AusLCI methodology for developing Life Cycle Inventory for Australian agriculture

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Executive Summary

This methodology report aims to provide more detailed explanation of the approach taken within the AusLCI life cycle inventory for agriculture. 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 AusLCI data. The document does not provide a detailed explanation of all the inventory data developed in AusLCI. Specific detail on the inventory calculations is provided within the inventory itself.

While this AusLCI report is focusing on agricultural LCI, it is done with a view to enable the broadest possible use of the data in LCA studies. In this report 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
- Soil acidification
- Soil erosion
- Soil organic carbon
- Particulate matter

Agricultural inventory 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 AusLCI is premised on the collection and publishing of publicly available data. The vast majority of this data has been sourced from agricultural statistics provided by the Australian Bureau of Statistics, industry publications on management inputs and practices, Gross Margin documents provided by the agricultural departments in each state, and survey data collected from a representative group of farmers in agro-ecological zones.

A total of 283 life cycle inventories for agriculture can be found in AusLCI, of this 179 broadacre inventories, 4 cotton, 5sugarcane, , 58 unallocated Bovine inventories and 15 Ovine inventories. This provides national coverage for dryland broad-acre cropping, pasture-based beef and sheep production, cotton and sugar. A small number of annual and perennial horticultural crops are included.

The data presented in AusCI 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.

Introduction to the AusLCI Database for Agriculture v2

The purpose of the AusLCI database for agriculture

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. AusLCI 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 AusLCI life cycle inventory for Australian agriculture. It also hopes to provide future developers of agricultural LCI with guidance as to the recommended practice to develop similar inventory data which will be consistent with the AusLCI data. The document does not provide a detailed explanation of all the inventory data developed in AusLCI. Specific detail on the inventory calculations is provided within the inventory itself.

Inventory scope and definitions

LCA and LCI

The different phases of a LCA are shown in Figure 1. The inventory analysis step consists of 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.

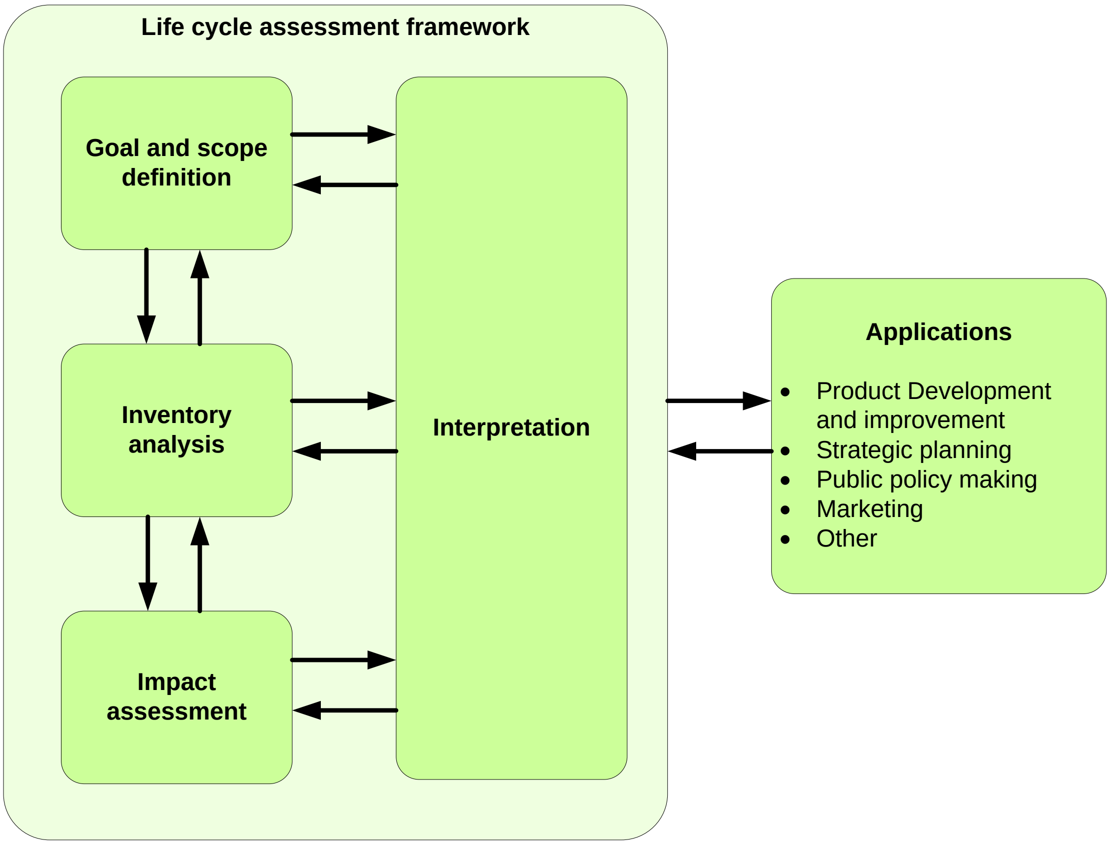


Figure 1: Life Cycle Assessment phases

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 and the AusLCI shadow database (shown in blue boxes in Figure 2). This database is modified version of a global database produced by ecoinvent®, 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 AusLCI due to licensing conditions but the inputs from this data are identified so that users can link to them once they download the AusLCI 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 agricultural LCIs produced in AusLCI are mostly from cradle to harvest.

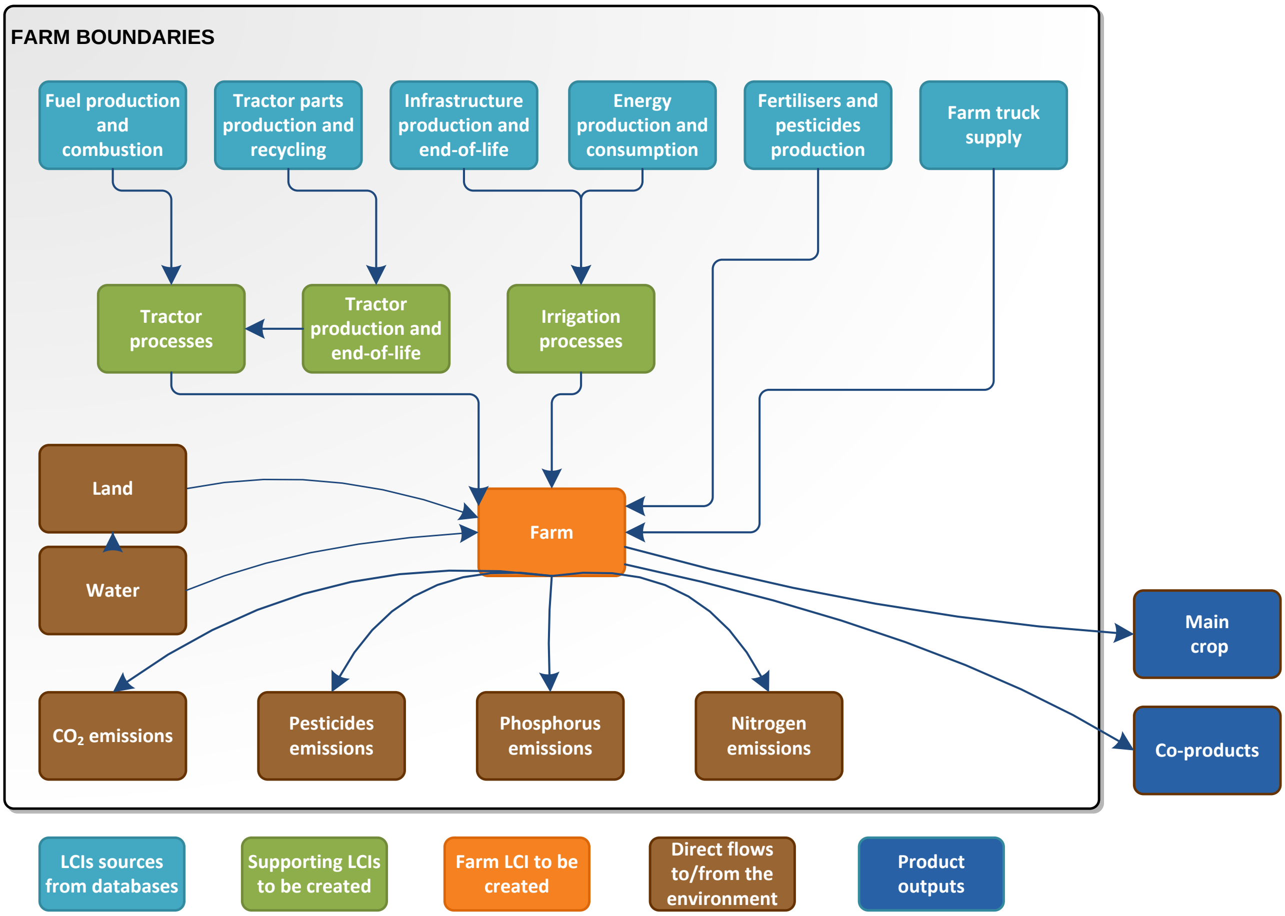


Figure 2: **LCIs interaction and farm LCI boundaries**

Category Indicators of Interest

While this AusLCI report is focusing on agricultural 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 impact categories for agricultural studies and attention has been put into supplying the inventory flows required as inputs to these indicators. These indicators are:

- Climate change
- Water scarcity
- Land use
- Eutrophication
- Ecotoxicity
- Human toxicity
- Terrestrial acidification
- Soil acidification
- Soil erosion
- Particulate matter
- Photo chemical oxidation potential
- Stratospheric ozone depletion
- Soil organic carbon

Climate Change

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 AusLCI greenhouse gas (GHG) flows are based on IPCC (Inter-Governmental Panel on Climate Change 2006) and National Inventory Report (O'Farrell 2018) methodologies. This includes emissions directly associated with production such as enteric methane, direct and indirect N_2O emissions from dung and urine, fertiliser use, burning of stubble and emission from crop residues. Changes in soil carbon from agricultural activities are included in the inventory but currently set to zero while investigation of the soil carbon trends in each region are investigated.

In addition to the emission sources listed above, there is considerable interest globally in the climate change impacts from Direct land use change (dLUC). DLUC is defined as a change in the use or management of land within the product system being assessed (International Organization for Standardization 2013). It's difficult to determine the appropriate allocation of dLUC for LCI inventory which are calculated at both regional and then averaged to national level. In ecoinvent and the Product Environmental Footprint PEF standard the production system is taken to be at a country level, and therefore for Australian production we have taken the same approach, treating the continent as the geographical extent of the production system. National DLUC values have been investigated for Australia as part of this project, however at the time of publication we had not found suitable values which for inclusion. Future investigation will be undertaken of the approach taken by Blonk Consultants (Blonk Consultants 2017) to adapt the IPCC(IPCC 2014) and PAS 2050(BSI 2012) approaches into a model for use in life cycle inventory. Blonk Consultants have developed a method based on national greenhouse accounts which describe what land use change has occurred over a 20-year period within national borders. This is then allocated to specific crops based expansion in area planted for each commodity. While the method has some drawbacks, its adoption in key international databases makes an important consideration for our agricultural inventory.

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

Water Scarcity

Elemental flows required to support a range of impact assessment approaches are included. Two aspects are used to describe water use in AusLCI. The first is the source of the water which are shown in Table 1 and the second is the catchment where the water is extracted. The catchment is used to enable the calculation of water footprint models which differentiate between water extracted based on the relative water stress in the supplying catchment. Figure 3 shows the catchment definitions used for Australia which were developed specifically for AusLCI. They are a mix of drainage divisions (of which there are 11 in Australia) and river basins (of which there are hundreds) as it needed to be as few as possible while capturing water stress differences particularly in the Murray Darling Basin.

Table 1: Water elementary flows in AusLCI

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

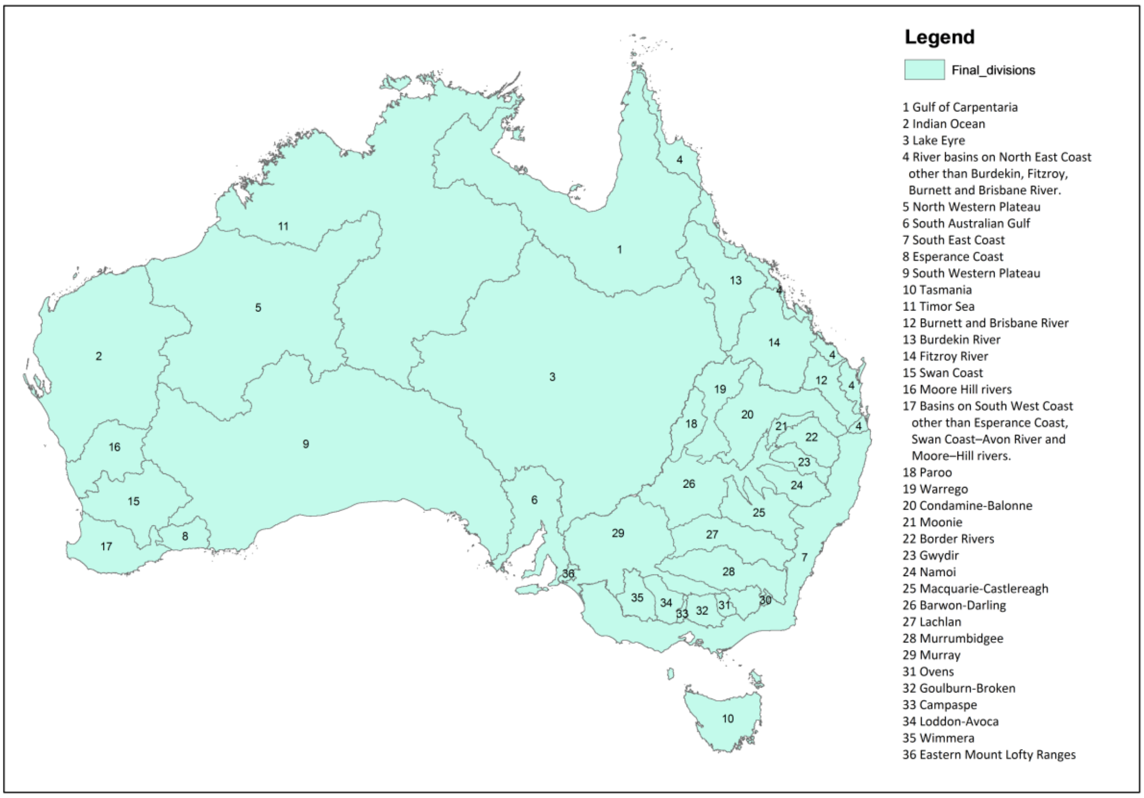
*Refers to rainwater intercepted and held in a tank – does not refer to rainwater falling on crops or other system which are considered part of natural flow.

** Refers to water evaporated from man-made storage facilities.

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 AusLCI to date.

To determine what catchments make up each AER the map in Figure 3 was intersected with the AER and beef regions GIS layers. The results of this intersection in provided in Appendix E.

Figure 3 Catchment definitions used in the AusLCI



Land use

There are a number of impact categories linked to Land use and land use change , especially for agricultural production. The difficulty for AusLCI is that the methodology for assessing impacts relating to land use is still in development. The approach taken in AusLCI is to provide enough information in the inventory to serve current and possible future developments in land use impact assessment.

Land occupation is relatively straightforward as a flow in LCIbeing the land cover and and use area occupied multiplied by the time for the production of crop or animal product. The flow description follow the recommendations of (Koellner, De Baan et al. 2013) It includes a full cycle from the end of the previous crop to the end of the crop under study. For most systems producing one crop per year this will result in one year being allocated to the crop production. Where land is taken out of production put into fallow as part of a rotation, the fallow crop is allocated (shared) across all crops in the rotation. In regions where double cropping is undertaken the occupation time will be shortened appropriately. The choice of classification system for land use categories is important to make the data globally applicable but also locally relevant. AusLCI uses the same land use categories as ecoinvent® which are shown in Appendix G.

Where land use change does occur it should be included in the inventory as land transformation flows describe in both the original use of the land (land transformation from) in the new use of the land (land transformation to). Note the climate change consequences of land occupation and transformation are included in the inventory section as described in climate change chapter above.

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 AusLCI does not record prior land use as this is generally impractical from a data supply point of view.

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

Impact Method	Basis for characterisation	Elementary flows required
Change in SOC (Brandão and Milà i Canals 2013)	Impact of land occupation and transformation on SOC stock compared to potential natural vegetation reference.	Occupation by land type Land transformation to- by land type Land transformation from- by land type
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

Eutrophication

Eutrophication is caused by nitrogen (N) and phosphorus (P) compound 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 climate change, Nitrate flows to water are estimated using Australian National Inventory Report methodology (Commonwealth of Australia 2018) for N that is leached. Phosphorus leaching and runoff are estimated by the method used by ecoinvent® (Nemecek, Kägi 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 (ABARES 2016)) to determine if leaching and run-off is occurring and to estimate the P-content of eroded soil (relevant for P transport to waterways). Soil erosion was calculated using the method described for soil erosion.

Percentage total P was calculated for 0-10 cm soil layer based on data from the Soil and Landscape Grid of Australia {Terrestrial Ecosystem Research Network, 2016 #433} and the intersection with the 2010 land use layer (ABARES 2016) for the land class corresponding to each agricultural sector. The 0-10 cm layer was created by taking a weighted average of the two published layers for 0-5 cm and 5-15 cm.

Ecotoxicity

Ecotoxicity is driven by the use of chemicals in cropping and livestock systems however the calculation of impacts from pesticides is highly dependent of local factors at the site of application and assumptions regarding when a pesticide is assumed to be in the environment.

LCA makes a clear distinction between the environment and the techno sphere (International Organization for Standardization 2006) with the techno sphere defined as the realm of human technological activity which translates in LCA terms to the sphere where the fate of substances is in human control. For most instances in LCA this boundary between the environment and the techno-sphere is clear. For example, petrol inside a vehicle is in the techno-sphere while the emissions from the exhaust pipe are released to the environment. For pesticide applications to crops the boundary is not so straightforward. Pesticides are substances designed to be toxic for specific targets are applied with an element of control however once the pesticide has been applied, there is little control of its fate, and the substance may be deemed to be in the environment. An additional complication is that the fate of pesticides is highly dependent on local factors such as climate, soil, application type and pesticide properties. Life cycle impact assessment (LCIA) typically adds emissions across a life-cycle and then applies global default fate and exposure pathways. However, in the case of pesticides, the loss of specific local data in the fate and exposure pathway model can lead to dramatic over or underestimation of impacts.

To deal with these issues and improve the accuracy and consistency of pesticide fate modelling in agriculture, LCA practitioners organised a three year project to develop a consensus based approach to the treatment of pesticides and their fate modelling in life cycle inventory development (Fantke, Anton et al. 2016). The final report from the working group is still to be published but the consensus produced from this group is that for life cycle inventory databases only instantaneous (primary) partitioning of pesticides between air, agriculture soil and drift off farm should be included. The off-farm drift should also be partitioned between soil and freshwater depending of the land cover type expected to be adjacent to the farm.

For LCA studies which are explicitly about agriculture, secondary fate functions should be modelled using local climate and soil data. This includes degradation, plant update and leaching of pesticides on the farm. The modelling of these secondary pathways is not yet possible for all pesticides so this has not been implemented in the current version of AusLCI.

Soil Acidity

Soil acidification is a natural process accelerated by agriculture. Soil acidifies because the concentration of hydrogen ions in the soil increases with the addition of fertiliser and removal of product (Figure 4). The main cause of soil acidification is inefficient use of nitrogen, followed by the export of alkalinity in produce {Soilquality.org.au, 2016 #354}. Ammonium based fertilisers are major contributors to soil acidification. Ammonium nitrogen is readily converted to nitrate and hydrogen ions in the soil. If nitrate is not taken-up by plants, it can leach away from the root zone leaving behind hydrogen ions thereby increasing soil acidity. In addition, most plant material is slightly alkaline and removal by grazing or harvest leaves residual hydrogen ions in the soil. Over time, as this process is repeated, the soil becomes acidic, but this trend can be ameliorated by the application of soil conditioners such as lime. The nitrogen cycle for cropping land use is described in Figure 5.

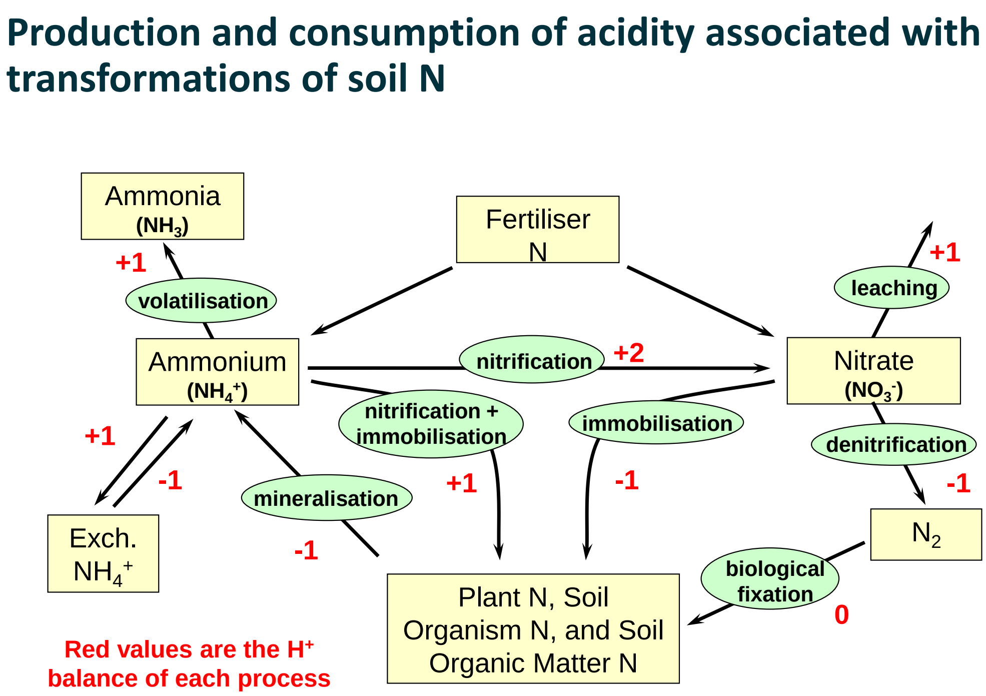


Figure 4. Production and consumption of H+ leading to net acid addition from nitrogen inputs into agricultural systems (source Jeffery Baldock, CSIRO).

