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# AusAgLCI methodology for developing Life Cycle Inventory



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**Rural Industries Research and  
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# **AusAgLCI methodology for developing Life Cycle Inventory**

By Tim Grant, Helene Cruyppenninck, Sandra Eady and Gonzalo Mata

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AusAg LCI –Methodology for developing life cycle inventory  
*Publication No. 14/046*  
*Project No. PRJ-007363*

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# Foreword

Over the last decade there has been a significant focus on the environmental impact of products and services across the economy, resulting in environmental product declarations and delivery agreements where the supplier is required to demonstrate an on-going improvement program of environmental sustainability. Once action is required, primary producers need to be able to make an objective assessment of their environmental impact (by Life Cycle Assessment, LCA) so that “hot spots” in their production system can be identified, and options to reduce these impacts can be investigated.

Country specific Life Cycle Inventory (LCI) for agricultural products is essential for Australian agriculture to undertake environmental impact studies related to food and fibre, especially where differences in management systems and regional climate, soils and vegetation significantly affect LCA results.

The goal of inventory collection for AusAgLCI was to provide underlying data to ensure Australian primary producers can readily, and objectively, demonstrate that their products are being produced in a responsible manner, in a system where environmental assessment is used to aid and drive improvements. This will assist producers to meet marketing requirements and to benchmark their production in global markets.

To this end, the AusAgLCI project has delivered a scientifically robust, standardised and transparent system for developing life cycle inventory specific to Australian agricultural production with key inventory being prepared for cotton, grains, horticulture, livestock feeds and sugar. Publication of AusAgLCI gives LCA practitioners access to country specific inventory that they can use to assess supply chains that contain Australian agricultural inputs.

The AusAgLCI database and guidelines are available for download at <http://alcas.asn.au/AusLCI/index.php/Datasets/Agriculture>

This report is an addition to RIRDC’s diverse range of over 2000 research publications and it forms part of our Global Challenges R&D program, which aims to improve agricultural productivity.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at [www.rirdc.gov.au](http://www.rirdc.gov.au). Purchases can also be made by phoning 1300 634 313.

**Craig Burns**  
Managing Director  
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# About the Author

Mr Tim Grant is a specialist in life cycle assessment (LCA) with sixteen years' experience developing and applying LCA and ecological footprints with a wide range of companies and organisations. His work spans across many different sectors including agriculture, energy, fuels, water products, buildings and waste management. He has taught LCA in six universities in Australia and Asia and runs professional development courses in LCA practice. Mr Grant is the Director of Life Cycle Strategies Pty Ltd and an Adjunct Research Fellow with CSIRO and prior to these positions worked as the Manager of Life Cycle Assessment program at RMIT University Centre for Design.

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Dr Sandra Eady is a Principal Research Scientist based at CSIRO Animal, Food and Health Sciences, Armidale, NSW. Dr Eady is a geneticist with expertise in developing national breeding programs and implementing them on-farm. Her current activities, in CSIRO's Sustainable Agriculture Flagship, expand her expertise in farming systems to the area of life cycle assessment, determining the carbon and water "footprint" for agricultural products, on-farm greenhouse gas emissions profiles and opportunities for biosequestration of carbon.

Mr Gonzalo Mata's research activities in the 25 years with CSIRO range from protein and amino acid metabolism in grazing sheep and satellite remote sensing of farming systems to LCA for inventory development of crop production with a focus on regional differentiation of global warming impacts, through the use of GIS in primary and secondary data collection.

# Acknowledgments

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# Executive Summary

This methodology report aims to provide more detailed explanation of the approach taken within the AusAgLCI life cycle inventory project. It also provides future developers of agricultural LCI with guidance on the recommended practice to develop similar inventory data which will be consistent with the AusAgLCI data. The document does not provide a detailed explanation of all inventory data developed in AusAgLCI. Specific detail on the inventory calculations is provided within the inventory itself.

While the AusAgLCI project is focusing on LCI, it is done with a view to enable the broadest possible use of the data in LCA studies. In this project we have nominated the main indicators for agricultural studies and attention has been put into supplying the inventory data required to inform these indicators. The nominated indicators are:

- Global warming
- Depletion of water resources
- Land use
- Eutrophication
- Ecotoxicity

AusAgLCI data are a subset of the AusLCI database and therefore share the same basic structure. Some considerations for structuring the inventory have been:

- Transparency of the modelled data- All assumptions and calculations should be apparent from within the datasets.
- Updateability - changes to the datasets over time should be as easy as possible through updating of key production parameters automatically propagating to update the entire inventory.
- Configurability – to allow users to use the datasets as a starting point which can be easily modified to the user's local circumstances.
- Simplicity – avoiding unnecessary disaggregation of the inventory. The whole farm growth stage is normally contained in one process. For perennials such as orchards, the establishment phase and mature operation phase are modelled separately.
- Modularity – tractors, irrigation, fertilisers and so on have been made as standalone modules for use within the inventory.

The AusAgLCI project is premised on the collection and publishing of publicly available data. The vast majority of this data has been sourced from Gross Margin documents provided by the agricultural departments in each state. Gross Margin documents provide farmers with a mass balance for the production of a crop and an economic balance which estimates the likely returns to the farmer. For many of the older Gross Margin documents, updates were required as practices have changed. This was particularly the case with pesticides, which are continually evolving.

A total of 176 life cycle inventories were developed by the project. Of this, 56 are agriculture products and the remaining inventory are input processes used by those inventories.

The data presented in AusAgLCI is provided by data suppliers with no warranties as to its accuracy or correctness. Like all LCI data, the AusAgLCI data should be used with caution, and it is the responsibility of the user to determine if the data is appropriate and adequate for their situation. Data contained in AusAgLCI covers individual unit processes, or cradle-to-gate processes where indicated, but not full life cycle data.

# Introduction to the AusAgLCI Database v1

## The purpose of the AusAgLCI database

Country specific Life Cycle Inventory (LCI) for agricultural products is essential for Australian agriculture to undertake environmental impact studies related to food and fibre, especially where differences in management systems and regional climate, soils and vegetation significantly affect LCA results. AusAgLCI delivers a framework for transparent and robust LCI in a form that can be accessed by Life Cycle Assessment (LCA) practitioners both within Australia and internationally.

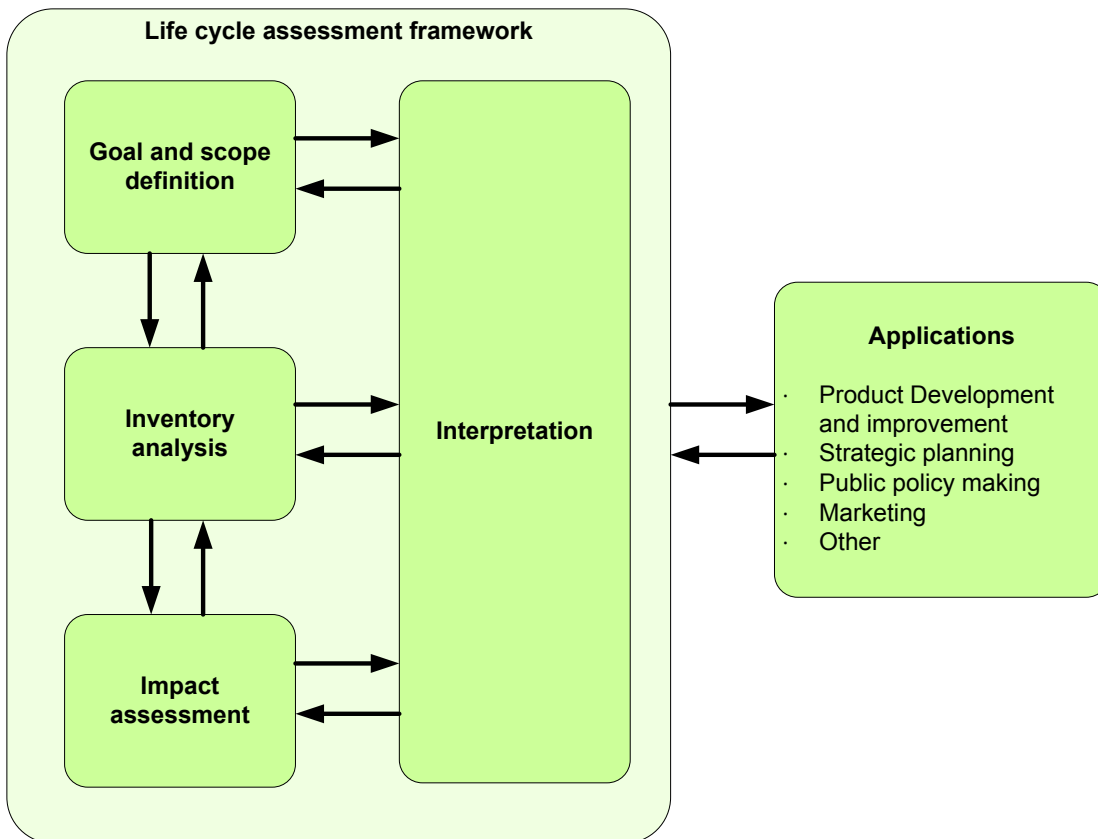
## The Purpose of This Document

This methodology report aims to provide more detailed explanation of the approach taken within the AusAgLCI life cycle inventory project. It also hopes to enable future developers of agricultural LCI with guidance as to the recommended practice to develop similar inventory data which will be consistent with the AusAgLCI data. The document does not provide a detailed explanation of all the inventory data developed in AusAgLCI. Specific detail on the inventory calculations is provided within the inventory itself.

## Project scope and definitions

### LCA and LCI

The different phases of a LCA are shown in Figure 1. The inventory analysis step consists in identifying the flows into or out of a product system, to or from nature. These 'inventory flows' include inputs such as water, energy and raw materials; and releases to air, soil, and water. This inventory analysis has to be conducted for each stage of the life cycle of a product. In order to simplify this inventory task, LCI databases supply LCA practitioners with relevant data for each of the processes in a supply chain. The LCIs provided in these databases are valid for a given process, technology, region and timeframe.



**Figure 1: Life Cycle Assessment phases**

Source (International Organization for Standardization 2006)

LCI is made up of individual unit processes which connect to produce the overall product system. The typical unit processes for agricultural products are shown in Figure 2, with the central farm process being supplied from many other unit processes such as tractor processes and irrigation processes, many of which are common to several agricultural commodities (shown in green boxes in Figure 2).

For inputs required by the agricultural process which have not been collected in this project, background data are supplied by the AusLCI shadow database (shown in blue boxes in Figure 2). This database is modified version of a global database produced by ecoinvent<sup>®</sup>, based in Switzerland (ecoinvent Centre 2010). Processes for which the inventories are supplied by the shadow database included pesticide manufacture, fertiliser, tractor production and tractor emissions. This background data is not published as part of AusAgLCI due to licensing conditions but the inputs from this data are identified so that users can link to them once they download the AusAgLCI unit processes. The background data are included in the calculations of the system processes for cradle to harvest inventory data.

Finally there are direct elementary flows (shown in brown boxes in Figure 2) within the farm process itself such as land occupation and emissions of pesticides, nitrate and nitrous oxide. The boundaries for the LCIs produced in AusAgLCI are mostly from cradle to harvest.

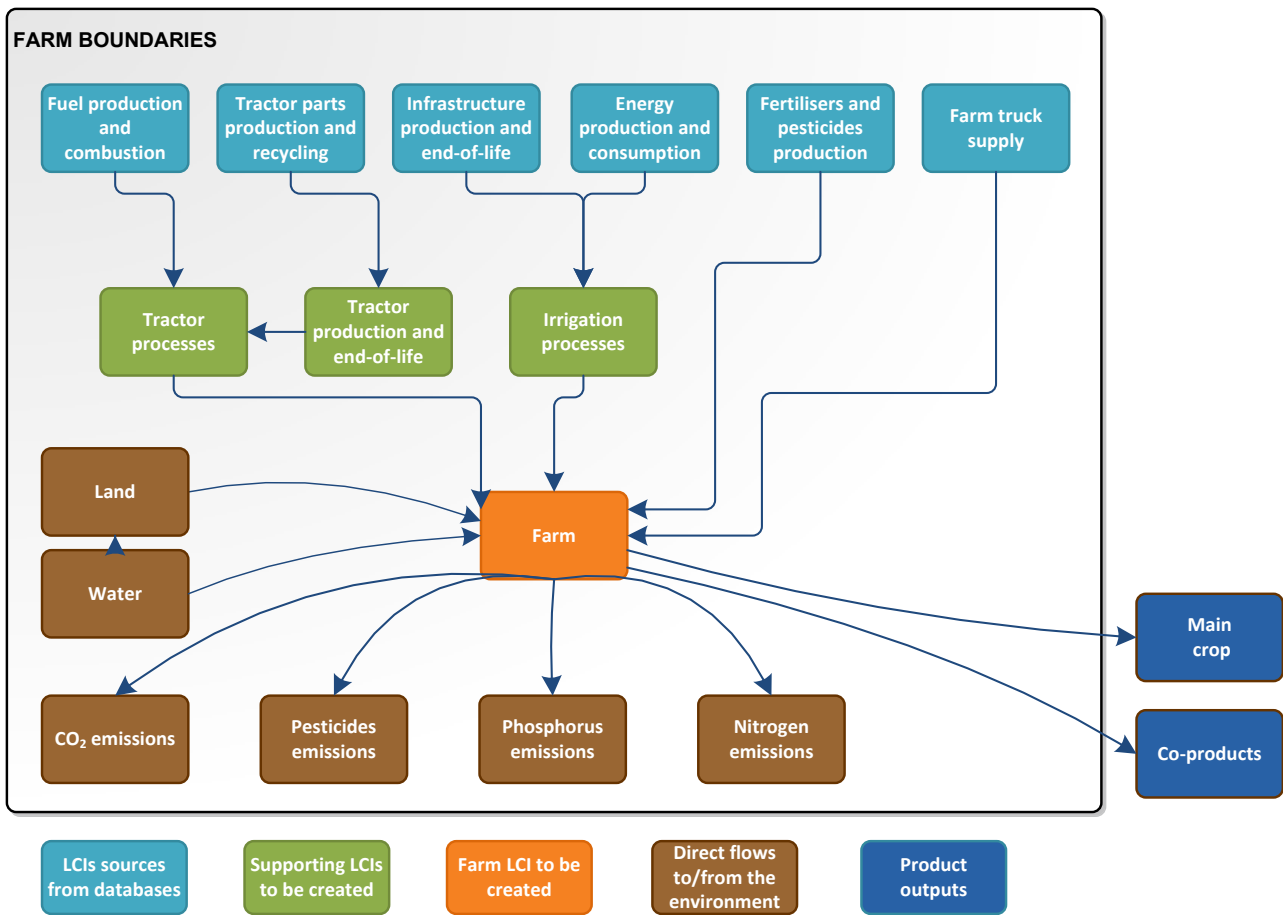


Figure 2: LCIs interaction and farm LCI boundaries

## Category Indicators of Interest

While the AusAgLCI project is focusing on LCI, it is done with a view to enable the broadest possible use of the data in LCA studies. The ISO standard 14044 (International Organization for Standardization 2006) states that a comprehensive set of environmental indicators should be included taking the product system into account. In this project we have envisaged what are the important indicators for agricultural studies and attention has been put into supplying the inventory flows required as inputs to these indicators. These indicators are

- Global warming
- Depletion of water resources
- Land use
- Eutrophication
- Ecotoxicity

## Global Warming

Unlike most environmental indicators, global warming has a large number of international agreements and methodologies which require adherence to standardised calculation approaches. To support this AusAgLCI greenhouse gas (GHG) flows are based on IPCC (2006) and National Inventory Report (DCCEE 2011) methodologies. This includes emissions directly associated with production such as direct and indirect GHG emissions from fertiliser use, burning of stubble and emission from crop residues.

Where the international methodology does not have consensus but there is insufficient causal link between the farm process and emission source, we have either excluded the flow altogether, for example soil carbon change, or included the flows in a separate module which can be added by the LCA practitioner where it is appropriate. An example of this is direct land use change.

## Water use

Elemental flows required to support a range of impact assessment approaches are included. The water flows proposed in AusLCI guidelines are shown in Table 1. To enable the use of the water flows in current water footprint models, the flows will be post scripted with an AU to identify the water flows as Australian. As agreement is reached on more local geographic regions for identifying water extraction characteristics, these can be added to the flows.

