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Life Cycle Assessment Methodology for Australian Rural Industries

RIRDC Publication No. 09/028

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Life Cycle Assessment Methodology for Australian Rural Industries

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URS Australia Pty Ltd

March 2009

RIRDC Publication No 09/028
RIRDC Project No PRJ-002940

ISBN 1 74151 832 6
ISSN 1440-6845

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Printing by Union Offset Printing, Canberra
Electronically published in March 2009

Foreword

Future Australian and international policy directions may require industries to account for their resource use and emissions. Rural primary industries utilise several types of resources and produce various emissions. Of particular importance within the Australian context is the use of water and energy resources, and generation of greenhouse gas emissions.

Life Cycle Assessment (LCA) is a method to analyse resource issues across the life cycle of a product. It can systematically identify key areas to improve environmental and economic performance, and can be applied to agricultural systems. A standardised LCA methodology for primary industries will help practitioners undertake LCA studies and greatly increase their value by providing results that are comparable between sectors and industries.

The LCA methodology proposed by URS in this report builds on lessons from a previous literature review within the same project and a workshop that presented a draft version of the methodology. The methodology focuses on energy and water use, and greenhouse gas emissions. It is intended to be consistent with recently developed the LCA standards ISO14040:2006 and ISO14044:2006. The methods for energy and greenhouse gas emission accounting generally follow established techniques, such as those of the Australian Greenhouse Office and the International Panel on Climate change. However, there are no established methods for water use accounting in LCA and the water impact categories may need refinement and further development.

The success of LCA is dependent on good quality data and will be greatly aided by cooperation across agricultural sectors, and sharing of data. There is likely to be further effort needed to obtain the necessary data on water resources and usage rates.

The project was funded by RIRDC, Cotton Research and Development Corporation, Dairy Australia, Sugar Research and Development Corporation, Australian Pork Limited, RIRDC Chicken Meat Program and Meat and Livestock Australia.

This report, an addition to RIRDC's diverse range of over 1800 research publications, forms part of our Global Competitiveness R&D program, which aims to identify the impediments to the development of a globally competitive Australian agricultural sector and supports research investments on options and strategies for removing these impediments.

Most of our publications are available for viewing, downloading or purchasing online through our website: www.rirdc.gov.au.

Peter O'Brien
Managing Director
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Acknowledgments

The authors would like to thank and acknowledge the input of Steve Wiedemann (FSA Consulting, Toowoomba, Queensland) and Simon Winter (RIRDC, Canberra). Warm thanks also to those who attended the LCA workshop in Canberra on 22nd August 2008 (Appendix 2) and the many useful responses and comments that helped to improve this document.

Thanks also to our colleagues at URS for their support and contributions in discussions. This research project has been funded by RIRDC, Cotton Research and Development Corporation, Dairy Australia, Sugar Research and Development Corporation, Australian Pork Limited, RIRDC Chicken Meat program and Meat and Livestock Australia.

Abbreviations

ABS	Australian Bureau of Statistics
APSIM	Agricultural Production Systems Simulator
AusLCI	Australian Life Cycle Inventory Database Initiative
DNDC	Denitrification – Decomposition
EPD	Environmental Product Declaration
FPCM	Fat and protein corrected milk
FU	Functional unit
GHG	Greenhouse gas
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
ISO	Internat5ional Standards Organisation
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
NGA	National greenhouse accounts
PAS	Publicly available specification

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Executive Summary

What the report is about

This report proposes a Life Cycle Assessment (LCA) methodology for application in Australian rural industries. A standardised LCA methodology will improve the consistency of LCA reporting and greatly increase the value of results by enhancing their comparability.

Who is the report targeted at?

The report is targeted at Australian rural primary industries and associated stakeholders.

Background

Life Cycle Assessment is a method to analyse resource uses and emissions across the life cycle of a product. It can systematically identify key areas to improve environmental and economic performance and can be applied to agricultural systems.

Aims/objectives

The LCA methodology will help primary industries to conduct LCA studies and prepare for any future requirements (either Australian and/or internationally) to account for resource uses and emissions.

Methods used

The initial stage of this research involved an extensive literature review of LCA research in the area of agricultural application, LCA methodologies and standards. The findings from this were utilised to develop a draft methodology, which was presented to key stakeholders at a workshop. During the workshop the most prominent aspects of the methodology were highlighted and discussed. Further comment on the methodology was provided in written form, from many of the stakeholders. The feedback and discussions from the workshop have been incorporated, along with further research and literature insights, to produce the proposed methodology.

Results/key findings

The methodology is consistent with the recently revised LCA standards ISO14040:2006 and ISO14044:2006. The methods for energy and greenhouse gas emission accounting generally follow established techniques such as those of the Australian Greenhouse Office and International Panel on Climate Change. There are no established methods for water use accounting in LCA but the methodology proposes a reporting framework based on accounting methods used by the Australian Bureau of Statistics and by the National Land & Water Resources Audit.

Implications for relevant stakeholders

The success of LCA is dependent on good quality data and currently there is a paucity of relevant Australian agricultural LCA data. This will only be improved through further research and development and data sharing across agricultural sectors. There is a particular need for effort in order to obtain the necessary data on water resources and usage rates.

1. Introduction

1.1 Introduction

This document is the second stage of a research project commissioned by the Rural Industries Research and Development Corporation (RIRDC) to develop an agreed Life Cycle Assessment (LCA) methodology for selected rural primary industries. These include meat and livestock, dairy, poultry, pig production, sugarcane, and cotton. A standard methodology for LCA studies will facilitate consistency in application and reporting. This will allow data to be shared and results compared both across Australia and against international studies.

The initial stage of the research project was a literature review [10] to synthesise key findings of LCA research and literature to date, and provide a foundation for the subsequent stages of the project. This is summarised in Section 1.2. Practitioners are advised to download the literature review for further background information [10].

1.1.1 Why standardise?

Many LCA studies are displayed in different formats, discuss different aspects and have different degrees of openness about data sources, accuracy of data and the underlying assumptions they have made. This makes it difficult to compare studies, not only in a practical sense (because of the time it takes understanding the structure) but also in a technical sense, because the comparability of any two studies cannot be known unless the accuracy of data and assumptions are known. This is the main reason why the International Standards, ISO 14040 LCA series was developed. The methodology herein is consistent with these international standards.

1.1.2 What is standardised?

There needs to remain some flexibility on what the LCA is used for and precisely what it examines. For example, there is a big difference between the comparison of 1 tonne of product produced in different countries, to an investigation of which part of the production chain contributes most to environmental impact. Hence there is a trade-off between 'standardisation' and flexibility.

Many of the sub-concepts (for examples how to report on water use, or nitrogen emissions) used within LCA are themselves new and challenging issues in their own right. LCA originated in Europe where water use is not such an issue as in Australia, but acid rain is (but is not in Australia). Water use itself is a contentious issue. Should the impact category for 'water use' be 'total water use' and what is total water use? Does that include rainfall? If not does this cause issues for the river that might be dry from the water that has been absorbed by a vast crop? Should just the rainfall that is needed for crops be calculated and included? Greenhouse gas (GHG) accounting methods are also new and still developing, especially with regard to nitrous oxide emissions.

These are some of the difficult issues and challenges that need consideration when undertaking a LCA. Throughout the document, where possible, we have provided recommendations about which method to use. However, the distinction between 'accounting methods' (how to measure a particular aspect) and the LCA method should be noted. Accounting methods are the techniques used to assess and measure the use of materials and emissions, and these provide the data for the LCA method. They are in effect separate from LCA and will evolve over time. Particularly with agricultural LCAs, many of the accounting methods and modelling techniques are constantly developing and improving in quality. This will subsequently improve the accuracy of agricultural LCAs and help address some of the variabilities (such as accounting for the nitrogen cycle) which lead to uncertainty of LCA results.

Therefore the main aspects that are standardised are the overall framework, the need to report on water use, energy use and greenhouse gas emissions, and the need for the reporting method to be open and transparent, so that LCA studies can be compared and data shared.

1.2 Summary of main findings from literature review

This section provides an overview of the literature review that was the initial stage of this research project [10]. Practitioners are advised to obtain this publication for further information. Only literature available in the public domain was covered in the review. The literature review found that the agricultural LCA literature is diverse in its goals, methodologies and coverage of agricultural issues. This diversity means that for some aspects of LCA there is limited similarity in the coverage and consensus is difficult to draw, however consensus was drawn for most areas. Clusters of studies predominately exist in the sectors of pig production, grains, sugar and dairy. A summary of the findings and areas for discussion for each of the main categories of LCA follow.

Goal and purpose of agricultural LCA

LCAs have had a wide variety of goals and purposes but generally have compared the environmental impact of farming practices or types of feed (e.g. for pigs).The intended future goal(s) of the LCAs for the Australian rural industries need to be established - to compare agricultural practices, feed choices, identify environmental improvements or help with reporting (e.g. future requirements such as National Greenhouse and Energy Reporting (NGER) or similar). Public disclosure of LCA for comparability or marketing purposes would require a critical review according to ISO14040.