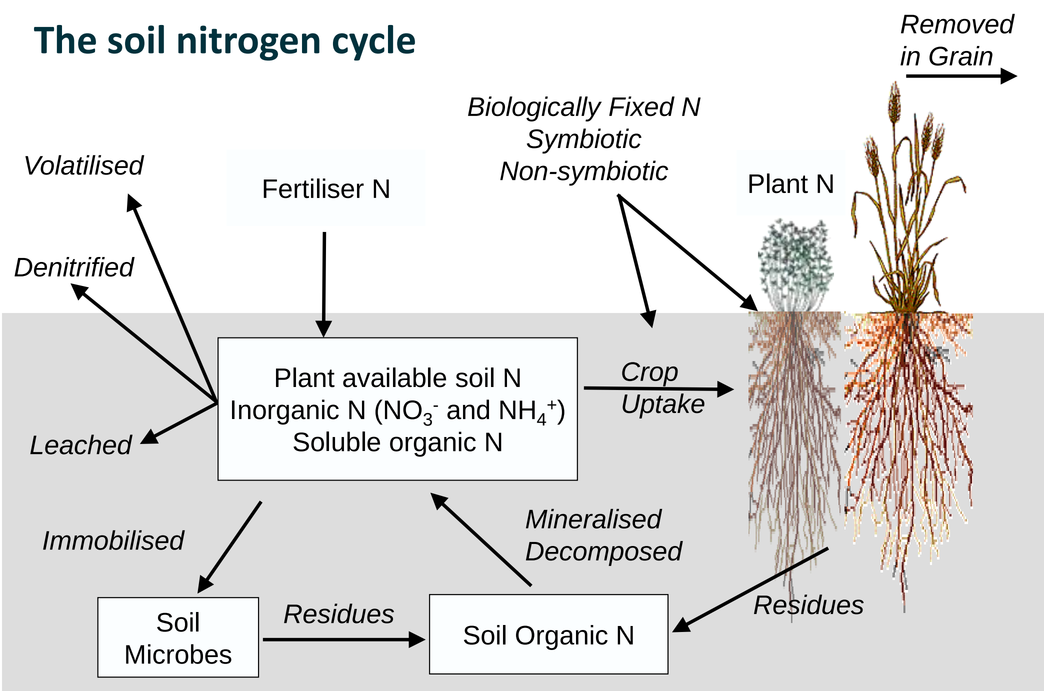


Figure 5. Nitrogen cycle where there are fertiliser and legume inputs of nitrogen (source Jeffery Baldock, CSIRO).

The approach taken to estimate change in soil acidity is based on the underlying chemistry of net acid addition rate (NAAR). NAAR can be expressed as cation flow into and out of the technosphere. Hydrogen ions accumulate with the addition of N fertiliser to the soil, the acidifying effect being dependent on the type of N fertiliser (greater for ammonium based fertilisers) and the amount of nitrate leached out of the root zone. This is countered by the addition of soil conditioners such as lime. The ash alkalinity of exported products also increases acidity. These chemical relationships have been modelled in AusLCI so that as the user varies inputs (fertiliser, lime) and outputs (kg of product) the hydrogen ion flow is adjusted.

The acidifying rate for fertilisers is based on the type of fertiliser and the level of leaching of nitrate in the soil profile (Jeff Baldock 2009). When leaching occurs the assumed fraction of N leached is 30% (to be consistent with the National Inventory Report method for indirect N_2O loss from leaching). The evapo-transpiration (ET):rainfall ratio is used to guide where leaching occurs (no leaching if ratio is >0.8 and <1). The proportion of a cropping or grazing region where leaching occurs was determined using the ET:rainfall based on average for climate data (1976-2005) sourced from {Queensland Government, 2016 #493}.

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

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

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

Development of an impact assessment method incorporating flows related to soil quality and its contribution to eco-system services is the topic of a UNEP-SETAC Working Group and it is envisaged that the inventory flow for soil acidity will be linked to this method.

Terrestrial acidification (ecosystem)

Terrestrial acidification is an ecosystem impact based on the change is pH in natural environments. It is affected by emission of acid gases in the atmosphere which a deposit in natural areas through atmospheric deposition and rain events. The main contribution from farm system is the emission of ammonia from fertiliser application which is calculated as a N flow that feeds into indirect N_2O emissions for Climate change using Australian National Inventory Report methodology (Commonwealth of Australia 2018). Nitrous oxides from burning of stubble and machinery emission of will have also affect terrestrial acidification..

Soil acidification (ecosystem-services)

The addition and accumulation of hydrogen ions in agricultural soil in similar to terrestrial acidification impact category but the endpoint is farm productivity, which is part of the ecosystem services, rather than natural species loss. The elementary flows for accumulation of hydrogen ions in the soil is implemented in the inventory. The pathway from emission through to damage to productivity have been modelled through to the point of increasing pH, accounting for buffering capacity and calculation of the number of years to critical pH. However, the final step to get from years to critical pH to reduction in provision of biomass for human use has not yet been developed.

Human Toxicity

While the work on pesticide fate models will have some impact on human toxicity the current partitioning models do not include plant uptake of pesticides, which is likely to be the most significant pathway for human toxicity. For this reason, the pesticide flows in the inventory do not fully support human toxicity impacts category. As the "product" compartment in the toxicity models is fully implemented this approach should be revisited.

Particulate matter

Particulate matter refers to fine particles and are measured as particulate matter less that 2.5um. Particulate matteris a significant effect on human health (Lim, Vos et al. 2012). Agriculture system contribute through emission from burning residues, from machinery emissions and from ammonia emissions which are known as secondary particulates through the formation of aerosols. All three of these sources are quantified in the inventory data, with all emissions being placed in the low population sub-compartment of air emissions, which has a lower characterisation factor to emissions in high population areas.

Photo oxidant formation potential

The inventory includes on farm emissions effecting PCOP including NOX, NMVOC, butadiene from burning and machinery emissions however as these are place in the low population sub-compartment the effect is likely to be small.

Stratospheric ozone depletion

With the reduction in CFC emissions, nitrous oxide is now the main contributor to ozone depletion.(Ravishankara, Daniel et al. 2009) Nitrous oxide is emitted from both foreground processes on farm and background processes especially in fertiliser production.

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, and ionising radiation.

Inventory flows

A summary of each impact category that the inventory will inform is given in Table 3, along with the environmental flows incorporated into the gate-to-gate farm processes (these are the flows occurring within the production boundary for the agricultural product, e.g. on-farm). The linking to background processes in existing libraries such as ecoinvent® database allows the inventory to be used to inform additional impact categories such as fossil and mineral depletion, fossil energy use, photo-oxidant formation (smog), ozone depletion, particulate emissions and ionising radiation.

Table 3. Impact category, environmental flows and units used in the gate-to-gate farm inventory.

Impact category	Environmental Flows in the Foreground System
Climate change	Methane (CH_4) from burning crop residues Nitrous oxide (N_2O) from nitrogen fertilisers, crop residues and burning crop residues Indirect N_2O emissions as fertiliser N moves through the land system and N from ammonia emissions are deposited in soils and re-emitted as N_2O. (Carbon dioxide from burning of fuel on-farm is accounted for in the background inventory.)
Water use	Water used by livestock, by catchment Evaporative loss from farm dams, by catchment Water used for irrigation, by catchment
Land use	Area of land occupied for the portion of the year that the product requires for a full production cycle, covering land preparation to harvest. Also includes allocation of land use for fallow across rotation.
Eutrophication	Nitrogen and phosphorus flows to fresh water
Ecotoxicity	Flow of pesticide active ingredients to air, water and soil.
Terrestrial acidification	Ammonia, nitrogen oxides, sulfur
Soil acidification	Hydrogen ions to soil
Soil quality	The elementary flow for soil erosion is soil to water.
Particulate Matter	PM<2.5um, PM2.5um-10um, PM>10um, ammonia, NOx
Photo oxidant formation potential	NO_X, NMVOC, butadiene, methane
Stratospheric ozone depletion	Nitrous oxide

Structure of the inventory

Introduction to data structure

AusLCI data for agriculture 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

AusLCI has developed foreground data for farming systems however these systems need to link to upstream inventory data, or background data. Four types of background data have been used in AusLCI agricultural inventory (and general AusLCI inventory) as shown in Table 4.

Table 4: Types of background data used in AusLCI

Data type	Description
AusLCI processes	Processes which have been published by the AusLCI including any data developed as part of the AusLCI agricultural projects (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).

Allocation

The AusLCI guidelines provide an allocation hierarchy for co-producing processes which is shown in Figure 6. 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 6: 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 – **For joint production , i**n 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).

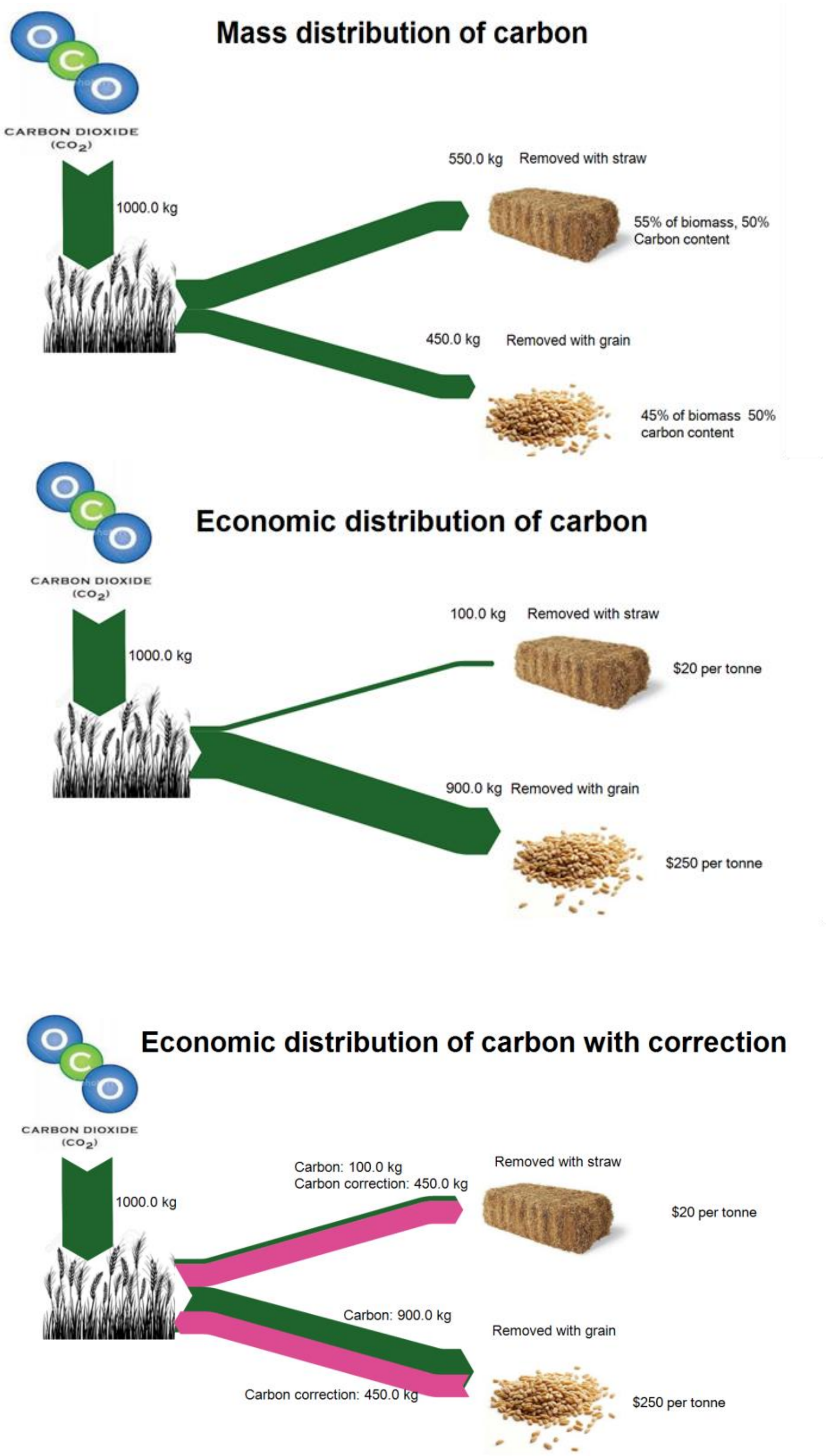
This hierarchy has been followed in the agriculture inventory in AusLCI and the interpretation is outlined in Table 5

Table 5: Approaches used to deal with coproduction in the AusLCI inventories

Situation	Approach Taken	Comments
Mixed cropping system	Separation of sub-systems has been used to model the impact of each crop independently. Where crops contribute nitrogen to the soil a negative synthetic nitrogen flow has been included. This is balances by additional nitrogen applications to crops which consume more nitrogen that is applied in the crop. Pasture phase is included from a	For LCA wanting to investigate the benefits of crop rotations and interaction with livestock, these interactions will need to be modelled.

	N fixation point of view but animal N excretions are not included	
Legumes in rotation with cereals	Nitrogen fixed by the legumes is credited to the legume crop in terms of applied fertiliser and associated fertiliser emissions	This credit approach is based on system expansion, which is inconsistent with the AusLCI guidelines but is the easiest separate the impacts of legumes from the cereals they are grown in rotation with.
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 an allocation is required to create inventory for straw. More work is required to developed national coverage for wheat production including the extent of straw production.
Dedicated manure crop/ fallowing of land	Allocated across all crop in the rotation in which the fallow is included.	Where land is kept fallow and weed-free to build a store of soil moisture, or a crop is grown specifically to fix nitrogen or improve land condition, impacts are allocated to all other crops in the rotation based on the fraction of time each crop occupies in the rotation.

Figure 7 Process for correcting carbon balance after coproduct allocation



Geographical scope

Geographical coverage of LCIs

The first step towards national coverage for the LCI was to identify those regions where farming systems were different enough to warrant separate inventory to describe production, and its environmental impact. This was done separately for plant and livestock production.

The process was to identify those regions where there was significant production and then look for biophysical classifications to group smaller areas which are similar.

For grass-fed livestock production, broad-acre crops, sugar[1] and cotton inventories a weighted average of Australian production has been developed, while for all other commodities (mainly horticulture) production was modelled on specific regions as coverage was not broad enough to attempt to produce a national average.

Broad-acre dry-land cropping

The distribution of dryland cropping land use for 2010 is shown in Figure 8 (ABARES 2016). Agro-ecological Regions (AER) (Williams, Hamblin et al. 2002) were used to define areas where similar production systems operate. Within each AER, data on production and area of crop planted are available at the Statistical Area Level 2 (SA2) (Australian Bureau of Statistics 2011). Broad-acre cropping is not undertaken in all AERs.

[1] A small area of sugar production in northern New South Wales is not currently included.

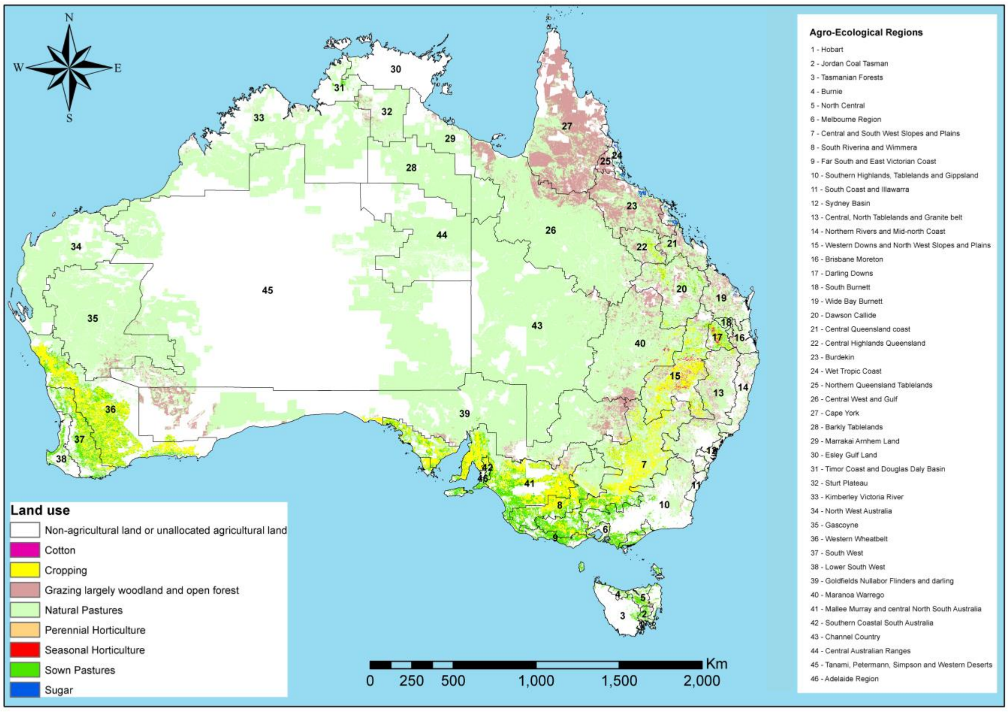


Figure 8. Land use in 2010 (ABARES 2016) for agro-ecological regions of Australia (Williams, Hamblin et al. 2002).

The distribution, amongst SA2s, for production and yield for two important broad-acre crops, wheat and canola, are shown in Figure 9.

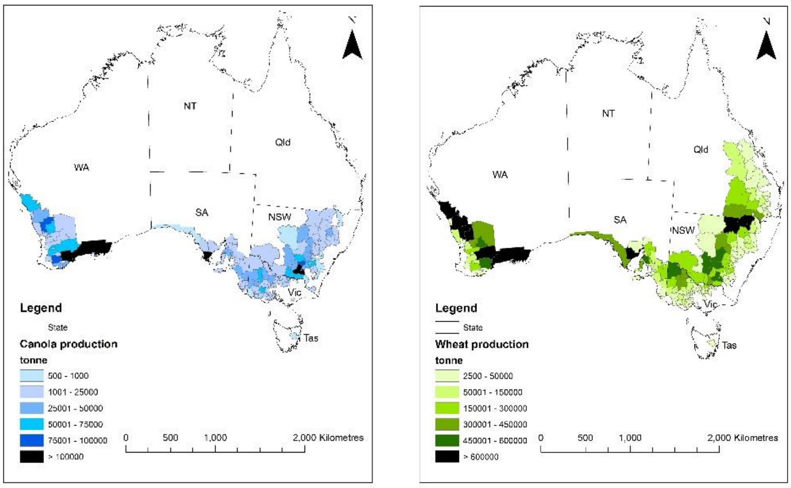


Figure 9. Production (t/year) for canola and wheat averaged over four years. Source: (Australian Bureau of Statistics 2015).

Livestock

The distribution of grazing land use for 2010 is shown in **Error! Reference source not found.**Figure 8 (ABARES 2016) and the livestock regions in Figure 10. Depending on the region and State different approaches were used to define areas where similar production systems operate. For the northern beef industry, and sheep in Queensland, these were based on Australian Bureau of Agricultural and Resource Economics and Sciences ABARES survey regions of northern Australia (Department of Agriculture and Water Resources 2016). For beef and sheep in New South Wales they were based on regions defined by NSW Department of Primary Industries (Phil Graham, NSW DPI, pers. comm.). For Victoria regions were based on the benchmark regions set up by Victorian Department of Primary Industries (Department of Primary Industries 2014), and in South Australian and Western Australia they were defined by rainfall zones (Rural Solutions SA PIRSA 2015). In Tasmania livestock regions were matched to descriptions provided by Department of Primary Industries (Department of Primary Industries Parks Water and Environment 2015).

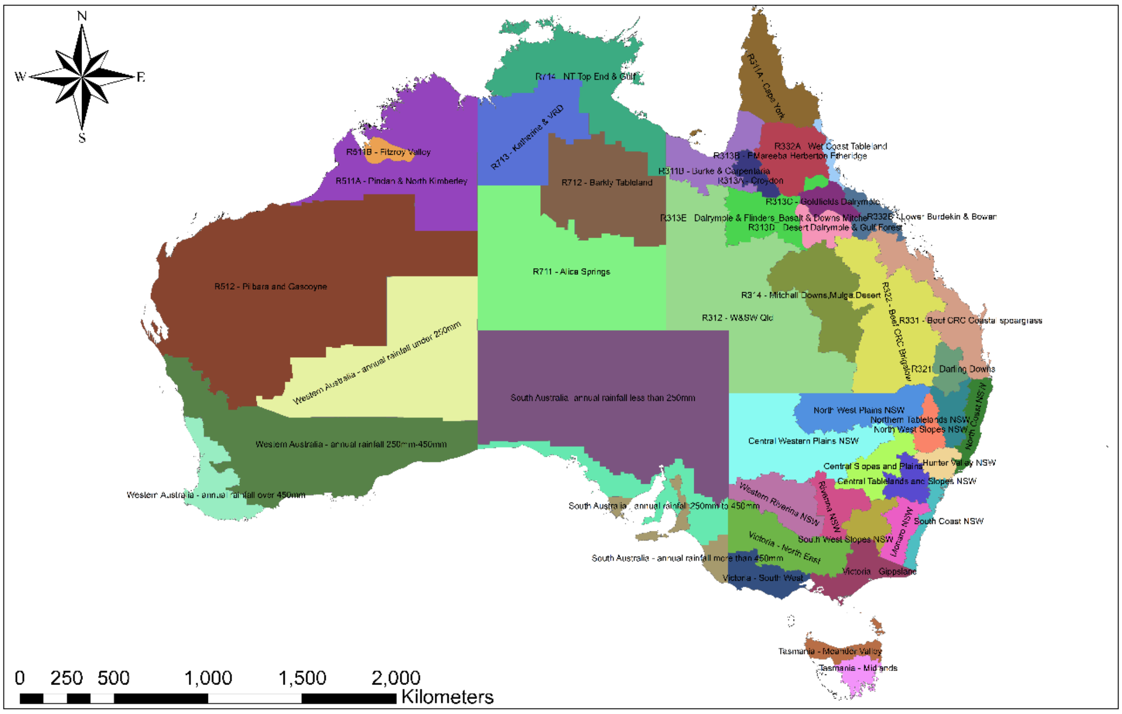


Figure 10. Livestock regions used to create life cycle inventory. Source: (Holmes, Sullivan et al. 2011), (New South Wales Department of Primary Industries 2016), (Rural Solutions SA PIRSA 2015) and (Department of Primary Industries Parks Water and Environment 2015).

Cotton and sugar production

Regions for cotton and sugar production were based on descriptions used by the respective industries. For cotton this covers Northern zone (Emerald and Dawson-Callide Districts), Central zone (Macintyre Valley, Darling Downs, St George-Dirranbandi, Namoi Valley, Gwydir Valley and Bourke) and Southern Zone (Macquarie Valley, Tandou and Southern NSW). For sugar the regions are all in Queensland and include wet tropics (Wet Tropics and Tablelands), Mackay, Burdekin (to Ayr north of Townsville), Herbert (to ingham, south of Townsville) and Southern region (Bundaberg). A full description of the difference in production systems is given in {Eady, 2014 #494}.

Collection of data

Data collection and modelling of data for inventory for the agricultural LCI was based on the following approach:

a) Methods used can be applied nationally across a range of agricultural regions

b) Required input data are publicly available nationally at a geographical scale that allows regional differences to be represented

c) Data quality standards for AusLCI are met {AusLCI Committee, 2014 #495}

d) Use point sourced data (from surveys, industry experts, scientific literature) is used to validate modelled inventory to check for outliers or anomalies.