**Table 1: Water elementary flows in AusLCI**

Direction of flow	Flow name
Inputs from nature	water, groundwater, non-fossil
Inputs from nature	water, groundwater, fossil
Inputs from nature	water, groundwater, unspecified
Inputs from nature	water, surface, river
Inputs from nature	water, surface, lake
Inputs from nature	water, surface, rainwater*
Inputs from nature	water, surface, unspecified
Inputs from nature	water, unspecified
Inputs from nature	water, ocean
Outputs to nature	water, release to groundwater, non-fossil
Outputs to nature	water, release to river
Outputs to nature	water, release to lake
Outputs to nature	water, release to estuary
Outputs to nature	water, release to ocean
Outputs to nature	water, evaporated

\*Refers to rainwater intercepted and held in a tank – does not refer to rainwater falling on crops or other system which are considered part of natural flow.

Rainfall, sometimes referred to as “green water” is not included in the inventory at this time as there is no clear methodology for how to treat natural processes or rainfall and runoff as compared to what happens when a farming system interacts with this process. Technically a land use change which changes run off characteristics could be taken into consideration however no such changes have been included in AusAgLCI to date.

## Land use

Land use and land use change is an important impact category in LCA, especially for agricultural production. The difficulty for AusAgLCI is that the methodology for assessing impacts relating to land use is still in development. The approach taken in AusAgLCI is to try and provide enough information in the inventory to serve current and possible future developments in land use impact assessment.

The land use approach taken by some common impact methods is shown in Table 2, along with the elementary flow that is required to use the method. We can see that land occupation is required with a classification of land type and/or the type of land use for all models. Currently AusAgLCI does not record prior land use as this is generally impractical from a data supply point of view. The choice of classification system for land use categories is important to make the data globally applicable but also locally relevant. AusAgLCI uses the same land use categories as ecoinvent<sup>®</sup> which are shown in Appendix G.

**Table 2: Common land use impact method and the inventory required to use them**

IMPACT METHOD	BASIS FOR CHARACTERISATION	ELEMENTARY FLOWS REQUIRED
Impact World +? (Saad, Margni 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.
ReCiPe Method (Goedkoop, Heijungs et al. 2009)	Based on direct and indirect impacts land occupation of biodiversity through exclusion of reestablishment. 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
Indirect land use change model (LCA 2.0 Undated)	Based on demand for global land markets as the driver for land use change. Based on NPP of land occupation. NPP is potential without fertiliser or irrigation.	Occupation by land type.

Land transformation is included as optional in the AusLCI guidelines but is compulsory in the ecoinvent<sup>®</sup> database. In AusAgLCI the approach has been to require strong evidence to annual and ongoing land transformation and to be directly related to the product system under study. This was not demonstrated for any of the production systems currently in the inventory.

In production systems where land is used from year-to-year for the same activity, the land transformation is entered as two flows which cancel each other out. For example land transformation from arable land, and land transformation to arable land. This simply states what the land was prior to occupation and what it will be after the application.

Specific emissions from land use or land use change are documented separately to the land occupation and land transformation flows.

## Eutrophication

Eutrophication is caused by nitrogen and phosphate emissions to water bodies which has the potential to increase biological activity, change species composition and in certain circumstance lead to excess algae production which can dramatically affect the water quality.

For consistency with the modelling of in climate change, nitrogen flows are estimated using Australian NIR methodology (DCCEE 2011). Phosphorus flows are estimated by the method used by ecoinvent<sup>®</sup> (Nemecek *et al.* 2007). Both methods are responsive to fertiliser inputs, use regional data (at the intersection of GIS layers for agro-ecological region (Williams, Hamblin *et al.* 2002) and land use (BRS 2010)) to determine if leaching and run-off is occurring (yes if >50% of the area meets conditions for leaching), and to estimate net export of soil (relevant for P transport to waterways).

The methods do not take into account more detailed spatial and temporal variation in weather and soil conditions. Approaches to quickly locate relevant data on nutrient flows at this finer scale were investigated, in the first instance using BiosEquil (Raupach *et al.* 2001). The work required to successfully complete this was beyond the scope of this project but would be a sensible future investment.

## **Ecotoxicity**

Ecotoxicity and a significant part of human toxicity is driven by the use of chemicals in cropping systems. The nature of pesticides is that they are toxic, at a minimum, to the target species for which they are designed. To measure the ecotoxicity of a pesticide within the farm boundary therefore makes little sense. To get around this problem the PestLCI model was used (Dijkman *et al.* 2012) which looks at the farm as part of the techno-sphere and only measures what leaves the farm to water, as drift and below the soil profile to groundwater.

Flows of specific active ingredients to soil, water and air were estimated from PestLCI, adapted to Australian conditions (Dijkman *et al.* 2012). The parameters in the model that have been modified for Australian conditions are climate related (temperature, precipitation, evaporation, solar radiation), soil characteristics (depth, proportion sand, silt and clay, pH, organic content, bulk density), and field data (slope). Profiles for use in PestLCI have been constructed from GIS layers at the intersection of agricultural land use and agro-ecological region. A number of pesticides used in Australia have been added to the model, using readily available data on key parameters (molecular weight, solubility, vapour pressure, half-life in soil). Air emissions from the farm from drift are recorded as emissions to soil, assuming they deposit on soil off the farm.

AusAgLCI also allows via a switch in the inventory to use the conventional approach to put 100% of pesticide applied into the soil compartment.

Regardless of which approach is used in the inventory, the emissions to the environment from the farm are evaluated by the eco-toxicity impact assessment methods (the most widely used being USETox; Rosenbaum *et al.* 2008) to determine the ultimate fate of the chemicals in the environment. These models use the same type of modelling used in PestLCI, but without farm or location specific information. Because both PestLCI and USEtox model degradation and movement of the pesticides as a linear process, the use of the two models do not represent any double counting of fate or degradation.

## **Other indicators**

In addition to the indicators above, the use of high quality upstream input data allows other indicators to be calculated including fossil and mineral depletion, photo oxidant formation, stratospheric ozone depletion, and ionising radiation.

## **Indicator model not fully supported**

### **Particulate matter formation**

Particulate matter, either directly from farming activities or indirectly from combustion of farm residues, is not included in the inventory currently due to a lack of available data.

## **Human Toxicity**

While the work on pesticide fate models will have some impact on human toxicity the current portioning models do not include plant uptake of pesticides which is most likely the most significant pathway for human toxicity. For this reason the method does not claim to support human toxicity impacts.

# Structure of the inventory

## Introduction to data structure

AusAgLCI data are a subset of the AusLCI database and therefore share the same basic structure. Some considerations for structuring the inventory have been:

- Transparency of the modelled data- All assumptions and calculations should be apparent from within the datasets.
- Updateability - changes to the datasets over time should be as easy as possible through updating of key production parameters automatically propagating to update the entire inventory.
- Configurability – to allow users to use the datasets as a starting point which can be easily modified to the user’s local circumstances.
- Simplicity – avoiding unnecessary disaggregation of the inventory. The whole farm growth stage is normally contained in one process. For perennials such as orchards produce and establishment phase and mature operation phase are modelled separately.
- Modularity – tractors, irrigation, fertilisers and so on have been made as standalone modules for use within the inventory.

## Background datasets used

AusAgLCI has developed foreground data for farm systems however these systems need to link to upstream inventory data, or background data. Four types of background data have been used in AusAgLCI (and AusLCI) shown in Table 3.

**Table 3: Types of background data used in AusAgLCI and AusLCI**

Data type	Description
AusLCI processes	Processes which have been published by the AusLCI project including any data developed as part of the AusAgLCI project(ALCAS 2013) .
Unreviewed AusLCI processes	AusLCI guidelines allow for small flows to be estimated. These unreviewed processes may be designed from scratch or may be modified versions of the shadow database.
Shadow database	The shadow database is a version of the ecoinvent® database which has been globally modified to use all available AusLCI data so it provides default background data for Australian production when no other data is available(Rouwette 2013).
ecoinvent® database	Where the input is not from Australian production and a global supply process is available in ecoinvent® this should be used at the input in preference to the shadow database(ecoinvent Centre 2010).

## Allocation

The AusLCI guidelines provide an allocation hierarchy for co-producing processes which is shown in Figure 3. Particular attention has been paid to the difference between combined production and joint production in this database. According to the UNEP/SETAC life cycle initiative global guidance principles on database development (UNEP/SETAC Life Cycle Initiative 2011) combined production is where the ratio of the two products produced can be independently varied while joint production the co-product is produced in a fixed ratio compared to the main product. For example in a mixed breed sheep farm the ratio of wool and meat produced can be varied by changing the flock structure (for instance, culling animals at a younger or older age) to change the ratio of products produced from the system. By contrast in almond production hulls and husks are produced at a fixed ratio to the almond kernels.

**Figure 3: Allocation hierarchy from AusLCI**

- 1 Avoid allocation by subdividing systems** - In accordance with the ISO 14040 standards: “Wherever possible, allocation should be avoided by dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes. If this is not possible then:
- 2 Publish inventories prior to allocation** – The co-production inventories should always be published in an un-allocated form and provide such information which would allow practitioners to use or test alternative allocation approaches. Having done this data should be provided to allow the inventory to be allocated based on the following:
- 3 Use underlying physical relationships between input and outputs** - In accordance with the ISO 14040 standards: “Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.” Where it’s not possible to establish such underlying physical relationships then:
- 4 Apply economic allocation to co-products** - For multi-output processes allocation of co-products based on economic relationships can be used. Such decisions are required in most life cycles, for elements such as fuels and materials production. Economic allocation requires price information for commodities. Short term fluctuation in prices could have an impact on the LCA results and therefore this should be avoided by looking at a long term price trend (for example 5 years).

This hierarchy has been followed in AusAgLCI and the interpretation is outlined in Table 4.

**Table 4: Approaches used to deal with coproduction in the AusAgLCI inventories**

Situation	Approach Taken	Comments
Mixed cropping system	No attempt has been made to allocate the impacts or benefits of one crop on the following crop. Each crop is treated independently even though there may be small benefits passed on from prior crop to following crop.	The data used for the inventory are from Gross Margin data which is based on typical practice in current farm conditions which included the presence of break crops and other mixed cropping and grazing effects. For LCA wanting to investigate the benefits of crop rotations and interaction with livestock, these interactions will need to be modelled.
Coproduction of products with positive economic value	Economic allocation used	This applies to sugar and its co-products (bagasse and molasses), cotton lint and seed, almonds kernels and almond hulls and husks, and canola meal and oil.
Coproduction of straw with wheat	No allocation	Currently ignored in most wheat crops as only small percentage of straw is removed for sale, and, after accounting for the value of straw, represents less than 1% of the value of wheat.
Coproduction of wheat with straw	Economic allocation	For the production of straw, economic allocation between wheat and straw inventory is used. While this appears inconsistent with the prior item, it is thought that only a small proportion of wheat farms actually produce straw. So from a wheat production perspective the straw production is insignificant, from a straw production perspective, 100% of straw comes from wheat farms producing straw, so and allocation is important aspect in the inventory for straw. More work is required to develop national coverage for wheat production including the extent of straw production.
Dedicated manure crop/ fallowing of land	All allocated to following crop	Where a crop is grown specifically to fix nitrogen or improve land condition, its impacts are allocated fully to the following crop.

## Uncertainty

The AusLCI requirements document recommends that data providers add uncertainty estimates to data provided into AusLCI. Where specific uncertainty data is not available, the uncertainty is to be estimated using the approach developed by the ecoinvent<sup>®</sup> database. This method involves the use of standard “basic” uncertainty for different types of flows which are then adjusted based on the data quality characteristics of the flows. The full detail of the estimation technique is provided in Appendix H.

Basic uncertainty factors, produced in the ecoinvent<sup>®</sup> guidelines are shown in Appendix H while Table 6 shows the selected basic uncertainties for specific flows in AusAgLCI.

The basic uncertainties are modified by the data quality indicators using a data pedigree matrix also developed as part of the ecoinvent® project. Five data quality characteristics used are shown in Table 6 along with the assumptions used to characterise the Gross Margin data used in AusAgLCI.

**Table 5: Basic uncertainty factors used for specific flows in AusAgLCI (square of the standard deviation assuming a lognormal distribution)**

Flow	Square of Standard deviation
Pesticides fraction to water	1.5
Pesticides fraction to soil	1.2
Heavy metals to soil	1.5
Soil erosion	1.05
All material and energy flows	1.05

**Table 6: Data quality score used for Gross Margin (GM) data input via pedigree matrix**

Flow	Square of Standard deviation	Comment
Reliability	Verified data based on assumptions	GMs are prepared by agronomists based on assumptions about local conditions
Completeness	Representative data from only some sites (<50%)	Usually GMs refer to typical farm in the region
Temporal correlation	Less than 3 years of difference to our reference year	Used regardless of the age of the GM as all GMs were updated with up to date information
Geographical correlation	Data from area under study	GMs have not been applied beyond the region they are from
Further technological correlation	Data from enterprises, processes and materials under study	GMs have only been used to model the crop which they represent

# Collection of data

## Data sources

The AusAgLCI project has been premised on the collection and publishing of publicly available data. The vast majority of this data has been sourced from Gross Margin documents provided by the agricultural departments in each state. A full list of Gross Margin publications and data sources can be found in the AusAgLCI Final Report (Eady *et al.* 2014). Gross Margin documents provide farmers with a mass balance for the production of a crop and an economic balance which estimate the likely returns to the farmer. For many of the older Gross Margin documents updates were required as practices have changed. This was particularly the case with pesticides, which are continually evolving and being updated. Gross Margin documents vary substantially in format and some interpretation is required to convert the data into life-cycle inventory. Figure 4 shows an example of how the Gross Margin documents have been interpreted to develop inventory.

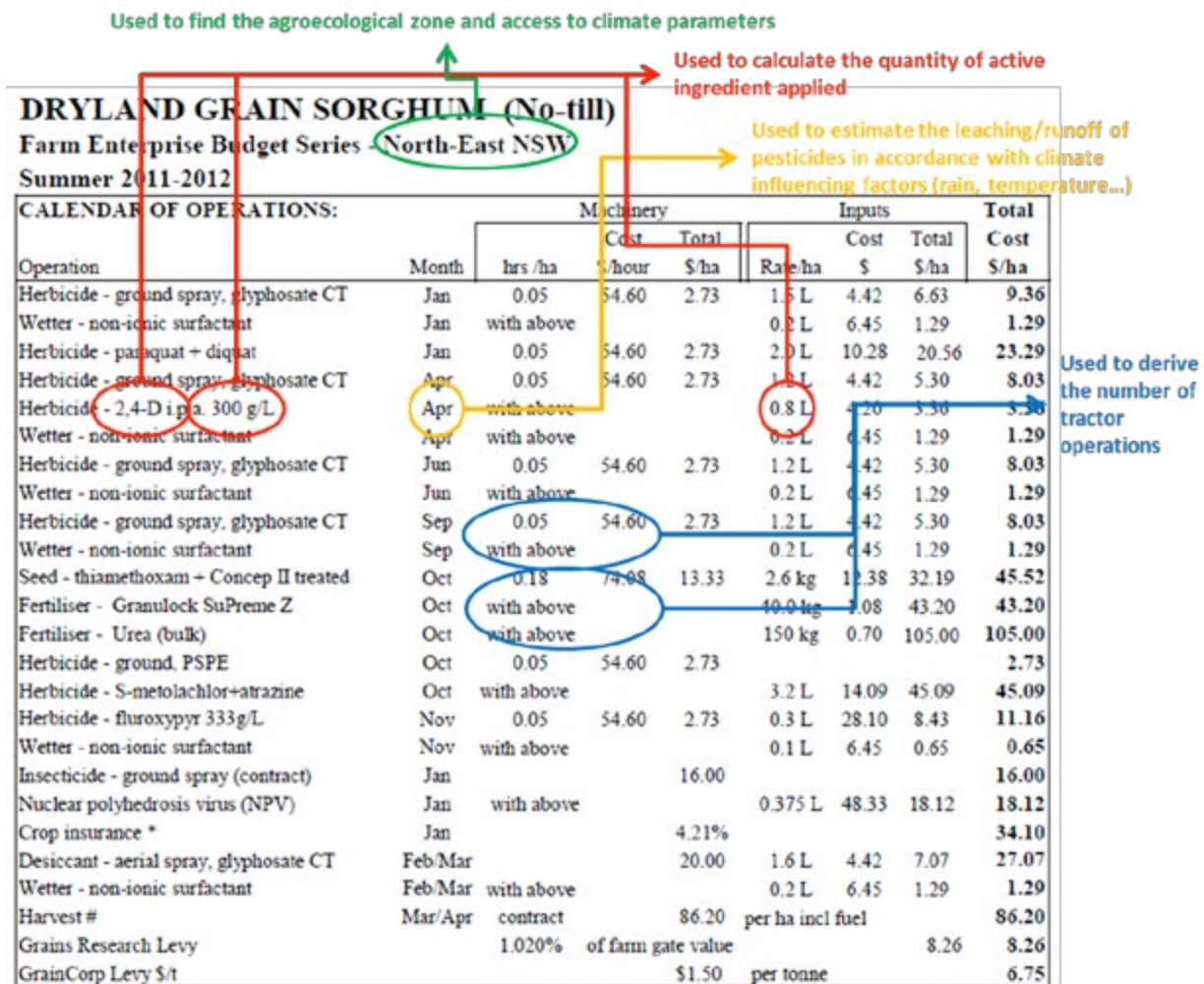


Figure 4: Use of information available in Gross Margin analyses for broad acre cropping systems

## Filling data gaps

Once the original inventory was developed it was reviewed by a panel of technical experts nominated by the relevant agriculture research body and updated to reflect any changes in the industry or to reflect more typical practice across a broader group of farms. The inventory was also supplemented by other data sources for things like machines, tractors, fertiliser composition and pesticide formulation. For some industries, for example cotton, there were industrywide surveys available for use in the inventory and these were used in preference to Gross Margin data. Assumptions around nitrogen flows were taken from the National Greenhouse Gas Inventory reports or the IPCC documents. There was also a substantial amount of expert opinion supplied by farm agronomists in the modification and supplementation of the gross margin data. This was documented in the review process during the production of the inventories.