LCA system boundary

The system boundary will largely depend on the goal of the study, for example is it for environmental improvement of the farm operationally, or the whole supply chain through to consumer. This will also determine whether to include factors such as emissions associated with the production of medicines, insecticides, machines, buildings and roads.

Functional unit

The functional unit (FU) is dependent on the goal of the study and the system boundary, and is generally chosen to reflect the way each commodity is traded. The FU is typically one kilogram of product, or one hectare of land used. Consensus is needed on the functional unit for livestock, for example one kilogram of bone free meat leaving the farm gate, one kilogram of live weight leaving the farm gate, or one tonne of carcass dressed weight. The choice can help avoid allocation (see below).

Allocation methods for co-products

Economic allocation has in the past been utilised but studies of beef and dairy products have shown this to increase uncertainty. The order of preference is system expansion, physical relationships/ causality, composition, and finally economic value. The choice will typically be decided by the availability of data.

Foreground and background data sources

Foreground data refers to data that should be collected directly from the primary processes including input processes, farm processes, and production processing. Background data refers to data from secondary sources such as mining and extraction (e.g. for fertilisers or capital equipment) or grain production (when used as an input). On-farm manure management is likely to be foreground and needs further consideration.

Data quality and variability

Uncertainty is rarely considered in LCA studies and even less so in LCAs of agricultural products. This hampers the ability to interpret the usefulness and legitimacy of results. Australian agricultural LCA should therefore maintain transparency, and the data quality should comply with ISO14040 standards. The LCA should include a description of data quality so that the audience can understand the reliability of a study's results and properly interpret the outcome. LCA should perform sensitivity analysis to quantify the variability of results due to cumulative effects of model imprecision, input uncertainty and data variability.

Data variability across different years needs to be carefully considered, single year data may not be representative and single or rare events should be excluded. Therefore, consideration needs to be given as to whether the LCA utilises single year data or takes an average, or (for example) compares a drought year with a normal year.

LCA software

It is suggested that software specifically designed for LCA, is utilised to perform agricultural LCA, as this would help with tracking changes and updating data. LCA data management is generally too tedious and cumbersome for a spreadsheet model to be utilised. Therefore, the use of software is recommended to ensure robustness, uncertainty analysis, and comprehensive coverage of processes and data volumes in LCA modelling.

Life cycle impact assessment method and impact categories

Industry may need to consider/ prepare going beyond water, GHG and energy issues to meet future requirements or comparisons with other countries. For example, eutrophication is widely noted as one of the major environmental impacts of agriculture, and has GHG implications, so its inclusion or exclusion needs to be considered carefully.

Toxicity has prominent consideration in Europe, and so if comparisons with other countries are likely this may need to be included. LCA involving water requires careful consideration of what types of water to include, e.g. surface, treated surface, groundwater, scheme water. There is also the question of whether or not infrastructure be included to recognise the benefits of rainwater capture and water reuse. Energy and GHG can be measured per kilogram of product or per hectare. The greatest uncertainty is often noted as nitrous oxide emissions from crops.

LCA Evaluation

The vast majority of studies reviewed have been contribution analysis - the contribution of the life cycle stages or groups of processes are compared to the total result and examined for relevance. Others compared various aspects of agriculture such as feed choice or farming practice. Contribution and comparative (e.g. comparing farming systems or feed choice) analysis will be appropriate for water, energy and GHG.

Compliance with international LCA standards

The study should comply with ISO14040, in order to be recognised as robust, and be comparable with other studies.

1.3 Conducting a Life Cycle Assessment

LCA is defined in ISO 14040 [1] as "the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle". LCA is therefore a "cradle-to-grave" assessment of the environmental burden of products at all stages in their life cycle – from extraction of resources, the production of materials, product parts and the product itself, the use of the product, through to the reuse, recycling or final disposal. The environmental burden can include all types of environmental impact but this methodology focuses on three impact categories: water use, energy use and greenhouse gas emissions.

This methodology is designed primarily for "cradle-to-farm-gate" studies meaning that all inputs into on-farm production for each commodity are traced back to primary resources such as coal, crude oil and mined ore. The methodology can easily be extended to cradle-to-abattoir or the complete cradle-to-consumer or cradle-to-cradle.

There are four phases in a LCA study:

- goal and scope definition;
- inventory analysis;
- impact assessment; and
- interpretation.

Figure 1 shows the relationship between the phases and emphasises how the interpretation phase is interlinked to each of the other phases. This is because the interpretation must assess each of the previous phases to ascertain such things as:

- accuracy of the results;
- data quality; and
- how the choice of system boundary, functional unit, impact categories and assessment influences the result.

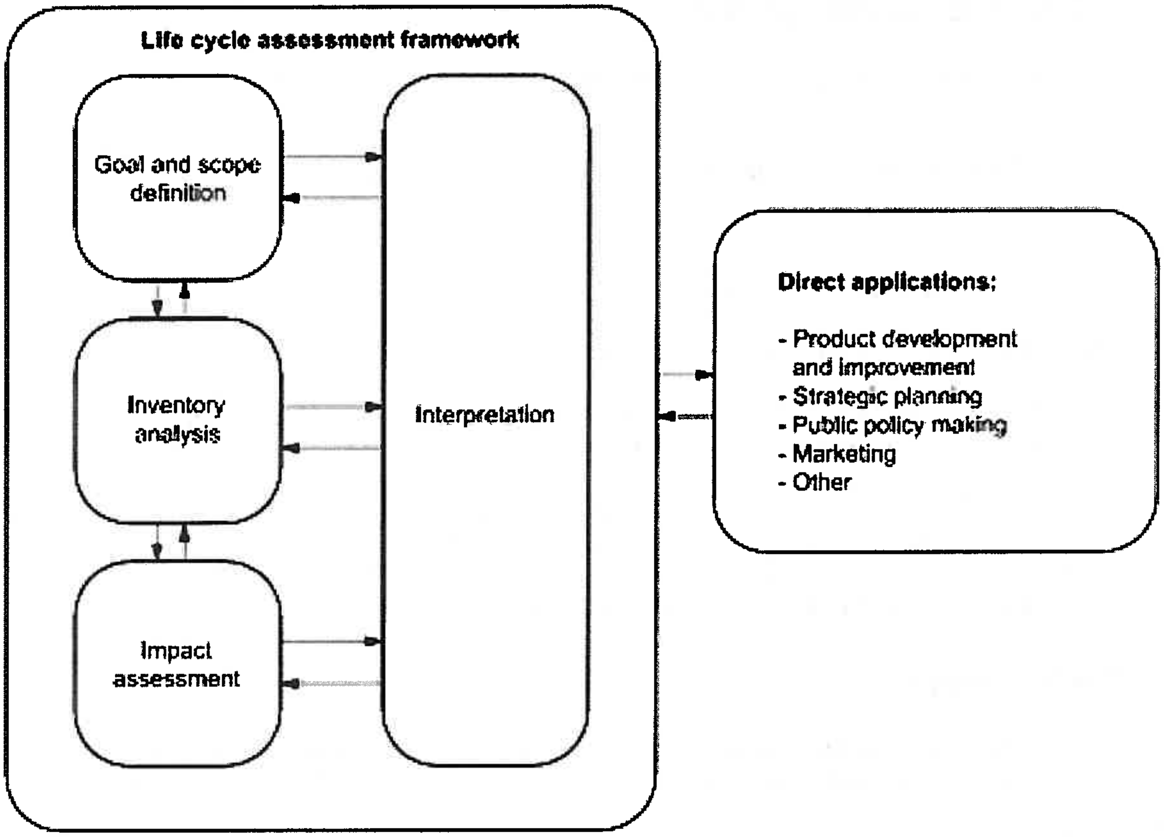

Figure 1: Stages of LCA (source: [1])

This methodology is based on establishing quantitative midpoint impacts of agricultural products. Midpoint analysis determines the quantities of water use, energy and GHG emissions, as opposed to endpoint analysis that would seek to place a more qualitative measure of end impact. For example, whereas midpoint analysis would report on the quantity of GHG emitted in producing 1 tonne of product, end-point analysis would seek to report on global warming potential, i.e. the contribution of 1 tonne of product to warming the climate. Thus endpoint analysis introduces further complexities in terms of calculations and choice of calculation methods, and therefore further uncertainties.

This methodology is also aimed at attributional LCA as opposed to consequential. Attributional LCA aims to describe the environmental properties of a lifecycle and its subsystems. Consequential LCA aims to describe the effects (or consequences) of changes within the lifecycle and thereby generate information on consequences of action and decisions. Consequential LCA generally uses systems expansions (avoiding allocation), whereas attributional LCA rarely uses allocation.