Data sources for broad-acre cropping and livestock inventory

For broad-acre cropping and livestock the approach taken in this iteration of the AusLCI was to use official statistics from the Australian Bureau of Statistics (for crop yield, numbers of livestock, fertiliser types), published surveys where more detailed information was required (for crop residue management, tillage practices, protein content of grain), published tools based on empirical relationships for estimation of inputs (such as N-fertiliser, lime, fuel use and seeding rates), and Gross Margin publications (reproductive rate, herd structure, classes of cattle sold, live weight and price of cattle sold, and pesticide inputs). A consistent approach was applied across each of the States. All data sources and methods applied are publicly available for verification or included as Appendices in the Methodology Report that will accompany the inventory database file. The inventory is representative for the five-year period from 2010 to 2014. An overview of inputs and data sources can be found in Table 6.

Table 6. Sources of data for reference flows, farm inputs and management practices.

Input	Data source
Crop Yield	Australian Bureau of Statistics (Australian Bureau of Statistics 2015) for dryland crop production at the level of SA2 form 2010/11 to 2014/15
Fertiliser type	State level statistics for fertiliser use in broad-acre cropping {Australian Bureau of Statistics, 2013 #322}
Fertiliser quantity	Generic Yield and N Calculator (Baldock 2012)
Place of fertiliser manufacture	Fertiliser industry data (Nick Drew, Fertilizer Australia, pers. comm.), Standard transport distance assumed for whole of Australia
Lime quantity	Net Acid Addition Rate (Jeff Baldock 2009).
Crop residue management	National data for broad-acre cropping land in Australia (Umbers, Watson et al. 2016)
Tillage practices	National survey data for broad-acre cropping land in Australia (Umbers, Watson et al. 2016)
Protein content of grain	Protein content of grain used to determine N demand (INRA, CIRAD et al. 2016)
Pesticide quantity	Various State Government Agriculture Department publications on pest control in crops and parasite control in livestock
Crop fuel use	Australian based fuel calculator (Salam 2010)
Seeding rates	Various State Government Agriculture Department Gross Margin publications
Livestock numbers	Australian Bureau of Statistics {Australian Bureau of Statistics, 2015 #264} for beef cattle and sheep numbers from 2010/11 to 2014/15
Water intake by livestock	Based on feed intake of livestock (Australian Farm Institute 2010) and adjusted for water content of pasture using monthly rainfall to estimate dry matter content of pasture
Evaporative water loss on-farm dams	Potential evaporation surface (Donohue, McVicar et al. 2013) and dam surface area (Crossman and Li 2015) estimated at SA2 level within livestock regions
Feed, supplements and pesticides	Various State Government Agriculture Department publications of Gross margins and performance benchmarking(Holmes, Sullivan et al. 2011, Department of Primary Industries 2014, Department of Primary Industries Parks Water and Environment 2015, Rural Solutions SA PIRSA 2015, New South Wales Department of Primary Industries 2016)
Lime & fertiliser on pasture	Various State Government Agriculture Department publications of Gross margins and performance benchmarking
Reproduction rate, herd/flock structure, rate of live weight gain	Various State Government Agriculture Department publications of Gross margins and performance benchmarking at livestock region level
Livestock turn-off (for meat and wool)	Various State Government Agriculture Department publications of Gross margins and performance benchmarking at livestock region level
Prices for different classes of livestock and wool	Various State Government Agriculture Department publications of Gross margins and performance benchmarking at livestock region level

Broad-acre dryland cropping

The methods used to acquire data for reference flows for cropping systems is detailed in the following sections.

Yield

Average yield (tonne grain/ha) for each significant broad-acre dryland crop (to give >95% national crop coverage) was estimated from 2010/11 to 2013/14 using agricultural production data from the Australian Bureau of Statistics {Australian Bureau of Statistics, 2015 #264}.

Seeding rate

Seeding rates for dryland canola crops were estimated using tools (Department of Agriculture and Food WA 2015, Pacific Seeds 2016), based on the expected yield, planting density required and seed weight. For other dryland crops seeding rates were draw from gross margin publications for each crop. Seed input was accounted for by subtracting the seed requirement from the reported yield.

Quantity of fertilizer applied

In the absence of crop specific data on fertiliser use from the Australian Bureau of Statistics, fertiliser inputs were calculated using the equations developed for each crop in the Generic Yield and Nitrogen Calculator (Baldock 2012). This approach gives a consistent method across all regions for estimating nitrogen (N) inputs, and the results were well aligned with regional estimation of fertiliser use from gross margin documents. The Tool was designed to estimate the N fertiliser requirement taking into account conditions such as prior legumes in the rotation and N mineralisation. The equations used in the N Calculator were adjusted so that they calculated the nett N requirement to grow the harvested grain plus lost N from leaching, volatilisation and denitrification, but not including residual soil N at the beginning or end of the cropping cycle. Data for the N content of grain for each crop was sourced from a feed database (INRA, CIRAD et al. 2016).

Our approach assumes the residual N pools in the soil (from crop residues, mineralisation, and fixation by a prior legume crop) are stable and that all of the fertiliser N required ends up in the harvested product or is lost through leaching and volatilisation (i.e. N in the soil organic matter pools on-farm are stable and the system is in a steady state). Phosphorus (P) fertiliser is also required for crops in Australia and 9.4 kg per ha was assumed as an average rate for replacement of P removed in grain for dryland crops (Department of Agriculture and Fisheries Queensland Government 2012).

As SOC is assumed not to change in the current version of inventory there is no need to balance fertiliser use to account for N made available (or bound up in organic matter) due to SOC change. When SOC change is implemented this will need to be added to the data.

Fertiliser mix

The mix of types of N fertilisers was based on statistics for fertiliser use in broad-acre cropping {Australian Bureau of Statistics, 2013 #322}. The dominant types of N fertilisers used in eastern Australia (including South Australian and Tasmania) are urea and mono-ammonium phosphate. In Western Australia, N is sourced from urea ammonium nitrate as well. The mix of fertiliser used in eastern and Western Australia was calculated by first determining how much mono-ammonium phosphate was needed to deliver 9.4kg P/ha, then the additional N required for the crop was assumed to come from urea for eastern Australia and a 50:50 mix of urea and urea ammonium nitrate for Western Australia.

(Center for International Development 2012)Fertiliser production

Emissions factors assumed for the production of different fertilisers and their transport were sourced from ecoinvent 3.1 (Weidema, Bauer et al. 2013). Transport to regional store is based on AusLCI default transport statistics from ABS {Australian Bureau of Statistics, 2017 #1492} , while transport to farm is standardised at 200km of truck transport for all States.

Pesticides production and use

Annual pesticide use (quantity of active pesticide ingredient; a.i.) was sourced from surveys of farm practice carried out by NSW DPI {Simmons, 2017 #498} describing the frequency and type of pesticide use for each crop. Where inventory in the shadow database could be found for specific a.i., this was used, otherwise a generic pesticide inventory was substituted, but with the CAS number specified for each a.i.

Field machinery operations

Cultivation practices are largely no or low-till for dryland farming in Australia. Table 7 gives the most recent survey data for cultivation practises for broad-acre cropping land in Australia (Umbers, Watson et al. 2016). Where an AER spanned multiple regions, average tillage practice for each AER was based on the proportion of area in each State.

Table 7. Cultivation practices for broad-acre cropping systems in Australia.

Cultivation practice by AER

AER No.	AER name	Cultivation practices		
		Zero/No-Till (0 to 30% soil disturbance)	Minimum tillage	Multiple tillage
5	**North Central**	10%	33%	58%
6	**Melbourne Region**	75%	16%	9%
7	**Central and South West Slopes and Pla**	80%	13%	7%
8	**South Riverina and Wimmera**	81%	10%	9%
9	**Far South and East Victorian Coast**	75%	16%	9%

AER No.	AER name	Cultivation practices		
		Zero/No-Till (0 to 30% soil disturbance)	Minimum tillage	Multiple tillage
10	**Southern Highlands, Tablelands and Gi**	80%	13%	7%
11	**South Coast and Illawarra**	80%	13%	7%
12	**Sydney Basin**	76%	10%	14%
13	**Central, North Tablelands and Granite**	76%	10%	14%
14	**Northern Rivers and Mid-north Coast**	76%	10%	14%
15	**Western Downs and North West Slopes a**	76%	10%	14%
16	**Brisbane_Moreton**	76%	10%	14%
17	**Darling Downs**	76%	10%	14%
18	**South Burnett**	76%	10%	14%
19	**Wide Bay _ Burnett**	76%	10%	14%
20	**Dawson_Callide**	77%	6%	16%
21	**Central Queensland coast**	77%	6%	16%
22	**Central Highlands Queensland**	77%	6%	16%
25	**Northern Queensland Tablelands**	77%	6%	16%
36	**Western Wheatbelt**	96%	3%	1%
37	**South West**	96%	3%	1%
38	**Lower South West**	96%	3%	1%
39	**Goldfields_Nullabor_Flinders and darl**	72%	19%	9%
40	**Maranoa_Warrego**	85%	6%	9%

Based on the proportion of each tillage practice, the fuel use for crop production in each AER was calculated using AusLCI inventory for machinery operations which are based on an Australian fuel calculator (Salam 2010).

Quantity of lime applied

In the absence of consistent national data on the quantity of lime applied to dryland crops, the rate of lime application was based on survey results (Simmons et al unpublished). Direct emissions from lime application on agricultural soils were calculated based on IPCC methods (Inter-Governmental Panel on Climate Change 2006). For the purpose of accounting spreading operations, the assumption is made that lime is applied every four years rather than annually.

Greenhouse gas emissions from cultivation

Australia has undertaken a large body of research on agricultural GHG emissions from cropping land and livestock systems, and employs a Tier 2 method for the estimation of emissions from the use of synthetic fertiliser, decomposition of crop residues, burning of crop residues, indirect N_2O emissions from leaching and volatilisation, and enteric methane and methane from manure management. A full description of the methods has been published by the Australian Department of the Environment (Department of the Environment 2015) and accepted as a Tier 2 accounting method for Kyoto Protocol and UNFCCC GHG reporting. Hence, the estimation of on-farm GHG emissions for AusLCI are based on the Tier 2 method employed by Australian for its national GHG accounts. To enable the use of these methods additional data is required on the area of land subject to leaching, the area of land in <600 mm/year rainfall zone (to know which emissions factor to apply for direct N_2O emissions from fertiliser) and crop residue management **Error! Reference source not found.**. Climate data were sourced from Bureau of Meteorology Climate Data Services (http://www.bom.gov.au/climate/data-services). Crop residue management on a AER basis was sourced from the GRDC farm survey (Umbers, Watson et al. 2016).

Table 8. Percentage area of cropland in each AER subject to leaching

AER	% area of cropland subject to leaching
AER01 Hobart	1.000
AER02 Jordan Coal Tasman	0.932
AER03 Tasmanian Forests	0.998
AER04 Burnie	1.000
AER05 North Central	0.997
AER06 Melbourne Region	0.787
AER07 Central and South West Slopes and Plains	0.337
AER08 South Riverina and Wimmera	0.623
AER09 Far South and East Victorian Coast	0.922
AER10 Southern Highlands, Tablelands and Gippsland	0.840
AER11 South Coast and Illawarra	0.965

AER	% area of cropland subject to leaching
AER12 Sydney Basin	0.719
AER13 Central, North Tablelands and Granite belt	0.206
AER14 Northern Rivers and Mid-north Coast	0.857
AER15 Western Downs and North West Slopes and Plains	0.111
AER16 Brisbane Moreton	0.397
AER17 Darling Downs	0.055
AER18 South Burnett	0.000
AER19 Wide Bay Burnett	0.076
AER20 Dawson Callide	0.015
AER21 Central Queensland coast	0.236
AER22 Central Highlands Queensland	0.017
AER23 Burdekin	0.058
AER24 Wet Tropic Coast	1.000
AER25 Northern Queensland Tablelands	0.435
AER26 Central West and Gulf	0.025
AER27 Cape York	0.777
AER28 Barkly Tablelands	0.000
AER29 Marrakai Arnhem Land	0.238
AER30 Esley Gulf Land	1.000
AER31 Timor Coast and Douglas Daly Basin	1.000
AER32 Sturt Plateau	0.833
AER33 Kimberley Victoria River	0.448
AER34 North West Australia	0.000
AER35 Gascoyne	0.000
AER36 Western Wheatbelt	0.111
AER37 South West	0.953
AER38 Lower South West	1.000
AER39 Goldfields Nullabor Flinders and darling	0.007

AER	% area of cropland subject to leaching
AER40 Maranoa Warrego	0.031
AER41 Mallee Murray and central North South Australia	0.228
AER42 Southern Coastal South Australia	0.906
AER43 Channel Country	0.000
AER44 Central Australian Ranges	0.000
AER45 Tanami, Petermann, Simpson and Western Deserts	0.001
AER46 Adelaide Region	0.872

Table 9. Fraction of above ground residues that are burnt

Crops	NSW	NT	QLD	SA	TAS	VIC	WA
Wheat	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Barley	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Maize	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Oats	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Rice	0.815	0.815	0.815	0.815	0.815	0.815	0.815
Sorgum	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Triticale	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Other cereals	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Pulse	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Tuber & roots	0	0	0	0	0	0	0
Peanuts	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Sugar	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Cotton	0	0	0	0	0	0	0
Hops	0	0	0	0	0	0	0
Oilseeds	0.22	0.23	0.06	0.12	0.09	0.21	0.06
Forage crops	0	0	0	0	0	0	0

Table 10. Fraction of above ground residues that are removed

Crops	NSW	NT	QLD	SA	TAS	VIC	WA
Wheat	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Barley	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Maize	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Oats	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Rice	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Sorgum	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Triticale	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Other cereals	0.05	0.01	0.04	0.09	0.16	0.07	0.11

Pulse	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Tuber & roots	1	1	1	1	1	1	1
Peanuts	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Sugar	0	0	0.03	0	0	0	0
Cotton	0	0	0	0	0	0	0
Hops	0	0	0	0	0	0	0
Oilseeds	0.05	0.01	0.04	0.09	0.16	0.07	0.11
Forage crops	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Table 11. Percentage area in <600mm/year rainfall zone

AER	Pastures	Horticulture - perennial	Sugar	Horticulture - seasonal	Cotton	Cropping
AER01_Hobart	9	89	0	89	0	89
AER02_Jordan_Coal_Tasman	81	94	0	0	0	94
AER03_Tasmanian_Forests	16	29	0	29	0	29
AER04_Burnie	50	50	0	50	0	50
AER05_North Central	21	13	0	13	0	13
AER06_Melbourne Region	39	57	0	57	0	57
AER07_Central and South West Slopes and Plains	73	87	0	87	87	87
AER08_South Riverina and Wimmera	89	98	0	98	98	98
AER09_Far South and East Victorian Coast	8	28	0	28	0	28
AER10_Southern Highlands, Tablelands and Gippsland	13	28	0	28	0	28
AER11_South Coast and Illawarra	1	0	0	0	0	1
AER12_Sydney Basin	0	0	0	0	0	0
AER13_Central, North Tablelands and Granite belt	3	4	0	4	4	4
AER14_Northern Rivers and Mid-north Coast	0	0	0	0	0	0
AER15_Western Downs and North West Slopes and Plains	77	79	0	79	79	79
AER16_Brisbane_Moreton	1	1	1	1	0	1
AER17_Darling Downs	11	26	0	26	26	26
AER18_South Burnett	0	0	0	0	0	0

AER	Pastures	Horticulture - perennial	Sugar	Horticulture - seasonal	Cotton	Cropping
AER19_Wide Bay _ Burnett	6	7	7	7	7	7
AER20_Dawson_Callide	50	67	0	0	67	67
AER21_Central Queensland coast	38	19	19	0	19	19
AER22_Central Highlands Queensland	96	0	0	0	99	99
AER23_Burdekin	57	5	5	5	0	5
AER24_Wet Tropic Coast	1	1	1	0	0	0
AER25_Northern Queensland Tablelands	1	1	1	1	0	1
AER26_Central West and Gulf	88	0	0	0	0	99
AER27_Cape York	2	0	0	0	0	0
AER30_Esley_Gulf Land	0	0	0	0	0	0
AER31_Timor Coast and Douglas_Daly Basin	0	0	0	0	0	0
AER32_Sturt Plateau	1	0	0	0	0	0
AER33_Kimberley_Victoria River	24	4	4	4	0	4
AER35_Gascoyne	100	0	0	0	0	100
AER36_Western Wheatbelt	100	100	0	0	0	100
AER37_South West	76	95	0	95	0	95
AER38_Lower South West	0	0	0	0	0	0
AER39_Goldfields_Nullabor_Flinders and darling	100	100	0	0	100	100
AER40_Maranoa_Warrego	96	100	0	100	100	100
AER41_Mallee_Murray and central North South Australia	98	100	0	100	0	100
AER42_Southern Coastal South Australia	56	91	0	91	0	91
AER43_Channel Country	100	0	0	0	0	100
AER46_Adelaide Region	75	76	0	76	0	76

Crop Rotations

Although each crop is presented as an independent inventory, in practice crops are grown in rotation with periods of fallow and/or sown pasture. It is proposed that changes in SOC which maybe calculated in the future for cropping systems, are estimated over the whole rotation rather than for individual crops within the rotation. This is because its not practical to separate the effects of impacts and interactions between the different crop rotations.

A representative crop rotation for each AER was based on ABS statistics from 2010/11 to 2013/14 (Australian Bureau of Statistics 2018) to achieve national coverage for all cropping regions. Rotations included all significant crops types and sown pasture (>5% of area planted in the region). Where similar legume crops occurred within a region (e.g. winter legumes) and together they contributed >5% of crop area, the most prevalent legume was modelled in the rotation. Periods of fallow and pasture were estimated from the literature {Lawes, 2015 #281}{Hochman, 2014 #284}, along with crop sequence within the rotation.

Table 12. Representative crop rotation for each Agro-ecological Region (AER) including fallow periods and pasture in rotation with crops.

AER	Crop rotation[a]
5	wBarley-sF-wWheat-sF-wFababean-sF-wOats-sF-wBarley-sF-wWheat-2yPasture
6	wBarley-sF-wWheat-sF-wCanola-sF-wBarley-sF-wFieldpea-sF-wWheat-2yPasture
7	wWheat-sF-wWheat-sF-wCanola-sF-wBarley-sF-wLupin-sF-wWheat-sF-wCanola-3yPasture
8	wWheat-sF-wFieldpea-sF-wWheat-sF-wF-sF-wCanola-sF-wBarley-2yPasture
9	wWheat-sF-wWheat-sF-wCanola-sF-wBarley-sF-wHay-2yPasture
10	wWheat-sF-wWheat-sF-wCanola-sF-wWheat-sF-wWheat-sF-wCanola-sF-wTriticale-sF-wOats-3yPasture
13	wWheat-sF-wWheat-sF-wCanola-sF-wBarley-sF-wWheat-sF-wF-sF-wChickpea-sF-wOats-sF-wBarley-sF-wF-sSorghum-wF-sF
15	wWheat-sF-wBarley-sF-wChickpea-sF-wF-sSorghum-wF-sF-wWheat-sF-wWheat-sF-wChickpean-sF-wWheat-sF-wWheat-sF-wF-sF-wWheat-sF
17	wWheat-sF-wBarley-sF-wChickpea-sF-wF-sSorghum-wF-sF-wWheat-sF-wF-sSorghum-wF-sMaize-wF-sSorghum-wF-sSorghum-wF-sF
19	wWheat-sF-wBarley-sF-wF-sPeanut-wF-sSorghum-wWheat-sF-wF-sMungbean-wF-sMaize-wF-sMungbean-wF-sF-wWheat-sF-wF-sSoybean-wF-sSorghum-wF-sF
20	wWheat-sF-wChickpea-sF-wF-sSorghum-wF-sF-wWheat-sF-wF-sSorghum-wF-sF-wWheat-sMungbean
21	wWheat-sF-wChickpea-sF-wF-sSorghum-wF-sMungbean-wF-sSorghum-wF-sF-wChickpea-sSorghum-wF-sSorghum-wF-sF

AER	Crop rotation[a]
22	wWheat-sF-wChickpea-sF-wWheat-sF-wF-sSorghum-wF-sF-wWheat-sF-wChickpea-sF-wF-sSorghum-wF-sSorghum-wF-sF
23	wF-sMaize-wF-sMaize-wF-sMaize-wF-sPeanut-wF-sMaize-wF-sMaize-wF-sF
25	wF-sMaize-wF-sMaize-wF-sMaize-wF-sPeanut-wF-sMaize-wF-sMaize-wF-sF
36	wWheat-sF-wWheat-sF-wWheat-sF-wLupin-sF-wWheat-sF-wWheat-sF-wWheat-sF-wCanola-sF- wWheat-sF-wWheat-sF-wWheat-sF-wLupin-sF-wWheat-sF-wWheat-sF-wWheat-sF-wCanloa-sF-wWheat-sF-wBarley-sF-wF-sF
37	wWheat-sF-wWheat-sF-wCanola-sF-wWheat-sF-wWheat-sF-wLupin-wWheat-sF-wWheat-sF-wCanola-wWheat-sF-wWheat-sF-wLupin-sF-wWheat-sF-wBarley-sF-wF-sF
39	wWheat-sF-wF-sF-wWheat-sF-wF-sF-wWheat-sF-wF-sF-wWheat-sF-wF-sF-wWheat-sF-wF-sF-wBarley-sF-wF-sF-wOats-3yPasture
40	wChickpea-sF-wWheat-sF-wWheat-sF-wF-sSorghum-wF-sF-wWheat-sF-wWheat-sF-wChickpea-sF-wWheat-sF-wWheat-sF-wF-sF-wWheat-sF
41	wWheat-sF-wWheat-sF-wCanola-sF-wBarley-sF-wF-sF-wWheat-sF-wWheat-sF-wBarley-sF-wLentil-sF-wWheat-sF-wWheat-sF-wLentil-sF-wWheat-sF-wF-sF-wBarley-sF
42	wWheat-sF-wWheat-sF-wCanola-sF-wWheat-sF-wBarley-sF-wLupin-sF-wWheat-sF-wCanola-sF

[a] w - winter crop, s - summer crop, F – fallow, xyPasture where x = continuous years of pasture.

Livestock

The methods used to acquire data for reference flows for livestock systems is detailed in the following sections.

Livestock numbers

Livestock numbers for beef cattle and sheep from 2010/11 to 2013/14 were sourced from the Australian Bureau of Statistics {Australian Bureau of Statistics, 2015 #264}. Grazing livestock numbers were divided into sheep, beef cattle and dairy cattle using a conversion of 11 dry sheep equivalents (DSE) for beef cattle and 15 DSE for dairy cattle. The proportion of livestock numbers was used to allocate grazing area and evaporative water loss from farm dams for the respective livestock region.