## Geographical scope

### Geographical coverage of LCIs

For the sugar<sup>1</sup> and cotton inventories a weighted average of Australian production has been developed, while for all other commodities production was modelled on specific regions as coverage was not broad enough to attempt to produce a national average.

### Geographical data used in the LCIs

The calculation of flows contributing to a number of the impact categories (global warming, eutrophication and ecotoxicity) includes climate parameters, which vary significantly across Australia. Many of those data are available as GIS layers and these were used to parameterise the flow models. The first step in this process was to segment Australia into regions where climate and soil parameters would be relatively uniform. We have used the agro-ecological regions defined by Williams et al. (2002) as shown in Figure 5. The regions have been intersected with the type of agricultural land use (ABARE-BRS 2010). The relevant types of agricultural land uses are: wheat, cotton, sugar, perennial horticulture, seasonal horticulture and grazing of pastures.

From the intersection between agro-ecological regions and the agricultural land use classification a total of 178 sub-regions were defined. Appendix D presents the relevant types of agricultural land uses defined and the agro-ecological regions where that land use class is found.

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<sup>1</sup> A small area of sugar production in northern New South Wales is not currently included.

## Agroecological regions of Australia and the Land Use Classes for products in the AusAgLCI database

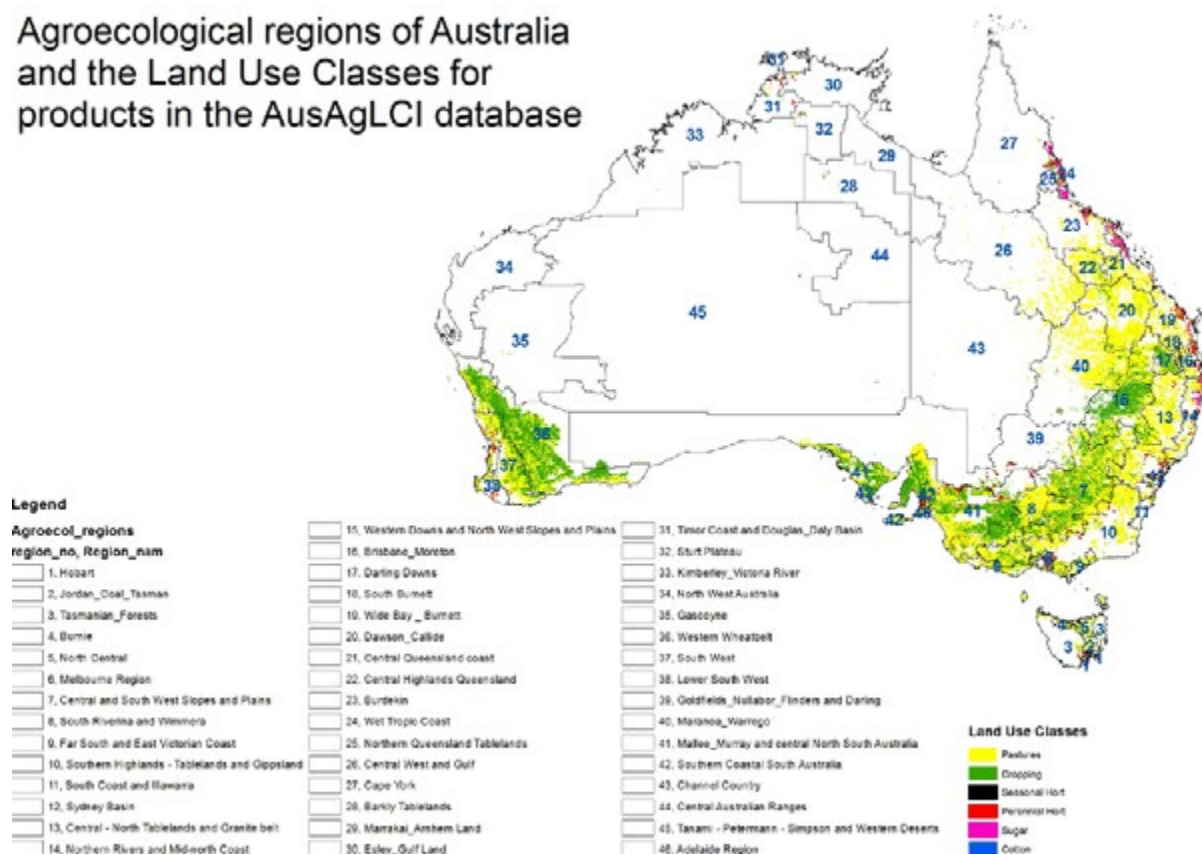


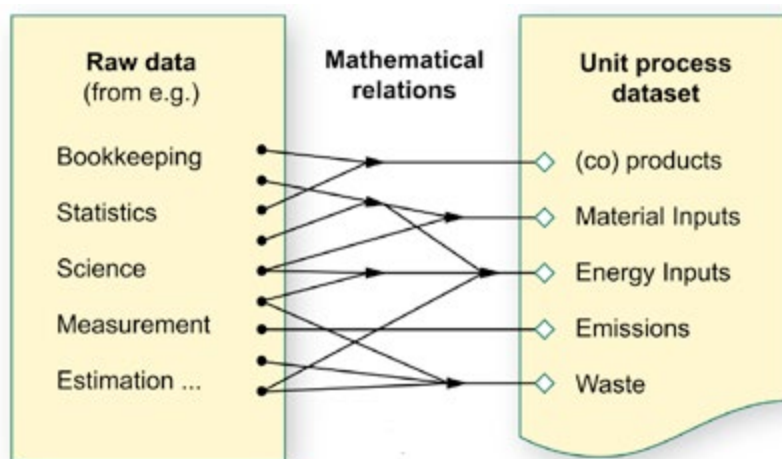
Figure 5: Agro-ecological regions and key land use classifications used in AusAgLCI (Williams, Hamblin et al. 2002; ABARE-BRS 2010)

## Technological and temporal scope

The life cycle inventories developed in AusAgLCI are based on current average technology where possible. This has been achieved by updating the gross margin documents with current practice as advised by technical specialists within the industry. This means that the temporal scope of the data is for 2013 and it should be suitable for use for up to 5 years, depending on the rate of change within industries.

## Data modelling

Figure 6 shows that inventory data are made up of primary data inputs which are transformed by mathematical relationships to produce the final inventory data. This structure separates the primary inputs from the mathematical relations, making updating the data easier in the future. Within the inventory the primary data are entered as parameters while the mathematical relations are entered as mathematical formula and the inventory flow is entered as a calculated parameter. This approach also provides transparency to users of the data as to the underlying assumptions and transformations involved in the inventory. It also allows the user to easily customise inventory for specific applications. For example, the impact of changing farm practices that reduce N<sub>2</sub>O emissions from fertiliser can be quickly evaluated by changing one value for the N<sub>2</sub>O emissions factor, and this will flow through to calculations throughout the inventory.



**Figure 6: Structure of inventory modelling**

Source: (UNEP/SETAC Life Cycle Initiative 2011)

## Transport

### Primary data

All farm inputs such as fertiliser and pesticides are assumed to have a transport distance of 200 km by articulated truck with average Australian transport efficiency. Additionally most of these inputs also have transport from the point of manufacture up to a regional storage point. While more specific data could be collected for each farm production region, the contribution of transport to the total farm impacts is typically less than 1% making the generic assumptions appropriate to the inventory.

Where transport of products has been required beyond the farm gate this has been estimated specifically for each agricultural commodity. This was required for sugar, cotton and almond production where the inventory modelling included some downstream processing.

### Mathematical relations data transformations

The total transport requirement was calculated by multiplying the mass of individual inputs by the net transport distance assumed for each of these inputs. The output of this calculation is used with the articulated truck, average freight transport inventory from the AusLCI database.

### Seed and seedlings

For broadacre crops - seed production is subtracted from the yield based on the recommended seed quantity in the gross margin report. While this is a simplification, as some crops may have seed produced elsewhere, the production process for seed is likely to be similar to the standard crop production. There overall impact of seed is well below 1% threshold of impact so this simplification is justified. For crops where seedlings are required these are modelled as a separate production process.

### Primary data required

Seed requirements are provided in the gross margin reports used for cropping system.

## Mathematical relations data transformation

Net crop yield is calculation from gross crop yield – seed requirement.

## Farm machinery

Machinery includes tractors and implements as well as any other mobile equipment used for land preparation, growing or harvesting processes.

Numerous and various tractors and implements are used in agricultural production processes. For some of those processes, inventories have already been developed in LCA databases such as ecoinvent<sup>®</sup> (ecoinvent Centre 2010). However, most of those processes refer to Swiss conditions and are not suitable for Australian conditions, mainly because crop yield, soil type and scale of operation, which impact on a tractor's fuel consumption, are not the same.

## Primary data required

The Table 7 lists the data required to produce a tractor process inventory. It was considered that production systems in the United States (technology, age of equipment, mode of operation) are similar to the Australian context.

**Table 7: Primary data required for tractor process inventories.**

Data	Unit	Source
Tractor power	kW	Manufacturer
Tractor life-time	Hours	(The University of Arizona 2002)
Tractor speed	km/h	(The University of Arizona 2002)
Fuel consumption	l/ha	Farm Fuel Calculator (Salam 2010)
Implement width	M	(The University of Arizona 2002)
Implement life-time	Hours	(The University of Arizona 2002)
Implement weight	Kg	Manufacturer
Type of fuel consumed	-	Manufacturer

## Mathematical relations data transformation

Tractors processes have a functional unit of one hectare of field processed. Inventories include:

- Tractor and implement production, maintenance and disposal. The impacts of these items are amortised over the expected life-time of the tractor and implement.
- Fuel consumption and combustion which has been sourced directly from the farm energy calculator or from crop specific information.

Equation 1 shows how tractor manufacture is calculated for each hectare of tractor operation. Step one of the calculation is to calculate the tractor mass from the tractor power based on a regression formula outlined in Appendix A. The second step calculates the time to process 1 ha. The third step divides the time to process 1 ha by the total life of the tractor and the final step is to multiply the fraction of tractor time by the tractor

mass. The impacts of the implement manufacture are calculated in exactly the same manner except that the implement mass is taken from manufactures' specification and are not derived from the tractor power correlation.

$$(1) \text{ Tractor mass} = \text{tractor power} * 37.408 + 686.37$$

$$(2) \text{ Time (h) to process 1 ha} = \frac{1}{\text{speed in kilometres per hour} * 1000} * \text{Width (m)} * m^2 \text{ in 1 ha}$$

$$(3) \text{ Fraction of tractor manufacture for 1 ha of operation} = \frac{\text{Time to process 1ha}}{\text{Total expected life}}$$

$$(4) \text{ Tractor manufacture (kg/ha)} = \text{fraction of manufacture for 1 ha} * \text{tractor mass}$$

**Equation 1: Formula to derive the mass of tractor manufacture to be allocated to 1 hectare of operation.**

## **Background data**

Background data for evaluating the environmental impacts of tractor processes (e.g. environmental impacts for the production of implement) are sourced from ecoinvent<sup>®</sup> (ecoinvent Centre 2010) databases, see Table 8.

**Table 8: Background data used for machinery inventories.**

DATA	SOURCE
Fuel production and combustion	<b>Tractor engine operation, on farm, per litre of diesel consumed/AU U</b> The inventory covers the production of diesel, its supply to the farm and the emissions from combustion in tractor engine. The basis for this inventory is an ecoinvent® process for tractor use however it is rescaled to 1 L of diesel used however it still has the same emission profile as the original ecoinvent® process.
Tractor production, repair, maintenance and disposal	<b>Tractor, production, per kg/CH/I U</b> The inventory takes into account the use of resources and the amount of emissions during the production, the maintenance and repair and the disposal of agricultural vehicles. Calculations were made based on a tractor of 3000 kg, with a useful life of 7000 hours and a repair factor of 0.74. The repair factor is the ratio inputs for repair compared to original manufacture.
Harvester production, repair, maintenance and disposal	<b>Harvester, production, per kg/CH/I U</b> The inventory takes into account the use of resources and the amount of emissions during the production, the maintenance and repair and the disposal of harvesters. Calculations were made based on a harvester of 10000 kg, with a useful life of 1300 hours and a repair factor of 0.55.
Implement production, repair, maintenance and disposal	<b>Agricultural machinery, general, production, per kg/CH/I U</b> The inventory takes into account the use of resources and the amount of emissions during the production, the maintenance and repair and the disposal of general agricultural machinery. Calculations are made with a mean machinery of 1000 kg, 1000 hours lifetime and 0.54 repair factor.

## Irrigation

Irrigation systems cover all the devices used for the purpose of watering fields and pastures. It includes the infrastructure as well as the water consumed and the energy to pump that water. The functional unit for irrigation is per m<sup>3</sup> of water irrigated and this includes the pump manufacture.

Irrigation infrastructure (other than the pump) has been calculated for seven irrigation systems ranging from drip irrigation up to centre pivot irrigation. This infrastructure is not linked to the pumping of water, as its life is not contingent on the amount of irrigation, but is linked to the setup of the crop, especially in horticulture. Local data has been used for replacement life of this infrastructure.

## Primary data

### a. Primary data required

Table 9 lists the primary data required for building irrigation inventories.

**Table 9: Primary data required for irrigation processes inventories.**

DATA	UNIT	SOURCE/COMMENT
Materials for irrigation infrastructure	kg	(FAO 2007) Details provided in Appendix B
Life-time	years	(P. Deuter 2012)
Quantity and origin of water used for irrigation	ML	Farm data
Total dynamic head	m	Combination of static lift , friction and the pressure head.
Pump efficiency	%	Ratio of fuel or electrical energy input to energy transferred to the pump. Assumed to be 80% for electric motors and 45% for diesel.
Motor efficiency	%	Ratio of energy from motor to energy transferred to water. Assumed to be average of 66%
Energy source for pump	%	Percentage diesel compared electrical pumping.
Location of irrigation system	-	The Australian state in which the irrigation is undertaken is used to determine which electricity grid should be used in the pumping inventory.
Water origin		The source of the water is used to help describe the elementary flow as being from surface water or groundwater.
Hours of use per year	Hours	Used for pump infrastructure calculation only default value is 3650
Flow rate	M3/hour	Used for pump infrastructure calculation only 3.6 used as default

## Mathematical relations data transformation

Standard pump energy calculation has been used to determine the diesel energy use and electrical energy use for irrigation supply as shown in Equation 2. In part one of the calculation the power required to pump 1 m<sup>3</sup> is calculated. In the second part of the calculation the amount of diesel energy required is calculated. In the third part the amount of energy required for pumping its calculated. The most important determinant in this calculation is the head required to be pumped. The value used in the calculation needs to include both the static head which is the lift required in the water and the dynamic head which refers to the backpressure applied from the irrigation system.

$$(1) \text{ Power kW} = \frac{\text{head(m)} * \text{gravity constant}(\frac{m}{s^2})}{\text{Pump efficiency \%} * \text{Motor efficiency \%}}$$

$$(2) \text{ Diesel pumping energy (MJ)} = \text{Fraction diesel} * \frac{\text{power}}{1000}$$

$$(3) \text{ Electrical pumping energy (kWh)} = \text{Fraction electrical} * \frac{\text{power}}{3600}$$

**Equation 2: Equation for calculating energy use for 1 M3 of water pumping.**

Equation 3 shows the how the pump infrastructure is calculated for irrigation processes. Background data for the pump is taken from an EPD for Flygt pump with a weight of 60kg.

$$(1) \text{ Duty of Pump (m3)} = \text{years of pump life} * \text{hours use per year} * \text{flow rate M3/hour}$$

$$(2) \text{ fraction of pump allocation per m3 irrigation} = \frac{1}{\text{duty of pump}}$$

**Equation 3: Equation for calculating pump infrastructure per M3 of irrigation.**

A separate unit process is developed for each irrigation supply which includes the state in which the irrigation is being undertaken to determine the source of electricity for electric pumping.