Consequential LCAs are generally built on sound attributional, standard LCA methodology and life cycle inventory (LCI) data that enable comparisons. In other words, attributional LCA is the foundation or building blocks of consequential LCA. Hence, with relevant LCA data for Australian agricultural conditions still developing, this methodology has adopted the attributional method that will provide a foundation for future consequential LCA studies (where required).

1.4 Normative references

This methodology is intended to comply with the internationally recognised LCA standardisation documents:

- ISO 14040/14044, Environmental Management – Life cycle assessment:
  - Principles and framework [1]; and
  - Requirements and guidelines [2].

Other reference documents which are significant are:

- IPCC, *Guidelines for National Greenhouse Gas Inventories.* National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change [24].
- PAS 2050 (Publicly Available Specification) – "*Specification for the assessment of the life cycle greenhouse gas emission of goods and services.*" This document, which is still in draft form, is being developed as a British Standard for the assessment and reporting of greenhouse gas emissions throughout the life cycle of either a good or service.

1.5 Principles

In accordance with this methodology having a foundation based on the above references (in particular the International Standards), the proposed methodology adheres to the following principles:

- **completeness** - information from the phases of a life cycle assessment is sufficient for reaching conclusions in accordance with the goal and scope definition;
- **relevance** –the inventory appropriately reflects the water use, energy use and GHG emissions of the functional unit and serves the decision-making needs of users;
- **consistency** - assumptions, methods and data are consistently applied throughout the study and are in accordance with the goal and scope definition performed before conclusions are reached;
- **data quality** - characteristics of data that relate to their ability to satisfy stated requirements;
- **transparency** - open, comprehensive and understandable presentation of information;
- **conservativeness** – conservative assumptions, values and procedures shall be used to ensure that water use, energy use and GHG emissions are not underestimated; and
- **accuracy** - the quantification of water use, energy use and GHG emissions is systematically neither over nor under actual use/emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. Sufficient accuracy is achieved to enable users to make decisions with reasonable assurance as to the integrity of the reported information.

These principles form the core of the methodology and it is essential that LCA studies adhere to them.

1.6 Scope of this document

This document describes the proposed standard methodology for applying LCA to assess environmental impacts of Australian agricultural practices and covers:

- goal and scope definition;
- system boundary and functional unit choice and decision consequences;
- life cycle inventory (LCI) analysis phase - involving the compilation and quantification of inputs and outputs for a product throughout its life cycle;
- life cycle impact assessment (LCIA) phase - aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product); and
- reporting and critical review of the LCA.

2. Goal and Scope

2.1 General

This methodology is designed to assess the environmental impact of agricultural processes using the three indicator categories of water use, energy use and GHG emissions. The goal of the LCA study must state:

- the intended application;
- why the study is being conducted;
- who the audience is;
- if the results are to be compared with other studies and be publicly disclosed (in this case they must undergo a critical review);
- the geographical region(s) of the agricultural practices included in the evaluation, throughout the life cycle of the product; and
- temporal aspects – the time period that the studies encompass.

The goal(s) of the LCA for the Australian rural industries could be to:

- compare agricultural practices (e.g. organic versus conventional);
- compare processing practices;
- compare feed choices for livestock;
- document the environmental impact of an agricultural commodity;
- identify environmental improvements;
- achieve improvements or opportunities for operational improvements; or
- a combination of the above.

The target audience may include farmers, processors, supermarkets, general public, policy makers, R&D organisations, non-governmental organisations, Australian and international end-consumers.

2.3 Scope

In general, the scope shall include water use, energy use and GHG emissions, for the whole of the life span of animals and plants.

2.3.1 Scope of GHG emissions

GHG emissions that need to be reported are:

- carbon dioxide (CO_2);
- methane (CH_4);

- nitrous oxide (N_2O);
- hydrofluorocarbons (HFCs);
- perfluorocarbons (PFCs); and
- sulphur hexafluoride (SF_6).

GHG emissions associated with growing of crops, feed preparations, drinking and service water for animals, shall be included over the entire life span that contributes to the final product.

The accurate measurement of N_2O emissions remains a difficult task. There is a need for emission factors to be developed for each region, so that geographic conditions, such as climate and soil conditions can be accurately incorporated in the analysis.

Carbon dioxide releases from biogenic carbon sources [1] shall be excluded from the calculation of GHG releases. Non-CO_2 emissions from livestock and manure shall be calculated using the highest tier approach in Australia (National Greenhouse Accounts (NGA) emission factors) or preferably through metering and monitoring data (see section 7), that is validated by mass and energy balances.

2.3.2 Scope of energy use

The analysis shall quantify energy use from, but may not be limited to:

- purchased electricity or self-generated electricity;
- fossil fuels (natural gas, furnace/fuel oil, refinery fuel gas, liquefied natural gas (LNG), liquefied petroleum gas (LPG), diesel, gasoline, etc);
- renewable energy sources, biofuels, (biodiesel, wood forest residues, biomass, biogas from anaerobic processes, landfill gas), geothermal, solar, wind, hydro, tidal and other;
- steam and refrigeration;
- chilled water or other working fluids;
- waste heat (from flue gases and off-gases and as a by-product of exothermic reactions); and
- compressed air.

Energy flows associated with: feed preparation and incorporation, drinking and service water for animals, shall be calculated and included over the entire life span of the animals that contribute to the final product.

2.3.3 Scope of water use

The use of the following types of water need to be considered:

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[1] Biogenic carbon refers to carbon from life processes, including animal exhalation and plant absorption through photosynthesis. The absorption of carbon dioxide by plants is not included as sequestration, because it is assumed that this is part of the natural cycle and the carbon dioxide will be shortly returned to atmosphere (in the consumption phase or shortly after). The exception are trees (grown in compliance with a nationally accredited sustainable forest sequestration scheme) or where plants become products that will bind the carbon for more than 100 years (see Section 7).

- collected rainwater (treated and untreated);
- collected surface water (treated and untreated);
- ground water (treated and untreated);
- saline and hyper saline water (low quality water for low quality uses);
- steam condensate;
- cooling water (treated and untreated) to and from the cooling towers;
- scheme water (for a centralised water treatment and sewerage works);
- grey water, potable water (human and animals), irrigation water, etc; and
- treated and untreated storm water run-on and run-off (if captured and used in processes/production activities).

Water flows associated with feed preparation and incorporation, drinking and service water for animals, shall be calculated and included over the entire life span of the animals that contribute to the final product.

2.4 Sources

2.4.1 Sources of GHG releases

The estimate of GHG emissions shall include emissions throughout the life cycle of the product arising from processes, inputs and outputs in the life cycle of a product, such as, but not limited to:

- consumption of fuels and energy that result in releases of GHGs;
- consumption of energy carriers that were themselves created using processes that have GHG emissions associated with them, e.g. electricity, fuel transport;
- chemical reactions, refrigerant loss and other fugitive releases;
- releases resulting from land use change (e.g. land clearing, development for irrigation;
- releases arising from livestock metabolism and other agricultural processes; and
- releases arising from waste and wastewater.

2.4.2 Sources of energy use

The estimated energy use throughout the life cycle of the product should include, but not be limited to:

- mining and extraction of raw material (e.g. coal, oil, phosphate rock);
- manufacturing of raw materials (e.g. for construction of meal processing facilities);
- cultivation, processing ;
- heating and cooling (e.g. in piggeries); and

- transport (e.g. feed, fuel, livestock).

2.4.3 Sources of water use

The estimated water use throughout the life cycle of the product should include, but not be limited to:

- mining and extraction of raw material (mining operations, dust suppression);
- manufacturing of materials (e.g. chemicals);
- irrigation and drinking water,
- cultivation and processing;
- heating and cooling (e.g. evaporative losses);
- transport; and
- evaporation, seepage, drainage etc.

2.5 Time and geographical coverage

Consideration should be given to the oscillating productivity of agricultural production systems. For example, many agricultural cropping systems oscillate between high yields one year followed by low yields the following year.

Therefore the time coverage that should be included in the study should cover that which can be considered as a representative production scenario for the specific crop under evaluation. This will normally be three or more years, due to the variation in energy inputs, fertilisers and pesticides consumed etc. See Section 4.3 for discussion of crop rotation issues. Extensive production systems (e.g. cattle production of natural pastures) will require a longer time to develop a representative production scenario than will intensive production systems (e.g. piggeries, cattle feedlots).

Where specific data is not available to account for regional or temporal differences, weighted averages of crop yield and other inputs/outputs are acceptable, but this must be clearly reported and justified in the study report.

Due to the large differences in climatic and other regional conditions throughout Australia, it is essential that the data and emission factors are appropriate for the region under study, i.e. where the feedstuff/ fodder are sourced and where the animal production occurs (see Section 5).

3. Functional Unit

The functional unit (FU) is the reference unit that is chosen to quantify the function of the system under study. The main purpose of the functional unit is to provide a reference to which the inputs and outputs are related [1]. This reference allows the results of the LCA study to be compared with other studies.