Herd structure and turn-off for beef cattle

Information to describe herd structure, reproduction and growth rates, classes and number of animals sold, live weight of cattle sold, and prices for all livestock products were drawn from a series of State Government Department of agriculture publications. For northern cattle production, the data representing herd structure, reproduction rate, growth rate, turn-off weights and profitability were drawn from the Beef Co-operative Research Centre (CRC) Gross Margin Templates in the herd modelling program Breedcow and Dynama {Holmes, 2011 #254;Department of Agriculture and Fisheries, 2011 #253}. For southern cattle production, data from Gross Margin publications {New South Wales Department of Primary Industries, 2016 #399;Department of Primary Industries Parks Water and Environment, 2015 #404;Rural Solutions SA PIRSA, 2015 #400} and farm bench-marking programs {Department of Primary Industries, 2014 #396} were used to construct Breedcow templates that reflected herds in each livestock region. Where States did not have current publications the best matching Gross Margin from a neighboring State was used. All Breedcow templates were scaled to reflect cattle numbers in the relevant region.

Flock structure and turn-off for sheep

Information to describe flock structure, reproduction and growth rates, classes and number of animals sold, live weight of sheep and quantity of wool sold, and prices for all livestock products were drawn from a series of State Government Department of agriculture publications. These are listed for sheep for each of the livestock regions in **Error! Reference source not found.**.

Gross Margins from State Departments of agriculture {New South Wales Department of Primary Industries, 2016 #399; Rural Solutions SA PIRSA, 2015 #400; Department of Primary Industries Parks Water and Environment, 2015 #404} were used to estimate flock structure, animal growth rate and reproduction rate. Where States did not have current publications the best matching Gross margin from a neighboring State was used. The flock structures were manually modelled in FarmGAS for each production system to estimate feed intake and GHG emissions.

Greenhouse gas emissions from livestock

A Microsoft Excel version of the FarmGAS software {Australian Farm Institute, 2010 #255} was used to estimate cattle GHG emissions. FarmGAS applies the National Inventory Report equations to calculate livestock emissions for a given herd size and structure, animal growth rate, and reproduction rate. The FarmGAS software for cattle and sheep was populated with seasonal data on livestock numbers, live weight, live weight gain and proportion of females lactating to estimate total GHG emissions for each livestock region from cattle and sheep as detailed in the section above on herd and flock structure. Information on the proportion of land area in each livestock region subject to leaching was used to model indirect N_2O emissions from leaching (Table 13).

Table 13. Proportion of the land area in each livestock region subject to leaching and annual rainfall for each region. Climate data were sourced from Bureau of Meteorology Climate Data Services (http://www.bom.gov.au/climate/data-services)

State	Livestock Region	% area of grazing land subject to leaching	Annual rainfall (mm)	Mean ambient temp (°C)
New South Wales	Central Slopes and Plains NSW	0	553	17.0
	Central Tablelands and Slopes NSW	21	725	13.8
	Central Western Plains NSW	0	284	18.9
	Hunter Valley NSW	41	852	17.8
	Monaro NSW	24	730	12.9
	North Coast NSW	98	1228	18.5
	Northern Tablelands NSW	25	826	14.4
	North West Plains NSW	0	404	19.6
	North West Slopes NSW	8	730	16.9

	Riverina NSW	0	413	16.6
	South Coast NSW	81	979	17.4
	South West Slopes NSW	10	647	14.8
	Western Riverina NSW	0	298	16.9
Western Australia	R511a - Pindan and North Kimberley WA	0	701	26.9
	R511b - Fitzroy Valley WA	0	680	27.4
	R512 - Pilbara and Gascoyne WA	0	267	25.2
Northern Territory	R711 - Alice Springs NT	0	263	21.8
	R712 - Barkly Tableland NT	0	438	25.7
	R713 - Katherine Victoria River Downs NT	0	778	26.9
	R714 - Top End and Gulf NT	27	1005	27.4
Queensland	R311a – Cape York	39	1242	27.0
	R311b - Burke & Carpentaria QLD	0	761	26.8
	R312 - West and South-West QLD	0	299	24.0
	R313b - Mareeba Herberton Etheridge QLD	1	758	23.4
	R313c - Goldfields Dalrymple QLD	0	583	23.4
	R313e - Dalrymple Flinders Downs Mitchell QLD	0	459	24.8
	R314 - Mitchell Downs Mulga Desert QLD	0	441	22.3
	R321 - Darling Downs QLD	1	674	17.3
	R322 - Brigalow QLD	0	560	21.0
	R331 - Coastal Speargrass QLD	6	747	20.5
	R332b - Lower Burdekin and Bowen QLD	16	822	23.5
South Australia	Annual rainfall < 250mm SA	0	175	19.0
	Annual rainfall > 450mm SA	8	564	16.0
	Annual rainfall 250mm to 450mm SA	0	337	16.9
Tasmania	Meander Valley TAS	87	973	12.2
	Midlands TAS	40	680	11.7
Victoria	Gippsland VIC	67	894	14.6
	North East VIC	12	530	14.5
	South West VIC	18	650	14.3
Western Australia	Annual rainfall < 250mm WA	0	242	21.3
	Annual rainfall > 450mm	10	626	18.2
	Annual rainfall 250mm to 450mm WA	0	298	18.5

Pesticides used in livestock production

Internal and external parasite treatments are included in the inventory for both cattle and sheep. For each livestock species a suite of pesticides was selected that reflects current usage of different drug families {Love, 2007 #220; Love, 2011 #221;Joshua, 2012 #503}. The use of different active ingredients is common in the industry to avoid drug resistance in the parasites.

Inputs of pesticides are modelled as an overall amount, with each treatment event assumed to use the available drugs in equal proportion. While this does not reflect practice (in that only one drug is given at any one time), it allows the full spectrum of drugs to be modelled in the absence of good data on drug rotations.

There is evidence that veterinary drugs pass through animals largely untransformed, killing the parasites en-route, and are excreted by the animals in faeces and urine {Boxall, 2005 #222;Strong, 1993 #223;FAO, 2004 #501}. Treatment of sheep for external parasites with backline and jetting products results in small quantities (approximately 5 mg/kg greasy wool) of pesticide residues in wool {Savage, 1998 #502} that is subsequently exported from the farm. Hence, all the active ingredient administered to sheep (less the amount exported in wool) is treated as an emission to soil. Where ecoinvent inventory could be found for specific pesticides, these were used, otherwise a generic pesticide inventory was substituted, but with the CAS number specified for each.

Vaccines are modelled as an organic chemical with no resulting emissions to the environment.

Frequency of both pesticide and vaccine treatment for cattle is based on Gross Margin publications for northern and southern beef listed in Table 6 and industry publications {Robson, 2007 #475}{Coventry, 2016 #476}{NSW Department of Primary Industries, 2016 #485}. Based on this information, vaccines were simplified to one annual vaccine for cows mated and one vaccine for calves weaned across all regions. Pesticide treatments ranged from 0-2 per year for weaners and cows mated, the frequency depending on the severity of parasite challenge.

Water use by livestock

Water use by livestock covers animal water requirements {Ridoutt, 2012 #208} and evaporative water loss from farm-water storages such as farm dams.

The formula below was used to estimate total water intake by livestock ($W_{\text{total intake}}$):

$$W_{\text{total intake}} = DMI \times 1.445 \times \exp(0.055T) + Milk_{prod}$$

Where DMI= dry matter intake (kg), T = mean ambient temperature (°C) and $Milk_{prod}$ = 20% increase in water intake for lactating females (L).

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

Annual farm dam evaporative loss is driven by the dam water surface area and the evaporation rate per unit area. Data for potential evaporation was sourced from the long-term annual Australian 5 km^2 potential evaporation surface {Donohue, 2013 #418}. Dam surface area was based on a preliminary version of the regional-scale surface hydrology polygons from Geoscience Australia {Crossman, 2015 #397}. This product maps farm dams over all of NSW, about half of Victoria and about two-thirds of Queensland. Water storage areas unlikely to be associated with livestock production (town supplies, horticultural regions, highly urbanised areas, > 0.1 km^2 surface area) were excluded. Where there is no mapping of dams, the dam surface area was estimated using livestock numbers. The relationship between dam density (m^2/km^2) and livestock density (DSE/km^2) was derived using Australian Bureau of Statistics data for sheep and cattle numbers at Statistical Area 2 (SA2) level, with sheep and cattle converted to DSE using factors of 1 and 10 respectively.

Livestock feed and supplements

A series of State Government Department of agriculture publications were used to identify inputs of livestock feed, such as grain and hay, and mineral supplements. Where the type of feed supplement for sheep was not specified the assumption was that the fodder comprised 50% hay and 50% wheat. The data sources are summarised in Table 6.

Lime and fertiliser application on pastures

Lime and fertiliser application is not routinely practiced across all the livestock regions, especially those in the rangelands (<250 mm rainfall). A series of State Government Department of agriculture publications were used (Table 6) to identify inputs of phosphorus fertiliser and these were simplified to two application rates of single superphosphate (8.8% P) – 5 kg P/ha/year for medium rainfall (250-450 mm) and 10kg P/ha/year for high rainfall, with the assumption that 20% of the area, identified in the grazing land use class in each livestock region, was fertilised {Australian Bureau of Agricultural and Resource Economics and Sciences, 2016 #263}.

A method for estimating lime application to pasture is yet to be determined.

Fertiliser spreading is generally done by truck but in the absence of data on fuel use, inventory for fertiliser spreading for board-acre cropping was used, similar to the approach used for lime spreading by truck. The estimated fuel use of 0.7 l/ha was similar to that calculated for lime spreading {Brock, 2012 #225}.

Energy inputs of fuel and electricity

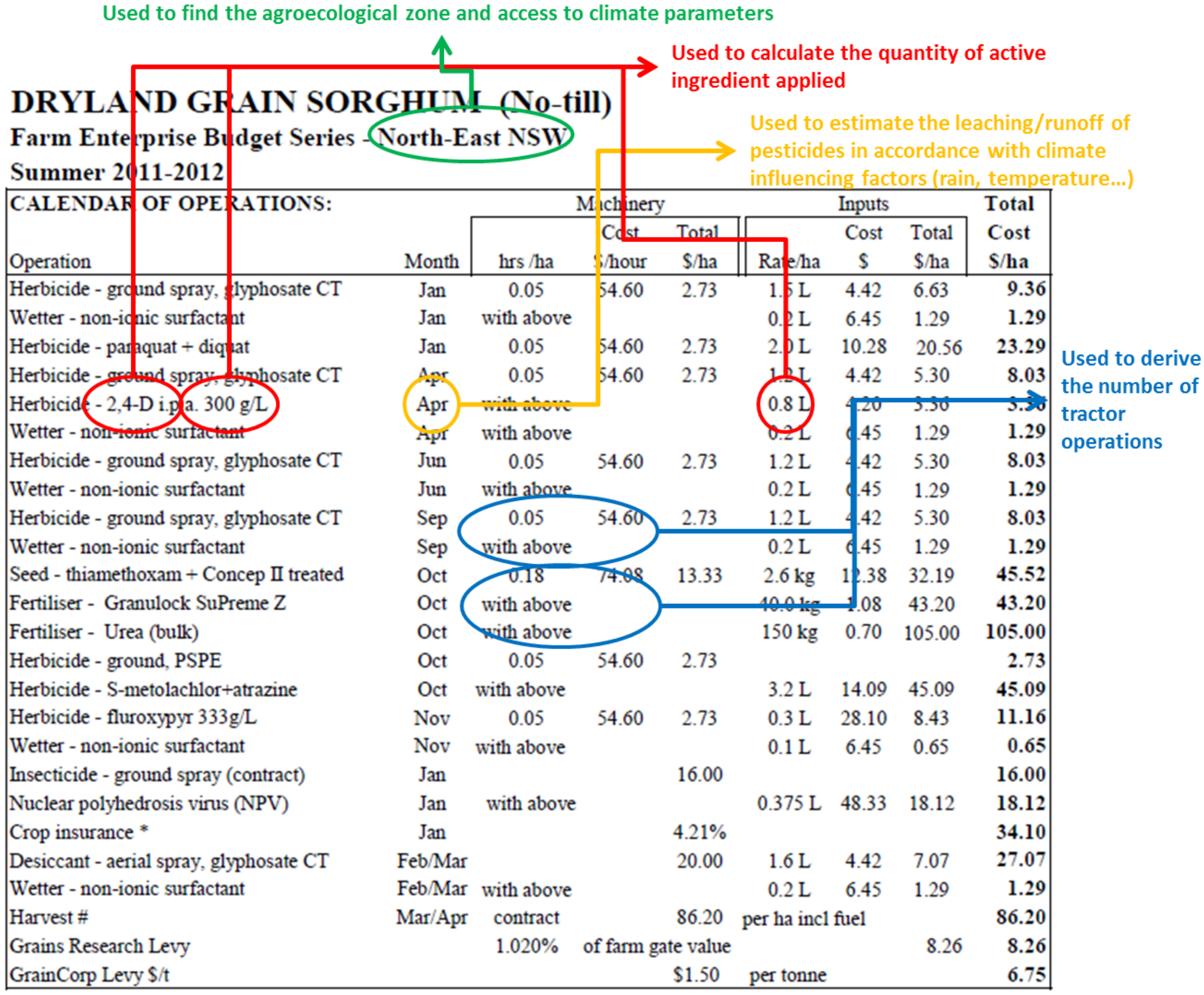
Electricity (kwh/kg LW cattle sold) and fuel (L diesel/kg LW cattle sold) were calculated from economic data reported in farm survey data from ABARES (http://apps.daff.gov.au/MLA/). Current electricity and fuel prices on a State basis were sourced from online tools for electricity and from industry publications for diesel {Australian Institute of Petroleum, 2016 #459}. As electricity costs are not reported separate the assumption is made that they make up 0.9% of total farm costs for beef and 1.1% for meat sheep {Whittle, 2011 #460}.

Table 14. Electricity and fuel inputs for livestock systems in Australia

Livestock System	Average cost for electricity (c/kWh)	Average cost for diesel (c/L)	Expenditure on electricity (c/kg LW)	Expenditure on diesel (c/kg LW)	Electricity use (kWh/kg LW)	Diesel use (L/kg LW)
Northern beef	27.3	121	1.73	9.70	0.047	0.080
Southern beef	28.0	117	1.85	9.41	0.066	0.081
Sheep meat	28.0	117	2.82	12.70	0.10	0.109

Data sources for annual and perennial horticulture, cotton and sugar

The majority of data for annual and perennial horticulture and cotton 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 AusLCI Final Report {Eady, 2014 #494}. 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. Specific pesticides were checked to ensure registration for use at the time. Gross Margin documents vary substantially in format and some interpretation is required to convert the data into life-cycle inventory. Figure 11 shows an example of how the Gross Margin documents are interpreted to develop inventory.



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

CALENDAR OF OPERATIONS:		Machinery			Inputs			Total
			Cost	Total		Cost	Total	Cost
Operation	Month	hrs /ha	$/hour	$/ha	Rate/ha	$	$/ha	$/ha
Herbicide - ground spray, glyphosate CT	Jan	0.05	54.60	2.73	1.5 L	4.42	6.63	**9.36**
Wetter - non-ionic surfactant	Jan	with above			0.2 L	6.45	1.29	**1.29**
Herbicide - paraquat + diquat	Jan	0.05	54.60	2.73	2.0 L	10.28	20.56	**23.29**
Herbicide - ground spray, glyphosate CT	Apr	0.05	54.60	2.73	1.2 L	4.42	5.30	**8.03**
Herbicide - 2,4-D i.p.a. 300 g/L	Apr	with above			0.8 L	4.20	3.36	**3.36**
Wetter - non-ionic surfactant	Apr	with above			0.2 L	6.45	1.29	**1.29**
Herbicide - ground spray, glyphosate CT	Jun	0.05	54.60	2.73	1.2 L	4.42	5.30	**8.03**
Wetter - non-ionic surfactant	Jun	with above			0.2 L	6.45	1.29	**1.29**
Herbicide - ground spray, glyphosate CT	Sep	0.05	54.60	2.73	1.2 L	4.42	5.30	**8.03**
Wetter - non-ionic surfactant	Sep	with above			0.2 L	6.45	1.29	**1.29**
Seed - thiamethoxam + Concep II treated	Oct	0.18	74.08	13.33	2.6 kg	12.38	32.19	**45.52**
Fertiliser - Granulock SuPreme Z	Oct	with above			40.0 kg	1.08	43.20	**43.20**
Fertiliser - Urea (bulk)	Oct	with above			150 kg	0.70	105.00	**105.00**
Herbicide - ground, PSPE	Oct	0.05	54.60	2.73				**2.73**
Herbicide - S-metolachlor+atrazine	Oct	with above			3.2 L	14.09	45.09	**45.09**
Herbicide - fluroxypyr 333g/L	Nov	0.05	54.60	2.73	0.3 L	28.10	8.43	**11.16**
Wetter - non-ionic surfactant	Nov	with above			0.1 L	6.45	0.65	**0.65**
Insecticide - ground spray (contract)	Jan			16.00				**16.00**
Nuclear polyhedrosis virus (NPV)	Jan	with above			0.375 L	48.33	18.12	**18.12**
Crop insurance *	Jan			4.21%				**34.10**
Desiccant - aerial spray, glyphosate CT	Feb/Mar			20.00	1.6 L	4.42	7.07	**27.07**
Wetter - non-ionic surfactant	Feb/Mar	with above			0.2 L	6.45	1.29	**1.29**
Harvest #	Mar/Apr	contract		86.20	per ha incl fuel			**86.20**
Grains Research Levy		1.020%	of farm gate value				8.26	**8.26**
GrainCorp Levy $/t				$1.50	per tonne			**6.75**

Figure 11: Use of information available in Gross Margin analyses

Data for sugar inventory was based on LCA studies undertaken for the industry {Renouf, 2010 #210}{Renouf, 2011 #211}.

Inventory quality and review

The creation of life cycle inventory draws on a complex and extensive range of data, model outputs and expert opinion. To ensure a high quality output, steps were taken during the project to draw data from official statistics and surveys, reputable publications, and to provide independent assessment, verification and review of both data used and the approaches taken to estimating inventory flows. Given the quantity of data involved, it is not possible to have every step independently assessed and verified, however, some key areas have had independent review as detailed in Table 15.

A certain level of reliance is placed on the publications used and an assessment has been made of data quality originating from these sources. Each data source has been assessed against the criteria applied in the “pedigree matrix” {ecoinvent Centre, 2007 #312} for LCI. These criteria are summarised in Uncertainty estimation

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 for the ecoinvent® 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 which are shown in Table 16. The full detail of the estimation technique is provided in Appendix I.

Basic uncertainty factors, produced in the ecoinvent® guidelines are shown in Appendix I while

Table 17 shows the selected basic uncertainties for specific flows in AusLCI.

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 17 along with the assumptions used to characterise the agricultural data used in AusLCI.

Table 16: Basic uncertainty factors used for specific flows in AusLCI (square of the standard deviation assuming a lognormal distribution)

. A qualitative assessment of data quality for AusLCI is summarised in **Error! Reference source not found.**. Generally data for cropping systems was assessed to be higher in quality than data for livestock systems. The main gaps in high quality data for cropping were in the area of fuel use and type of fertiliser used, whilst with livestock there were gaps in quality data for the type and quantity of feed supplements, some regional descriptions of livestock systems, and use of fuel and electricity on-farm.

However, overall the quality of data used for AusLCI rated highly with only three areas scoring less than average rating. These gaps provide guidance on future areas for investment in inventory improvement. This quality of inventory positions Australian agriculture as an international leader in having good quality and regionally specific LCI, available to give national coverage of major production systems.

Table 15. Summary of reviews undertaken for key data aspects of the inventory.

Process Reviewed	Reviewer
Check that the northern beef cattle herd structure, live weights, live weigh gain and reproduction rates in the Beef CRC Templates are consistent with field data collected over the last 5-10 years	Steven Bray and co-authors {Bray, 2015 #331}
Check that the greenhouse gas emissions from northern beef cattle are consistent with other published estimates	Journal referees for {Eady, 2016 #406}
Verification that the National Inventory Report equations for greenhouse gas emissions for cropping systems are correctly implemented	Richard Eckard, University of Melbourne
Assessment of the suitability of data for international environmental accreditation programs	Jan Henke and Andreas Feige, Meo Carbon
Check that the definition of New South Wales livestock regions and distribution of production systems across regions are representative	Phil Graham, NSW DPI
Check that the methods for estimating cropping inputs (fertiliser, fuel, lime, tillage practices, stubble management) is appropriate and in agreement with industry data	Ross Kingwell, AEGIC Dylan Hirsch, CBH
Assessment of the suitability of approaches taken for estimating soil acidity flows, erosion flows and change in soil carbon are the best and most appropriate for LCI	Annette Cowie, NSW DPI Aaron Simmons, NSW DPI Mike Grundy, CSIRO
General check of cropping data against industry norms to identify outliers or anomalies, based on farmer interviews from each major production region	Annette Cowie, NSW DPI Aaron Simmons, NSW DPI Alex Murray, NSW DPI

Uncertainty estimation

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 for the ecoinvent® 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 which are shown in Table 16. The full detail of the estimation technique is provided in Appendix I.

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Table 17 along with the assumptions used to characterise the agricultural data used in AusLCI.