## Fertilisers and lime

Nutrients in the form of fertilisers are at the heart of the agricultural production system and they lead to significant series of emissions and processes. The production of inorganic fertilisers used in agriculture is generally energy-intensive. The transport of these products from the storage to the farm is taken into account, although it is relatively small in terms of overall environmental impact, while fertilizer packaging is excluded from the system.

The use of nitrogen and phosphorus fertilisers led to a series of emissions which have effects on global warming and eutrophication.

Lime application are modelled using standard NIR (DIICCSRTE 2013) emission factors for carbon dioxide. While the application of urea leads to an emission of carbon dioxide, this is included as a biogenic carbon dioxide emission as the initial inputs of CO<sub>2</sub> into the manufacture of urea in ecoinvent<sup>®</sup> is not counted as a fossil carbon input.

## Primary data

The primary data required to model the inventory flows related to nitrogen fertilisers are listed Table 10. These consist of the amount and type of fertiliser, the nitrogen content and a series of emission factors that are all derived from standard government sources.

**Table 10: Primary data required for fertiliser use and N related emissions.**

DATA	UNIT	SOURCE
Type of fertilisers	-	Farm/Gross margin
Quantity of fertiliser applied	kg/ha	Farm/Gross margin
Fertiliser N	kg N/kg	Fertiliser manufacturer
Fertiliser heavy metal content	kg metal/kg fertiliser	Fertiliser manufacturer
Emission factor for direct N <sub>2</sub> O from N	Kg N as N <sub>2</sub> O/kg N applied	(Department of Climate Change and Energy Efficiency 2011)– Varies by crop type
Fraction of farm area designated as having leaching occur where precipitation exceeds evaporation.	Fraction of farm area	(Department of Climate Change and Energy Efficiency 2011)
Fraction of N leached when in areas where leaching occurs.	Fraction of N	Value used is 0.3(Department of Climate Change and Energy Efficiency 2011)
EF N <sub>2</sub> O factor from leached N	Fraction of N	(Department of Climate Change and Energy Efficiency 2011)
Fraction of nitrogen applied emitted as ammonia	Fraction of N	(Department of Climate Change and Energy Efficiency 2011)
Fraction of N volatilisation	Fraction of N converted to NH <sub>3</sub>	(Department of Climate Change and Energy Efficiency 2011)
Atmospheric deposition of ammonia	Fraction of NH <sub>3</sub> produced	(Department of Climate Change and Energy Efficiency 2011)

Table 11 shows the primary data required to model the flows derived from phosphorus fertilisers. This is principally the type and quantity of fertiliser and its phosphorus content. It's also necessary to know the amount of fertiliser from mineral sources as compared to slurry and manure sources. For phosphorus derived from soil erosion the amount of soil erosion per year is sourced from GIS data based on each agro ecological region and its intersection with the type of agricultural land use.

**Table 11: Primary data required for fertiliser use and P related emissions**

Data	Unit	Source
Type of fertiliser	-	Farm Gross margin
Quantity of fertiliser applied	kg/ha	Farm Gross margin
P content of fertiliser	kg P/kg	Manufacturer
P <sub>2</sub> O <sub>5</sub> mineral	kg P <sub>2</sub> O <sub>5</sub> /ha	Farm Gross margin
P <sub>2</sub> O <sub>5</sub> slurry	kg P <sub>2</sub> O <sub>5</sub> /ha	Farm Gross margin
P <sub>2</sub> O <sub>5</sub> manure	kg P <sub>2</sub> O <sub>5</sub> /ha	Farm Gross margin
Rate of soil erosion	kg/ha/year	Derived from GIS layer
Enrichment factor	-	Wilke & Schaub 1996 quoted in (Nemecek and Kagi 2007)

## Mathematical relations and data transformation

The use of nitrogen fertilisers leads to 3 emission sources for nitrous oxide (N<sub>2</sub>O). These are direct emissions from application of nitrogen (Equation 4), indirect emissions from leaching and run-off nitrogen (Equation 5) and indirect emissions from every deposition of ammonia emitted as a result of nitrogen application (Equation 8). In addition to nitrous oxide there are also emissions of nitrate to surface waters (Equation 6) and ammonia to air (Equation 7). All the formula used here are taken from Australian National Greenhouse Accounts, National Inventory Report 2009 (Department of Climate Change and Energy Efficiency 2011) . Equation 9 shows the calculation for the net emissions of ammonia after accounting for the ammonia lost to deposition and conversion to N<sub>2</sub>O.

According to current IPCC methodology no emissions are allocated to nitrogen fixing crops due to poor quality of data on these emission factors. For residues standard factors from NIR (DIICCSRTE 2013) are used.

The emission factors for estimating the N atmospheric emission from fertilisers are those used for the Australian National Greenhouse Accounts and are recalled in Appendix C.

$$\text{Direct atmospheric } N_2O \text{ emissions (kg } N_2O/ha = N \text{ applied} * EF \text{ direct } N_2O * 44/28$$

### Equation 4 Direct atmospheric N<sub>2</sub>O emissions

$$N_2O \text{ from Nitrogen leaching and runoff kg } N_2O/ha = N \text{ applied (kg/ha)} * \text{Fraction wet} * \text{Fraction leached} * N_2O \text{ EF factor from leached N} * 44/28$$

### Equation 5: N<sub>2</sub>O emissions from leaching and runoff

$$NO_3 \text{ from Nitrogen leaching and runoff } \left(\frac{kg}{ha}\right) = N \text{ applied (kg/ha)} * \text{Fraction wet} * \text{Fraction leached} * NO_3 \text{ EF factor from leached N} * 62/$$

28

**Equation 6: NO<sub>3</sub> emissions to surface waters from leaching and runoff**

$$\text{Ammonia (kg)} = \text{N applied (kg)} * \text{Fraction volatilisation} * 17/28$$

**Equation 7: Rate of Ammonia (NH<sub>3</sub>) emissions from nitrogen application**

$$N_2O \text{ from deposition of } NH_3 \text{ kg/ha} = NH_3 \text{ emitted} * \text{fraction } NH_3 \text{ deposition} * 44/28$$

**Equation 8: N<sub>2</sub>O emissions from deposition of ammonia**

$$NH_3 \text{ from deposition of } \frac{NH_3 \text{ kg}}{\text{ha}} = NH_3 \text{ emitted} * (1 - \text{fraction } NH_3 \text{ deposition})$$

**Equation 9: Net emissions of ammonia from fertiliser.**

For phosphorus emissions to water the method used by the ecoinvent<sup>®</sup> database (Nemecek and Kagi 2007) has been used, with regional data used for soil erosion. Two sources of phosphorus to surface water are included (soluble Equation 10 and particulate Equation 12) and one is included to groundwater (Equation 11) The default values used are all listed in Appendix C.

$$\text{P to surface water} = \text{Average P lost through runoff} * \left( 1 + \frac{0.2}{80 \text{ P2O5 mineral}} + \frac{0.7}{80 \text{ P2O5 slurry}} + \frac{0.4}{80 \text{ P2O5 manure}} \right)$$

**Equation 10: Phosphorus emission to surface water from fertiliser application**

$$\text{P to groundwater} = \text{Average P lost to groundwater} * \left( 1 + \frac{0.2}{80 \text{ P2O5 slurry}} \right)$$

**Equation 11: Phosphorus emission to groundwater from fertiliser application**

$$\begin{aligned} \text{P to emissions from erosion (kg/ha/year)} \\ = 10000 * \text{quantity of soil eroded (kg/ha/year)} * \text{P content of soil} \\ * \text{enrichment factor for P} * \text{fraction of soil which reaches rivers} \end{aligned}$$

**Equation 12: Phosphorus emissions from soil erosion**

## Background data

The background data for fertiliser production has been taken from the ecoinvent<sup>®</sup> database where the inventories have been adjusted so that they represent 1 kg of total fertiliser used rather than 1 kg of fertiliser as N or 1 kg of fertiliser as P, as they are modelled in the ecoinvent<sup>®</sup> database.

## Pesticides

### Primary data

Table 12 shows the primary data required for modelling the pesticide flows in the inventory.

**Table 12: Primary data required for pesticides**

DATA	UNIT
Type of herbicides	
Quantity of herbicide applied	kg
Active substance content	kg active/kg product
Type of insecticide	
Quantity of insecticide applied	kg
Active substance content	kg active/kg product
Type of fungicide	
Quantity of fungicide applied	kg
Active substance content	kg active/kg product

### Mathematical relations data transformations

Table 13 shows the secondary data used for providing the flows that will inform the environmental impacts from pesticides use. The inventory flow is simply the multiplication of the active ingredient by the fraction released to each compartment.

**Table 13: Secondary data required for pesticides**

DATA	SOURCE
Fraction of active substance released into soil	Default value = 0% (Dijkman, Birkved et al. 2012). Alternative value = 100% (ecoinvent Centre 2010).
Fraction of active substance released into air assumed to then be emitted to soil off farm.	Default value calculated with PestLCI 2.0 (Dijkman, Birkved et al. 2012). Alternative value = 0% (ecoinvent Centre 2010).
Fraction of active substance released into ground water	Default value calculated with PestLCI 2.0 (Dijkman, Birkved et al. 2012). Alternative value = 0% (ecoinvent Centre 2010).
Fraction of active substance released into surface water	Default value calculated with PestLCI 2.0 (Dijkman, Birkved et al. 2012). Alternative value = 0% (ecoinvent Centre 2010).

## **b. Pesticides database**

To estimate the fate of active ingredients into the environment (soil, water, air), PestLCI 2.0 is used. This model has been developed by the Technical University of Denmark (Dijkman, Birkved et al. 2012). This model is capable of estimating pesticide emissions to air, surface water and groundwater for use in LCI modelling. After calculating the primary distribution of pesticides between crop and soil, specific modules calculate the pesticide's fate, thus determining the pesticide emission pattern for the application. The calculations in PestLCI involve climate, soil and farm parameters. These parameters are listed Table 14, and are defined for Australia at the level of the agro-ecological region intersection with the crop land use category. The list of regions is provided in Appendix D. The data supply from many of the PestLCI parameters have been sourced from GIS data. The GIS references used are provided in Appendix E.

An alternative approach is implemented in the data which allows the pesticide fate to be modelled in the same way as it is in the current ecoinvent<sup>®</sup> database with 100% of the pesticide being emitted to the soil compartment. This will initially only be available currently in the SimaPro implementation (Life Cycle Strategies Pty Ltd 2013) of the data due to limitations in implementing parameter switches in the AusLCI data.

**Table 14: Input parameters to PestLCI 2.0**

PARAMETER TYPE	PARAMETERS	UNIT	COMMENT
Application	Month	-	
Application	Application type	-	Boom, cross flow, bare soil, aerial etc.
Application	Nozzle distance	m	
Field	Dimension (width, length)	m	
Field	Slope	%	
Field	Annual irrigation	mm	
Field	Tillage type		Conventional, reduced, no tillage
Climate	Latitude	°	
Climate	Longitude	°	
Climate	Elevation	m	
Climate	Average temperature	°C	[Tmax + Tmin]/2, average over period 1980 - 1999
Climate	Monthly and annual minimal temperature	°C	Average over period 1980 - 1999
Climate	Monthly and annual maximal temperature	degC	Average over period 1980 - 1999
Climate	Monthly and annual rainfall	mm	Average over period 1980 - 1999
Climate	Monthly and annual number of rainy days	mm	Average over period 1980 - 1999
Climate	Monthly and annual average rainfall on rainy days	mm	= rainfall / days with rainfall>1mmm
Climate	Monthly and annual rain frequency	days <sup>-1</sup>	= nb of days in month / nb of rainy days
Climate	Annual potential evaporation	mm	Calculation based on (Linacre 1977)
Climate	Monthly and annual solar irradiation	Wh.m <sup>-2</sup> .day <sup>-1</sup>	Average over period 1980 – 1999 <sup>2</sup>
Soil	Starting depth (for each soil layer)	m	Start depth of layer - always 0
Soil	pH (for each soil layer)	-	pH in soil
Soil	f(clay) (for each soil layer)	%	Clay content (fraction of clay) in soil
Soil	f(sand) (for each soil layer)	%	Sand content (fraction of sand) in soil
Soil	f(silt) (for each soil layer)	%	Silt content (fraction of silt) in soil
Soil	f(OC) (for each soil layer)	%	Organic carbon content (fraction of organic carbon) in soil
Soil	Soil bulk density	kg/m <sup>3</sup>	Soil bulk density

<sup>2</sup> 1980-1999 was used in for PestLCI as a number of the other GIS data layers used in PestLCI ( NWLRA, BioSequill) used this rainfall data.

Soil	Soil water fraction	fraction	Mean annual relative soil water content
Soil	Fraction of macropores	fraction	Fraction of soil pores being macropores
Soil	Soil moisture content	fraction	Annual mean moisture
Soil	Drainage depth	m	Assumed to be zero for Australia where fields are not artificially drained.
Soil	Irrigation water	MI	

Source (Dijkman, Birkved et al. 2012)

## Background data

The background data for pesticide production has been taken from the ecoinvent<sup>®</sup> database. In some instances an inventory for a specific chemical is available and have been used otherwise where no data was available a generic pesticide inventories was used. All these inventories have been sourced from the shadow database. The inventories used to model the production of active ingredients are provided in Appendix E.

## Land occupation

Land occupation includes the area of land occupied multiplied by the time it is occupied. The land use class is matched using the standard land classifications outlined in Appendix G. The specific land classifications chosen are listed in Table 15. No specific land transformation was included for any of the inventories due to the difficulty in allocating specific land transformations to individual crops and little evidence of recent land transformation in Australian production systems.

**Table 15: Land types used for AusAgLCI inventories**

Agriculture process	Land occupation	Land transformation
Cotton irrigated	Annual crop, irrigated	None
Cotton dryland	Annual crop, non-irrigated	None
Sugar irrigated	Permanent crop, irrigated, intensive	None
Sugar not irrigated	Permanent crop, non-irrigated, intensive	None
Grains dryland	Annual crop, non-irrigated	None
Grains irrigated	Annual crop, irrigated	None
Irrigated annual horticulture	Annual crop, irrigated, intensive	None
Irrigated perennial horticulture	Perennial crop, irrigated, intensive	None
Forage sorghum	Annual crop, irrigated	None
Irrigated maize	Annual crop, irrigated, intensive	None
Lucerne hay	Perennial crop, non-irrigated	None

# How to use AusAgLCI

## Conditions of use

The data presented in AusLCI (of which AusAgLCI is a subset) is provided by data suppliers with no warranties as to its accuracy or correctness. Like all LCI data the AusLCI data should be used with caution, and 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 Australian life cycle assessment Society (ALCAS), or the suppliers of data into AusLCI. By using the data you agree that 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.

## Formats available

On the AusLCI website the data is presented in as individual unit processes and as fully calculated system processes. The individual unit processes contained just the flow data from the individual processes. These can be used to understand the types of products and elementary flows flow into each process has but do not describe the full life cycle impacts of the process.

The system processes contain the sum of all of the life cycle elementary flows from cradle-to-farm gate. These can be used in LCA modelling but you cannot see the technical detail in the processes.

On the website two international LCA formats are supplied for gate-to-gate unit processes. One of these is EcoSpold 1 which is in format used by ecoinvent<sup>®</sup> 2. As soon as converters are available data will be published in EcoSpold 2 format. LCI is also supplied in the ILCD format which is used by the European Union data project

The third possibility for users who have SimaPro LCA software and access to an ecoinvent<sup>®</sup> licence is to have the AusLCI connected with unit process data. This provides the same unit processes as on the AusLCI website but with links to the background and other connected unit processes. This allows users to modify the unit processes and calculate the full life cycle impacts of the modified processes. In the SimaPro format the original parameters used to model the AusAgLCI data are accessible. Currently it is not possible to export these parameters into other formats.