The choice of functional unit is particularly critical when comparing different systems. For example, if comparing milk from Country A to milk from Country B, the comparison may be affected by different quantities of the nutrients fat and protein in each. In this case the functional unit of one kilogram of milk product may not produce comparable results. The functional unit choice of one kilogram of fat and protein corrected milk (FPCM) can therefore be used, so that one kilogram of Country A milk corresponds to 1.09 kg FPCM of Country B.

There are three main types of functional unit that can be used depending on the goal of the study:

- Weight: 1 kg of the specified product; 1 tonne or a representative quantity (e.g. 20,000 eggs which is about 1 tonne);
- Cultivated area: 1 hectare; and
- Quality: energy corrected milk; fat content, protein content (e.g.1 kg protein and fat corrected milk or 1 tonne of 12% protein corrected wheat for bread making) or a combination.

Further examples of functional units for agricultural products are provided in Table 1.

Table 1: Examples of functional unit choice

Commodity	Functional Unit		
	Weight	**Area**	**Quality**
Meat (beef pork)	1 kg of meat consumed in Australia (or exported) 1kg of Hot Standard Carcass Weight (HSCW) of animal produced in/exported from Australia 1kg of HSCW over 1 year (averaged) 1 average kg pig growth between 29 kg to 115 kg	1 hectare of land 1 hectare over one year	1 kg of protein corrected meat
Chicken	1 kg of live weight at farm gate 1 kg of primary processed meat at point of distribution (the primary processing company's own distribution centre) 1 kg meat at point of purchase 1 kg of meat consumed in Australia		1 kg of protein corrected meat
Dairy	Amount sold to dairy per year by standard herd	1 hectare of land	1 kg of fat and protein corrected milk
Sugar	1 tonne of raw sugar 1 tonne of sugarcane biomass	1 hectare of land	1 kW electricity 1 ML ethanol or other liquid fuel
Cotton	1 kg of processed cotton 1 kg of cotton clothes	1 hectare of land	1000 pairs of dry hands (e.g. comparing hand towels with electric dryers)

4. System Boundaries

4.1 General

The system boundary determines which unit processes will be included in the study, and what type of "upstream data" may be omitted. System boundary settings can help reduce the quantity of LCA data needed, provided that no significant information is lost. The cut-off criteria, whereby the system boundaries are chosen, are typically determined by the goal and scope, the intended application and audience, assumptions made, and data and cost constraints.

It is important to explicitly state the reasoning and criteria for the setting of the system boundary, in order to enable the results of the study to be assessed against its goal. This should include a statement on any deletions of life cycle stages, processes, inputs or outputs. Any deletions should only be made if the deletion does not significantly change the overall conclusions of the study.

The criteria for deletions should be based on the significance of the processes or activities to the energy use, water use and GHG emissions, based the overall life cycle. Therefore processes/activities that together do not contribute to more than **one per cent of the total environmental impact** for any impact category can be omitted from the inventory analysis. An assessment of the deletion and the significance to the study's findings should be made in the final report.

Which unit processes to include in the study and the level of detail to which these unit processes will be studied need to be determined. This is an iterative process, and additional data may need to be collected before a decision is made on what to include as an input or output.

This methodology is designed primarily for cradle-to-farm-gate studies. It can easily be extended to cradle-to-abattoir and the complete cradle-to-consumer or cradle-to-cradle.

Depending on the goal and scope of the study the system boundary should consider such aspects as:

- pre-farm processes, for example;
  - mining and extraction of fertiliser inputs;
  - machinery manufacture;
  - fertiliser and chemical production and transportation to farm;
  - seed production;
  - feed production and transport;
  - mining and extraction of material inputs to chemicals production; and
  - chemicals and fuel production, formulation and transportation to farm;

Note: Genetic material production or upstream breeding systems are generally not required as the significance to the system is typically less than 1% and therefore insignificant.

- on-farm processes, for example;
  - crop production, chicken production, cotton production, dairy product production, livestock production, sugar production (within each process all practices that lead to GHG emissions/removals, energy or water use must be included, such as planting and harvesting,

cultivation, fertiliser application, irrigation, maintenance, moving stock, storage, watering stock, waste management, enteric fermentation and nitrous oxide production);

  - manufacture, maintenance and decommissioning of capital equipment;
  - additional operations such as lighting and heating;
  - co-products (manure, soil conditioners, etc.);
  - waste material and reuse (e.g. on-farm effluent management); and
  - land use changes that have occurred on or after 1st January 2008 [2], especially due to acquiring and expanding newer farm areas.

- post farm-gate (processing);
  - transport from farm to downstream processing;
  - milling, production and packaging;
  - abattoir and rendering processes;
  - secondary processing (e.g. small goods, cotton goods); and
  - distilling (sugar/ethanol).
- post farm-gate (retail)
  - storage;
  - distribution to retail outlets;
  - transportation to retail outlets;
  - cold storage and preservation processes in supermarkets and retail outlets; and
  - transport to end-consumers.

The transportation category shall include all modes (road, rail, air, and by ship) of transportation occurring in-between the life cycle stages.

Electricity production and consumption will be based on state and territory specific average emission factors by default. However more accurate and specific use of data associated with actual source of purchased electricity and other energy resources is encouraged if data are available and the sources of methodology are transparently disclosed. Electricity will need to be traced throughout its life cycle, i.e. from the mining and extraction of fuel through to power plant through distribution to use points (line losses are included).

Possible exclusions are:

- manufacture, transportation, and end-of-life disposal of buildings, transportation and packaging infrastructure, capital equipment and auxiliary machineries;

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[2] This is selected in order to be consistent with the date proposed in PAS 2050.

- life cycle traceability of historical land use changes in countries of origin outside Australia, agricultural additives and products such as synthetic hormones, animal health inputs, etc;
- post-consumption waste treatment and disposal (including human wastes);
- human energy inputs to processes and/or pre-processing (e.g. manual harvesting processes); and
- GHG emission offset mechanisms whether voluntary, or nationally/internationally recognised schemes/mechanisms.

All sources of energy and water use, and greenhouse emissions anticipated to make a material contribution (more than 1%) to the total life cycle inventory per functional unit to be included. The sum of all excluded sources (individually less than 1%) should not be anticipated to exceed 5% of the total life cycle inventory per functional unit. Where a single source of energy and water use and GHG emissions accounts for more than 50% of the likely total life cycle inventory per functional unit, the above threshold rule (inclusion of at least 95%) shall apply to the remaining life cycle inventory.

The ISO standards (14040 and 14049) can be used as guides to list the processes that are included and excluded, with justification.

4.2 Examples of system boundaries

Appendix 4 contains system flow diagrams for each agricultural sector under consideration within this methodology. Each diagram shows the functional unit options depending on the choice of system boundary. In general the wider the system boundaries the more data required, but the choice of functional unit can also have a bearing on data requirements. For instance, choosing the functional unit of one kilogram of hot standard carcass weight, and a system boundary of 'cradle to farm gate', removes the need for allocation (see section 6) between the main product (meat) and the co-products (bone, etc.). This is because the production of co-products occurs in the abattoir which is outside the system boundary. The limitation of this boundary however is that it only studies the system up to the farm gate, and so the environmental burdens of processing, (and therefore potential environmental performance improvements) are not considered. This does not give a complete picture of the lifecycle environmental impacts of red meat delivered to the consumer. It is however useful to compare different farming systems such as organic versus conventional.

4.3 Specific issues for agricultural sectors

4.3.1Crops

For crop production LCAs, it is not necessary to include the production of seeds as the relative contribution to environmental impact is small. The exception to this is where the seed production would be expected to be, or shown to, represent more than 1% of the impact to any impact category (for example where small organic farms may be studied). The on-farm planting stage however, is to be included in all LCA studies.

In general, LCA studies of one type of crop (i.e. the primary crop) that involves rotations or break crops, only need to consider the primary crop under study. The effects, emissions, and sequestration effects of a break crop are attributed to that break crop. Although the main function of the break crop is generally to provide organic nitrogen for subsequent crops or reduce pests, they are also harvested as an economic crop and can be regarded as a separate product, or as a co-product where the study includes the whole system.

Only years or periods representative of the typical production scenario should be used. If climatic conditions or events were unusual then this must be reported and explained. Where there are no representative years (i.e. due to differences in fertiliser applications after a break crop and anticipated field emissions) the entire period between break crops should be included in the study.

If the LCA goal is to study the whole system (e.g. including three years of main crop and the break crop), for example to compare it with another farming system, then the break crop should be included in the study.

Similarly, sugar LCAs should take into account the typical number of ratoons performed that is representative for the region studied and include the replanting phase. The impacts can then be normalised to a yearly basis (see section 8).

In this version of the methodology and with current data restrictions, the emphasis is on establishing good quality data that is representative of industry standards and transparent reporting, so that LCA may become increasingly accurate and easier to perform.