Table 16: Basic uncertainty factors used for specific flows in AusLCI (square of the standard deviation assuming a lognormal distribution)

Our Rating	Reliability	Completeness	Temporal correlation	Geographical correlation	Technological correlation
✓	Non-quantified estimate	Representativeness unknown or data from a small number of sites and from shorter periods	Age of data unknown or more than 15 years of difference to the time period of the dataset	Data from unknown or distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)	Data on related processes on laboratory scale or from different technology
✓✓	Quantified estimate (e.g. by industry expert)	Representative data from only one site for the market considered or some sites but from shorter periods	Less than 15 years of difference to the time period of the dataset	Data form area with slightly similar production conditions	Data on related processes or materials
✓✓✓	Non-verified data based on qualified	Representative data from only some sites (<50%) relevant for the market	Less than 10 years of difference to the time	Data from area with similar production conditions	Data from processes and materials under

Our Rating	Reliability	Completeness	Temporal correlation	Geographical correlation	Technological correlation
	estimates	considered or >50% of sites but for shorter periods	period of the dataset		study but from different technology
✓✓✓✓	Verified data partly based on assumptions or non-verified data based on measurements	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even our normal fluctuations	Less than 6 years of difference to the time period of the dataset	Average data from larger area in which area under study is included	Data from processes and materials under study (i.e. identical technology) but from different enterprises
✓✓✓✓✓	Verified data based on measurements	Representative data from all sites relevant for the market considered, over an adequate period to even our normal fluctuations	Less than 3 years of difference to the time period of the dataset	Data from area under study	Data from enterprises, processes and materials under study

Table 17: Qualitative assessment of data used in to generate crop and livestock inventory for AusLCI

Activity data, Input or Inventory reference flow	Source of data	Parameter names	Base uncertainty	Reliability	Completeness	Temporal correlation	Geographical correlation	Technological correlation
				Cropping				
Tillage practices	GRDC survey data.	Frac_No_till Frac_Min_till Frac_Multi_till	1.05	✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Fertiliser and pesticide application methods	GM publications by state government agricultural agencies	Nb_Spraying, Nb_Fertilizer	1.05	✓✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Sowing and harvest applications	Assumptions on practice – assumed no uncertainty on the number of harvest and planting operations.	Nb_Grain_collection, Nb_Harvesting_200kW, Nb_Planting_clay20	None					
Fuel use by	AusLCI inventory based on	Fuel_Ha	1.05	✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓

agricultural machinery for cropping	published calculator for Australian conditions								
Pesticides quantity	Survey data collected by DPI NSW	M_*CAS_No.*	1.05	✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Fertiliser application rates	Yield and N Calculator, industry publications for P and lime application rates from NSW DPI survey data	M_*Fertlisername* P_fert	1.05	✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓
Soil conditioner types and application rates	Survey data collected by DPI NSW	M_lime	1.05	✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓
Crop Yield	ABS statistics at SA2 level for 2010-2014	Yield	1.05	✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Seed input	GM publications by state government agricultural agencies	Seed_input	1.05	✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓
Fallow	ABS statistics at SA2 level for 2010-2014	Duration	1.05	✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Quantity of pesticide, partitioning parameters and adjacent land use for estimating pesticide fate	Climate data was sourced from Bureau of Meteorology Climate Data Services and soil data was sourced from the Soil and Landscape Grid of Australia. Type and quantity of pesticides from GM publications by state government agricultural agencies	PestLCISoil_*CAS_No.* PestLCIOF__*CAS_No.* PestLCICrop_*CAS_No.* PestLCIAir_*CAS_No.* PestLCIGWII_*CAS_No.* PestLCIDegrII_*CAS_No.* PestDefualtSoil_*CAS_No.* Frac_OF_agr Frac_OF_nat Frac_OF_freshwater	1.45	✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓
Particulates, Nox and heavy metal emissions from burning	From National Pollutant Inventory (NPI) workbook	EFburn_*emission* Burn_efficiency	1.5	✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓
Stubble management	From National Inventory Report 2014, Vol 1 (2016)	Fburnt Fremoved Fresremaining	1.05	✓✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Emission factors for estimating N2O in cropping systems	From National Inventory Report 2014, Vol 1 (2016)	EFN_DS_nonirrc_b600mm EFN_DS_nonirrc_a600mm EFN_leachS	1.4	✓✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓

		EFN_residues						
Crop residue fractions, N leaching fractions and lime CO2 emissions		FracN_GASF NCag_barley_Resi NCbg_barley_Resi Res_barley Res_ab_barley FracN_Leach FracWet EFC_lime_nonirrc	1.05	✓✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Duration land is used	Assumed to be time from planting one crop to next, 12 months for dryland crops, life of perennial horticulture in establishment and production phases	Duration	NA					
Area of land used for crop	Assumed to be 1 ha	Surface	NA					
Livestock								
Livestock numbers	ABS statistics at SA2 level for 2010-2014	Cattle Cows Calves_weaned	1.05	✓✓✓✓	✓✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Price for livestock products	GM publications by state government agricultural agencies	P_*Productname*	1.05	✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Livestock supplements and feed	GM publications by state government agricultural agencies	Dry_mix Wet_mix Hay Copra Molasses Cottonseed Sorghum_graz Oats_graz Silage Protein_Pellets Wheat	1.05	✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓
Livestock growth and reproduction rates	GM publications by state government agricultural agencies	Modelled externally to SimaPro	NA	✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓

Livestock product turn-off	GM publications by state government agricultural agencies	KG_*Productname*	1.05	✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓
Pesticides and vaccines use for livestock	GM publications by state government agricultural agencies	Vaccine_vol	1.05	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Plastic identification tags for livestock	Industry suppliers of ID tags	ID_tag	1.05	✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Dry matter intake of livestock	FarmGas modelling	DMI	1.05	✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Water intake by livestock as drinking water	Scientific literature on water intake	Water	1.05	✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Evaporative water loss from farm dams used to supply drinking water for livestock	Scientific literature on dam density and climate data to estimate evaporative loss	Evap_water_loss	1.05	✓✓✓✓	✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Total N leached to ground water in livestock systems	FarmGas modelling	TotN_LeachGW	1.5	✓✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Fuel and electricity use for livestock enterprises	ABS statistics and MLA publications	Elec Fuel	1.05	✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓✓
Emissions factor for entertic methane	From National Inventory Report 2014, Vol 1 (2016)	EF_Ent	1.2	✓✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
N2O emaissions for livestock		DU_N2O LEACH_N2O ATMOS_N2O EFN_Leach	1.4					
Area grazed by livestock in each Livestock Region	ABARES for land use	HA_GRAZING	1.05	✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Proportion of the grazing land fertilised with P	Estimate from industry	PR_fert	1.05	✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Common to Cropping and Livestock								

Parameters to estimate proportion of area where Fracwet=1	Climate data was sourced from Bureau of Meteorology Climate Data Services and soil data was sourced from the Soil and Landscape Grid of Australia	External data sources to SimaPro	NA	✓✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓
Ash alkalinity of products and inputs	Data for Net Acid Addition Rate sources from the scientific literature and technical reports.	AF_*Product and inputs*	1.05	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓✓
Parameters for RUSLE	Scientific literature	RUSLE_*Factor*	1.05	✓✓✓✓✓	✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Elementary flow data for soil organic matter	Climate data was sourced from Bureau of Meteorology Climate Data Services; soil data was sourced from the Soil and Landscape Grid of Australia; and technical reports.	External data sources to SimaPro; run in APSIM	NA	✓✓✓✓	✓✓✓✓	✓✓✓	✓✓✓	✓✓✓✓
N and P content in fertilisers	Assumed to have extremely low uncertainty when average across supply.	N_in_*Fertilisername*	None					
Metal content in fertiliser	From Vic DPI fertiliser survey 2008-09	*Metal*_in_*Fertilisername*	2	✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓
Heavy metals released from fertiliser	From Vic DPI fertiliser survey 2008-09	FracS_*Metal*	2	✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓
Emission factor for lime	National Inventory Report 2014, Vol 1 (2016)	EFC_lime_nonirrc	1.05	✓✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Emission factor for N mineralisation	EFsoilCminN2ON	EFsoilCminN2ON	1.4	✓✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Emission factor metals	From NPI workbook	EF_*Metal*	5	✓✓✓	✓✓✓✓✓	✓	✓✓✓	✓✓✓✓
Emissions factor for oxides of N	From NPI workbook	EF_Oxides_of_nitrogen	1.5	✓✓✓	✓✓✓✓✓	✓	✓✓✓	✓✓✓✓
Emissions factors for particulates	From NPI workbook	EF_Particulate_matter	2	✓✓✓	✓✓✓✓✓	✓	✓✓✓	✓✓✓✓
Average distance to supply farm inputs	Industry feedback on proximity of sources to farms	Supply_distance KM_*Productname*	2	✓✓	✓✓✓	✓✓✓✓✓	✓✓✓	✓✓✓✓✓
P content of soil	Soil and Landscape Grid of Australia	P_in_soil	1.05	✓✓✓✓✓	✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓

Carbon content of products	Various literature sources	CC_*Productname*	1.05	✓✓✓✓	✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Dry matter of products and crop residues	Various literature sources	DM_*name*	1.05	✓✓✓✓	✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Direct land use change	Blonk Tool modelling carbon stocks form … and area from ……	DLUC_value	2	✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓
Change in soil carbon	APSIM using future climate, N inputs, tillage and residue management from inventory	Soil_C_Change_value SOC_change	1.5	✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓

Data modelling

Figure 12 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_2O emissions from fertiliser can be quickly evaluated by changing one value for the N_2O emissions factor, and this will flow through to calculations throughout the inventory.

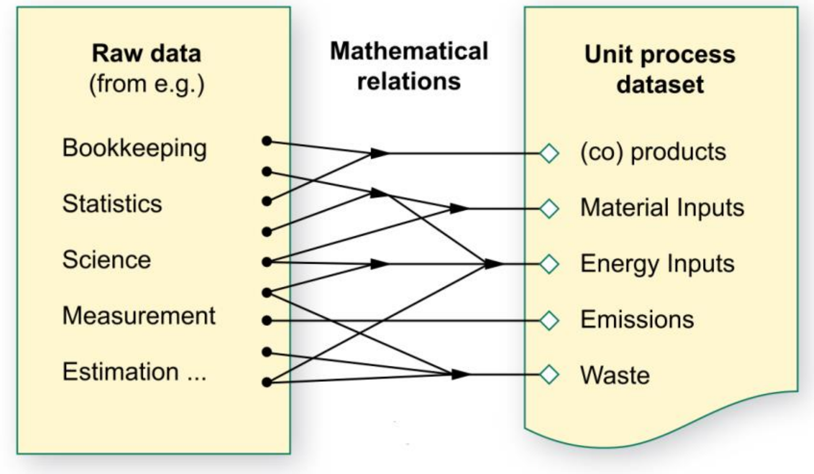

Figure 12: Structure of inventory modelling

Source: {UNEP/SETAC Life Cycle Initiative, 2011 #1141}

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.

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® {ecoinvent Centre, 2010 #923}. 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 18 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 18: Primary data required for tractor process inventories.

Data	Unit	Source
Tractor power	kW	Manufacturer
Tractor life-time	Hours	{The University of Arizona, 2002 #977}
Tractor speed	km/h	{The University of Arizona, 2002 #977}
Fuel consumption	l/ha	Farm Fuel Calculator {Salam, 2010 #975}
Implement width	M	{The University of Arizona, 2002 #977}
Implement life-time	Hours	{The University of Arizona, 2002 #977}
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.

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

$$(2)\text{Time (h)to process 1 ha} = \frac{1}{\text{speed in kilometres per hour} * 1000} * \mathit{Width}\ (m) * m2\ in\ 1\ ha$$

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

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

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® {ecoinvent Centre, 2010 #923} databases, see Table 19.

Table 19: Background data used for machinery inventories.

DATA	SOURCE
Fuel production and combustion	***Tractor engine operation, on farm, per litre of diesel consumed/AU U*** 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	***Tractor, production, per kg/CH/I U*** 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	***Harvester, production, per kg/CH/I U*** 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	***Agricultural machinery, general, production, per kg/CH/I U*** 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 m3 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 required

Table 20 lists the primary data required for building irrigation inventories.

Table 20: **Primary data required for irrigation processes inventories.**

DATA	UNIT	SOURCE/COMMENT
Materials for irrigation infrastructure	kg	{FAO, 2007 #1010} Details provided in Appendix B
Life-time	years	{P. Deuter, 2012 #1011}
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^3 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 is 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.

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

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

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

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.

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

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

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 climate change and eutrophication.

Lime application are modelled using standard National Inventory Report {DIICCSRTE, 2013 #1119} 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_2 into the manufacture of urea in ecoinvent® 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 21. These consist of the amount and type of fertiliser, the nitrogen content and a series of emission factors that are all derived from National Inventory Report {Department of Environment and Energy, 2016 #488}.

Table 21: Primary data required for fertiliser use and N related emissions.

Data	Unit	Source
Type of fertilisers	-	State level statistics for fertiliser use in broad-acre cropping {Australian Bureau of Statistics, 2013 #322}
Quantity of fertiliser applied	kg/ha	Generic Yield and N Calculator {Baldock, 2012 #318}
Fertiliser N	kg N/kg	Fertiliser manufacturer
Fertiliser heavy metal content	kg metal/kg fertiliser	Fertiliser manufacturer
Emission factor for direct N_2O from N	Kg N as N_2O/kg N applied	{Department of Environment and Energy, 2016 #488}– Varies by crop type
Fraction of farm area designated as having leaching occur where precipitation exceeds evaporation.	Fraction of farm area	{Department of Environment and Energy, 2016 #488}
Fraction of N leached when in areas where leaching occurs.	Fraction of N	Value used is 0.3 {Department of Environment and Energy, 2016 #488}
EF N_2O factor from leached N	Fraction of N	{Department of Environment and Energy, 2016 #488}
Fraction of nitrogen applied emitted as ammonia	Fraction of N	{Department of Environment and Energy, 2016 #488}
Fraction of N volatilisation	Fraction of N converted to NH_3	{Department of Environment and Energy, 2016 #488}
Atmospheric deposition of ammonia	Fraction of NH_3 produced	{Department of Environment and Energy, 2016 #488}

Table 22 shows the primary data required to model the flows derived from phosphorus fertilisers. This is principally the type and quantity of fertiliser and the phosphorus content. It is 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 estimated by RUSLE and the P-content of soil based on each cropping and livestock region and its intersection with the type of agricultural land use.

Table 22: Primary data required for fertiliser use and P related emissions

Data	Unit	Source
Type of fertiliser	-	State level statistics for fertiliser use in broad-acre cropping {Australian Bureau of Statistics, 2013 #322}
Quantity of fertiliser applied	kg/ha	Industry publications, farmer survey.
P content of fertiliser	kg P/kg fertiliser	Manufacturer
P_2O_5 mineral	kg P_2O_5/ha	Farm Gross margin
P_2O_5 slurry	kg P_2O_5/ha	Farm Gross margin
P_2O_5 manure	kg P_2O_5/ha	Farm Gross margin
Rate of soil erosion	kg/ha/year	RUSLE
P content of soil (0-10 cm)	Kg P/kg soil	Soil and Landscape Grid of Australia {Terrestrial Ecosystem Research Network, 2016 #433}
Enrichment factor	-	Wilke & Schaub 1996 quoted in {Nemecek, 2007 #829}

Mathematical relations and data transformation

Annual nitrous oxide (N_2O) production from the addition of synthetic fertilisers is calculated as {Department of Environment and Energy, 2016 #488}:

$E_{ij} = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times Cg)$

Where:

E_{ij} = annual emissions from fertiliser (Gg N_2O)

M_{ij} = mass of fertiliser applied in production system j (Gg N)

EF_{ij} = emission factor (Gg N_2O-N/Gg N applied) (EF = 0.0005 for cropping regions <600mm annual rainfall; EF = 0.0085 for cropping regions >600mm annual rainfall and for irrigated crop)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Application of crop residues

The mass of N in crop residues returned to soils is calculated as:

$M_{ijk} = (P_{ij} \times R_{AGj} \times (1 - F_{ij} - FFOD_{ij}) \times DM_j \times NC_{AGj}) + (P_{ij} \times R_{AGj} \times R_{BGj} \times DM_j \times NC_{BGj})$

Where:

M_{ij} = mass of N in crop residues (Gg N)

P_{ij} = annual production of crop (Gg)

R_{AGj} = above ground residue to crop ratio (kg crop residue/kg crop) (Canola = 2.10)

R_{BGj} = below ground-residue to above ground residue ratio (kg /kg) (Canola = 0.33)

DM_j = dry matter content (kg dry weight/kg crop residue) (Canola = 0.96)

NC_{AGj} = nitrogen content of above-ground crop residue (kg N/kg DM) (Canola = 0.009)

NC_{BGj} = nitrogen content of below-ground crop residue (kg N/kg DM) (Canola = 0.01)

F_{ij} = fraction of crop residue that is burnt (See Table 14)

$FFOD_{ij}$ = fraction of the crop residue that is removed (See Table 14)

Annual nitrous oxide production from the return of crop residues is calculated as:

$E_i = \Sigma_i\Sigma_k\Sigma_l (M_{ijkl} \times EF \times Cg)$

Where:

E_j = annual emissions from crop residues (Gg N_2O)

M_{ijkl} = mass of N in crop residues (Gg N)

EF = 0.01 (Gg N_2O-N/Gg N) IPCC default emission factor

C_g = 44/28 factor to convert from elemental mass of N_2O to molecular mass

Leaching from soils and surface runoff

Indirect N_2O emissions from leaching and runoff are only assumed in areas where the ratio of evapotranspiration rate: rainfall is <0.8 or >1 (which would occur under irrigation). The proportion of area in each cropping region is given in ???. Climate data to determine ET: rainfall was sourced from the Australian Bureau of Meteorology Climate Data Services (http://www.bom.gov.au/climate/data-services).

Annual nitrous oxide production from leaching and runoff is calculated for inorganic fertiliser N applied to soils and crop residue {Department of Environment and Energy, 2016 #488}.

The mass of inorganic fertiliser N applied to soils that is lost through leaching and runoff is calculated as:

$M_{ij=1} = M_{ij} \times FracWET_{ij} \times FracLEACH$

Where:

$M_{ij=1}$ = mass of synthetic fertiliser lost through leaching and runoff (Gg N)

M_{ij} = mass of fertiliser in each production system (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff (ET: rainfall <0.8 and > 1)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

The mass of crop residue that is lost through leaching and runoff is calculated as:

$M_{ij=4} = M_{ij} \times FracWET_{ij} \times FracLEACH$

Where:

$M_{ij=4}$ = mass of crop residue lost through leaching and runoff (Gg N)

M_{ij} = mass of crop residue N (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff (ET: rainfall <0.8 and > 1)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

Atmospheric nitrogen deposition

As there is no animal waste or sewerage sludge applied to broad-acre cropping land in Australia, the only source of N for atmospheric deposition is from volatilisation of inorganic fertiliser. The mass of inorganic fertiliser N volatilised is calculated as {Department of Environment and Energy, 2016 #488}:

$M_{ij=1} = TM_{ij=1} \times FracGASF_j$

Where:

$M_{ij=1}$ =mass of synthetic fertiliser volatilised (Gg N)

TM_{ij} = total mass of fertiliser (Gg N)

$FracGASF_j$ = 0.1 (Gg N/Gg applied) IPCC (2006) default

Annual nitrous oxide production from atmospheric deposition is calculated as:

$E = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times Cg)$

Where:

E = annual emissions from atmospheric deposition (Gg N_2O)

M_{ij} = mass of N volatilised (Gg N)

EF_{ij} = emissions factor (Gg N_2O-N/Gg N) (EF = 0.0005 for cropping regions <600mm annual rainfall; EF = 0.0085 for cropping regions >600mm annual rainfall and for irrigated crop)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Burning of agricultural residues

As the practice of burning canola stubble is close to 20% in some States, non-CO_2 GHG emissions from burning of residual crop material (CH_4, N_2O, CO, NO_x and NMVOCs) have been included in the overall estimate of GHG emissions. CO_2 emissions are not included as it is assumed an equivalent amount of CO_2 was taken up by the growing crop.

The mass of fuel burnt is calculated as:

$M_{ij} = P_{ij} \times R_j \times S_j \times DM_j \times Z \times F_{ij}$

Where:

M_{ij} = mass of residue burnt from crop (Gg)

P_{ij} = annual production of crop (Gg)

R_j = residue to crop ratio (kg crop residue/kg crop) (Canola = 2.11)

S_j = fraction of crop residue remaining at burning (Canola = 0.5)

DM_j = dry matter content (kg dry weight/kg crop residue) (Canola = 0.96)

Z = burning efficiency (fuel burnt/fuel load) = 0.96

F_{ij} = fraction of the annual production of crop that is burnt (See Table 14)

The mass of fuel burnt is converted to an emission of CH_4, CO or NMVOC by multiplying by the carbon content of the fuel, and an EF. That is:

$E_{ij} = M_{ij} \times CC_j \times EF_g \times Cg$

Where:

E_{ij} = annual emission from burning crop residue (Gg)

CC_j = carbon mass fraction in crop residue (Canola = 0.4)

EF_g = emission factor (Gg element /Gg burnt) (CH_4=0.0035; CO=0.078; NMVOC=0.0091)

C_g = factor to convert from elemental mass of gas to molecular mass

For N_2O and NO_x an additional term in the algorithm, the nitrogen to carbon ratio (NC_j), is required in order to calculate the fuel nitrogen content. Hence:

$E_{ijk} = M_{ij} \times NC_j \times EF_g \times C_g$

Where:

E_{ij} = annual emission from burning crop residue (Gg)

NC_j = nitrogen content in above ground residue (Canola = 0.009)

EF_g = emission factor (Gg element /Gg burnt) (N_2O=0.0076; NO_x=0.21)

C_g = factor to convert from elemental mass of gas to molecular mass

Lime application

For lime application, the annual emissions of CO_2 are calculated as {Department of Environment and Energy, 2016 #488}.

:

$E_{ij} = ((M_{ij} \times FracLime_{ij} \times P_{j=1} \times EF_{j=1}) + (M_{ij} \times (1- FracLime_{ij}) \times P_{j=2} \times EF_{j=2})) \times C_g / 1000$

Where: E_{ij} = annual emission of CO_2 from lime application (Gg)

M_{ij}= mass of limestone and dolomite applied to soils (t)

$FracLime_{ij}$ = fraction limestone (assumed to be 1 for canola production)

$P_{j=1}$ = fractional purity of limestone = 0.9

$P_{j=2}$ = fractional purity of dolomite = 0.95

$EF_{j=1}$ = 0.12 IPCC (2006) default emission factor for limestone

$EF_{j=2}$ = 0.13 IPCC (2006) default emission factor for dolomite

C_g= 44/12 factor to convert elemental mass of CO_2 to molecular mass

Mineralisation associated with loss of soil organic matter

Where a loss of soil carbon in cropland remaining cropland occurs, this loss will be accompanied by a simultaneous mineralisation of N[2]. This mineralised N is considered as an additional source of N available for conversion to N_2O just as mineralised N released through the decomposition of crop residues.

The IPCC (2006) method, using country specific parameters and EFs, is used to calculate N_2O emissions from this source. The C:N value used is 10, reflecting the approximate median value extracted from a survey of national estimates (Snowdon et al. 2005). The country specific emission factor for fertiliser additions to non-irrigated crops (0.002) is then applied.

In years in which cropland remaining cropland is a net C sink there is no symmetrical response as N inputs do not mitigate the emission of a greenhouse gas.

Annual nitrous oxide production is calculated as {Department of Environment and Energy, 2016 #488}:

$E_j = \Sigma_i (M_i \times NC \times EF \times C_g)$

Where:

E_j = annual emissions from mineralisation associated with loss of soil C (Gg N_2O)

M_i = loss of soils carbon in croplands remaining croplands (G_g)

NC = nitrogen to carbon ratio for cropland soils

EF = 0.002 (Gg N_2 O-N/G_g N).

Cg = 44/28 factor to convert elemental mass of N_2O to molecular mass

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[2] Note in current inventory the SOC loss has not been included due to high uncertainty and is the subject of ongoing research project.

While it is anticipated that SOC changes will be included in AusLCI in the future they are currently set to zero while preliminary results are being assessed. It is also worth noting is that but accounting convention in the National Inventory Report {Department of Environment and Energy, 2016 #488}, a SOC gain cannot result in a negative GHG emission with respect to N_2O. However, for undertaking an N balance to determine nett nitrogen inputs, a positive SOC gain should be taken into account.