## Linking to background databases

The linking of unit processes to background databases is a complicated process which is not recommended by individual data users. It is suggested that people wanting to access the linked data should access it through one of the software tools wherever data has been assembled and checked by AusLCI. Users wishing to connect the unit process data to a background data base should follow the specification outlined on the AusLCI website.

# Appendix A Machinery data

## 1.1 Tractor weight

To simplify the process of estimating weights of tractors, a database of tractors (n=426) was created using tractor specifications for major brands in Australia (Case, Massey-Ferguson, Fendt, New Holland, John Deere). The relationship between tractor power (likely to be known by the farmer) and tractor weight is strong ( $r^2=0.91$ ). Data was obtained from manufacturer's specifications, with tractors sourced from Case (n=75), Massey-Ferguson (n=60), Fendt (n=31), New Holland (n=108), and John Deere (n=152)

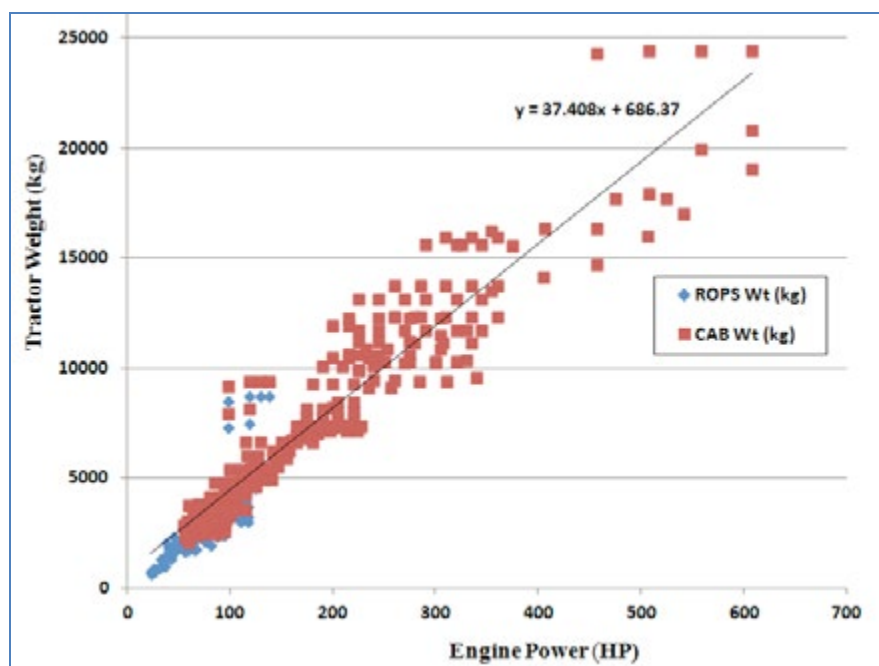


Figure 7: Plot of tractor weight (kg) versus engine power (HP) for 426 tractors.

Source AusAgLCI Project team Meeting 18 January 2012 Discussion Paper: FARM ENERGY INPUTS Prepared by Russell Lyons  
Note ROPS = Roll over protection structures and CABS is for tractors with full cabins.

## 1.2 Broad-acre tractor data

Table 16 shows the detailed parameters used for building LCI for broad-acre tractor processes.

**Table 16: Parameters for estimating the environmental impact of manufacture, operation and maintenance of broad-acre tractor processes**

	TRACTOR PARAMETERS				IMPLEMENT PARAMETERS		FUEL USE
	Power	Weight	Lifetime	Speed	Lifetime	Weight	
	kW	kg	hours	km/h	hours	kg	l/ha
Aerial sprayer							1.85
Cultivating, broadacre crop	135	8000	10	7.3	2250	4800	13.6
Disc ploughing, broadacre crop	135	8000	8	4.5	2250	1500	13.69
Fertilizing, broadacre crop, pre & post-emergence	125	8000	25	30	1200	1700	0.7
Grader operation, broadacre crop, medium load factor	118	8000	5	2.5	1200	0	18.5
Grain collection, broadacre, in-field with tractor+bin	150	8000	12	8	3000	2000	2.1
Harvesting, broadacre crop, combine <200kW		3000	8	8		10719	5.8
Hay baling, large square bales, broadacre crop	57	8000	10	3	1800	1500	2.32
Hay baling, round bales, broadacre crop	57	8000	10	3	1800	1500	2.53
Hay baling, small square bales, broadacre crop	57	8000	10	3	1800	1500	2.11
Hay mowing, broadacre crop	57	8000	10	3	1800	1500	4.58
Hay raking, broadacre crop	57	8000	10	3	1800	500	0.41
Liming, broadacre crop, pre & post-emergence	125	8000	25	12	1200	1700	1.15
Planting, broadacre crop, soil clay content >20%	220	8000	9	20	3000	13800	6.2
Planting, broadacre crop, soil clay content 0-10%	220	8000	9	20	3000	13800	3.4
Planting, broadacre crop, soil clay content 10-20%	220	8000	9	20	3000	13800	4.4
Scarifiying, broadacre crop	57	8000	8	3.7	2250	500	6.82
Spraying, broadacre crop, pre & post-emergence	125	8000	25	30	3000	4800	0.7
Windrowing, broadacre crop	85	8000	5.4	7.6	1700	1540	4.8

Table 17 shows the detailed parameters used for building LCIs for horticulture tractor processes.

**Table 17: Parameters for estimating the environmental impact of manufacture, operation and maintenance of horticulture tractor processes**

	Tractor parameters				Implement parameters		Fuel use
	Power	Weight	Lifetime	Speed	Lifetime	Weight	
	kW	kg	hours	km/h	hours	kg	l/ha
Source	(1)	(2)	(1)	(3)	(1)	(4)	(4)
Air blast spraying, orchards	50	6600	5	3.8	2700	1500	11.4
Bed forming, horticulture	100	6600	6	3.6	2700	1500	11.6
Boom spraying, horticulture, pre & post-emergence	75	6600	6	15	2700	1500	2.5
Cultivating, large implement, horticulture	206	6600	6	8	2700	5283	18.5
Cultivating, medium implement, horticulture	100	6600	7	3.6	2700	2200	9.9
Fertiliser side dressing, horticulture	50	6600	8	4	2700	700	4.2
Fertiliser spreading, horticulture	50	6600	6	11	2700	700	2
Harvesting, specialised machine, horticulture, 150 kW combine		3000	3	2.5		10000	110
Harrowing, horticulture	50	6600	9	5	2700	1000	2.8
Inter-row cultivation, horticulture	80	6600	6	4.5	2700	1500	9
Inter-row tractor, horticulture	80	6600	6	4.5	2700	0	9
Offset disc harrowing, horticulture	100	6600	6	4.5	2700	4480	17.2
Precision planting, horticulture	100	6600	4	3	2700	2000	20.8
Ripping, large implement, horticulture	206	6600	5	5.2	2700	1000	34
Ripping, medium implement, horticulture	100	6600	5	2.8	2700	550	21
Rotary hoeing, medium implement, horticulture	100	6600	3	2.4	2700	940	46.6
Seedling transplanting, horticulture	50	6600	6	1.8	2700	1500	16.3

<sup>(1)</sup> (Rod Menzies & associates)  
<sup>(2)</sup> Calculated with: tractor weight = tractor power (HP)\*37.408+686.37, empirical formula derived from the analysis of data from about 300 tractors  
<sup>(3)</sup> (The University of Arizona 2002)  
<sup>(4)</sup> Sourced from various suppliers websites  
<sup>(5)</sup> (Salam 2010)

Table 18 presents the detailed parameters used for building LCIs for cotton tractor processes.

**Table 18: Parameters for estimating the environmental impact of manufacture, operation and maintenance of cotton tractor processes**

	TRACTOR PARAMETERS				IMPLEMENT PARAMETERS		FUEL USE
	Power	Weight	Lifetime	Speed	Lifetime	Weight	
	kW	kg	hours	km/h	hours	kg	l/ha
<b>Bed forming, cotton</b>	125	16000	25	8	1200	2000	8
<b>Boom spraying, cotton</b>	125	16000	25	16	1200	1200	0.7
<b>Cultivating, cotton</b>	125	16000	25	4	1200	2000	5
<b>Discing, cotton</b>	125	16000	25	4	1200	2000	9.5
<b>Fertiliser spreading, cotton</b>	125	16000	25	8	1200	2000	2.3
<b>Fertilising, cotton</b>	125	16000	25	8	1200	2000	5.9
<b>Levelling, cotton</b>	125	16000	25	4	1200	4500	44
<b>Mulching, cotton</b>	125	16000	25	4	1200	2500	7.7
<b>Planting, cotton</b>	125	16000	25	4	1200	2500	3.5
<b>Rolling, cotton</b>	125	16000	25	3	1200	2000	3.1
<b>Root cutting, cotton</b>	125	16000	25	4	1200	2000	3.4
<b>Harvesting, cotton</b>		3000	5	8		15000	40
<b>Picking, cotton</b>		4000	5	6		2381	21.8

## Appendix B Irrigation systems data

Table 19 through to Table 25 shows the components of the irrigation systems used in the AusAgLCI. Data derived from FAO Handbook on Pressurised Irrigation Techniques (FAO 2007).

**Table 19: Bill of material for drip irrigation system**

COMPONENT	QUANTITY FOR 1HA
<b>System distribution network</b>	
63 mm HDPE pipe, 6.0 bars	180 m
16 mm LDPE pipe, 4.0 bars	4430 m
Drippers, 4 litres/h, 1 bar	8750 pcs
63 mm x 2 in PP adaptor	1 pc
16 mm x 3/4 in PP adaptor	108 pcs
63 mm PP elbow	1 pc
63 mm PP end plug	1 pc
63 mm x 3/4 in PP clamp saddle	54 pcs
3/4 in nipple (galvanised iron or PVC )	54 pcs
3/4 in tee (galvanised iron or PVC )	54 pcs
3/4 in brass shut-off valves	108 pcs
<b>Head control</b>	
2 in brass check valve	1 pc
2 in brass shut-off valve	2 pcs
3/4 in brass shut-off valve	2 pcs
2 in tee (galvanised iron or PVC)	3 pcs
2 in nipple	4 pcs
3/4 in nipple	4 pcs
1 in air valve	1 pc
2 in gravel filter complete	1 pc
2 in disk filter, c/with gauges, etc.	1 pc
Fertilizer injector complete, up to 150 litres/h	1 pc

**Table 20: Bill of material for microsprinklers system**

Microsprinklers	Quantity for 1 ha
<b>System distribution network</b>	
75 mm black HDPE, 6.0 bars	120 m
32 mm black LDPE, 4.0 bars	2040 m
75 mm x 2 in PP adaptor	1 pc
32 mm x 1 in PP adaptor	24 pcs
75 mm PP end plug	1 pc
32 mm PP end plug	24 pcs
75 mm x 1 in PP clamp saddle	24 pcs
1 in brass shut-off valve	24 pcs
1 in nipple	24 pcs
Low capacity sprinklers, full circle, 160 litres/h at 2.0 bars, 11 m wetted diameter, complete with supporting stake and connector tube	408 pcs
<b>Head control</b>	
2 in brass check valve	1 pc
2 in brass shut-off valve	2 pcs
2 in tee (galvanised iron or PVC)	3 pcs
2 in nipple	4 pcs
1 in air valve (single automatic)	1 pc
2 in filter screen type 60 mesh	1 pc

**Table 21: Bill of material for travelers spray booms**

	Quantity for 1.5 ha
<b>Reel machine</b>	
Kifco T27x980 Ag-Rain® Water-Reel®	1 pc
<b>Reel pipe</b>	
75 mm HDPE pipe, 3 bars	300 m
<b>Boom with sprayers</b>	
Pipeline	4 m
wheeled trolley (model R50/2)	1700 kg
end spray nozzle	32 pcs

**Table 22: Bill of materials for Centre Pivot irrigation system –covering 46ha**

Material	Quantity for 46 ha
Rubber	462 kg
LDPE	100 kg
Steel	2500 kg
surface	46.3 kg
PVC for head	40 kg

**Table 23: Bill of materials for Hose move sprinkler irrigation system covering 1 ha**

Material	Quantity for 1 ha
HDPE	89 kg
LDPE	54 kg
PP	1 kg
PVC	57 kg
Steel	98 kg
PVC head	0.2 kg
Steel head	0.2 kg
lifetime head	50 kg

**Table 24: Bill of materials for travelling gun irrigation system covering 40ha**

Material	Quantity for 40 ha
LDPE	4.5 kg
PP	0.3 kg
PVC	0.8 kg
Aluminum	1464.1 kg
lifetime	10 kg
PVC head	0.2 kg
Steel head	0.2 kg

**Table 25: Bill of Materials for under-tree irrigation system covering 1 ha**

Material	Quantity for 1 ha
HDPE	78.8 kg
LDPE	242.5 kg
PP	0.24 kg
PVC	0.35 kg
PVC head	0.03 kg
Steel head	0.03 kg

# Appendix C Parameters for fertilisers emissions

## 1.3 Parameters for nitrogen emissions

The emission factors and other constant used to model atmospheric emissions from fertilizers are shown in Table 26. (Department of Climate Change and Energy Efficiency 2011)

**Table 26: Parameters for calculating N emissions from fertiliser use on farm.**

TYPE	PARAMETER NAME- USED IN INVENTORY MODELS	VALUE
<b>Direct N emissions kg N as N<sub>2</sub>O/kg N</b>		
Irrigated pasture	EFN DS irrp	0.004
Irrigated crop	EFN DS irrc	0.021
Non-irrigated pasture	EFN DS nonirrp	0.004
Non-irrigated crop	EFN DS nonirrc	0.003
Sugar cane	EFN DS sc	0.0125
Cotton	EFN DS cot	0.005
Horticulture/vegetables	EFN DS hort	0.021
<b>N<sub>2</sub>O emissions factors (% applied N) for manure applied to crops and pastures</b>		
Organic	EFN DO org	1.56
Sewage sludge	EFN DO sew	0.9
Unknown effluent	EFN DO awms	0.4
Cattle slurry	EFN DO cattle	0.25
Pig slurry	EFN DO pig	0.45
Poultry litter	EFN DO poultry	0.5
<b>Other data for N emissions</b>		
Fraction leached	FracN LEACH	0.3
Atmospheric deposition of N	EFN atmodep	0.01
Emission factor for leaching and run-off	EFN leachS	0.0125
Fraction of fertilizer as NH <sub>3</sub>	FracN GASF	0.1
<b>Availability of Nitrogen for leaching and runoff</b>		
<b>NSW</b>		
Irrigated pasture	fracN wet irrp NSW	1
Irrigated crop	fracN wet irrc NSW	1

	TYPE	PARAMETER NAME- USED IN INVENTORY MODELS	VALUE
NT	Non-irrigated pasture	fracN wet nonirrp NSW	0.334
	Non-irrigated crop	fracN wet nonirrc NSW	0.192
	Sugar cane	fracN wet sc NSW	0.99
	Cotton	fracN wet cot NSW	0.246
	Horticulture/vegetables	fracN wet hort NSW	0.599
	Irrigated pasture	fracN wet irrp NT	1
	Irrigated crop	fracN wet irrc NT	1
	Non-irrigated pasture	fracN wet nonirrp NT	0.811
	Non-irrigated crop	fracN wet nonirrc NT	0.777
QLD	Sugar cane	fracN wet sc NT	0
	Cotton	fracN wet cot NT	0
	Horticulture/vegetables	fracN wet hort NT	0.857
	Irrigated pasture	fracN wet irrp QLD	1
	Irrigated crop	fracN wet irrc QLD	1
	Non-irrigated pasture	fracN wet nonirrp QLD	0.128
	Non-irrigated crop	fracN wet nonirrc QLD	0.043
	Sugar cane	fracN wet sc QLD	0.656
	Cotton	fracN wet cot QLD	0.075
SA	Horticulture/vegetables	fracN wet hort QLD	0.293
	Irrigated pasture	fracN wet irrp SA	1
	Irrigated crop	fracN wet irrc SA	1
	Non-irrigated pasture	fracN wet nonirrp SA	0.708
	Non-irrigated crop	fracN wet nonirrc SA	0.279
	Sugar cane	fracN wet sc SA	0
	Cotton	fracN wet cot SA	0
	Horticulture/vegetables	fracN wet hort SA	0.667
Tas	Irrigated pasture	fracN wet irrp Tas	1