4.3.2 Chicken meat, dairy and livestock

As discussed above, it is not necessary to account for upstream breeding or genetic material production unless the burden is anticipated (e.g. by looking at studies of similar systems) or calculated as being 1% or more of the total burden of any of the impact categories.

For chicken meat it will not generally be required to include the hatchery or breeder units as the ratio of these to growout farms will be more than 1 to 30. Therefore the burden to any impact category will typically be very small and less than 1% of the total. Where the ratio is larger (e.g. where studying smaller operations), then there may be a requirement to include hatcheries.

5. Data

5.1 General

The data quality should comply with ISO14040 standards and therefore LCAs should include a description of data quality so that the audience can understand the reliability of the study results and properly interpret the outcome.

Data collection should focus on the aspects that make a significant contribution to the impacts being assessed [11].

5.2 Data Collection

5.2.1 Data Collection

Two main distinctions are made with data:

- primary (foreground) data which are collected directly from the participants in production (e.g. farmers and food processors); and
- secondary (background) data which are derived from published sources or other sources.

5.2.2 Primary (Foreground) data

For accuracy, input processes, farm processes and production processing need to be sourced as foreground data. Table 2 lists primary data that should be included for both crop and livestock LCAs, where appropriate to the goal and system boundaries.

Table 2: Primary data for crops, sugar, dairy, cotton and livestock

Crops	Livestock
• on-farm crop management • crop production and processing • on-site power generation/ co-generation • on-farm waste management • cotton processing and production • sugar mills • distillers	• animal production and management • pasture management processes (e.g. hay making, silage) • rendering plants • meat processing and packaging • on-farm waste management including manure management • on-site power generation/ co-generation • small goods manufacture

Composting, or more broadly effluent and manure management, can make a significant contribution to GHG emissions (for intensive livestock it may be the largest on-farm GHG emitter). If the effluent and manure is managed on-farm the foreground data on this process should be collected including total manure generated, processes and end use. Effluent and manure may be classified as a co-product that needs to be included in the LCA as an energy / fertiliser resource. If manure management and processing is offsite the emissions could be regarded as Scope 3 (under the GHG reporting protocols) and therefore background.

5.2.3 Secondary (background) data

Secondary data is collected for background processes (e.g. mining and extraction, transport, fertiliser production) where more general information may be used, as opposed to the case specific information required for foreground processes. Medicines, insecticides, machines, buildings and roads can be excluded where cost and time of data collection are extensive, and the significance of these to environmental impact is less than 1%. They may also be excluded if the study is comparing two farming systems in which there would be similar machinery usage, and therefore impacts. The reasoning for this exclusion must be clearly stated in the LCA report. Table 3 lists the secondary data that should be included for both crop and livestock LCAs, where appropriate to the goal and system boundaries.

Table 3: Secondary data for crops and livestock

Crops	Livestock
• mining and extraction of resources (fuels, materials etc) • chemicals and fertiliser production and formulation • machinery, buildings • purchased electricity production • transmission and distribution losses • off-farm waste management • transportation • packaging • retailing • consumption phase and disposal	• feed processing (fodder production); • mining and extraction of resources • chemicals and fertiliser production and formulation • composting, machinery, buildings • purchased electricity production • transmission and distribution losses • off-farm waste management transportation • packaging • retailing • consumption phase and disposal

Inclusion of embodied energy associated with materials and infrastructure/capital goods is optional as long as there is no double counting of flows. Life cycle water and energy use flows and GHG emission flows associated with relevant water/ energy supply and/ or transport infrastructure shall be included if emissions and environmental benefits associated with elimination/avoidance of, relevant public water and energy supply infrastructure use are asserted.

Given the significance of fertiliser production, the source and production method of the fertilisers applied should be investigated to ensure that the data used are appropriate [11]. Fertiliser production data available in databases may not be representative of fertilisers used in Australia.

5.2.4 Data Sources

Primary (foreground) data sources include: feedlot manufacturers, farm businesses, processing plants, sugar mills, electricity co-generation plants and distillers (sugar/ethanol). Secondary (background) data sources comprise previous and past LCA studies, Australian LCI databases, publicly available literature and reports, unpublished reports from Meat and Livestock Australia (MLA), and other industry sources, Australian Bureau of Statistics (ABS), etc..

Appendix 3 provides an example of data sources from a sugar study. The following is an example of where specific on-farm data were obtained for a dairy LCA (source [19]):

- Data sources of inputs into dairy manufacturing plant:
  - volume of raw milk intake per year (data sources: Financial department, monthly bills);
  - quantities of other intermediate dairy products per year (data sources: Financial department, monthly bills);
  - quantities of other ingredients per year (data sources: Financial department, monthly bills);
  - annual electricity use (data sources: monthly bills; electricity meters);
  - annual gas (or other fuel) account for thermal energy (data sources: monthly bills);
  - the annual water consumption on-site (data sources: monthly bills);
  - the total distance travelled per year for raw milk, chemicals, packaging materials and other ingredients (data sources: tanker records, monthly fuel bills);
  - the annual consumption of chemicals such as caustic soda, nitric acid (HNO_3 60%) and hydrochloric acid (HCl) (data sources: monthly bills, number of containers); and
  - the annual consumption of packaging materials such as kraftliner, plastic bottles (polypropylene), steel, cardboard, wood and foil (data sources: monthly bills, number of bags, boxes etc).
- Data sources of outputs from dairy manufacturing plant:
  - annual quantities of products manufactured, i.e. milk powder, market milk, cheese, whey, butter and dessert / yoghurt (data sources: Financial department, monthly bills);
  - annual emissions to air such as boiler emissions (data source: license data, samples);
  - annual emissions to water, i.e. volume and wastewater characteristics, i.e. biological oxygen demand) BOD, total N, total P, Ca, Mg, Na, Alkalinity and pH (data sources: license data, samples);
  - annual quantities of solid waste such as boiler and fly ash, packaging material etc. (data sources: monthly bills); and
  - annual quantities of wastewater sludge and fate (land applied, pig food, etc).

5.3 Data Quality

Organisations need to reduce uncertainty of data by using the best quality data achievable. For GHG emissions, water and energy use, the following aspects should be considered when selecting data:

- temporal specificity – age of the data and the length of time over which they have been collected. Data throughout the lifecycle should reflect the period accurately, e.g. in terms of climate variability, data for machinery used (old or new), etc;
- geographical specificity – area from which data is collected (e.g. district, country, region), e.g. nitrous oxide emissions specific to regions to account for soil and climatic conditions, or transport distances are regionally specific;

- technological specificity – whether the data an associated with one technology or a mixture, i.e. the technology and machinery used is representative of that actually used;
- reliability – the extent to which the data can be trusted, based on an assessment of the sources of data, the methods used to collect the data and the verification procedures used; and
- completeness – degree to which the set of data represents the population of interest (is the sample size large enough, is the periodicity of measurement sufficient, etc.).

For crops the following aspects are particularly significant and warrant collection of good quality data [11]:

- Agricultural yields;
- Field emissions;
- Fertiliser use (specific types used and quantities);
- On-farm fuel use;
- Irrigation (water use and electricity demand);
- Transport of crops to processing facility (if transported by road); and
- Capital goods (seeding and harvesting machines, on-farm produce storage).

For animal products the following are significant and require good quality data:

- Pasture management, including fodder production;
- Stocking rates (animals per ha of pasture) and animal yields;
- Enteric fermentation;
- On-farm waste management including manure management;
- On-farm fuel use;
- Water and electricity use;
- Transport of animals to processing facility (if transported by road); and
- Capital goods.

5.4 Data Uncertainty

Data uncertainty (i.e. low validity and reliability) can be divided into two categories:

- lack of data – that can be a complete lack of data (data gaps) and/or a lack of representative data; and
- data inaccuracy.

Data gaps can often be solved through input-output modelling, using information for similar products or the main ingredients of a product, and applying the law of mass conservation. A lack of temporal, geographical and technological correlation between the data used and needed may be accounted for by applying uncertainty factors to the non-representative data.

The major uncertainty in agricultural LCA arises from the inherent variability in biological systems, particularly in the following areas:

- temporal variation in production due to seasonal factors;
- livestock population characteristics;
- spatial variation in crop yields and quality;
- varying approaches to management between farm businesses;
- CH_4 emissions from enteric fermentation in domestic livestock;
- CH_4 and N_2O emissions from manure management;
- CH_4 and N_2O emissions from savannah burning;
- CH_4 and N_2O emissions from agricultural residue burning;
- direct and indirect N_2O emissions from agricultural soils;
- indirect N_2O emissions from nitrogen used in agriculture.

Practitioners are referred to the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories [15].

Data inaccuracy may be addressed by using a statistical simulation method known as Monte Carlo simulation. The statistical principle is simple, a calculation is repeated multiple times, each time a random value is chosen for each flow, for example an emission or raw material input. The resulting range of all calculation results form a distribution from which uncertainty information can be derived with basic statistical methods. Specific software is needed for this and often comes as an add-on to LCA software.