Phosphorus emissions to water

For phosphorus emissions to water the method used by the ecoinvent® database {Nemecek, 2007 #829} has been used, with regional data used for soil erosion. Two sources of phosphorus to surface water are included (soluble Equation 4 and particulate Equation 6) and one is included to groundwater (Equation 5) 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 4: 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 5: 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 6: Phosphorus emissions from soil erosion

Background data

The background data for fertiliser production has been taken from the ecoinvent® 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® database.

Pesticides

Estimation of the quantity of pesticides used in agricultural are based on the registered label application rates, not direct measure in-field of actual application rates.

Primary data

Table 23 shows the primary data required for modelling the pesticide flows in the inventory.

Table 23: 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 24 shows the secondary data used for providing the flows that will refine the modelling of environmental impacts from pesticides use. The inventory flow is simply the multiplication of the active ingredient by the fraction released to each compartment. The fractions are calculated using the consensus-based model based on PestLCI {Dijkman, 2012 #973} These off farm drifting is further split between fresh water, natural land and agriculture land using an analysis of cropland boundary land cover in Australia. {Latham, 2014 #3214}

Table 24: Secondary data required for pesticides

DATA	SOURCE
Fraction of active ingredient deposited on soil on the field of application.	From Default value calculated with PestLCI 2.0 {Dijkman, 2012 #973} based on primary partitioning
Fraction of active ingredient released into air assumed to then be emitted to soil off farm.	From Default value calculated with PestLCI 2.0 {Dijkman, 2012 #973} based on primary partitioning
Fraction of active ingredient deposited on crop.	From Default value calculated with PestLCI 2.0 {Dijkman, 2012 #973} based on primary partitioning
Fraction of active substance released into surface water	Default value calculated with PestLCI 2.0 {Dijkman, 2012 #973}.
Fraction of active substance deposited into surface water	Default value calculated with PestLCI 2.0 {Dijkman, 2012 #973} and multiplied by % of land next to the field that is fresh waste for the region - source: based on Global Land Cover GIS layer {Latham, 2014 #3214}
Fraction of active substance deposited into natural land offsite	Default value calculated with PestLCI 2.0 {Dijkman, 2012 #973} and multiplied by % of land next to the field that is natural land for the region – based on Global Land Cover GIS layer {Latham, 2014 #3214}
Fraction of active substance deposited into agricultural land offsite	Default value calculated with PestLCI 2.0 {Dijkman, 2012 #973} and multiplied by % of land next to the field that is agricultural land for the region - based on Global Land Cover GIS layer {Latham, 2014 #3214}

The calculations in PestLCI involve climate, soil and farm parameters. These parameters are listed Table 25, and are defined for Australia at the level of the agro-ecological region intersection with the crop land use category. The list of regions are 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 F.

Table 25: 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	$days^{-1}$	= nb of days in month / nb of rainy days
Climate	Annual potential evaporation	mm	Calculation based on {Linacre, 1977 #1018}
Climate	Monthly and annual solar irradiation	$Wh.m^{-2}.day^{-1}$	Average over period 1980 – 1999[3]
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^3	Soil bulk density
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

[3] 1980-1999 was used in for PestLCI as a number of the other GIS data layers used in PestLCI (NWLRA, BioSequil) used this rainfall data.

PARAMETER TYPE	PARAMETERS	UNIT	COMMENT
Soil	Drainage depth	m	Assumed to be zero for Australia where fields are not artificially drained.
Soil	Irrigation water	Ml	

Source {Dijkman, 2012 #973}

Background data

The background data for pesticide production has been taken from the ecoinvent® 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 F.

Land occupation

Land occupation includes the area of land occupied multiplied by the time it is occupied. Periods of fallow over a full crop rotation period are accounted for, resulting in greater than 1 $ha.yr^{-1}$ for an annual crop cycle. The land use class is matched using the standard land classifications outlined in Appendix H. The specific land classifications chosen are listed in Table 27. 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 most of Australian production systems.

Soil Erosion

In assessing potential erosion models against the criteria identified as important for LCA {Vidal Legaz, 2016 #351}, the Revised Universal Soil Loss Equation (RUSLE) {Renard, 1991 #2928}came the closest to delivering estimates of soil flows to water and CEMSYS {Leys, 2010 #360} for soil flows to air, and the use of these two models are the preferred approach.

From a water erosion perspective, RUSLE is good in that it is the appropriate geo-spatial scale, is open and available for use, and easily parameterised in LCI. It gives a differentiated result for management interventions and uncertainty estimates can be generated. In other LCA studies this is the model that has been most often adopted.

From a wind erosion perspective, CEMSYS gives good spatial coverage for Australia with the ability to reflect management interventions but to enable this functionality further research is required. The model has not been implemented in AusLCI at this time.

To date the inventory in AusLCI is parametrised to implement RUSLE for soil water erosion based on GIS data for each component of the equation {Teng, 2016 #344}, giving the end-user the ability to change parameters to reflect management interventions. These estimates of soil erosion were used to update other environmental flows where erosion plays a role i.e. eutrophication.

Using RUSLE to predict elementary flows of soil loss allows results to be sensitive to the following management interventions:

- Adjustments to slope length and steepness through actions such as contour banks
- Soil cover management such as cover crops and stubble retention

- Soil erosion control practices such as contour ploughing

Soil Organic Carbon

Changes in soil organic carbon can be estimated using an impact method such as the biological production protential (BPP) model developed by {Brandão, 2013 #1189}.

The goal is to produce a trend for long term change in soil organic carbon (SOC; at depth of 0-30cm) for permanent pastures and for crops (and sown pasture) within a representative cropping system (specific crop rotation and management interventions/practices) in each AER.

Although experimental research on direct measurement of soil carbon (SCaRP; {Baldock, 2013 #414}) demonstrated that it is difficult to detect by measurement the effect of management interventions even over the long-term, we believe the application of the best-parametrised models for Australian broad-acre cropping and grazing provide a means of modelling the expected SOC response, in management systems that are reasonably stable over the medium term.

A review of models that can predict SOC was undertaken and APSIM {Keating, 2003 #266} is the recommended model for cropping; it is a purpose - built tool that provides accurate predictions {O'Leary, 2016 #367} of crop production in relation to climate, crop type, soil and management factors (including crop rotations). APSIM is structured around plant, soil and management modules including a C and N cycling module and has been well validated for Australian conditions. Using APSIM, SOC has been modelled under defined cropping systems (specified rotations and management) to arrive at a medium term estimate of change (over 62 year time horizon using future climate), and this estimate has been used to calculate an average annual SOC change for the crop rotation. Changes in SOC are estimated over the whole rotation rather than for individual crops within the rotation. Responses in SOC are complex to model in that they do not usually occur within the crop growing period, as it is the biomass return post-harvest that contributes the most to the SOC pools and there are significant interactions with N availability, which can be altered by both fertiliser application rates and N fixing by legumes. Details of the crop SOC modelling have been published by (Luo, Eady et al. 2019)

The recommended model for grazing land is a modified version of RothC (Ryan Farquharson, CSIRO, pers. comm.) that mimics the manner in which soil carbon is modelled for the National Inventory Report by FullCAM {Richards, 2004 #886}, once again using future climate over a +50 year time horizon.

Results for SOC modelling, in the context of the impact they have on product carbon footprints, will be published first in peer reviewed journal papers before incorporation into national life cycle inventory. The structure for incorporating change in SOC has been built into the inventory structure but has not yet been populated with data.

Particulate Matter

For the agriculture data particulate matter emission from burning are taken from the National Pollutant Inventory workbook {Environment Australia, 1999 #5337} which provide emission factors for four different crops.

Table 26 Emission from prescribed burning in g/kg of material burnt

NPI Substance	Oats	Rice	Maize	Sugar Cane
Antimony	0.000759	0.000184	0.000322	0.000133
Arsenic	0.0000495	0.000012	0.000021	0.0000087
Butadiene	0.0895	0.0358	0.0537	0.0358

NPI Substance	Oats	Rice	Maize	Sugar Cane
Cadmium	0.00102	0.000248	0.000434	0.00018
Chromium (VI)	0.000512	0.000124	0.000217	0.0000899
Carbon monoxide	68	41	54	35.5
Cobalt	0.000182	0.000044	0.000077	0.0000319
Copper	0.000363	0.000088	0.000154	0.0000638
Lead	0.000842	0.000204	0.000357	0.000148
Manganese	0.00208	0.000504	0.000882	0.000365
Mercury	0.000215	0.000052	0.000091	0.0000377
Nickel	0.000297	0.000072	0.000126	0.0000522
Oxides of nitrogen	2.21	2.21	2.21	6.9
Particulate matter	16.5	4	7	2.9
Selenium	0.0000825	0.00002	0.000035	0.0000145
TOC	10	4	6	4
Zinc	0.00139	0.000336	0.000588	0.000244

Source: {Environment Australia, 1999 #5337}

Table 27: Land types used for AusLCI 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
Grass-fed livestock products	Grassland, natural, for livestock grazing	None

How to use AusLCI

Conditions of use

The data presented in AusLCI (of which AusLCI 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® 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® 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 AusLCI 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 uses. 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)

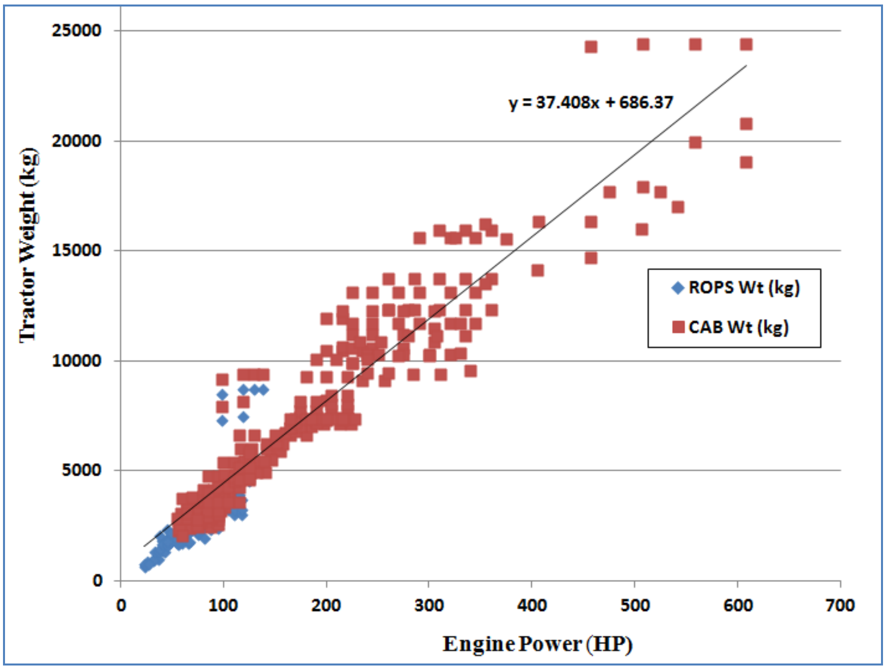

Figure 13: Plot of tractor weight (kg) versus engine power (HP) for 426 tractors.

Source AusLCI 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 28 shows the detailed parameters used for building LCI for broad-acre tractor processes.

Table 28: Parameters for estimating the environmental impact of manufacture, operation and maintenance of broad-acre tractor processes

Process	Tractor parameters				Implement parameters		Fuel use
	Power	Weight	Lifetime	Speed	Lifetime	Weight	l/ha
	kW	kg	hours	km/h	hours	kg	
cultivating, broadacre crop	135	7459	8000	10	2250	4800	13.6
Fertilizing, broadacre crop, pre & post-emergence	125	6957	8000	25	1200	1700	0.7
grain collection, broadacre, in-field with tractor and bin	150	8211	8000	12	3000	2000	2.1
harvesting, broadacre crop, combine less than 200kW/AU U	200	10719	8000	8	3000	10719	12
hay baling, round bales, broadacre crop	57	3546	8000	10	1800	1500	2.53
hay mowing, broadacre crop	57	3546	8000	10	1800	1500	4.58
hay raking, broadacre crop	57	3546	8000	10	1800	500	0.41
liming, broadacre crop, pre & post-emergence	125	6957	8000	25	1200	1700	1.15
planting, broadacre crop, soil clay content greater than 20%	220	11723	8000	9	3000	13800	6.2
planting, broadacre crop, soil clay content 0 to 10%	220	11723	8000	9	3000	13800	3.4
planting, broadacre crop, soil clay content 10 to 20%	220	11723	8000	9	3000	13800	4.4
spraying, broadacre crop, pre & post-emergence	125	6957	8000	25	3000	4800	0.7
disc ploughing, broadacre crop	135	7459	8000	8	2250	1500	13.69

Table 29: Parameters for estimating the environmental impact of manufacture, operation and maintenance of horticulture tractor processes

	Tractor parameters				Implement parameters		Fuel use
	Power	Weight	Lifetime	Spee d	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

(1) {Rod Menzies & associates, #976}
(2) Calculated with: tractor weight = tractor power (HP)*37.408+686.37, empirical formula derived from the analysis of data from about 300 tractors
(3) {The University of Arizona, 2002 #977}
(4) Sourced from various suppliers websites
(5) {Salam, 2010 #975}

Table 30: 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**
Bed forming, cotton	125	16000	25	8	1200	2000	8
Boom spraying, cotton	125	16000	25	16	1200	1200	0.7
Cultivating, cotton	125	16000	25	4	1200	2000	5
Discing, cotton	125	16000	25	4	1200	2000	9.5
Fertiliser spreading, cotton	125	16000	25	8	1200	2000	2.3
Fertilising, cotton	125	16000	25	8	1200	2000	5.9
Levelling, cotton	125	16000	25	4	1200	4500	44
Mulching, cotton	125	16000	25	4	1200	2500	7.7
Planting, cotton	125	16000	25	4	1200	2500	3.5
Rolling, cotton	125	16000	25	3	1200	2000	3.1
Root cutting, cotton	125	16000	25	4	1200	2000	3.4
Harvesting, cotton		3000	5	8		15000	40
Picking, cotton		4000	5	6		2381	21.8

Appendix B *Irrigation systems data*

Table 31 through to Table 37 shows the components of the irrigation systems used in the AusLCI. Data derived from FAO Handbook on Pressurised Irrigation Techniques {FAO, 2007 #1010}.

Table 31: Bill of material for drip irrigation system

COMPONENT	QUANTITY FOR 1HA
System distribution network	
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
Head control	
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 32: Bill of material for microsprinklers system

Microsprinklers	Quantity for 1 ha
System distribution network	
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
Head control	
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 33: Bill of material for travelers spray booms

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

Table 34: 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 35: 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 36: 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 37: 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 38. {Department of Climate Change and Energy Efficiency, 2011 #889}

Table 38: Parameters for calculating N emissions from fertilisers use on farm.

	TYPE	PARAMETER NAME- USED IN INVENTORY MODELS	VALUE
Direct N emissions kg N as N_2O/kg N			
	Irrigated pasture	EFN_DS_irrp_b600mm	0.004
	Irrigated crop	EFN_DS_irrc_b600mm	0.0085
	Non-irrigated pasture < 600 mm rainfall	EFN_DS_nonirrp_b600mm	0.002
	Non-irrigated pasture > 600 mm rainfall	EFN_DS_nonirrp_a600mm	0.002
	Non-irrigated crop < 600 mm rainfall	EFN_DS_nonirrc_b600mm	0.0005
	Non-irrigated crop > 600 mm rainfall	EFN_DS_nonirrc_a600mm	0.0085
	Sugar cane < 600 mm rainfall	EFN_DS_sc_b600mm	0.0199
	Sugar cane > 600 mm rainfall	EFN_DS_sc_a600mm	0.0199
	Cotton < 600 mm rainfall	EFN_DS_cot_b600mm	0.0055
	Cotton > 600 mm rainfall	EFN_DS_cot_a600mm	0.0055
	Horticulture/vegetables < 600 mm rainfall	EFN_DS_hort_b600mm	0.0085
	Horticulture/vegetables > 600 mm rainfall	EFN_DS_hort_a600mm	0.0085
N_2O emissions factors (% applied N) for manure applied to crops and pastures			
	Organic	EFN_DO_org	0.01
	Sewage sludge	EFN_DO_sew	0.009
	Unknown effluent	EFN_DO_awms	0.01
	Cattle slurry	EFN_DO_cattle	0.01
	Pig slurry	EFN_DO_pig	0.01
	Poultry litter	EFN_DO_poultry	0.01
Other data for N emissions			
	Fraction leached	FracN_LEACH	0.3
	Atmospheric deposition of N	EFN_atmodep	0.01
	Emission factor for leaching and run-off	EFN_leachS	0.0075
	Fraction of fertilizer as NH3	FracN_GASF	0.1
	Fraction of fertilizer as NH3	FracN_GASM	0.2
	Residues emissions	EFN_residues	0.01
	Emission factor for mineralisation	EFN_mineral	0.002
	Burning efficiency	Burn_efficiency	0.96
Availability of Nitrogen for leaching and runoff			
NSW			

	Type	Parameter name- used in inventory models	Value
	Irrigated pasture	fracN wet irrp NSW	1
	Irrigated crop	fracN wet irrc NSW	1
	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	0.932
	Horticulture/vegetables	fracN wet hort NSW	0.599
NT			
	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
	Sugar cane	fracN wet sc NT	0
	Cotton	fracN wet cot NT	0
	Horticulture/vegetables	fracN wet hort NT	0.857
QLD			
	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	0.713
	Horticulture/vegetables	fracN wet hort QLD	0.293
SA			
	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
	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
Vic			
	Irrigated pasture	fracN wet irrp Vic	1
	Irrigated crop	fracN wet irrc Vic	1

	TYPE	PARAMETER NAME- USED IN INVENTORY MODELS	VALUE
	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
WA			
	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	1
	Horticulture/vegetables	fracN wet hort WA	0.911

Source {Department of Climate Change and Energy Efficiency, 2011 #889}

1.4 Parameters for phosphorus emissions

Table 39: Detailed parameters for modelling phosphorus emissions

	Parameter	Unit	Definition
Fertilisers data			
	P_2O_5min	kg/ha	Mineral fertilisers applied
	P_2O_5sl	kg/ha	Slurry or liquid sewage sludge applied
	P_2O_5man	kg/ha	Solid manure applied
Phosphorus leaching to ground water – Pgw			
	Pgw	kgP/ha.a	Pgwl*Fgw
	Pgwl	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.
	Fgw	[-]	1+0.2/80P2O5sl, slurry correction factor
P run-off to surface waters – Pro			
	Pro	kgP/ha.a	Prol*Fro
	Prol	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.
	Fro	[-]	1+0.2/80P2O5min + 0.7/80P2O5sl + 0.4/80P2O5man
P emissions through erosion by water to surface waters - Per			
	Per	kgP/ha.a	1000*Ser*Pcs*Fr*Ferw
	Ser	t/ha.a	Quantity of soil eroded
	Pcs	kgP/kg soil	P content was calculated for 0-10 cm soil layer in each region for each land use class based on data from the Soil and Landscape Grid of Australia {Terrestrial Ecosystem Research Network, 2016 #433}
	Rusle	-	Default average value of 1.86
	Ferw	-	Default average value of 0.2

Table 40: RUSLE parameters in MJ mm/ ha.hr.y

AE regions	R_factor	LS_factor	C_factor	K_factor	P_factor
	RUSLE_R	***RUSLE_LS***	***RUSLE_C***	***RUSLE_K***	***RUSLE_P***
AER01_Hobart	1461	4.54	0.033	0.027	1.00
AER02_Jordan_Coal_Tasman	1403	5.06	0.029	0.027	1.00
AER03_Tasmanian_Forests	1468	7.79	0.019	0.027	1.00
AER04_Burnie	1449	6.22	0.021	0.027	1.00
AER05_North Central	1454	8.85	0.017	0.027	1.00
AER06_Melbourne Region	1445	7.48	0.016	0.027	1.00
AER07_Central and South West Slopes and Plains	1448	11.92	0.016	0.027	1.00

AE regions	R_factor	LS_factor	C_factor	K_factor	P_factor
	RUSLE_R	*RUSLE_LS*	*RUSLE_C*	*RUSLE_K*	*RUSLE_P*
AER08_South Riverina and Wimmera	1441	6.60	0.040	0.027	1.00
AER09_Far South and East Victorian Coast	1433	3.09	0.030	0.027	1.00
AER10_Southern Highlands, Tablelands and Gippsland	1495	13.79	0.023	0.027	1.00
AER11_South Coast and Illawarra	1620	15.86	0.011	0.026	1.00
AER12_Sydney Basin	1522	16.08	0.014	0.027	1.00
AER13_Central, North Tablelands and Granite belt	1507	1.58	0.035	0.027	1.00
AER14_Northern Rivers and Mid-north Coast	1555	7.64	0.014	0.027	1.00
AER15_Western Downs and North West Slopes and Plains	1553	9.75	0.012	0.027	1.00
AER16_Brisbane_Moreton	1511	2.42	0.020	0.027	1.00
AER17_Darling Downs	1625	14.59	0.024	0.027	1.00
AER18_South Burnett	1533	4.62	0.010	0.027	1.00
AER19_Wide Bay _ Burnett	1616	8.56	0.013	0.026	1.00
AER20_Dawson_Callide	1592	8.24	0.014	0.027	1.00
AER21_Central Queensland coast	1727	11.30	0.016	0.026	1.00
AER22_Central Highlands Queensland	1653	23.86	0.016	0.024	1.00
AER23_Burdekin	1535	12.69	0.010	0.026	1.00
AER24_Wet Tropic Coast	1503	3.90	0.032	0.027	1.00
AER25_Northern Queensland Tablelands	1550	11.64	0.010	0.027	1.00
AER26_Central West and Gulf	1531	9.99	0.010	0.027	1.00
AER27_Cape York	1510	3.26	0.014	0.027	1.00
AER28_Barkly Tablelands	1511	10.34	0.015	0.027	1.00
AER29_Marrakai_Arnhem Land	1580	10.98	0.012	0.026	1.00
AER30_Esley_Gulf Land	1529	11.28	0.011	0.027	1.00
AER31_Timor Coast and Douglas_Daly Basin	1882	4.61	0.020	0.026	1.00
AER32_Sturt Plateau	1111	8.05	0.017	0.026	1.00

AE regions	R_factor	LS_factor	C_factor	K_factor	P_factor
	RUSLE_R	*RUSLE_LS*	*RUSLE_C*	*RUSLE_K*	*RUSLE_P*
AER33_Kimberley_Victoria River	1520	10.51	0.022	0.027	1.00
AER34_North West Australia	1447	7.08	0.047	0.027	1.00
AER35_Gascoyne	1494	7.41	0.028	0.027	1.00
AER36_Western Wheatbelt	1222	6.66	0.025	0.027	1.00
AER37_South West	1335	6.56	0.037	0.027	1.00
AER38_Lower South West	1383	7.10	0.038	0.027	1.00
AER39_Goldfields_Nullabor_Flinders and darling	3777	9.22	0.022	0.025	1.00
AER40_Maranoa_Warrego	2119	2.91	0.026	0.026	1.00
AER41_Mallee_Murray and central North South Australia	2634	7.06	0.016	0.026	1.00
AER42_Southern Coastal South Australia	2387	5.83	0.024	0.026	1.00
AER43_Channel Country	2492	12.56	0.020	0.025	1.00
AER44_Central Australian Ranges	4296	13.15	0.014	0.025	1.00
AER45_Tanami, Petermann, Simpson and Western Deserts	2106	11.23	0.018	0.026	1.00
AER46_Adelaide Region	2872	6.85	0.016	0.026	1.00

Table 41: P content of soil by AER

AER name	P content of soil
AER01_Hobart	0.0003
AER02_Jordan_Coal_Tasman	0.0003
AER03_Tasmanian_Forests	0.0004
AER04_Burnie	0.0006
AER05_North Central	0.0003
AER06_Melbourne Region	0.0003
AER07_Central and South West Slopes and Plains	0.0003
AER08_South Riverina and Wimmera	0.0003
AER09_Far South and East Victorian Coast	0.0004

AER name	P content of soil
AER10_Southern Highlands, Tablelands and Gippsland	0.0004
AER11_South Coast and Illawarra	0.0003
AER12_Sydney Basin	0.0003
AER13_Central, North Tablelands and Granite belt	0.0004
AER14_Northern Rivers and Mid-north Coast	0.0005
AER15_Western Downs and North West Slopes and Plains	0.0004
AER16_Brisbane_Moreton	0.0006
AER17_Darling Downs	0.0009
AER18_South Burnett	0.0007
AER19_Wide Bay _ Burnett	0.0005
AER20_Dawson_Callide	0.0005
AER21_Central Queensland coast	0.0004
AER22_Central Highlands Queensland	0.0004
AER23_Burdekin	0.0003
AER24_Wet Tropic Coast	0.0003
AER25_Northern Queensland Tablelands	0.0011
AER26_Central West and Gulf	0.0003
AER27_Cape York	0.0004
AER30_Esley_Gulf Land	0.0002
AER31_Timor Coast and Douglas_Daly Basin	0.0002
AER32_Sturt Plateau	0.0002
AER33_Kimberley_Victoria River	0.0002
AER35_Gascoyne	0.0002
AER36_Western Wheatbelt	0.0002
AER37_South West	0.0002
AER38_Lower South West	0.0003
AER39_Goldfields_Nullabor_Flinders and darling	0.0003
AER40_Maranoa_Warrego	0.0003

AER name	P content of soil
AER41_Mallee_Murray and central North South Australia	0.0003
AER42_Southern Coastal South Australia	0.0002
AER43_Channel Country	0.0003
AER46_Adelaide Region	0.0002

Appendix D *List of agro-ecological regions used in AusLCI*

Table 42 shows the list of agro-ecological regions, and the agricultural use for AusLCI cropping inventories (last 6 columns).