	TYPE	PARAMETER NAME- USED IN INVENTORY MODELS	VALUE
<b>Vic</b>	Irrigated crop	fracN wet irrc Tas	1
	Non-irrigated pasture	fracN wet nonirrp Tas	0.991
	Non-irrigated crop	fracN wet nonirrc Tas	0.985
	Sugar cane	fracN wet sc Tas	0
	Cotton	fracN wet cot Tas	0
	Horticulture/vegetables	fracN wet hort Tas	0.996
	Irrigated pasture	fracN wet irrp Vic	1
	Irrigated crop	fracN wet irrc Vic	1
	Non-irrigated pasture	fracN wet nonirrp Vic	0.855
	Non-irrigated crop	fracN wet nonirrc Vic	0.438
	Sugar cane	fracN wet sc Vic	0
	Cotton	fracN wet cot Vic	0
	Horticulture/vegetables	fracN wet hort Vic	0.702
<b>WA</b>			
	Irrigated pasture	fracN wet irrp WA	1
	Irrigated crop	fracN wet irrc WA	1
	Non-irrigated pasture	fracN wet nonirrp WA	0.508
	Non-irrigated crop	fracN wet nonirrc WA	0.223
	Sugar cane	fracN wet sc WA	0.759
	Cotton	fracN wet cot WA	0.759
	Horticulture/vegetables	fracN wet hort WA	0.911

Source (Department of Climate Change and Energy Efficiency 2011)

## 1.4 Parameters for phosphorus emissions

Table 27: Detailed parameters for modelling phosphorus emissions

Parameter	Unit	Definition
<b>Fertilisers data</b>		
P <sub>2</sub> O <sub>5</sub> min	kg/ha	Mineral fertilisers applied
P <sub>2</sub> O <sub>5</sub> sl	kg/ha	Slurry or liquid sewage sludge applied
P <sub>2</sub> O <sub>5</sub> man	kg/ha	Solid manure applied
<b>Phosphorus leaching to ground water – P<sub>gw</sub></b>		
P <sub>gw</sub>	kgP/ha.a	P <sub>gw</sub> l*F <sub>gw</sub>
P <sub>gw</sub> l	kgP/ha.a	Average quantity of P leached to ground water, default value of 0.07 for arable land, 0.06 for pastures and meadows.
F <sub>gw</sub>	[-]	1+0.2/80P <sub>2</sub> O <sub>5</sub> sl, slurry correction factor
<b>P run-off to surface waters – P<sub>ro</sub></b>		
P <sub>ro</sub>	kgP/ha.a	P <sub>ro</sub> l*F <sub>ro</sub>
P <sub>ro</sub> l	kgP/ha.a	Correction factor for fertilisation. Default value of 0.175 for arable land, 0.25 for intensive permanent pastures and meadows, and 0.15 for extensive permanent pastures and meadows.
F <sub>ro</sub>	[-]	1+0.2/80P <sub>2</sub> O <sub>5</sub> min + 0.7/80P <sub>2</sub> O <sub>5</sub> sl + 0.4/80P <sub>2</sub> O <sub>5</sub> man
<b>P emissions through erosion by water to surface waters - P<sub>er</sub></b>		
P <sub>er</sub>	kgP/ha.a	1000*Ser*P <sub>cs</sub> *Fr*F <sub>erw</sub>
Ser	t/ha.a	Quantity of soil eroded
P <sub>cs</sub>	kgP/kg soil	Default average value of 0.00095
Fr	-	Default average value of 1.86
F <sub>erw</sub>	-	Default average value of 0.2

## Appendix D List of agro-ecological regions used in AusAgLCI

Table 28 shows the list of agro-ecological regions, and the agricultural use for AusAgLCI inventories (last 6 columns).

**Table 28: Agro-ecological regions and land use categories for AusAgLCI inventories**

REGION NUMBER	REGION NAME	PASTURES	HORTICULTURE – PERENNIAL	SUGAR	HORTICULTURE – SEASONAL	COTTON	CROPPING
1	Hobart	x	x		x		x
2	Jordan Coal Tasman	x	x				x
3	Tasmanian Forests	x	x		x		x
4	Burnie	x	x		x		x
5	North Central	x	x		x		x
6	Melbourne Region	x	x		x		x
7	Central and South West Slopes and Plains	x	x		x	x	x
8	South Riverina and Wimmera	x	x		x	x	x
9	Far South and East Victorian Coast	x	x		x		x
10	Southern Highlands, Tablelands and Gippsland	x	x		x		x
11	South Coast and Illawarra	x					x
12	Sydney Basin	x	x		x		x
13	Central, North Tablelands and Granite belt	x	x		x	x	x
14	Northern Rivers and Mid-north Coast	x	x	x	x		x
15	Western Downs and North West Slopes and Plains	x	x		x	x	x
16	Brisbane Moreton	x	x	x	x		x
17	Darling Downs	x	x		x	x	x
18	South Burnett	x	x				x
19	Wide Bay Burnett	x	x	x	x	x	x
20	Dawson Callide	x	x			x	x
21	Central Queensland coast	x	x	x		x	x

REGION NUMBER	REGION NAME	PASTURES	HORTICULTURE – PERENNIAL	SUGAR	HORTICULTURE – SEASONAL	COTTON	CROPPING
22	Central Highlands Queensland	x				x	x
23	Burdekin	x	x	x	x		x
24	Wet Tropic Coast	x	x	x			
25	Northern Queensland Tablelands	x	x	x	x		x
26	Central West and Gulf	x					x
27	Cape York	x	x	x	x		x
28	Barkly Tablelands						
29	Marrakai Arnhem Land						
30	Esley Gulf Land	x	x				x
31	Timor Coast and Douglas Daly Basin	x	x				x
32	Sturt Plateau	x	x		x		x
33	Kimberley Victoria River	x	x	x	x		x
34	North West Australia						
35	Gascoyne	x					x
36	Western Wheatbelt	x	x				x
37	South West	x	x		x		x
38	Lower South West	x	x		x		x
39	Goldfields Nullabor Flinders and darling	x	x			x	x
40	Maranoa Warrego	x	x		x	x	x
41	Mallee Murray and central North South Australia	x	x		x		x
42	Southern Coastal South Australia	x	x		x		x
43	Channel Country	x					x
44	Central Australian Ranges						
45	Tanami, Petermann, Simpson and Western Deserts						
46	Adelaide Region	x	x		x		x

## Appendix E GIS layers used in AusAgLCl

Table 29 provides a detail of the GIS layers used in the AusAgLCl project. Some data have been accessed directly from GIS layers while others have been calculated using a combination of layers. The following GIS data were extracted for each of the 178 zones created by the intersection of the Agro-Ecological regions and the 6 agricultural land use classes (Appendix D) extracted from the Australian Land Use and Management Classification, version 7 (ABARE, 2010).

**Table 29: GIS layers used in AusAgLCl project**

Parameter	unit	Zonal Statistics calculated	Level of acquisition	Comment	Source
Location			GIS	Name of agro ecological region	
Latitude (degrees)	deg		GIS	To calculate from agro ecological zone	
Longitude (degrees, E+ W-)	deg		GIS	To calculate from agro ecological zone	
Elevation (m)	mm	YES	GIS	To calculate from agro ecological zone	DEM
Average temperature	degC	YES	GIS	Calculated from $[T_{max} + T_{min}]/2$	Available from <a href="http://data.daff.gov.au/anrdl/metadata_files/pa_mmmmdtr9cl_03611a13.xml">http://data.daff.gov.au/anrdl/metadata_files/pa_mmmmdtr9cl_03611a13.xml</a>
Monthly and annual minimal temperature	degC		GIS	1: TempMin 00 (annual) to 12, average over period 1980 – 1999 2: Layer for same time period also available from ABARES 3: other time periods from BOM	1: <a href="ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/">ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/</a> ; 2: <a href="http://data.daff.gov.au/anrdl/metadata_files/pa_mmmmdtr9cl_03611a00.xml">http://data.daff.gov.au/anrdl/metadata_files/pa_mmmmdtr9cl_03611a00.xml</a> ; 3: <a href="http://www.bom.gov.au/jsp/nc/climate_averages/temperature/index.jsp">http://www.bom.gov.au/jsp/nc/climate_averages/temperature/index.jsp</a>
Monthly and annual maximal temperature	degC	YES	GIS	TempMax 00 (annual) to 12, average over period 1980 – 1999	<a href="ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/">ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/</a> ; 2: <a href="http://data.daff.gov.au/anrdl/metadata_files/pa_mmmmdtr9cl_03611a00.xml">http://data.daff.gov.au/anrdl/metadata_files/pa_mmmmdtr9cl_03611a00.xml</a>

Parameter	unit	Zonal Statistics calculated	Level of acquisition	Comment	Source
Monthly and annual rainfall	mm	YES	GIS	2: Layer for same time period also available from ABARES 3: other time periods from BOM	<a href="#">tadata_files/pa_mmmmdtr9cl_037_11a00.xml</a> ; 3: <a href="http://www.bom.gov.au/jsp/nc/c/climate">http://www.bom.gov.au/jsp/nc/c/climate</a>
Monthly and annual number of rainy days	mm	YES	calculation	Rain 00 (annual) to 12, average over period 1980 – 1999 2: Layer for same time period also available from ABARES 3: other time periods from BOM	1: <a href="ftp://ftp.eoc.csiro.au/pub/pub/pbriggs/nlwra/ForcingMet/">ftp://ftp.eoc.csiro.au/pub/pub/pbriggs/nlwra/ForcingMet/</a> ; 2: <a href="http://data.daff.gov.au/anrdl/me_tadata_files/pa_mamf_r9cl_033_11a00.xml">http://data.daff.gov.au/anrdl/me_tadata_files/pa_mamf_r9cl_033_11a00.xml</a> ; 3: <a href="http://www.bom.gov.au/jsp/nc/c/climate_averages/rainfall/index.jsp">http://www.bom.gov.au/jsp/nc/c/climate_averages/rainfall/index.jsp</a>
Monthly and annual average rainfall on rainy days	mm	YES	calculation	Data was obtained from BOM based on “nb rainy days > 1mm” annual and monthly mean for period 1961–1990	<a href="http://www.bom.gov.au/jsp/nc/cc/climate_averages/raindays/index.jsp">http://www.bom.gov.au/jsp/nc/cc/climate_averages/raindays/index.jsp</a> . Downloaded as grid and converted to a raster for use in GIS
Monthly and annual rain frequency	days <sup>-1</sup>		calculation	Monthly average rainfall over days with rainfall >1mm. = rainfall / rainy days (mathematical calc from zonal stats)	
Annual potential evaporation (mm)	mm	YES	calculation	Calculation 2: Layer for same time period also available from ABARES 3: Available from BOM for period 1975-2005	2: <a href="http://data.daff.gov.au/anrdl/metadata_files/pa_ampe_r9cl_01512a00.xml">http://data.daff.gov.au/anrdl/metadata_files/pa_ampe_r9cl_01512a00.xml</a> ; 3: <a href="http://www.bom.gov.au/jsp/nc/c/climate_averages/evaporation/index.jsp">http://www.bom.gov.au/jsp/nc/c/climate_averages/evaporation/index.jsp</a>

Parameter	unit	Zonal Statistics calculated	Level of acquisition	Comment	Source
Monthly and annual solar irradiation Jan	$\text{Wh} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$	YES	GIS	SolarMJDay 00 (annual) to 12 - average over period 1980 – 1999 Layer for same time period also available from ABARES	1: <a href="ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/">ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/</a> ; 2: <a href="http://data.daff.gov.au/anrdl/metadata_files/pa_rmmisr9cl__03511a00.xml">http://data.daff.gov.au/anrdl/metadata_files/pa_rmmisr9cl__03511a00.xml</a>
start soil layer 1 (m)	m		GIS	start depth of layer - always 0	
start soil layer 2 (m)	m		GIS	start depth of layer	(ASRIS 2011)
pH layer 1	-		GIS	pH in soil	(ASRIS 2011)
pH layer 2	-		GIS	pH in soil	(ASRIS 2011)
f(sand) layer 1	-		GIS	clay content (fraction of clay) in soil	(ASRIS 2011)
f(sand) layer 2	-		GIS	clay content (fraction of clay) in soil	(ASRIS 2011)
f(silt) layer 1	-		GIS	silt content (fraction of silt) in soil	(ASRIS 2011)
f(silt) layer 2	-		GIS	silt content (fraction of silt) in soil	(ASRIS 2011)
f(OC) layer 1	-		GIS	organic carbon content (fraction of organic carbon) in soil	(ASRIS 2011)
f(OC) layer 2	-		GIS	organic carbon content (fraction of organic carbon) in soil	(ASRIS 2011)

Parameter	unit	Zonal Statistics calculated	Level of acquisition	Comment	Source
Soil bulk density (kg/m <sup>3</sup> )	kg/m <sup>3</sup>		GIS	soil bulk density	(ASRIS 2011)
soil bulk density (kg/m <sup>3</sup> ) A Horizon	kg/m <sup>3</sup>		GIS	soil bulk density A Horizon	(ASRIS 2011)
soil bulk density (kg/m <sup>3</sup> ) B Horizon	kg/m <sup>3</sup>		GIS	soil bulk density B Horizon	(ASRIS 2011)
Slope	%		GIS	slopepercent (Slope of 9" digital elevation model)	<a href="http://data.daff.gov.au/anrdl/me_tadata_files/pa_msf_r9cl_00311a00.xml">http://data.daff.gov.au/anrdl/me_tadata_files/pa_msf_r9cl_00311a00.xml</a>
Soil water fraction	fraction		GIS	Mean annual relative soil water content	BiosEquil (Raupach, Kirby et al. 2001) <a href="http://data.daff.gov.au/anrdl/me_tadata_files/pa_mrswcr9cl_03811a00.xml">http://data.daff.gov.au/anrdl/me_tadata_files/pa_mrswcr9cl_03811a00.xml</a>
Soil moisture content	fraction		GIS	Annual mean moisture Index	NLWRA

## Appendix F *Pesticides inventories*

Table 30 shows the list of inventories used in AusAgLCI to model the production of active ingredients. Where the ecoinvent<sup>®</sup> inventory did not have a specific active ingredient a generic process was used.

**Table 30: Inventories used for modeling active ingredients production**

PESTICIDE ACTIVE INGREDIENT	ECOINVENT <sup>®</sup> INVENTORY USED FOR PRODUCTION OF THE PESTICIDE
2,4-D	2,4-D, at regional storehouse/RER U
Abamectin	Insecticides, at regional storehouse/RER U
Acetochlor	Herbicides, at regional storehouse/RER U
Aclonifen	Aclonifen, at regional storage/RER U
Aldicarb	Insecticides, at regional storehouse/RER U
Alpha-cypermethrin	Insecticides, at regional storehouse/RER U
Amidosulfuron	Herbicides, at regional storehouse/RER U
Asulam	Herbicides, at regional storehouse/RER U
Atrazine	Atrazine, at regional storehouse/RER U
Azoxystrobin	Fungicides, at regional storehouse/RER U
Benomyl	Fungicides, at regional storehouse/RER U
Bentazone	Herbicides, at regional storehouse/RER U
Bifenthrin	Insecticides, at regional storehouse/RER U
Bromoxynil	Herbicides, at regional storehouse/RER U
Cadusafos	Insecticides, at regional storehouse/RER U
Carbofuran	Carbofuran, at regional storehouse/RER U
Chlorfenvinphos	Insecticides, at regional storehouse/RER U
Chlormequat chloride	Growth regulators, at regional storehouse/RER U
Chlorothalonil	Chlorothalonil, at regional storage/RER U
Chlorpyrifos	Insecticides, at regional storehouse/RER U
Chlorpyrifos-methyl	Insecticides, at regional storehouse/RER U
Chlorsulfuron	Herbicides, at regional storehouse/RER U
Clodinafop-propargyl	Herbicides, at regional storehouse/RER U
Clofentezine	Insecticides, at regional storehouse/RER U
Clomazone	Herbicides, at regional storehouse/RER U