5.5 Data Variability

LCA should perform uncertainty analysis (see section 8) to quantify the uncertainty of the results due to cumulative effects of model imprecision, input uncertainty and data variability. Data variability across different years needs to be carefully considered and disclosed. As discussed earlier, single year data may not be representative and single or rare events should be excluded. Therefore, consideration needs to be given as to whether the LCA utilises single year data or takes an average across years, or (for example) compares a drought year with a normal year.

In order to reduce uncertainty of large sources of GHG (in particular N_2O field emissions), emission factors need to be developed for each region of geographic (taking into account factors such as soil conditions) and climatic differences. This can be achieved through further research that meters and monitors different regions periodically.

There are two ways to address data variability:

- firstly to use data that is specific to the geographic origin;
- (if the former is not possible) utilise a suitable data set and include appropriate justification and include a sensitivity analysis incorporating the variability ranges.

Three main factors have been identified as influencing variability in sugarcane production and are relevant for other crops [11]:

- **Environmental conditions climate, soil type, and topography**. These variables directly influence water use, nutrient losses from fields and, to some extent, fuel use for cultivation and harvesting (more fuel used for cultivating heavier soils and for harvesting in hilly areas due to less efficient haul-out). Environmental conditions also influence yield potential (i.e. the likely crop growth that can be achieved with given climate/soil type/water availability). This is the main determinant of fertiliser usage rates since, in theory, nutrients are applied to match the expected requirements of the plant for growth. In practice however this does not always occur, the tendency being to over-apply fertilisers.

- **Agronomic practices.** This includes crop cycle and rotation (number of ratoon crops in the case of sugarcane, or the use of break crops), tillage intensity (conventional tillage versus minimum-till), row spacing and controlled traffic (to control tractor movements), irrigation method (furrow, spray, or trickle), fertiliser application method (surface applied versus incorporated, single versus split application), water management (use of tail-water dams), management of harvest residues, and specifically for sugarcane, harvesting method (green cane harvesting versus burnt cane harvesting).

- **Geographic location relative to supporting infrastructure**. This includes sources of fertiliser (imported versus domestically produced), distances for transporting fertilisers and agro-chemicals, distances for transporting the crop to processing plants, and mode of crop transport (rail versus road);

As well as factors similar to the above, variability in animal production is likely to arise from factors such as enteric fermentation. Although standard emission factors are acceptable, they may at times or in certain circumstances, overestimate (but also underestimate) emissions of GHG. Therefore direct periodic measurement is encouraged in order to increase accuracy.

Where data are difficult to obtain and/or due to regional variability, the use of appropriate software such as APSIM [3] may be justified. The accuracy of the software and the reasoning for its use should be clearly explained. The use of software and its accuracy is likely to increase as these products are further refined and informed by experimental data.

5.6 Data Validation Techniques

The following methods to validate data may be used:

- metering and measurement – large sample size with repeatable results and greater number of periodicity of measurement, e.g. nitrous oxide measurement from waste dumps, methane from enteric fermentation, etc.;

- process mass and energy balances;

- comparison of process technology with inputs and outputs and published data;

- comparison and analysis of emission factors with published sources; and

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[3] APSIM, Agricultural Production Systems sIMulator, simulates biophysical processes in farming systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk [22].

- qualitative assessment for data gaps by informed professional judgements and expert panel approach.

5.7 Data Calculation

5.7.1 Computation

It is suggested that software specifically designed for LCA, such as Simapro is utilised to perform agricultural LCA. This will aid in calculations and enable life cycle tracing and summation of emissions and flows. Use of the softwares will enable the practitioner or the study owner to process large volumes of data in a relatively short time span. However, in regards to water use impacts and wastewater flows, the range of processes readily available in LCA software databases is limited. Therefore, there is considerable work to be done to build these water related processes 'bottom-up' and account them throughout the life cycle of a product or a service.

6 Allocation

6.2 General

Allocation is the method of determining how to share the environmental burdens, where more than one product is produced in the process under study. These are known as co-products, such as beef being produced as a co-product in the production of milk. There are three main ways to address allocating environmental burdens to co-products, discussed below. Due to inherent inaccuracies of some allocation methods the preference is to avoid allocation. Current data availability and potential issues in obtaining the necessary data in avoiding allocation, need careful consideration.

Water use, energy use and GHG emissions should be attributed to co-products according to the following order of preference (which is consistent with ISO 14044):

1) **Avoid allocation** by:

- dividing the unit process to be allocated into two or more sub-processes; and
- expanding the product system to include the additional functions related to the co-products.

  Examples of avoiding allocation include (please see literature review for further examples [10]):

  - In one beef study allocation was avoided due to the functional unit choice (live weight) and system boundary (cradle to farm gate), which meant that the by-products are created beyond the farm gate and did not need further consideration.
  - Systems expansions – e.g. subtracting the environmental burden of beef production alone, from that of a dairy system, in order to assess the environmental burden of milk production.
  - Systems expansion – in a comparative study of environmental benefits for sugar producers to improve energy efficiency through green energy, co-generation or fuel ethanol [6] allocation was avoided by expanding the system to include augmented production of equivalent amounts of each product by the conventional route – electricity from coal, petrol from petroleum.

2) **Allocation by physical property** - the inputs and outputs of the system should be partitioned between the different products or functions in a way which reflects the underlying physical relationships between them; i.e. they shall reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

   An example of physical allocation is by biological causality. In a milk-beef study the base for the so-called 'biological' allocation was the fact that there is a causal relationship between the dairy cow's feed mix and its production of milk, calves and meat [7]. Calculation was based on Swedish fodder tables for the supply of energy and protein to cover the dairy cow's milk production, maintenance and pregnancy. This gave an overall allocation of 85% to the product milk and 15% to the meat and surplus calves. The division was based on the official Swedish feeding recommendations as to what proportion of the dairy cow's feed intake is needed for milk production.

3) **Economic allocation** - the inputs and outputs are allocated between the products and functions in a way which reflects the product values.

   Two examples of economic allocation are:

- The income of the products was divided as 92% for milk, 6% for meat from the culled cow and 2% for the surplus calf [7]. This was based on average calculations from the Swedish Dairy Association of the yearly income per dairy cow.
- Another study [8] used an economic allocation between milk, meat and exported crops from the farm of 91%, 8.2% and 0.8% respectively.

6.2 Greenhouse Gas Allocation

6.2.1 Waste

Where waste generates GHG releases (e.g. organic matter disposed of in a landfill), allocation of emissions from the waste shall be treated as follows:

- Carbon dioxide emissions from waste - no GHG emissions shall be incurred where CO_2 arises from the biogenic carbon fraction of the waste;
- Where CO_2 arises from the fossil carbon fraction of the waste, the GHG emissions incurred shall be allocated to the life cycle of the product that gave rise to the waste.

For non-carbon dioxide emissions from waste:

- Releases of GHGs, other than CO_2 arising from the biogenic and fossil carbon fraction of the waste, shall be allocated to the life cycle of the product that gave rise to the waste.

Where methane from waste is combusted to generate useful energy:

- No GHG emissions shall be incurred where the methane being combusted is derived from the biogenic component of the waste; and
- GHG emissions shall be allocated to the useful energy produced where the methane being combusted is derived from the fossil component of the waste.

Where methane is combusted without the generation of useful energy (i.e. flaring):

- No GHG emissions shall be incurred where the methane being combusted is derived from the biogenic component of the waste; and
- GHG emissions shall be allocated to the life cycle of the product that gave rise to the waste when the methane being combusted is derived from the fossil component of the waste.

6.2.2 Energy

Water use, energy use and GHG emissions shall be allocated in proportion to either the calorific value of useful energy delivered or the economic value of the useful energy delivered. This rule applies to renewable energy production, transmission and usage as well. All renewable energy production and consumption should be accredited/certified by National GreenPower Accreditation Program (www.greenpower.gov.au).

6.2.3 Transport

Where more than one product is being transported by a transport system (e.g. a truck, ship, aircraft, train), the emissions arising from the transport system shall be allocated to the product on the basis of:

- where mass is the limiting factor for the transport system: the relative mass of the different products being transported; or
- where volume is the limiting factor for the transport system: the relative volume of the different products being transported.

Transport shall include the energy use and GHG emission releases associated with the return journey of a vehicle where the vehicle does not transport products on its return.

7. Greenhouse Gas Calculation and Considerations

7.1 GHG Emissions Contribution

Contribution is to be calculated by multiplying activity data (e.g. MJ of electricity consumed) by an emission factor (e.g. kg of CO_2-e).