Table 42: Agro-ecological regions and land use categories for AusLCI 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
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

REGION NUMBER	REGION NAME	PASTURES	HORTICULTURE – PERENNIAL	SUGAR	HORTICULTURE – SEASONAL	COTTON	CROPPING
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 *Water catchments in AER and Beef Regions.*

Table 43 and Table 44 shows the coverage of water catchments in each Agro-ecological and livestock regions respectively.

Table 43: Fraction of catchment area covered in Agro-ecological regions

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

Agroecological region	Catchment name	Fraction
Western Downs and North West Slopes and Plains	South_East_Coast_NSW_VIC_and_SA	0.007
	Burnett_and_Brisbane_River_QLD	0.022
	Condamine_Balonne_NSW_and_QLD	0.154
	Moonie_QLD	0.059
	Border_Rivers_NSW_and_QLD	0.149
	Gwydir_NSW	0.115
	Namoi_NSW	0.190
	Macquarie_Castlereagh_NSW	0.092
	Barwon_Darling_NSW	0.212
Brisbane Moreton	NE_Coast_other_than_Burd_Fitz_QLD	0.491
	South_East_Coast_NSW_VIC_and_SA	0.008
	Burnett_and_Brisbane_River_QLD	0.501
Darling Downs	Burnett_and_Brisbane_River_QLD	0.045
	Condamine_Balonne_NSW_and_QLD	0.805
	Border_Rivers_NSW_and_QLD	0.150
South Burnett	Burnett_and_Brisbane_River_QLD	0.952
	Condamine_Balonne_NSW_and_QLD	0.048
Wide Bay Burnett	NE_Coast_other_than_Burd_Fitz_QLD	0.488
	Burnett_and_Brisbane_River_QLD	0.483
	Fitzroy_River_QLD	0.025
Dawson Callide	Fitzroy_River_QLD	0.897
	Condamine_Balonne_NSW_and_QLD	0.102
Central Queensland coast	NE_Coast_other_than_Burd_Fitz_QLD	0.375
	Burdekin_River_QLD	0.038
	Fitzroy_River_QLD	0.587
Central Highlands Queensland	Burdekin_River_QLD	0.655
	Fitzroy_River_QLD	0.341
Burdekin	GuloCarpentaria_NT_and_QLD	0.009
	Lake_Eyre_NSW_QLD_NT_and_SA	0.038
	NE_Coast_other_than_Burd_Fitz_QLD	0.098
	Burdekin_River_QLD	0.792
	Fitzroy_River_QLD	0.062
Wet Tropic Coast	NE_Coast_other_than_Burd_Fitz_QLD	0.991
	Burdekin_River_QLD	0.008
Northern Queensland Tablelands	GuloCarpentaria_NT_and_QLD	0.017
	NE_Coast_other_than_Burd_Fitz_QLD	0.785
	Burdekin_River_QLD	0.199
Central West and Gulf	GuloCarpentaria_NT_and_QLD	0.466
	Lake_Eyre_NSW_QLD_NT_and_SA	0.483
	Burdekin_River_QLD	0.038
	Warrego_NSW_and_QLD	0.013
Cape York	GuloCarpentaria_NT_and_QLD	0.843
	NE_Coast_other_than_Burd_Fitz_QLD	0.155
Barkly Tablelands	GuloCarpentaria_NT_and_QLD	0.067
	Lake_Eyre_NSW_QLD_NT_and_SA	0.133
	Timor_Sea_NT_and_WA	0.800
Marrakai Arnhem Land	GuloCarpentaria_NT_and_QLD	0.837
	Lake_Eyre_NSW_QLD_NT_and_SA	0.149
	Timor_Sea_NT_and_WA	0.014
Esley Gulf Land	GuloCarpentaria_NT_and_QLD	0.268
	Timor_Sea_NT_and_WA	0.732
Timor Coast and Douglas Daly Basin	Timor_Sea_NT_and_WA	1.000
Sturt Plateau	GuloCarpentaria_NT_and_QLD	0.663
GuloCarpentaria_NT_and_QLD	Timor_Sea_NT_and_WA	0.337
Kimberley Victoria River	Indian_Ocean_WA	0.014
	North_Western_Plateau_WA_and_NT	0.137

Agroecological region	Catchment name	Fraction
	Timor_Sea_NT_and_WA	0.849
North West Australia	Indian_Ocean_WA	0.999
Gascoyne	Indian_Ocean_WA	0.651
	North_Western_Plateau_WA_and_NT	0.046
	South_Western_Plateau_WA	0.179
	Moore_Hill_rivers_WA	0.123
Western Wheatbelt	Indian_Ocean_WA	0.156
	Esperance_Coast_WA	0.099
	South_Western_Plateau_WA	0.098
	Swan_Coast_WA	0.400
	Moore_Hill_rivers_WA	0.156
	SW_Coast_other_than_Esp_Avon_WA	0.091
South West	Swan_Coast_WA	0.199
	Moore_Hill_rivers_WA	0.217
	SW_Coast_other_than_Esp_Avon_WA	0.584
Lower South West	Swan_Coast_WA	0.146
	SW_Coast_other_than_Esp_Avon_WA	0.853
Goldfields Nullabor Flinders and darling	Lake_Eyre_NSW_QLD_NT_and_SA	0.113
	Southstralian_GulSA	0.103
	Esperance_Coast_WA	0.010
	South_Western_Plateau_WA	0.522
	Swan_Coast_WA	0.017
	Barwon_Darling_NSW	0.099
	Lachlan_NSW	0.024
	Murray_NSW_VIC_and_SA	0.111
Maranoa Warrego	Paroo_NSW_and_QLD	0.082
	Warrego_NSW_and_QLD	0.308
	Condamine_Balonne_NSW_and_QLD	0.387
	Moonie_QLD	0.031
	Macquarie_Castlereagh_NSW	0.008
	Barwon_Darling_NSW	0.183
Mallee Murray and central North South Australia	Lake_Eyre_NSW_QLD_NT_and_SA	0.019
	Southstralian_GulSA	0.177
	South_East_Coast_NSW_VIC_and_SA	0.098
	South_Western_Plateau_WA	0.148
	Lachlan_NSW	0.023
	Murrumbidgee_NSW	0.006
	Murray_NSW_VIC_and_SA	0.397
	Loddon_Avoca_VIC	0.031
	Wimmera_VIC	0.079
	Eastern_Mount_Lofty_Ranges_SA	0.020
Southern Coastal South Australia	Southstralian_GulSA	0.814
	South_Western_Plateau_WA	0.121
	Murray_NSW_VIC_and_SA	0.007
	Eastern_Mount_Lofty_Ranges_SA	0.058
Channel Country	Lake_Eyre_NSW_QLD_NT_and_SA	0.917
	Paroo_NSW_and_QLD	0.029
	Barwon_Darling_NSW	0.011
	Murray_NSW_VIC_and_SA	0.040
Central Australian Ranges	Lake_Eyre_NSW_QLD_NT_and_SA	0.613
	Timor_Sea_NT_and_WA	0.387
Tanami, Petermann, Simpson and Western Deserts	Indian_Ocean_WA	0.017
	Lake_Eyre_NSW_QLD_NT_and_SA	0.151
	North_Western_Plateau_WA_and_NT	0.319
	South_Western_Plateau_WA	0.323
	Timor_Sea_NT_and_WA	0.186

Agroecological region	Catchment name	Fraction
Adelaide Region	Southstralian_GulSA	1.000

Table 44: Fraction of catchment area covered in livestock regions

Livestock region	Catchment name	Fraction
R322 - Beef CRC Brigalow	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.001
	F_NE_Coast_other_than_Burd_Fitz_QLD	0.00004
	F_Burnett_and_Brisbane_River_QLD	0.035
	F_Burdekin_River_QLD	0.293
	F_Fitzroy_River_QLD	0.124
	F_Warrego_NSW_and_QLD	0.013
	F_Condamine_Balonne_NSW_and_QLD	0.105
	F_Moonie_QLD	0.172
	F_Border_Rivers_NSW_and_QLD	0.220
	F_Barwon_Darling_NSW	0.036
Western Australia-over 450mm	F_Swan_Coast_WA	0.158
	F_Moore_Hill_rivers_WA	0.113
	F_SW_Coast_other_than_Esp_Avon_WA	0.729
Central Slopes and Plains	F_Namoi_NSW	0.073
	F_Macquarie_Castlereagh_NSW	0.534
	F_Barwon_Darling_NSW	0.015
	F_Lachlan_NSW	0.379
Central Tablelands	F_South_East_Coast_NSW_VIC_and_SA	0.289
	F_Macquarie_Castlereagh_NSW	0.479
	F_Lachlan_NSW	0.233
Central Western Plains	F_Paroo_NSW_and_QLD	0.012
	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.277
	F_Namoi_NSW	0.001
	F_Macquarie_Castlereagh_NSW	0.103
	F_Barwon_Darling_NSW	0.359
	F_Lachlan_NSW	0.071
	F_Murray_NSW_VIC_and_SA	0.178
Monaro NSW	F_South_East_Coast_NSW_VIC_and_SA	0.446
	F_Lachlan_NSW	0.150
	F_Murrumbidgee_NSW	0.351
	F_Murray_NSW_VIC_and_SA	0.00032
	F_MiddaMidda_VIC	0.054
North Coast NSW	F_NE_Coast_other_than_Burd_Fitz_QLD	0.00018
	F_South_East_Coast_NSW_VIC_and_SA	1.000
North West Slopes NSW	F_Border_Rivers_NSW_and_QLD	0.052
	F_Gwydir_NSW	0.244
	F_South_East_Coast_NSW_VIC_and_SA	0.009
	F_Namoi_NSW	0.695
	F_Macquarie_Castlereagh_NSW	0.00001
Northern Tablelands NSW	F_Condamine_Balonne_NSW_and_QLD	0.00003

Livestock region	Catchment name	Fraction
	F_NE_Coast_other_than_Burd_Fitz_QLD	0.00003
	F_Border_Rivers_NSW_and_QLD	0.334
	F_Gwydir_NSW	0.130
	F_South_East_Coast_NSW_VIC_and_SA	0.493
	F_Namoi_NSW	0.043
R311a	F_Gulf_of_Carpentaria_NT_and_QLD	0.667
	F_NE_Coast_other_than_Burd_Fitz_QLD	0.333
Western Riverina NSW	F_Lachlan_NSW	0.117
	F_Murrumbidgee_NSW	0.230
	F_Murray_NSW_VIC_and_SA	0.653
	F_Goulburn_Broken_VIC	0.00000
	F_Campaspe_VIC	0.00001
	F_Loddon_Avoca_VIC	0.00001
R313e - Dalrymple	F_Gulf_of_Carpentaria_NT_and_QLD	0.768
	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.226
	F_Burdekin_River_QLD	0.006
R311b - Burke	F_Gulf_of_Carpentaria_NT_and_QLD	1.000
R314 - Mitchell	F_Paroo_NSW_and_QLD	0.030
	F_Warrego_NSW_and_QLD	0.560
	F_Condamine_Balonne_NSW_and_QLD	0.072
	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.133
	F_Burdekin_River_QLD	0.196
	F_Fitzroy_River_QLD	0.009
Riverina NSW	F_Lachlan_NSW	0.355
	F_Murrumbidgee_NSW	0.581
	F_Murray_NSW_VIC_and_SA	0.063
	F_Ovens_VIC	0.00008
South Coast NSW	F_South_East_Coast_NSW_VIC_and_SA	1.000
	F_Murrumbidgee_NSW	0.00001
South West Slopes NSW	F_South_East_Coast_NSW_VIC_and_SA	0.00007
	F_Lachlan_NSW	0.152
	F_Murrumbidgee_NSW	0.692
	F_Murray_NSW_VIC_and_SA	0.155
	F_MiddaMidda_VIC	0.00018
Tasmania - Midlands	F_Tasmania_TAS	1.000
R511a - Pindan & North	F_North_Western_Plateau_WA_and_NT	0.362
	F_Timor_Sea_NT_and_WA	0.638
South Australia-less than 250mm	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.456
	F_Southstralian_Gulf_SA	0.086
	F_South_Western_Plateau_WA	0.419
	F_Timor_Sea_NT_and_WA	0.002
	F_Murray_NSW_VIC_and_SA	0.038
R313b - EMareeba	F_Gulf_of_Carpentaria_NT_and_QLD	0.513
	F_NE_Coast_other_than_Burd_Fitz_QLD	0.363
	F_Burdekin_River_QLD	0.124

Livestock region	Catchment name	Fraction
R313c - Goldfields Dalrymple	F_Gulf_of_Carpentaria_NT_and_QLD	0.012
	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.066
	F_NE_Coast_other_than_Burd_Fitz_QLD	0.015
	F_Burdekin_River_QLD	0.907
R321 - Darling	F_Condamine_Balonne_NSW_and_QLD	0.708
	F_Moonie_QLD	0.001
	F_NE_Coast_other_than_Burd_Fitz_QLD	0.00001
	F_Border_Rivers_NSW_and_QLD	0.209
	F_South_East_Coast_NSW_VIC_and_SA	0.00023
	F_Burnett_and_Brisbane_River_QLD	0.082
R331 - Beef CRC Coastal	F_NE_Coast_other_than_Burd_Fitz_QLD	0.377
	F_South_East_Coast_NSW_VIC_and_SA	0.00008
	F_Burnett_and_Brisbane_River_QLD	0.332
	F_Burdekin_River_QLD	0.020
	F_Fitzroy_River_QLD	0.269
	F_Condamine_Balonne_NSW_and_QLD	0.002
R312 - W&SW Qld	F_Gulf_of_Carpentaria_NT_and_QLD	0.300
	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.279
	F_Paroo_NSW_and_QLD	0.196
	F_Warrego_NSW_and_QLD	0.154
	F_Condamine_Balonne_NSW_and_QLD	0.071
R332a - Wet Coast Tableland	F_Gulf_of_Carpentaria_NT_and_QLD	0.001
	F_NE_Coast_other_than_Burd_Fitz_QLD	0.992
	F_Burdekin_River_QLD	0.008
R511b - Fitzroy Valley	F_North_Western_Plateau_WA_and_NT	0.527
	F_Timor_Sea_NT_and_WA	0.473
R512 - Pilbara and Gascoyne	F_Indian_Ocean_WA	0.207
	F_North_Western_Plateau_WA_and_NT	0.224
	F_South_Western_Plateau_WA	0.269
	F_Timor_Sea_NT_and_WA	0.113
	F_Moore_Hill_rivers_WA	0.188
R711 - Alice Springs	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.444
	F_North_Western_Plateau_WA_and_NT	0.025
	F_South_Western_Plateau_WA	0.018
	F_Timor_Sea_NT_and_WA	0.514
R712 - Barkly Tableland	F_Gulf_of_Carpentaria_NT_and_QLD	0.070
	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.179
	F_Timor_Sea_NT_and_WA	0.751
Tasmania - Meander Valley	F_South_East_Coast_NSW_VIC_and_SA	0.001
	F_Tasmania_TAS	0.999
South Australia-250mm to 450mm	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.027
	F_Southstralian_Gulf_SA	0.245
	F_South_East_Coast_NSW_VIC_and_SA	0.048
	F_South_Western_Plateau_WA	0.380
	F_Murray_NSW_VIC_and_SA	0.279

Livestock region	Catchment name	Fraction
	F_MiddaMidda_VIC	0.001
	F_Eastern_Mount_Lofty_Ranges_SA	0.021
R713 - Katherine & VRD	F_Gulf_of_Carpentaria_NT_and_QLD	0.239
	F_North_Western_Plateau_WA_and_NT	0.044
	F_Timor_Sea_NT_and_WA	0.716
North West Plains NSW	F_Paroo_NSW_and_QLD	0.007
	F_Warrego_NSW_and_QLD	0.089
	F_Condamine_Balonne_NSW_and_QLD	0.110
	F_Moonie_QLD	0.002
	F_Border_Rivers_NSW_and_QLD	0.047
	F_Gwydir_NSW	0.112
	F_Namoi_NSW	0.121
	F_Macquarie_Castlereagh_NSW	0.014
	F_Barwon_Darling_NSW	0.498
Hunter Valley NSW	F_South_East_Coast_NSW_VIC_and_SA	0.997
	F_Namoi_NSW	0.00029
	F_Macquarie_Castlereagh_NSW	0.003
Victoria - North East	F_Wimmera_VIC	0.215
	F_South_East_Coast_NSW_VIC_and_SA	0.056
	F_Murrumbidgee_NSW	0.0000045
	F_Murray_NSW_VIC_and_SA	0.244
	F_MiddaMidda_VIC	0.0002
	F_Ovens_VIC	0.049
	F_Goulburn_Broken_VIC	0.191
	F_Campaspe_VIC	0.034
	F_Loddon_Avoca_VIC	0.211
R714 - NT Top End & Gulf	F_Gulf_of_Carpentaria_NT_and_QLD	0.444
	F_Timor_Sea_NT_and_WA	0.556
South Australia-more than 450mm	F_Lake_Eyre_NSW_QLD_NT_and_SA	0.008
	F_Southstralian_Gulf_SA	0.409
	F_South_East_Coast_NSW_VIC_and_SA	0.472
	F_South_Western_Plateau_WA	0.053
	F_Murray_NSW_VIC_and_SA	0.011
	F_MiddaMidda_VIC	0.0001
	F_Eastern_Mount_Lofty_Ranges_SA	0.046
Victoria - Gippsland	F_South_East_Coast_NSW_VIC_and_SA	0.765
	F_Murray_NSW_VIC_and_SA	0.199
	F_MiddaMidda_VIC	0.0002
	F_Ovens_VIC	0.034
	F_Goulburn_Broken_VIC	0.001
R332b - Lower Burdekin & Bowen	F_NE_Coast_other_than_Burd_Fitz_QLD	0.419
	F_Burdekin_River_QLD	0.569
	F_Fitzroy_River_QLD	0.012
Victoria - South West	F_Wimmera_VIC	0.100
	F_South_East_Coast_NSW_VIC_and_SA	0.898

Livestock region	Catchment name	Fraction
	F_Campaspe_VIC	0.0000004
	F_Loddon_Avoca_VIC	0.002
Western Australia-250mm-450mm	F_Indian_Ocean_WA	0.066
	F_Esperance_Coast_WA	0.063
	F_South_Western_Plateau_WA	0.504
	F_Swan_Coast_WA	0.228
	F_Moore_Hill_rivers_WA	0.085
	F_SW_Coast_other_than_Esp_Avon_WA	0.053
Western Australia-under 250mm	F_North_Western_Plateau_WA_and_NT	0.580
	F_South_Western_Plateau_WA	0.293
	F_Timor_Sea_NT_and_WA	0.113
	F_Swan_Coast_WA	0.005
	F_Moore_Hill_rivers_WA	0.009

Appendix F *GIS layers used in AusLCI for PestLCI*

Table 45 provides a detail of the GIS layers used in the AusLCI 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 45: GIS layers used in AusLCI project

Parameter	unit	Zonal Statitics 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 [Tmax + Tmin]/2	**Available from http://data.daff.gov.au/anrdl/metadata_files/pa_mmmdtr9cl__03611a13.xml**
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:ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/; 2:http://data.daff.gov.au/anrdl/metadata_files/pa_mmmdtr9cl__03611a00.xml; 3:http://www.bom.gov.au/jsp/ncc/climate_averages/temperature/index.jsp**
Monthly and annual maximal temperature	degC	YES	GIS	TempMax 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	**ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/; 2: http://data.daff.gov.au/anrdl/metadata_files/pa_mmmdtr9cl__03711a00.xml; 3:http://www.bom.gov.au/jsp/n**

Parameter	unit	Zonal Statitics calculated	Level of acquisition	Comment	Source
					cc/climate
Monthly and annual rainfall	mm	YES	GIS	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:ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/; 2: http://data.daff.gov.au/anrdl/metadata_files/pa_mamf_r9cl__03311a00.xml; 3:http://www.bom.gov.au/jsp/ncc/climate_averages/rainfall/index.jsp**
Monthly and annual number of rainy days	mm	YES	calculation	Data was obtained from BOM based on "nb rainy days > 1mm" annual and monthly mean for period 1961-1990	**http://www.bom.gov.au/jsp/ncc/climate_averages/raindays/index.jsp. Downloaded as grid and converted to a raster for use in GIS**
Monthly and annual average rainfall on rainy days			calculation	Monthly average rainfall over days with rainfall >1mm. = rainfall / rainy days (mathematical calc from zonal stats)	
Monthly and annual rain frequency	$days^{-1}$		calculation	'= nb of days in month / nb of 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:http://data.daff.gov.au/anrdl/metadata_files/pa_ampe_r9cl__01512a00.xml; 3:http://www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp**
Monthly and annual solar irradiation Jan	$Wh.m^{-2}.day^{-1}$	YES	GIS	SolarMJDay 00 (annual) to 12 - average over period 1980 – 1999 Layer for same time period also available from ABARES	**1:ftp://ftp.eoc.csiro.au/pub/pbriggs/nlwra/ForcingMet/; 2:http://data.daff.gov.au/anrdl/metadata_files/pa_mmisrr9cl__0**

Parameter	unit	Zonal Statitics calculated	Level of acquisitio n	Comment	Source
					3511a00.xml
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 #1146}**
pH layer 1	-		GIS	pH in soil	**{ASRIS, 2011 #1146}**
pH layer 2	-		GIS	pH in soil	**{ASRIS, 2011 #1146}**
f(sand) layer 1	-		GIS	clay content (fraction of clay) in soil	**{ASRIS, 2011 #1146}**
f(sand) layer 2	-		GIS	clay content (fraction of clay) in soil	**{ASRIS, 2011 #1146}**
f(silt) layer 1	-		GIS	silt content (fraction of silt) in soil	**{ASRIS, 2011 #1146}**
f(silt) layer 2	-		GIS	silt content (fraction of silt) in soil	**{ASRIS, 2011 #1146}**
f(OC) layer 1	-		GIS	organic carbon content (fraction of organic carbon) in soil	**{ASRIS, 2011 #1146}**
f(OC) layer 2	-		GIS	organic carbon content (fraction of organic carbon) in soil	**{ASRIS, 2011 #1146}**
Soil bulk density (kg/m3)	kg/m 3		GIS	soil bulk density	**{ASRIS, 2011 #1146}**
soil bulk density (kg/m3) A Horizon	kg/m 3		GIS	soil bulk density A Horizon	**{ASRIS, 2011 #1146}**
soil bulk density (kg/m3) B Horizon	kg/m 3		GIS	soil bulk density B Horizon	**{ASRIS, 2011 #1146}**
Slope	%		GIS	slopepercent (Slope of 9” digital elevation model)	**http://data.daff.gov.au/anrdl/metadata_files/pa_msf__r9cl__0031**

Parameter	unit	Zonal Statitics calculated	Level of acquisition	Comment	Source
					1a00.xml
Soil water fraction	fraction		GIS	Mean annual relative soil water content	**BiosEquil {Raupach, 2001 #971}** **http://data.daff.gov.au/anrdl/metadata_files/pa_mrswcr9cl__03811a00.xml**
Soil moisture content	fraction		GIS	Annual mean moisture Index	**NLWRA**

Appendix G *Pesticides inventories*

Table 46 shows the list of inventories used in AusLCI to model the production of active ingredients modelled. Where the ecoinvent® inventory did not have a specific active ingredient a generic process was used.

