested cane to sugar mills by cane rail or road (depending on the region), milling of sugarcane to produce bulk raw sugar and co-products (molasses, surplus bagasse and exported electricity).
<b>Products represented</b>	<p>The following products are represented as an Australian average:</p> <ul style="list-style-type: none"> <li>- raw sugar, at mill gate</li> <li>- molasses (C-grade), at mill gate</li> <li>- electricity from bagasse, exported</li> <li>- bagasse, surplus, at mill gate.</li> </ul> <p>Mill mud and mill ash are considered wastes, with the impacts included in the inventory and assigned to the associated product / co-products.</p>
<b>Supporting processes</b>	<p>Bagasse combustion</p> <p>Land application of mill mud to cane fields</p>
<b>Regional coverage</b>	A single dataset representing typical Australian sugarcane milling. No differentiation between mills.
<b>Time period</b>	The available data sources were not specific about the temporal representation, but is considered to represent current practices (early 2020s).
<b>Functional unit</b>	Per 1 tonne raw sugar, at mill gate (and co-products).
<b>Reference flow</b>	Milling of 100 tonne cane.
<b>Allocation</b>	Molasses electricity and surplus bagasse outputs are considered co-products to which elementary flows are allocated accordingly. The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products (economic, mass, energy). The default allocation is economic allocation based on assumed split of economic values across the mill products (Renouf et al., 2011).
<b>Sources of activity data (inputs)</b>	A generic model of the mass and energy balance of Australian sugar mills was used to estimate product and co-product outputs and the amount of surplus electricity available for export as a co-product. The modelling assumptions were validated through consultation with sugar milling companies.
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	The direct emissions from bagasse combustion at the mill were derived from those reported by sugar mills to the National Pollutant Inventory and GHG EFs from the NIR (Commonwealth of Australia, 2025b, a).
<b>Industry review</b>	Compiled activity data and assumptions were discussed with sugar milling representatives.
<b>Sense-checking of results generated by inventory</b>	Sence-checking was conducted by comparing the results generated from the new AusLCI data for raw sugar with results generated from a parallel LCA study commissioned by Sugar Research Australia (SRA) (Clarke and Wiedemann, 2026), and also from LCI available for other international cane growing regions in other databases (ecoinvent® and World Food LCA databases).

# Cotton

## On farm cotton production

LCI data for cotton at the farm gate and processed lint at the gin gate had been updated by a project funded by the Cotton Research and Development Corporation CRDC and CSIRO under Project CSP2102 titled 'Greenhouse gas baseline and accounts for the Australian cotton, 2021-2025' (Sevenster et al., 2023a). In the LCAGMetrics project the cotton LCI data was further updated to be consistent with the updates applied across all the agriculture sectors, in terms of updated NIR factors, allocation switch and data formats.

<b>Production systems represented</b>	The data represents regional cotton growing production systems in Australia, producing harvested cotton boll at the farm gate, including land preparation, annual cultivation, sowing, fertilising, pest control and weed management, irrigation and harvesting.
<b>Products represented</b>	<p>The following products are represented</p> <ul style="list-style-type: none"> <li>- Cotton, cotton seed, harvested, on farm (cotton boll)</li> </ul> <p>Inventory is provided at three scales:</p> <ul style="list-style-type: none"> <li>- each cotton growing region</li> <li>- aggregated production-weighted average for Queensland (QLD) and New South Wales (NSW) the main producing states</li> <li>- aggregated production-weighted average for Australia.</li> </ul>
<b>Supporting processes</b>	<p>Spraying, aerial, cotton</p> <p>Bed forming, cotton</p> <p>Boom spraying, cotton</p> <p>Cultivating, cotton</p> <p>Discing, cotton</p> <p>Fertiliser spreading, cotton</p> <p>Fertiliser application, cotton</p> <p>Harvesting basket cotton picker</p> <p>Levelling, cotton</p> <p>Mulching, cotton</p> <p>Round bale cotton picking</p> <p>Planting, cotton</p> <p>Rolling, cotton</p> <p>Root cutting, cotton</p>
<b>Regional coverage</b>	<p>Regions represented (and contribution to production):</p> <p>QLD</p> <ul style="list-style-type: none"> <li>- Central Queensland</li> <li>- Darling Downs</li> <li>- Macintyre Balonne</li> </ul> <p>NSW</p> <ul style="list-style-type: none"> <li>- Macquarie</li> <li>- Southern NSW</li> <li>- Northern NSW</li> </ul>
<b>Production coverage</b>	Represent 100% of Australian production.
<b>Time period</b>	The available data sources allowed representation of the 5-year reference period from 2016 - 2020

<b>Functional unit</b>	Per 1 tonne harvested cotton at transport siding
<b>Reference flow</b>	One hectare of production
<b>Allocation</b>	Not relevant
<b>Sources of activity data (inputs)</b>	All dated derived from a comprehensive LCA study of Australian cotton conducted by CSIRO as part of a CRDC project (Sevenster et al., 2023a)
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	<p>GHG emissions for foreground systems (nitrous oxide, emission from residues etc.) were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025b, a).</p> <p>Nitrogen releases to air (ammonia) and water (nitrate) were calculated using methods and factors from the latest NIR report (Commonwealth of Australia, 2025b, a) (as precursors of nitrous oxide).</p> <p>Losses of pesticides to air, water and soil were estimated using partitioning fractions derived from the PestLCI tool (Dijkman et al., 2012).</p>
<b>Industry review</b>	The data prepared as part of the Cotton Research and Development Corporation (CRDC) project had previously been prepared in close consultation with industry, therefore an industry review was not needed.
<b>Sence-checking of results generated by inventory</b>	Sence-checking was conducted by comparing the results generated from the LCI with previously generated results from the CRDC project (Sevenster et al., 2023a). As the underlying dataset was the same the results were consistent.