The reporting of emissions in terms of Scope 1, Scope 2 and Scope 3 is not necessary as these emissions are already taken into account in the LCA process (see [12] for further information). The different 'scopes' were developed for reporting of GHG emissions at the facility or organisational level to account for both direct and indirect emissions. Direct emissions are the result of burning fuel directly by an organisation, these are Scope 1. Factors such as purchased electricity are Scope 2 whereas Scope 3 emissions account for such aspects as extraction and production of materials and electricity transmission losses. As these aspects are already accounted for in the LCA process they should not be included as this could lead to double counting.

7.1.1. Material Contribution

Calculations shall include all emissions within the system boundary that are likely to make a material contribution to the life cycle GHG emissions of the product.

7.1.2 Threshold for inclusion

For GHG emissions arising from the life cycle of a product, the assessment of GHG emissions shall include:

- all sources of emissions anticipated to make a material contribution (more than 1%) to the life cycle GHG emissions of the functional unit; and
- at least 95% of the anticipated life cycle GHG emissions of the functional unit.
- Where a single source of GHG emissions accounts for more than 50% of the likely life cycle GHG emissions of a product, the 95% threshold rule shall apply to the remaining GHG emissions associated with the anticipated life cycle GHG emissions the product.

Where less than 100% of the anticipated life cycle GHG emissions have been determined, the assessed emissions shall be scaled up to represent 100% of the GHG emissions associated with the functional unit. This is to account for minor raw materials or activities that were excluded from the analysis by dividing the estimated emissions by the proportion of emissions calculated for the anticipated life cycle GHG emissions (see Section 7.3.1, step 5). Anticipated emissions are emissions that are calculated for the life cycle, based on experience, expert knowledge of processes, literature and based on current understanding.

7.1.3 Carbon sequestration

Net removal from the atmosphere of carbon remaining over a 100 year time period (this is the chosen *minimum* sequestration period – hence emissions must be sequestered in the product for *at least* this period of time) following the creation of the product (life cycle of timber fibre, cement or other materials) shall be included in the assessment of life cycle emissions of the product. For products incorporating wood fibre, reductions in GHG emissions shall only be included in the assessment of the life cycle emissions of the product if the fibre is obtained from:

- A recycling or reuse source; or
- A source that has demonstrated compliance with nationally accredited sustainable forest management.

7.1.4 Soil carbon

Changes to soil carbon (either releases or sequestration) for agricultural systems shall be included by calculating at the:

- minimum using highest tier approach in Australia (NGA Emission Factors or other higher emission and soil factors if readily available with geographic specificity); or
- maximum statistically sampled, laboratory analysed, and tested and monitored data for a complete year validated by mass and energy balances.

7.1.5 Treatment of land use change

GHG releases occurring as a result of direct land use change that is associated with inputs to the life cycle of a product or service and that have occurred on or after 1st January 2008[4] especially due to acquiring and expanding newer farm areas shall be included in the assessment of GHG emissions of the product.

The GHG emission releases shall be amortised annually over the 20 years following the land use change (in other words they are divided amongst the 20 years following the land use change) onwards with zero per cent environmental discount rate (this is in agreement with PAS 2050). Water and energy use associated with the land use changes are not required to be included. Where the timing of land use change cannot be demonstrated to be after 1st January 2008, it shall be assumed that the land use change occurred on 1st January of the year in which the life cycle assessment is being carried out.

The GHG emissions from land use change for selected countries, by previous and current land use, is shown in Appendix 6.

7.1.6 Offsetting

This LCA methodology is designed to examine the GHG intensity of the production process across the lifecycle, before any external measures to offset GHG emissions. Therefore, GHG emissions offset mechanisms (including but not limited to voluntary, national or internationally recognised offset schemes or mechanisms) shall not be used at any point in the LCA study, in order to claim reduction in the GHG emissions. This does not include the use of an energy source that results in reduced GHG releases, such as combined heat and power or renewable energy.

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[4] This date is selected in order to be consistent with the date proposed in PAS 2050.

7.2 General Inclusions and Considerations

7.2.1 Recycling and Reuse

Processes (including transport from the place of reprocessing to the place where it forms an input) required to recycle a product or a flow or a stream to a state where it is an input to the life cycle of the product being processed shall be assessed for GHG emissions, energy and water use and the assessment included in the life cycle inventory.

7.2.2 Final disposal of products/materials

GHG emissions, energy, and water use impacts arising from materials or products that are disposed of permanently (e.g. through landfill, incineration, burial, wastewater) shall be included.

7.3 Calculation Methods

7.3.1 Calculation of the GHG emissions of products

The following method shall be used to calculate the GHG emissions for a functional unit [4]:

1. Primary activity data and secondary data shall be converted to GHG emissions by multiplying the activity data by the emission factor for the activity. This shall be recorded as GHG emissions per functional unit of product.

2. GHG emissions data shall be converted into carbon dioxide equivalent (CO_2e) emissions by multiplying the individual GHG emissions figures by the relevant global warming potential (GWP).

3. Any carbon sequestered as part of the life cycle of the product in accordance with Section 7.1.3 shall be expressed as CO_2e and deducted from the total calculated at step 2 above.

4. The results shall be added together to obtain GHG emissions in terms of CO_2e emissions per functional unit. When the result is calculated, the result shall be:

- for business to customer transactions: the complete product life cycle GHG emissions arising from the product (including the use phase), and separately only the use phase GHG emissions arising from the product; or

- for business to business transactions: the GHG emissions occurring up to that point where the business to business transaction occurred.

5. The GHG emissions shall then be scaled to account for the minor raw materials or activities that were excluded from the analysis by dividing the estimated emissions by the proportion of emissions calculated for the anticipated life cycle GHG emissions.

7.3.2 Nitrous Oxide field emissions

Direct monitoring and measurement of N_2O emissions is the preferred method of establishing emission levels. However, it is recognised that this is currently impractical to perform for many activities considered in agricultural LCA studies.

Therefore the best available method should be used and could include a combination of modelling software and emission factors such as:

- International Panel on Climate Change (IPCC) methodology guidelines on producing greenhouse gas inventories [23],

- APSIM (Agricultural Production Systems sIMulator) simulates biophysical processes in farming systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk [22].

- DNDC – (DeNitrification-DeComposition) is a computer simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems. The model can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases including nitrous oxide (N_2O), nitric oxide (NO), dinitrogen (N_2), ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2) [24].

The reason and method in establishing the best available technique shall be clearly stated in the LCA report.

In the long term nitrous oxide levels need to be established on a regional/farm level as accuracy levels will need to improve greatly. Recent research [13] has shown that IPCC methods can over estimate N_2O emissions, so it is the interests of the farm sector to establish regional/farm level emissions factors.

The issue of N emission is likely to be more important for sugarcane than for other crops since cane tends to be grown in conditions that cause high N losses due to metabolic and microbial processes taking place in soils (high N availability, high moisture, high temperatures and the presence of organic matter) [11].

8. Life Cycle Impact Assessment

8.1 General

The life cycle impact assessment stage (LCIA) is where the magnitude and significance of the environmental impacts throughout the life cycle of the product (specifically the functional unit) are evaluated. The methodology proposed in this document focuses on energy and water use, and GHG emissions. It is therefore only necessary to report on these categories, although reporting of additional impact categories is optional.

8.2 Impact Categories

8.2.1 Energy

The reporting of energy should be divided into the following categories, and reported in MJ per functional unit:

- total energy use;
- non-renewable energy –e.g. fossil fuels; and
- renewable energy.

8.2.2 GHG Emissions

Refer to Section 7.3.

8.2.3 Water Use

There are no established life cycle impact categories for aggregating different types of water flows and uses. There are several challenges in the development of suitable impact categories for water use:

- the impact categories must be able to be consistently applied throughout the life cycle of the product;
- temporal and spatial aspects of water resources and use;
- water use is not only quantitative but also qualitative, in that the use of different water sources has different environmental implications (and water can be transformed from high to low quality through a process);
- sustainability (and environmental impact) of water use by agriculture is a contentious issue, which is related to the scarcity of the resource and recharge time;
- competing uses – e.g. damming of water by upstream users affecting downstream users. Can this be accounted for?
- data availability – quantities used, sustainability of the resource (e.g. recharge rate and size of aquifer); and
- there are large differences throughout Australia on the water sources and availability.

There are two reporting categories proposed to report water use, and the reporting of both is advocated. It is however, accepted that the 'sustainable use of water' is a developing field and is open to different interpretations. The method proposed here is intended to reduce controversy and is in line with developed methods of the Australian Government [17, 18].

The first class of reporting, is to report on the water used under the following indicators (in line with Australian Bureau of Statistics, Water Account Australia [17]):

- **self-extracted** water is defined as water extracted directly from the environment for use, and includes water from rivers, lakes, farm dams, groundwater and other water bodies;
- **distributed** water is water supplied to a user, often through a non-natural network (piped or open channel), and where an economic transaction has occurred for the exchange of this water. Water supplied by irrigation water providers through natural waterways and bores falls under the definition of distributed water; and
- **reuse** water refers to wastewater that may have been treated to some extent, and then used again without first being discharged to the environment. It excludes water that is reused onsite, for example on-farm water reuse or water being constantly recycled within a manufacturing plant.