Table 46: Inventories used for modeling active ingredients production

PESTCIDE ACTIVE INGREDIENT	ECOINVENT® 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
Butroxydim	Herbicides, at regional storehouse/RER U
Cadusafos	Insecticides, at regional storehouse/RER U
Carbendazim	Fungicides, at regional storehouse/RER U
Carbofuran	Carbofuran, at regional storehouse/RER U
Carfentrazone-ethyl	Herbicides, 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
Clethodim	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
Clopyralid	Herbicides, at regional storehouse/RER U
Cloquintocet-mexyl	Pesticide unspecified, 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
Fluquinconazole	Herbicides, at regional storehouse/RER U
Fluroxypyr	Herbicides, at regional storehouse/RER U
Flutriafol	Fungicides, 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
Haloxyfop	Herbicides, at regional storehouse/RER U
Haloxyfop-ethoxyethyl	Herbicides, at regional storehouse/RER U
Haloxyfop-etotyl	Herbicides, at regional storehouse/RER U
Haloxyfop-P-methyl	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
Ioxynil	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
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	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
Oxyfluorfen	Herbicides, at regional storehouse/RER U
Paraquat	Herbicides, at regional storehouse/RER U
Paraquat dichloride	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
Prothioconazole	Fungicides, at regional storehouse/RER U
Prothiophos	Insecticides, at regional storehouse/RER U
Pyridate	Herbicides, at regional storehouse/RER U
Pyroxasulfone	Herbicides, at regional storehouse/RER U
Quizalofop-P-ethyl	Herbicides, at regional storehouse/RER U
Rimsulfuron	Herbicides, at regional storehouse/RER U
Saflufenacil	Herbicides, at regional storehouse/RER U
Simazine	Herbicides, at regional storehouse/RER U
S-metolachlor	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
Tebufenozide	Insecticides, at regional storehouse/RER U
Terbuthylazin	Herbicides, at regional storehouse/RER U
Terbuthylazine	Herbicides, at regional storehouse/RER U
Terbutryn	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
Tri-allate	Herbicides, 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 H *Land use classes*

Table 47 shows the land use classes used in AusLCI- which are taken from the ecoinvent® data guidelines{Weidema, 2012 #937} .

Table 47: Land use classes used in AusLCI

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, savanna).
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
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,	Annual crop production based on natural precipitation (rainfed agriculture) but

LAND USE CLASS	DESCRIPTION
fallow	set aside for fallow within a crop rotation.
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 (rain-fed 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.
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

LAND USE CLASS	DESCRIPTION
	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 I *Uncertainty approach from ecoinvent®*

The uncertainty estimate approach which AusLCI has adopted from ecoinvent® 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 48. It is assumed that, for instance, CO_2 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 49). 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 50.

Table 48: Default basic uncertainty (variance σ_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
demand of:				**pollutants emitted to air:**			
thermal energy, electricity, semi-finished products, working material, waste treatment services	1.05	1.05	1.05	CO_2	1.05	1.05	
transport services (tkm)	2.00	2.00	2.00	SO_2	1.05		
Infrastructure	3.00	3.00	3.00	NMVOC total	1.50		
resources:				NO_X, N_2O	1.50		1.40
primary energy carriers, metals, salts	1.05	1.05	1.05	CH_4, NH_3	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	
pollutants emitted to water:				PM10	2.00	2.00	
BOD, COD, DOC, TOC, inorganic compounds (NH_4, PO_4, NO_3, 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_3, PO_4			1.50	radionuclides (e.g., Radon-222)		3.00	
pollutants emitted to soil:							
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 #344})

The square of the geometric standard deviation (95% interval – SDg95) is then calculated with the formulae shown in Equation 7.

Table 49: Pedigree matrix used to assess the quality of data sources, derived from (Source:{ecoinvent Centre, 2007 #344})

Indicator score	1	2	3	4	5 (default)
Reliability	Verified[3] data based on measurements[4]	Verified data partly based on assumptions *or* non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	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 *or* >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered *or* some sites but from shorter periods	Representativeness unknown or data from a small number of sites *and* from shorter periods
Temporal correlation	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
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown *or* distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale *or* from different technology

Source:{ecoinvent Centre, 2007 #344}

Table 50: 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 #344}

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

Where :

U_1 basic uncertainty factor

U_2 uncertainty factor of reliability

U_3 uncertainty factor of completeness

U_4 uncertainty factor of temporal correlation

U_5 uncertainty factor of geographical correlation

U_6 uncertainty factor of technological correlation

Equation 7: Calculation of variance for uncertainty estimation

Appendix J *Full List of Agricultural Inventories Produced*

This section lists the inventories produced within AusLCI. The LCIs produced by the AusLCI 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.

Agricultural commodities

Sugar

The sugar inventories are the culmination of many years of LCA and LCI studies undertaken at University of Queensland {Renouf, 2010 #1099;Renouf, 2011 #1100}. These inventories have been modified to meet the requirements of AusLCI and after a review of data by sugar industry stakeholders.

Table 51 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 51: 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 52.

Sugar cane supporting inventories

Table 52: 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 53 lists the inventories developed for the grain sector. One hundred and seventy 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 53: Inventories developed for the grain production

NAME	UNIT	TYPE
barley, dryland AER 36, WA/AU U	kg	Material
barley, dryland, AER 12, NSW/AU U	kg	Material
barley, dryland, AER 13, NSW/AU U	kg	Material
barley, dryland, AER 14, NSW/AU U	kg	Material
barley, dryland, AER 15, NSW_Qld/AU U	kg	Material
barley, dryland, AER 16, Qld/AU U	kg	Material
barley, dryland, AER 17, NSW_Qld/AU U	kg	Material
barley, dryland, AER 18, Qld/AU U	kg	Material
barley, dryland, AER 19, Qld/AU U	kg	Material
barley, dryland, AER 37, WA/AU U	kg	Material
barley, dryland, AER 39, SA_WA/AU U	kg	Material
barley, dryland, AER 41, Vic_SA/AU U	kg	Material
barley, dryland, AER 42, SA/AU U	kg	Material
barley, dryland, AER 5, Tasmania/AU U	kg	Material
barley, dryland, AER 6, Vic/AU U	kg	Material
barley, dryland, AER 7, NSW_Vic,/AU U	kg	Material
barley, dryland, AER 8, NSW_Vic/AU U	kg	Material
barley, dryland, AER 9, NSW_Vic/AU U	kg	Material
canola, dryland, AER 10, NSW_Vic/AU U	kg	Material
canola, dryland, AER 12, NSW_Vic/AU U	kg	Material
canola, dryland, AER 13, NSW/AU U	kg	Material
canola, dryland, AER 15, NSW_Qld/AU U	kg	Material
canola, dryland, AER 36, WA/AU U	kg	Material
canola, dryland, AER 37, WA/AU U	kg	Material
canola, dryland, AER 41, SA/AU U	kg	Material
canola, dryland, AER 42, SA/AU U	kg	Material
canola, dryland, AER 6, Vic AU/ U	kg	Material
canola, dryland, AER 7, NSW_Vic/AU U	kg	Material
canola, dryland, AER 8, NSW_Vic/AU U	kg	Material
canola, dryland, AER 9, NSW_Vic AU/ U	kg	Material
cereal hay and silage, dryland, AER 10, NSW_Vic/AU U	kg	Material
cereal hay and silage, dryland, AER 13, NSW/AU U	kg	Material
cereal hay and silage, dryland, AER 14, NSW/AU U	kg	Material
cereal hay and silage, dryland, AER 15, NSW_Qld/AU U	kg	Material
cereal hay and silage, dryland, AER 16, Qld/AU U	kg	Material
cereal hay and silage, dryland, AER 17, Qld/AU U	kg	Material
cereal hay and silage, dryland, AER 36, WA/AU U	kg	Material
cereal hay and silage, dryland, AER 37, WA/AU U	kg	Material
cereal hay and silage, dryland, AER 38, WA/AU U	kg	Material

Name	Unit	Type
cereal hay and silage, dryland, AER 41, Vic_SA/AU U	kg	Material
cereal hay and silage, dryland, AER 42, SA/AU U	kg	Material
cereal hay and silage, dryland, AER 7, NSW_Vic/AU U	kg	Material
cereal hay and silage, dryland, AER 8, NSW_Vic/AU U	kg	Material
cereal hay and silage, dryland, AER 9, Vic/AU U	kg	Material
chickpeas, dryland, avoided N, AER 13, NSW/AU U	kg	Material
chickpeas, dryland, avoided N, AER 15, NSW_Qld/AU U	kg	Material
chickpeas, dryland, avoided N, AER 17, Qld/AU U	kg	Material
chickpeas, dryland, avoided N, AER 20, Qld/AU U	kg	Material
chickpeas, dryland, avoided N, AER 21, Qld/AU U	kg	Material
chickpeas, dryland, avoided N, AER 22, Qld/AU U	kg	Material
chickpeas, dryland, avoided N, AER 40, NSW_Qld/AU U	kg	Material
chickpeas, dryland, avoided N, AER 41, Vic_SA/AU U	kg	Material
chickpeas, dryland, avoided N, AER 7, NSW_Vic/AU U	kg	Material
chickpeas, dryland, avoided N, AER 8, NSW_Vic/AU U	kg	Material
faba beans, dryland, avoided N, AER 15, NSW_Qld/AU U	kg	Material
faba beans, dryland, avoided N, AER 41, Vic_SA/AU U	kg	Material
faba beans, dryland, avoided N, AER 42, SA/AU U	kg	Material
faba beans, dryland, avoided N, AER 5, Tasmania/AU U	kg	Material
faba beans, dryland, avoided N, AER 7, NSW_Vic/AU U	kg	Material
faba beans, dryland, avoided N, AER 8, NSW_Vic/AU U	kg	Material
field bean, dryland, avoided N, AER 8, NSW_ Vic/AU U	kg	Material
field beans, dryland, avoided N, AER 13, NSW/AU U	kg	Material
field beans, dryland, avoided N, AER 15, NSW_Qld/AU U	kg	Material
field beans, dryland, avoided N, AER 20, Qld/AU U	kg	Material
field beans, dryland, avoided N, AER 41, Vic_SA/AU U	kg	Material
field beans, dryland, avoided N, AER 42, SA/AU U	kg	Material
field beans, dryland, avoided N, AER 7, NSW_Vic/AU U	kg	Material
field peas, dryland, avoided N, AER 41, Vic_SA/AU U	kg	Material
field peas, dryland, avoided N, AER 42, SA/AU U	kg	Material
field peas, dryland, avoided N, AER 6, Vic/AU U	kg	Material
lentils, dryland, avoided N, AER 41, Vic_SA/AU U	kg	Material
lentils, dryland, avoided N, AER 8, NSW_Vic/AU U	kg	Material
lucerne hay, dryland, avoided N, AER 10, NSW_Vic/AU U	kg	Material
lucerne hay, dryland, avoided N, AER 12, NSW_Vic/AU U	kg	Material
lucerne hay, dryland, avoided N, AER 16, NSW_Vic/AU U	kg	Material
lucerne hay, dryland, avoided N, AER 39, NSW_Vic/AU U	kg	Material
lucerne hay, dryland, avoided N, AER 5, NSW_Vic/AU U	kg	Material
lucerne hay, dryland, avoided N, AER 6, NSW_Vic/AU U	kg	Material
lucerne hay, dryland, avoided N, AER 7, NSW_Vic/AU U	kg	Material

NAME	UNIT	TYPE
lucerne hay, dryland, avoided N, AER 8, NSW_Vic/AU U	kg	Material
lucerne hay, dryland, avoided N, AER 9, NSW_Vic/AU U	kg	Material
lupins, dryland, avoided N, AER 15, NSW_Qld/Au U	kg	Material
lupins, dryland, avoided N, AER 36, WA/AU U	kg	Material
lupins, dryland, avoided N, AER 37, WA/AU U	kg	Material
lupins, dryland, avoided N, AER 41, Vic_SA/AU U	kg	Material
lupins, dryland, avoided N, AER 42, SA/AU U	kg	Material
lupins, dryland, avoided N, AER 7, NSW_Vic/AU U	kg	Material
maize, dryland, AER 13, NSW/AU U	kg	Material
maize, dryland, AER 15, NSW_Qld/AU U	kg	Material
maize, dryland, AER 16, Qld/AU U	kg	Material
maize, dryland, AER 17, Qld/AU U	kg	Material
maize, dryland, AER 18, Qld/AU U	kg	Material
maize, dryland, AER 19, Qld/AU U	kg	Material
maize, dryland, AER 20, Qld/AU U	kg	Material
maize, dryland, AER 22, Qld/AU U	kg	Material
maize, dryland, AER 25, Qld/AU U	kg	Material
maize, dryland, AER 7, NSW_Vic/AU U	kg	Material
maize, dryland, AER 8, NSW_Vic/AU U	kg	Material
mung beans, dryland, avoided N, AER 13, NSW/AU U	kg	Material
mung beans, dryland, avoided N, AER 15, NSW_Qld/AU U	kg	Material
mung beans, dryland, avoided N, AER 17, Qld/AU U	kg	Material
mung beans, dryland, avoided N, AER 19, Qld/AU U	kg	Material
mung beans, dryland, avoided N, AER 20, Qld/AU U	kg	Material
mung beans, dryland, avoided N, AER 21, Qld/AU U	kg	Material
mung beans, dryland, avoided N, AER 22, Qld/AU U	kg	Material
mung beans, dryland, avoided N, AER 40, NSW_Qld/AU U	kg	Material
mung beans, dryland, avoided N, AER 7, NSW_Vic/AU U	kg	Material
oats grain, dryland, AER 10, NSW_Vic/AU U	kg	Material
oats grain, dryland, AER 13, NSW/AU U	kg	Material
oats grain, dryland, AER 14 NSW/AU U	kg	Material
oats grain, dryland, AER 15, NSW_Qld/AU U	kg	Material
oats grain, dryland, AER 36, WA/AU U	kg	Material
oats grain, dryland, AER 37, WA/AU U	kg	Material
oats grain, dryland, AER 38, WA/AU U	kg	Material
oats grain, dryland, AER 39, SA_WA/AU U	kg	Material
oats grain, dryland, AER 41, Vic_SA/AU U	kg	Material
oats grain, dryland, AER 5, Tasmania/AU U	kg	Material
oats grain, dryland, AER 7, NSW_Vic/AU U	kg	Material
oats grain, dryland, AER 8, NSW_Vic/AU U	kg	Material

NAME	UNIT	TYPE
peanut, dryland, avoided N, AER 18, Qld/AU U	kg	Material
peanut, dryland, avoided N, AER 19, Qld/AU U	kg	Material
peanut, dryland, avoided N, AER 25, Qld/AU U	kg	Material
sorghum, dryland, AER 13, NSW/AU U	kg	Material
sorghum, dryland, AER 15, NSW_Qld/AU U	kg	Material
sorghum, dryland, AER 16, Qld/AU U	kg	Material
sorghum, dryland, AER 17, Qld/AU U	kg	Material
sorghum, dryland, AER 18, Qld/AU U	kg	Material
sorghum, dryland, AER 19, Qld/AU U	kg	Material
sorghum, dryland, AER 20, Qld/AU U	kg	Material
sorghum, dryland, AER 21, Qld/AU U	kg	Material
sorghum, dryland, AER 22, Qld/AU U	kg	Material
sorghum, dryland, AER 40, NSW_Qld/AU U	kg	Material
soybeans, dryland, avoided N, AER 13 NSW/AU U	kg	Material
soybeans, dryland, avoided N, AER 14 NSW/AU U	kg	Material
soybeans, dryland, avoided N, AER 15, NSW_Qld/AU U	kg	Material
soybeans, dryland, avoided N, AER 16, Qld/AU U	kg	Material
soybeans, dryland, avoided N, AER 17, Qld/AU U	kg	Material
soybeans, dryland, avoided N, AER 19, Qld/AU U	kg	Material
soybeans, dryland, avoided N, AER 7, NSW_Vic/AU U	kg	Material
sunflowers, dryland, AER 13 NSW/AU U	kg	Material
sunflowers, dryland, AER 15, NSW_Qld/AU U	kg	Material
sunflowers, dryland, AER 17, Qld/AU U	kg	Material
sunflowers, dryland, AER 20, Qld/AU U	kg	Material
sunflowers, dryland, AER 7, NSW_Vic/AU U	kg	Material
sunflowers, dryland, AER 8, NSW_Vic/AU U	kg	Material
triticale, dryland, AER 10, NSW_Vic/AU U	kg	Material
wheat, dryland, AER 10, NSW_Vic/AU U	kg	Material
wheat, dryland, AER 12, NSW_Vic/AU U	kg	Material
wheat, dryland, AER 13, NSW/AU U	kg	Material
wheat, dryland, AER 14, NSW_Qld/AU U	kg	Material
wheat, dryland, AER 15, NSW_Qld/AU U	kg	Material
wheat, dryland, AER 16, Qld/AU U	kg	Material
wheat, dryland, AER 17, Qld/AU U	kg	Material
wheat, dryland, AER 18, Qld/AU U	kg	Material
wheat, dryland, AER 19, Qld/AU U	kg	Material
wheat, dryland, AER 20, Qld/ AU U	kg	Material
wheat, dryland, AER 21, Qld/AU U	kg	Material
wheat, dryland, AER 22, Qld/ AU U	kg	Material
wheat, dryland, AER 36, WA/AU U	kg	Material

NAME	UNIT	TYPE
wheat, dryland, AER 37, WA/AU U	kg	Material
wheat, dryland, AER 38, WA/AU U	kg	Material
wheat, dryland, AER 39, SA_WA/AU U	kg	Material
wheat, dryland, AER 40, NSW_Qld/AU U	kg	Material
wheat, dryland, AER 41, Vic_SA/AU U	kg	Material
wheat, dryland, AER 42, SA/AU U	kg	Material
wheat, dryland, AER 5, Tasmania/AU U	kg	Material
wheat, dryland, AER 6, Vic/AU U	kg	Material
wheat, dryland, AER 7, NSW_Vic/AU U	kg	Material
wheat, dryland, AER 8, NSW_Vic/AU U	kg	Material
wheat, dryland, AER 9, NSW_Vic AU/ U	kg	Material

The grain production involves numerous industry specific tractor processes for which inventories were developed and are listed in Table 54.

Table 54: 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

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 55: 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 56.

Table 56: 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 57 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 57: 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 58.

Table 58: 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
Havesting 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

Inventories developed to support LCA modelling in the livestock industry have been included. Table 59 lists the inventories which have been selected according to the industry's priorities.

Insert table of livestock inventories.

Table 59: +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, Graslan 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, 30% urea, 5.5% P, at production/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 60: List of irrigation processes inventories developed

NAME	UNIT	TYPE
Irrigation, drip irrigation system/AU U	m3	Processing

Name	Unit	Type
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
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 60 have been developed for 1ha of field processed.

Glossary

Term	Definition
LCA	Life Cycle Assessment method of calculating the environmental impacts of products and services from cradle to grave.
LCI	Life Cycle Inventory – the second stage of LCA where unit processes are connected and total exchanges with the environment are calculated.
LCI data	Data which contain the input and outputs required to deliver a specified product.
LCIA	The third stage of LCA where inventory is linked to environmental indicators.
AusLCI Shadow database	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 AusLCI
AusLCI	Australian life cycle inventory database project developed and hosted by the Australian Life Cycle Assessment Society
Agro-ecological Region (AER)	A national scheme developed {Williams, 2002 #262} which characterises Australia into 46 zones based on climate and soil characteristics.
Agro-ecological Zones (AEZ)	Grain Research Development Corporation (GRDC) classification of Australia's 16 grain growing zones developed in 1998
PEST LCI	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, 2012 #973}

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