## Post-farm cotton ginning

<b>Production systems represented</b>	The data represents the ginning of cotton typical of that occurring in Queensland and New South Wales, including transport of harvested cotton bolls to mills, ginning operations to produce cotton lint and cotton seed.
<b>Products represented</b>	<p>The following products / co-products are represented :</p> <ul style="list-style-type: none"> <li>- Cotton lint, at cotton gin</li> <li>- Cotton seed, at cotton gin</li> <li>- Cotton seed oil, at cotton gin</li> <li>- Cotton seed meal, at cotton gin</li> </ul> <p>Cotton gin trash is considered a residue, which does not receive any allocated impacts and is considered 'cut-off' from the process.</p> <p>Inventory is provided at one scale:</p> <ul style="list-style-type: none"> <li>- Australian average</li> </ul>
<b>Regional coverage</b>	A single dataset representing typical Australian sugarcane milling. No differentiation between mills.
<b>Time period</b>	The available data sources were not specific about the temporal representation, but is considered to represent current practices (early 2020s).
<b>Functional unit</b>	Per 1 tonne processed cotton lint at gin gate
<b>Reference flow</b>	Ginning of 100 tonne cotton
<b>Allocation</b>	Cotton seed is considered a co-product to which elementary flows are allocated accordingly. Other cotton processing residues are considered wastes with no allocation. The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products (economic, mass, energy). The default allocation is economic allocation based on economic values for gin products.
<b>Sources of activity data (inputs)</b>	A generic model of cotton gins was developed informed by other existing LCI models of cotton ginning in the ecoinvent® database.
<b>Sence-checking of results generated by inventory</b>	Sence-checking was conducted by comparing the results generated from the LCI with previously generated results from the CRDC project (Sevenster et al., 2023a). As the underlying dataset was the same the results were consistent.

# Rice

## Rice on farm production and post-farm processing

<b>Production systems represented</b>	<p>The data represents vertically integrated rice growing and processing in Australia's main rice producing region.</p> <p>The rice growing inventory includes land cultivation, sowing, fertilising, pest control and weed management, and harvest of wet paddy rice.</p> <p>The rice processing inventory includes transport of wet paddy rice to the processing plant, drying and storage and milling in white rice and co-products.</p>
<b>Products represented</b>	<p>The products / co-products represented are:</p> <p>For rice growing:</p> <ul style="list-style-type: none"> <li>- Rice, wet paddy rice, on farm</li> </ul> <p>For rice processing</p> <ul style="list-style-type: none"> <li>- rice, white, at processor gate (including broken rice)</li> <li>- rice bran, at processor gate</li> <li>- rice husk, at processor gate.</li> </ul> <p>Inventory is provided at one scale:</p> <ul style="list-style-type: none"> <li>- regional average for one region.</li> </ul>
<b>Supporting processes</b>	Sowing, aerial, rice AU.
<b>Regional coverage</b>	Production in the Riverina region of southern NSW, representative of most of Australia's rice production.
<b>Production coverage</b>	Production in the Riverina region represent the majority of rice grown in Australia (approximately 95%) (Australian Bureau of Statistics, 2024).
<b>Time period</b>	Production in the 5-year reference period 2019 - 2023
<b>Functional unit</b>	Per 1 tonne harvested wet paddy rice at farm.
<b>Allocation</b>	<p>For rice growing, no allocation was required.</p> <p>For rice processing, husks and bran outputs are considered co-products to which elementary flows are allocated accordingly. The inventory is parameterised to enable different allocation methods for assigning impacts to the multiple products (economic, mass, energy). The default allocation is economic allocation based on economic values at the time.</p>
<b>Sources of production data</b>	Yields for rice growing and processing were provided by Australia's main rice producer.
<b>Sources of activity data</b>	For both rice growing and processing, details of practices and inputs were consistent with gross margin information for rice (Ward, 2018) and validated by an Australian rice producer.
<b>Models for estimating direct emissions / releases to the environment (outputs)</b>	<p>Methane emissions from paddy fields were calculated using the emission factors from the latest NIR (Commonwealth of Australia, 2025b, a). The national inventory emission factor of 1.06 kg CH<sub>4</sub> / ha /day flooded was multiplied by the number of days flooded.</p> <p>Other GHG emissions for foreground systems (nitrous oxide, cane burning emissions, emission from residues etc.) were also calculated based on the latest NIR</p> <p>Nitrogen releases to air (ammonia) and water (nitrate) were calculated using methods and factors from the latest NIR (Commonwealth of Australia, 2025b, a)(as precursors of nitrous oxide).</p> <p>Losses of pesticides to air, water and soil were estimated using partitioning fractions derived from the PestLCI tool (Dijkman et al., 2012).</p>
<b>Industry review</b>	Data and assumption were validated by an Australian rice producer.
<b>Sense-checking of results generated by inventory</b>	The LCI data were sense-checked by comparing the impact assessment results generated from the LCI data with the results reported in other published LCA studies, which were identified from the work of Clune et al. (2017).

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