PESTICIDE ACTIVE INGREDIENT	ECOINVENT® INVENTORY USED FOR PRODUCTION OF THE PESTICIDE
Clopyralid	Herbicides, at regional storehouse/RER U
Cyanamide	Growth regulators, at regional storehouse/RER U
Cyfluthrin	Insecticides, at regional storehouse/RER U
Cypermethrin	Insecticides, at regional storehouse/RER U
Cyprodinil	Fungicides, at regional storehouse/RER U
Dazomet	Pesticide unspecified, at regional storehouse/RER U
Deltamethrin	Insecticides, at regional storehouse/RER U
Desmedipham	Herbicides, at regional storehouse/RER U
Dicamba	Dicamba, at regional storehouse/RER U
Dichlofluanid	Fungicides, at regional storehouse/RER U
Diclofop-methyl	Herbicides, at regional storehouse/RER U
Dicofol	Insecticides, at regional storehouse/RER U
Diflufenican	Herbicides, at regional storehouse/RER U
Dimethoate	Insecticides, at regional storehouse/RER U
Dimethomorph	Fungicides, at regional storehouse/RER U
Diquat dibromide	Herbicides, at regional storehouse/RER U
Diuron	Diuron, at regional storehouse/RER U
Emamectin benzoide	Insecticides, at regional storehouse/RER U
Endosulfan	Insecticides, at regional storehouse/RER U
Esfenvalerate	Insecticides, at regional storehouse/RER U
Ethephon	Growth regulators, at regional storehouse/RER U
Ethofumesate	Herbicides, at regional storehouse/RER U
Fenamiphos	Insecticides, at regional storehouse/RER U
Fenbutatin oxide	Insecticides, at regional storehouse/RER U
Fenoxaprop-P ethyl ester	Herbicides, at regional storehouse/RER U
Fenpropidin	Fungicides, at regional storehouse/RER U
Fenpropimorph	Fungicides, at regional storehouse/RER U
Fenthion	Insecticides, at regional storehouse/RER U
Flamprop-m-isopropyl	Herbicides, at regional storehouse/RER U
Fluazifop-p-butyl	Herbicides, at regional storehouse/RER U
Fluazinam	Fungicides, at regional storehouse/RER U

PESTICIDE ACTIVE INGREDIENT	ECOINVENT® INVENTORY USED FOR PRODUCTION OF THE PESTICIDE
Fluquinconazole	Herbicides, at regional storehouse/RER U
Fluroxypyr	Herbicides, at regional storehouse/RER U
Folpet	Folpet, at regional storage/RER U
Fosetyl-aluminium	Fosetyl-Al, at regional storage/RER U
Glufosinate ammonium	Herbicides, at regional storehouse/RER U
Glyphosate	Glyphosate, at regional storehouse/RER U
Glyphosate	Glyphosate, at regional storehouse/RER U
Haloxypop-ethoxyethyl	Herbicides, at regional storehouse/RER U
Imidacloprid	Insecticides, at regional storehouse/RER U
Indoxacarb	Insecticides, at regional storehouse/RER U
Iodosulfuron	Herbicides, at regional storehouse/RER U
loxynil	Herbicides, at regional storehouse/RER U
Iprodion	Fungicides, at regional storehouse/RER U
Isoproturon	Isoproturon, at regional storage/RER U
Isoxaflutole	Herbicides, at regional storehouse/RER U
Kresoxim-methyl	Fungicides, at regional storehouse/RER U
Lambda-cyhalothrin	Insecticides, at regional storehouse/RER U
Linuron	Linuron, at regional storehouse/RER U
Malathion	Insecticides, at regional storehouse/RER U
Maleic hydrazide	Growth regulators, at regional storehouse/RER U
Mancozeb	Mancozeb, at regional storage/RER U
MCPA	MCPA, at regional storehouse/RER U
Mepiquat chloride	Growth regulators, at regional storehouse/RER U
Metalaxil	Fungicides, at regional storehouse/RER U
Metamitron	Metamitron, at regional storage/RER U
Metam-sodium	Dithiocarbamate-compounds, at regional storehouse/RER U
Metazachlor	Herbicides, at regional storehouse/RER U
Methabenzthiazuron	Herbicides, at regional storehouse/RER U
Methamidophos	Insecticides, at regional storehouse/RER U
Methidathion	Insecticides, at regional storehouse/RER U
Methiocarb	Insecticides, at regional storehouse/RER U

PESTICIDE ACTIVE INGREDIENT	ECOINVENT® INVENTORY USED FOR PRODUCTION OF THE PESTICIDE
Methomyl	Insecticides, at regional storehouse/RER U
Methoxyfenozide	Insecticides, at regional storehouse/RER U
Metiram	Fungicides, at regional storehouse/RER U
Metolachlor	Metolachlor, at regional storehouse/RER U
Metribuzin	Herbicides, at regional storehouse/RER U
Metsulfuron-methyl	Herbicides, at regional storehouse/RER U
Napropamide	Napropamide, at regional storage/RER U
Omethoate	Herbicides, at regional storehouse/RER U
Paraquat	Herbicides, at regional storehouse/RER U
Parathion	Parathion, at regional storehouse/RER U
Parathion, methyl	Parathion, at regional storehouse/RER U
Pendimethalin	Pendimethalin, at regional storage/RER U
Phenmedipham	Herbicides, at regional storehouse/RER U
Pirimicarb	Insecticides, at regional storehouse/RER U
Prochloraz	Fungicides, at regional storehouse/RER U
Prometryn	Herbicides, at regional storehouse/RER U
Propachlor	Propachlor, at regional storehouse/RER U
Propamocarb	Fungicides, at regional storehouse/RER U
Propaquizafop	Herbicides, at regional storehouse/RER U
Propiconazole	Fungicides, at regional storehouse/RER U
Propyzamide	Herbicides, at regional storehouse/RER U
Prosulfocarb	Prosulfocarb, at regional storage/RER U
Prothiophos	Insecticides, at regional storehouse/RER U
Pyridate	Herbicides, at regional storehouse/RER U
Rimsulfuron	Herbicides, at regional storehouse/RER U
Simazine	Herbicides, at regional storehouse/RER U
Spinosad	Insecticides, at regional storehouse/RER U
Spirotetramat	Insecticides, at regional storehouse/RER U
Sulprofos	Insecticides, at regional storehouse/RER U
Tau-fluvalinate	Insecticides, at regional storehouse/RER U
Tebuconazole	Fungicides, at regional storehouse/RER U

PESTICIDE ACTIVE INGREDIENT	ECOINVENT® INVENTORY USED FOR PRODUCTION OF THE PESTICIDE
Tebufenozide	Insecticides, at regional storehouse/RER U
Terbuthylazin	Herbicides, at regional storehouse/RER U
Thiabendazole	Fungicides, at regional storehouse/RER U
Thiacloprid	Insecticides, at regional storehouse/RER U
Thiamethoxam	Insecticides, at regional storehouse/RER U
Thidiazuron	Herbicides, at regional storehouse/RER U
Thifensulfuron-methyl	Herbicides, at regional storehouse/RER U
Thiram	Fungicides, at regional storehouse/RER U
Tolyfluanide	Fungicides, at regional storehouse/RER U
Tralkoxydim	Herbicides, at regional storehouse/RER U
Triadimefon	Fungicides, at regional storehouse/RER U
Triadimenol	Insecticides, at regional storehouse/RER U
Triasulfuron	Herbicides, at regional storehouse/RER U
Tribenuron-methyl	Herbicides, at regional storehouse/RER U
Triclopyr	Herbicides, at regional storehouse/RER U
Trifloxystrobin	Fungicides, at regional storehouse/RER U
Trifluralin	Herbicides, at regional storehouse/RER U
Triflusulfuron-methyl	Herbicides, at regional storehouse/RER U
Trinexapac-ethyl	Growth regulators, at regional storehouse/RER U

## Appendix G Land use classes

Table 31 shows the land use classes used in AusAgLCI- which are taken from the ecoinvent<sup>®</sup> data guidelines(Weidema, Bauer et al. 2012) .

**Table 31: Land use classes used in AusAgLCI**

LAND USE CLASS	DESCRIPTION
Unspecified	
Unspecified, natural (non-use)	
Forest, unspecified	Areas with tree cover >15%.
Forest, primary (non-use)	Forests (tree cover >15%), minimally disturbed by humans, where flora and fauna species abundance is near pristine.
Forest, secondary (non-use)	Areas originally covered with forest or woodlands (tree cover >15%), where vegetation has been removed, forest is re-growing and is no longer in use.
Forest, extensive	Forests (tree cover >15%), with extractive use and associated disturbance like hunting, and selective logging, where timber extraction is followed by re-growth including at least three naturally occurring tree species, with average stand age >30 years and deadwood > 10 cm diameter exceeds 5 times the annual harvest volume.
Forest, intensive	Forests (tree cover >15%), with extractive use, with either even-aged stands or clear-cut patches exceeding 250 m length, or less than three naturally occurring species at planting/seeding, or average stand age <30 years, or deadwood less than 5 times the annual harvest volume.
Wetland, coastal (non-use)	Areas tidally, seasonally or permanently waterlogged with brackish or saline water. Includes costal marshland and mangrove. Excludes coastal land with infrastructure or agriculture.
Wetland, inland (non-use)	Areas partially, seasonally or permanently waterlogged. The water may be stagnant or circulating. Includes inland marshland, swamp forests and peat bogs.
Shrub land, sclerophyllous	Shrub-dominated vegetation. May be used or non-used. Includes also abandoned agricultural areas, not yet under forest cover
Grassland, natural (non-use)	Grassland vegetation with scattered shrubs or trees (e.g., steppe, tundra, savannah).
Grassland, natural, for livestock grazing	Grasslands where wildlife is replaced by grazing livestock.
Arable land, unspecified use	Land suitable for crop production, in unspecified use
Pasture, man made	Arable land used for forage production or livestock grazing.
Pasture, man made, extensive	+ no artificial fertiliser applied, mechanically harvested less than 3 times per year or equivalent livestock grazing
Pasture, man made, intensive	+ artificial fertiliser applied, or mechanically harvested 3 times or more per year or equivalent livestock grazing

LAND USE CLASS	DESCRIPTION
Annual crop	Cultivated areas with crops that occupy the land < 1 year, e.g. cereals, fodder crops, root crops, or vegetables. Includes aromatic, medicinal and culinary plant production and flower and tree nurseries.
Annual crop, non-irrigated	Annual crop production based on natural precipitation (rainfed agriculture).
Annual crop, non-irrigated, extensive	+ Use of fertiliser and pesticides is significantly less than economically optimal.
Annual crop, non-irrigated, intensive	+ Fertiliser and pesticides at or near the economically optimal level.
Annual crop, irrigated	Annual crops irrigated permanently or periodically. Most of these crops could not be cultivated without an artificial water supply. Does not include sporadically irrigated land.
Annual crop, irrigated, extensive	+ Use of fertilizer and pesticides is significantly less than economically optimal.
Annual crop, irrigated, intensive	+ Fertiliser and pesticides at or near the economically optimal level.
Annual crop, flooded crop	Areas for rice cultivation. Flat surfaces with irrigation channels. Surfaces regularly flooded.
Annual crop, greenhouse	Crop production under plastic or glass.
Field margin/hedgerow	Land between fields with natural vegetation.
Heterogeneous, agricultural	Agricultural production intercropped with (native) trees.
Permanent crop	Perennial crops not under a rotation system which provide repeated harvests and occupy the land for >1 year before it is ploughed and replanted; mainly plantations of woody crops.
Permanent crop, non-irrigated	Perennial crops production based on natural precipitation (rainfed agriculture).
Permanent crop, non-irrigated, extensive	+ Use of fertilizer and pesticides is less than economically optimal.
Permanent crop, non-irrigated, intensive	+ Fertiliser and pesticides at economically optimal level.
Permanent crop, irrigated	Perennial crops irrigated permanently or periodically. Most of these crops could not be cultivated without an artificial water supply. Does not include sporadically irrigated land.
Permanent crop, irrigated, extensive	+ Use of fertilizer and pesticides is significantly less than economically optimal.
Permanent crop, irrigated, intensive-	+ Fertiliser and pesticides at or near the economically optimal level.
Cropland fallow (non-use)	Cropland, temporarily not in use (<2 years).
Urban/industrial fallow (non-use)	Areas with remains of industrial buildings; deposits of rubble, gravel, sand and industrial waste. Can be vegetated.

LAND USE CLASS	DESCRIPTION
Urban, continuously built	Buildings cover most of the area. Roads and artificially surfaced area cover almost all the ground. Non-linear areas of vegetation and bare soil are exceptional. At least 80% of the total area is sealed.
Urban, discontinuously built	Most of the area is covered by structures. Buildings, roads and artificially surfaced areas, associated with areas with vegetation and bare soil, which occupy discontinuous but significant surfaces. Less than 80% of the total area is sealed.
Urban, green area	Areas with vegetation within urban fabric. Includes parks with vegetation.
Industrial area	Artificially surfaced areas (with concrete, asphalt, or stabilized, e.g., beaten earth) devoid of vegetation on most of the area in question, which also contains buildings and/or areas with vegetation.
Mineral extraction site	Areas with open-pit extraction of industrial minerals (sandpits, quarries) or other minerals (opencast mines). Includes flooded gravel quarries, except for riverbed extraction. Landfill or mine dump sites, industrial or public.
Dump site	Landfill or mine dump sites, industrial or public.
Construction site	Areas under construction development, soil or bedrock excavations, earthworks.
Traffic area, road network	Motorways, including associated installations (stations).
Traffic area, rail network	Railways, including associated installations (stations, platforms).
Traffic area, rail/road embankment	Vegetated land along motorways and railways.
Bare area (non-use)	Areas permanently without vegetation (e.g., deserts, high alpine areas).
Snow and ice (non-use)	Areas permanently covered with snow or ice considered as undisturbed areas.
Inland waterbody, unspecified	Freshwater bodies.
River, natural (non-use)	Natural watercourses.
Lake, natural (non-use)	Natural stretches of water.
River, artificial	Artificial watercourses serving as water drainage channels. Includes canals.
Lake, artificial	Reservoir in a valley because of damming up river.
Seabed, unspecified	Area permanently under seawater.
Seabed, natural (non-use)	Natural seabed.
Seabed, bottom fishing	Seabed disturbed by bottom trawling or fishing dredge
Seabed, sediment displacement	Seabed disturbed by dumping or shellfish- or sediment-dredging
Seabed, infrastructure	Seabed disturbed by infrastructure like harbours or platforms
Seabed, drilling and mining	Seabed disturbed by drilling and mining, including cuttings and tailings disposal

## Appendix H *Uncertainty approach from ecoinvent<sup>®</sup>*

The uncertainty estimate approach which AusLCI has adopted from ecoinvent<sup>®</sup> 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 shown in Table 32. 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.

Data sources are then assessed according to the five characteristics "reliability", "completeness", "temporal correlation", "geographic correlation" and "further technological correlation" (see Table 33). 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. These uncertainty factors are shown in Table 34.

**Table 32: Default basic uncertainty (variance  $\sigma_b^2$  of the log transformed data, i.e. the underlying normal distribution) applied to intermediate and elementary exchanges when no sampled data are available.**

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  
(Source:(ecoinvent Centre 2007))

The square of the geometric standard deviation (95% interval – SDg95) is then calculated with the formulae shown in Equation 13.

**Table 33: Pedigree matrix used to assess the quality of data sources, derived from (Source:(ecoinvent Centre 2007))**

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

Source:(ecoinvent Centre 2007)

**Table 34: Default uncertainty factors (contributing to the square of the geometric standard deviation) applied together with the pedigree matrix (Source: Swiss Centre for Life Cycle Inventories, 2010)**

Indicator score	1	2	3	4	5
Reliability	1.00	1.05	1.10	1.20	1.50
Completeness	1.00	1.02	1.05	1.10	1.20
Temporal correlation	1.00	1.03	1.10	1.20	1.50
Geographical correlation	1.00	1.01	1.02		1.10
Further technological correlation	1.00		1.20	1.50	2.00

Source: (ecoinvent Centre 2007)

$$SD_{g95} := \sigma_g^2 = \exp^{\sqrt{[\ln(U_1)]^2 + [\ln(U_2)]^2 + [\ln(U_3)]^2 + [\ln(U_4)]^2 + [\ln(U_5)]^2 + [\ln(U_6)]^2}}$$

Where :

U<sub>1</sub> basic uncertainty factor

U<sub>2</sub> uncertainty factor of reliability

U<sub>3</sub> uncertainty factor of completeness

U<sub>4</sub> uncertainty factor of temporal correlation

U<sub>5</sub> uncertainty factor of geographical correlation

U<sub>6</sub> uncertainty factor of technological correlation

**Equation 13: Calculation of variance for uncertainty estimation**

# Appendix I *Full List of Agricultural Inventories Produced*

This section lists the inventories produced within AusAgLCI. The LCIs produced by the AusAgLCI project are of two types:

- LCIs for supporting processes, used in the production of several agricultural commodities (e.g. harvesting, drip irrigation)
- LCIs for agricultural commodities identified by the project stakeholders as priority commodities (e.g. wheat, tomatoes)

Both levels of inventories are available at: [give web address auslci.com.au](http://give.web.address.auslci.com.au).

## Agricultural commodities

### Sugar

The sugar inventories are the culmination of many years of LCA and LCI studies undertaken at University of Queensland (Renouf, Wegner et al. 2010; Renouf, Wegner et al. 2011). These inventories have been modified to meet the requirements of AusAgLCI and after a review of data by sugar industry stakeholders.

Table 35 presents the list of inventories developed for the sugar industry. As sugar growing varies depending on the production region, inventories have been supplied for 5 growing regions in Queensland and an average of all regions. An inventory for sugar milling is provided which produces raw sugar, electricity and molasses.

**Table 35: Inventories developed for the sugar production**

NAME	UNIT	TYPE
Sugarcane, harvested, at mill, average QLD/AU U	t	Material
Sugarcane, harvested, at mill, Bundaberg/AU U	t	Material
Sugarcane, harvested, at mill, Burdekin/AU U	t	Material
Sugarcane, harvested, at mill, Herbert/AU U	t	Material
Sugarcane, harvested, at mill, Mackay/AU U	t	Material
Sugarcane, harvested, at mill, Wet tropics/AU U	t	Material
Electricity from sugar mill, exported, at mill, QLD/AU U	kWh	Material
Molasses, from sugar, at mill, QLD/AU U	t	Material
Sugar, raw, at mill, QLD/AU U	t	Material

The sugar production involves numerous industry specific tractor processes and transport operation, for which inventories were developed. These are shown in Table 36.

### c. Sugar cane supporting inventories

**Table 36: List of sugar cane supporting inventories**

NAME	UNIT	TYPE
Harvest and haulout, burnt cane/AU U	t	Processing
Harvest and haulout, green cane/AU U	t	Processing
Shed, bare floor/AU U	m2	Processing
Locomotive, cane train/RER/I U	p	Transport
Rail bins, cane transport/AU U	p	Transport
Railway track, cane transport/AU U	my	Transport
Transport, cane, rail/AU U	tkm	Transport
Combustion, bagasse, in mill, QLD/AU U	t	Waste treatment
Land application of bagasse boiler ash to cane fields/AU U	t	Waste treatment
Land application of mill mud to cane fields/AU U	t	Waste treatment

### Grain

Table 37 lists the inventories developed for the grain sector. Sixteen grain commodities were identified as priority commodities for inventory development by grains research and development Corporation (GRDC).

In addition to those selected commodities, inventories were developed for tractor processes commonly used in the production of grains.

**Table 37: Inventories developed for the grain production**

NAME	UNIT	TYPE
Barley, Feed grade, no-till, Northern East NSW, at farm/AU U	kg	Material
Barley, Malt grade, Short Fallow, No-till, Central West NSW, at farm/AU U	kg	Material
Canola, No-till, Great Southern WA, at farm/AU U	kg	Material
Canola, No-till, North East NSW, at farm/AU U	kg	Material
Chickpeas, No-till, North East NSW, at farm/AU U	kg	Material
Lupins, Medium Rainfall Zone SA, at farm/AU U	kg	Material
Sorghum, no-till, North East NSW, at farm/AU U	kg	Material
Wheat, Central East, NSW, at farm/AU U	kg	Material
Wheat, Darling Downs, QLD, at farm/AU U	kg	Material
Wheat, High Rainfall Zone, SA, at farm/AU U	kg	Material
Wheat, Kellerberrin region, WA, at farm/AU U	kg	Material
Wheat, Low Rainfall Zone, SA, at farm/AU U	kg	Material
Wheat, Medium Rainfall Zone, SA, at farm/AU U	kg	Material
Wheat, Narrogin region, WA, at farm/AU U	kg	Material
Wheat, no-till, Central QLD, at farm/AU U	kg	Material
Wheat, North West NSW, at farm/AU U	kg	Material

The grain production involves numerous industry specific tractor processes for which inventories were developed and are listed in Table 38.

**Table 38: Broadacre supporting inventories**

NAME	UNIT	TYPE
Cultivating, broadacre crop/AU U	ha	Processing
Disc ploughing, broadacre crop/AU U	ha	Processing
Fertilizing, broadacre crop, pre & post-emergence/AU U	ha	Processing
Grader operation, broadacre crop, medium load factor/AU U	ha	Processing
Grain collection, broadacre, in-field with tractor+bin/AU U	ha	Processing
Harvesting, broadacre crop, combine <200kW/AU U	ha	Processing
Hay baling, large square bales, broadacre crop/AU U	ha	Processing
Hay baling, round bales, broadacre crop/AU U	ha	Processing
Hay baling, small square bales, broadacre crop/AU U	ha	Processing
Hay mowing, broadacre crop/AU U	ha	Processing
Hay raking, broadacre crop/AU U	ha	Processing
Liming, broadacre crop, pre & post-emergence/AU U	ha	Processing
Planting, broadacre crop, soil clay content >20%/AU U	ha	Processing
Planting, broadacre crop, soil clay content 0-10%/AU U	ha	Processing
Planting, broadacre crop, soil clay content 10-20%/AU U	ha	Processing
Scarifiying, broadacre crop/AU U	ha	Processing
Spraying, aerial, broadacre crop/AU U	ha	Processing
Spraying, broadacre crop, pre & post-emergence/AU U	ha	Processing
Windrowing, broadacre crop/AU U	ha	Processing

## Horticulture

Table 39 lists the inventories developed for the horticulture sector.

Nine horticultural crops were identified as priority commodities for inventory development by HAL. In the case of crops like avocado and banana, the production process is in two stages: one stage for land preparation or plantation establishment, one stage for the pick production period. In these cases, one inventory per stage was produced, that are further combined in the commodity inventory.

**Table 39: List of inventories developed for the horticulture sector**

NAME	UNIT	TYPE
Avocado, Hass, Brisbane Moreton, growing to harvest/AU U	Ha a	Material
Avocado, Hass, Brisbane Moreton, harvested, at farm/AU U	kg	Material
Avocado, Hass, Brisbane Moreton, orchard establishment/AU U	ha	Material
Banana, Cavendish, Wet tropics, harvested, at farm/AU U	kg	Material
Banana, Cavendish, Wet tropics, plant cycle/AU U	ha	Material
Banana, Cavendish, Wet tropics, ratoon cycle/AU U	ha	Material
Broccoli, winter, Lockyer Valley, harvested, at farm/AU U	kg	Material
Capsicum, Burdekin, harvested, at farm/AU U	kg	Material
Lettuce, winter, Lockyer Valley, harvested, at farm/AU U	kg	Material
Potato, Lockyer Valley, harvested, at farm/AU U	kg	Material
Strawberry, Brisbane Moreton, harvested, at farm/AU U	kg	Material
Sweet corn, Lockyer Valley, harvested, at farm/AU U	kg	Material
Tomato, trellis, Burdekin, harvested, at farm/AU U	kg	Material
Almonds, Unshelled, South Australia/AU U	kg	Material
Almonds orchard establishment, South Australia/AU U	kg	Material
Almond kernels, at huller and sheller/AU U	kg	Material

In addition to those selected commodities, inventories were developed for tractor processes as well as for consumables and fertilisers commonly used in their production and these are listed in Table 40.

**Table 40: Horticulture supporting inventories**

NAME	UNIT	TYPE
Expanded vermiculite, at plant/CH U	kg	Material
Green manure seeds/AU U	kg	Material
Peat, imported /AU U	kg	Material
Plastic bag, banana bunch cover/AU U	p	Material
Plastic Mulch, 25micron, at plant /AU U	m2	Material
Potting mix production and application, for seedlings/AU U	l	Material
Seedling, for transplant, at nursery/AU U	p	Material
Wheat straw, for mulching/AU U	kg	Material
Wire, for fencing, trellis, gates, at regional storehouse /AU U	kg	Material
Air blast spraying, orchards/AU U	ha	Processing
Bed forming, horticulture/AU U	ha	Processing
Boom spraying, horticulture, pre & post-emergence/AU U	ha	Processing
Cultivating, large implement, horticulture/AU U	ha	Processing
Cultivating, medium implement, horticulture/AU U	ha	Processing
Fertiliser side dressing, horticulture/AU U	ha	Processing
Fertiliser spreading, horticulture/AU U	ha	Processing
Harrowing, horticulture/AU U	ha	Processing
Harvesting, specialised machine, horticulture, 150 kW combine/AU U	ha	Processing
Inter-row cultivation, horticulture/AU U	ha	Processing
Inter-row tractor, horticulture/AU U	ha	Processing
Offset disc harrowing, horticulture/AU U	ha	Processing

### Cotton

Table 41 shows the list the inventories developed for the cotton industry.

Four regions were identified as the appropriate breakdown of the cotton industry into growing regions.

**Table 41: List of inventories developed for the cotton industry**

NAME	UNIT	TYPE
Cotton, RoundUp Ready Flex Bollgard II, irrigated, Central zone/AU U	kg	Material
Cotton, RoundUp Ready Flex Bollgard II, irrigated, Northern zone/AU U	kg	Material
Cotton, RoundUp Ready Flex Bollgard II, irrigated, Southern zone/AU U	kg	Material
Cotton, RoundUp Ready Flex Bollgard II, dryland, Central zone/AU U	kg	Material
Cotton, seed cotton, Australia, at farm/AU U	kg	Material
Cotton, ginning/AU U	kg	Processing
Cotton, lint, at gin/AU U	kg	Material
Cotton, seed, at gin/AU U	kg	Material

### Cotton supporting inventories

In addition to those regions, inventories were developed for specific cotton tractor processes which are listed in Table 42.

**Table 42: Cotton supporting inventories**

NAME	UNIT	TYPE
Bed forming, cotton/AU U	ha	Processing
Boom spraying, cotton/AU U	ha	Processing
Cultivating, cotton/AU U	ha	Processing
Discing, cotton/AU U	ha	Processing
Fertiliser spreading, cotton/AU U	ha	Processing
Fertiliser application, cotton/AU U	ha	Material
Harvesting basket cotton picker/AU U	ha	Processing
Levelling, cotton/AU U	ha	Processing
Mulching, cotton/AU U	ha	Processing
Round bale cotton picking/AU U	ha	Processing
Planting, cotton/AU U	ha	Processing
Rolling, cotton/AU U	ha	Processing
Root cutting, cotton/AU U	ha	Processing
Spraying, aerial, cotton/AU U	ha	Processing

## Livestock inventories

While no animal production inventories have been included in AusAgLCI at this point, inventories developed to support LCA modelling in the livestock industry have been included. Table 43 lists the inventories which have been selected according to the industry's priorities.

**Table 43: +List of inventories developed for the meat and lamb industry**

NAME	UNIT	TYPE
Bulldozer operation, medium load factor/AU U	hr	Processing
Canola meal, at oil mill/RER U	kg	Material
Canola oil, at oil mill/AU U	kg	Material
Cattle transport, km per head, prime mover + b-double AU/U	km	Processing
Control of Brigalow suckers, Graslán aerial application/AU U	ha	Processing
Cotton oil, at oil mill/AU U	kg	Material
Cottonseed meal, at oil mill/RER U	kg	Material
Dipping cattle for external parasites, per head through plunge dip/AU U	p	Processing
Dry Season Mix, 10% urea, 3.2% P, with protein meal, at regional store/AU U	t	Material
Dry Season Mix, 30% urea, 3.2% P, with protein meal, at regional store/AU U	t	Material
Forage Sorghum, irrigated, Darling Downs QLD/AU U	kg	Material
Forage Sorghum, irrigated, Northern Victoria/AU U	kg	Material
Lucerne hay establishment, dryland, Northern Zone NSW/AU U	p	Material
Lucerne hay, dryland, Northern Zone NSW/AU U	kg	Material
Maize, silage irrigated, Darling Downs QLD/AU U	kg	Material
Maize, silage irrigated, Northern Victoria/AU U	kg	Material
Milling wheat/AU U	t	Processing
Mineral block, 30% Urea 4.4% P, at regional store/AU U	t	Material
Oaten Hay, export, medium rainfall zone SA/AU U	kg	Material
Pre-mix trace element, ruminant mineral supplement, at regional store/AU U	kg	Material
Savanna burning, open eucalypt woodland, late dry season, Qld & NT/AU U	ha	Processing
Savanna woodland burning, Qld & NT/AU U	ha	Processing
Sheep drenching, internal parasite control/AU U	p	Processing
Sheep jetting, external parasite control/AU U	p	Processing
Weaner Block, 7.1% Urea 0.5% P, at regional store/AU U	t	Material
Wet Season Mix, 0% N 14% P, at regional store/AU U	t	Material

## Irrigation inventories

A series of processes were developed which were required for range of different farm systems. There are predominantly to do with pumping for irrigation and irrigation infrastructure.

**Table 44: List of irrigation processes inventories developed**

NAME	UNIT	TYPE
Irrigation, drip irrigation system/AU U	m3	Processing
Irrigation, hose move sprinkler irrigation system/AU U	m3	Processing
Irrigation, flood or furrow irrigation system/AU U	m3	Processing
Irrigation, solid set sprinkler irrigation system/AU U	m3	Processing
Irrigation, travel spray boom irrigation system/AU U	m3	Processing
Irrigation, travelling gun irrigation system/AU U	m3	Processing
Irrigation, undertree irrigation system/AU U	m3	Processing
Irrigation, Centre pivot system/AU U	m3	Processing
Pumping, irrigation, 10m total pumping head, 100% electricity, QLD/AU U	m3	Processing
Pumping, irrigation, 10m total pumping head, 50% electricity, NSW/AU U	m3	Processing
Pumping, irrigation, 15m total pumping head, 100% diesel, NSW/AU U	m3	Processing
Pumping, irrigation, 15m total pumping head, 100% diesel, Qld/AU U	m3	Processing
Pumping, irrigation, 20m total pumping head, 100% electricity, QLD/AU U	m3	Processing
Pumping, irrigation, 25m total pumping head, 100% diesel, NSW/AU U	m3	Processing
Pumping, irrigation, 40m total pumping head, 100% electricity, QLD/AU U	m3	Processing
Pumping, irrigation, 45m pumping depth, 0% electricity, NSW/AU U	m3	Processing
Pumping, irrigation, 50m total pumping head, 100% electricity, QLD/AU U	m3	Processing
Pumping, irrigation, 64.5m total pumping head, 100% electricity, QLD/AU U	m3	Processing
Pumping, irrigation, 65m total pumping head, 100% electricity, QLD/AU U	m3	Processing
Pumping, irrigation, 70m pumping depth, 100% diesel, Vic/AU U	m3	Processing
Pumping, irrigation, 70m total pumping head, 100% diesel, Qld/AU U	m3	Processing
Pumping, irrigation, 70m total pumping head, 100% diesel, Vic/AU U	m3	Processing
Pumping, irrigation, 80m total pumping head, 100% electricity, NSW/AU U	m3	Processing
Centre pivot irrigation system, production, per ha/AU U	ha	Processing
Drip irrigation system (sugarcane), production, per ha/AU U	ha	Processing
Drip irrigation system, production, per ha/AU U	ha	Processing
Hose move sprinkler irrigation system, production, per ha/AU U	ha	Processing

Flood or furrow irrigation system, production, per ha/AU U	ha	Processing
Solid set sprinkler irrigation system, production, per ha/AU U	ha	Processing
Travel spray boom irrigation system (sugarcane), production, per ha/AU U	ha	Processing
Travel spray boom irrigation system, production, per ha/AU U	ha	Processing
Travelling gun irrigation system (sugarcane), production, per ha/AU U	ha	Processing
Undertree irrigation system, production, per ha/AU U	ha	Processing

Based on the common agricultural practices in Australia, the processes listed in Table 44 have been developed for 1ha of field processed.

# Glossary

Term	Definition
<b>LCA</b>	Life Cycle Assessment method of calculating the environmental impacts of products and services from cradle to grave.
<b>LCI</b>	Life Cycle Inventory – the second stage of LCA where unit processes are connected and total exchanges with the environment are calculated.
<b>LCI data</b>	Data which contain the input and outputs required to deliver a specified product.
<b>LCIA</b>	The third stage of LCA where inventory is linked to environmental indicators.
<b>AusLCI Shadow database</b>	The shadow database is a set of background data adapted from ecoinvent® 2.2 to better fit the Australian situation. This data is used in the absence of available AusLCI process for background processes using in AusAgLCI
<b>AusLCI</b>	Australian life cycle inventory database project developed and hosted by the Australian Life Cycle Assessment Society
<b>AusAgLCI</b>	Australian agricultural life cycle inventory project being undertaken by CSIRO on behalf of the RIRDC to develop agricultural inventories data to be included in AusLCI.
<b>Agro-ecological zone</b>	A national zoning scheme developed by Williams which characterises character rises Australia into 46 zones based on climate and soil characteristics.(Williams, Audsley et al. 2006)
<b>PEST LCI</b>	The computer-based model developed by Dijkman for partitioning pesticide emissions from farms to surface water, groundwater, and off farm soil using local farm level data.(Dijkman, Birkved et al. 2012)

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## AusAgLCI methodology for developing Life Cycle Inventory

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