The second category to report on is the assessment of the sustainability of water use within the following two definitions [18, 20]:

- *Surface water sustainable flow regimes*: the volume and pattern of water diversions from a river that include social, economic and environmental needs; and
- *Groundwater sustainable yield*: the volume of water extracted over a specific time frame that should not be exceeded to protect the higher social, environmental and economic uses associated with the aquifer.

The sustainable use of water shall be reported as a percentage:

- Water removed from rivers as a percentage of sustainable flow regimes; and
- Groundwater abstraction as a percentage of sustainable yield.

See NLWRA (2001) [18 & 20] for further explanation on definitions and calculations. Further details of the water availability assessment methods can be found in Appendix 5 and also on the ANRA website [21].

Wastewater is only necessary to be reported as a quantity in ML, for each stage of life cycle under analysis. Further versions of this methodology may expand on this by requiring qualitative impact categories to be reported on. The proactive reporting of impact categories that practitioners would like to report on, beyond the scope of this methodology, is encouraged.

8.3 Normalisation and Weighting

Normalisation and weighting are optional steps in the impact assessment methodology. Owing to a lack of an agreed normalisation and weighting method for Australia and the inherent robustness and greater demands on the state of the environment data with respect to Australian conditions, these two steps are not compulsory in the impact assessment phase.

Normalisation is defined by ISO 14042 as 'calculation of the magnitude of indicator results relative to reference information'. The reference information could relate to a given community (e.g. Australia, New Zealand or Europe), person (e.g. an Australian citizen) or other system, over a given period of time (i.e. water use/person/year). Normalisation helps to better understand the relative importance and magnitude of the impact category results for each product system under study. For further information see [14].

Weighting involves assigning numerical factors to (normalised) indicator results for each impact category, according to their relative importance [14]. The impact category results are multiplied by these factors and possibly aggregated. Weighting is based on value choices such as monetary values of the products, standards or expert knowledge. For further information see [14].

Weighting shall not be used for comparative assertions that are disclosed to the public.

8.4 Life cycle interpretation

Life cycle interpretation is the phase in which the results of the analysis and all choices and assumptions that were made during the analysis, are evaluated for soundness and robustness, and overall conclusions are drawn.

The interpretation stage involves the:

- evaluation of completeness, sensitivity and consistency;
- identification of the significant issues based on the results of the LCI and LCIA stages; and
- development of conclusions, limitations and recommendations.

8.4.1 Completeness check

A completeness check should be performed to ensure that all data and relevant information needed for the interpretation are available and complete. There is a requirement to report on any information or data that is missing and assess how this affects achieving the goal and scope of the LCA. If the necessary information cannot be obtained the goal and scope should be adjusted accordingly. Where missing information is considered unnecessary, the reason should be recorded.

The completeness check can be performed by [14]:

- utilising an internal or external LCA expert and/or technical expert(s) to check for completeness based on their knowledge, and if possible based on a comparison of the study with similar previous studies;
- where errors or gaps are found:
  - justify them, if they are justifiable;
  - assess their validity and influence;
  - if possible and necessary, reiterate the previous step in the methodology and adapt the study results by correcting the errors or gaps found; and
  - report any remaining issues explicitly and justify these together with the results of the study;
- Special attention should be given to comparisons. If the completeness of the data differs between alternative systems the influence of this difference should be estimated (e.g. by contribution analysis, perturbation analysis or sensitivity analysis); and

- in addition to a data-oriented completeness check, analyse and discuss, if necessary, the completeness of the procedures followed.

8.4.2 Consistency check

A consistency check shall be performed to determine whether the assumptions, methods and data are consistent with the goals and scope. Analysis of results and sensitivity analyses are pointless if the assumptions and models used in the LCA are inconsistent with the goal and scope of the study or inconsistent across the various options.

The consistency check should assess the differences in data quality throughout the life cycle of the product system and between different product systems to ensure they are consistent with the goal and scope. Where appropriate to the study, the check will determine if consistency has been applied:

- across regional and temporal differences;
- to allocation rules and the system boundary across all product systems; and
- to the elements of the impact assessment.

The consistency check is performed through several methods [14]:

- Check for unexpected results:
  - based on expert knowledge; and
  - if possible based on a comparison of the results of the study with the results of previous related studies. In particular check for differences between the options being compared as regards to data sources, data accuracy, technical level, temporal aspects, geographical representativeness and functions.
- If inconsistencies are found:
  - justify them, if they are justifiable;
  - assess their validity and influence;
  - if possible and necessary, reiterate previous steps in the methodology and adapt the study results by removing the inconsistencies found; and
  - report any remaining inconsistencies explicitly and justify these together with the results of the study.
- In addition to a data-oriented consistency check, analyse and discuss the consistency of the procedures followed.

For further information refer to ISO 14043 [16].

8.4.3 Contribution analysis

It is recommended that the main focus of the interpretation is undertaken through contribution analysis. Contribution analysis calculates the overall contribution of different processes in the life cycle to the overall environmental impact. For most LCA studies it is recommended that the analysis is split into pre-farm, on-farm, and post-farm (which may be further split into processing and consumption). Contribution analysis to the impact categories of water use, energy use and GHG emissions should then be performed. This will identify and examine the contribution of the life stages or groups of processes to the total result, by expressing it as, for example, a percentage of the total. Key points are:

- special attention should be given to processes or process data whose data quality gives reason for concern or which are based on estimation. If the contribution analysis shows that the contribution of these processes or flows may be substantial then this may be reason to seek improved data;

- if possible, the results should be compared with similar previous studies; and

- report results of the contribution analysis as tables, bar charts or pie charts.

8.4.4 Sensitivity check

The reliability of the final results and the conclusions reached need to be assessed. In essence, this element of the interpretation phase assesses the influence of variations in process data, model choices and other variables, on the results. Therefore sensitivity analysis involves deliberate changes to variables in order to determine the robustness of the results with regard to these variations. The uncertainty analysis uses empirical data on the uncertainty ranges of specific data to calculate the total error range of the results and the effect on the conclusions. Consideration shall be given to:

- the issues that were predetermined by the goal and scope;

- the results from all of the phases of the study; and

- previous experiences and expert judgements.

If the results are to be compared with other studies in a comparative assertion that will be disclosed to the public, the evaluation shall include interpretive statements based on the sensitivity analysis. The results of the sensitivity analysis will determine whether more detailed sensitivity analysis is required.

For simplified LCA the sensitivity analysis should be performed by the following methods [14]:

- selecting and justifying a limited set of issues based on the results of contribution analysis, perturbation analysis and the subjects identified as key issues (e.g. influence of future scenarios, effect of data quality, key data sensitivity, possible contribution of missing processes);

- conduct sensitivity analyses on the issues selected, at the level of:

  - the inventory table;

  - the environmental profile;

  - the normalised environmental profile; and

  - the weighting results.

- report the issues identified, the results and possible uncertainties in table or graphic format;

- if possible compare the sensitivity and uncertainty analyses results with the results of other similar studies;

- special attention should be given to processes and process data whose data quality was identified as a concern or data that was estimated. If this shows significant effects on the LCA results, then this may be reason to go back to the data collection step and attempt to collect improved data quality; and

- special attention should also be given to differences in completeness between alternative systems, to assess if the results are very sensitive to changes in any missing data.

For detailed LCA the selection of the set of issues to conduct sensitivity analysis for, should be comprehensive instead of limited. Monte Carlo simulations may be used to conduct uncertainty analysis.

8.4.5 Identification of eco-efficiency management priorities in selected foreground processes

The significance and contribution analysis will help to identify the priority areas for improvements in environmental performance (or eco-efficiency). The study should report on the key areas identified for eco-efficiency improvements (e.g. energy use in heating) and potential methods for improvement, for example:

- fertiliser use efficiency and reduction in associated GHG emissions;
- improved yields/unit of inputs;
- insulation and/or passive solar heating methods and potential reduction in energy use and GHG emissions; or
- improved irrigation methods and reduction in water use.

8.5 Limitations

As per ISO 14040 and 14044: 2006, the results and findings of the case studies should be qualified and transparently discussed in regard to the inherent limitations posed by the LCA methodology, the input-output data coverage, the choice of system boundaries, and the impact assessment methodology. The data and model uncertainties should be shown as part of sensitivity/scenario analysis in the life cycle evaluation phase. The following limitations should be recognised:

- LCA is a linear steady state model;
- input and output data coverage;
- uncertainties associated with data sources and types;
- limited life cycle traceability of some specialty materials and processes; and
- impact assessment methodology (mid point indicators and not actual damages).

9. Reporting

9.1 Reporting Requirements

Reporting should be performed in accordance with ISO 14040 and ISO 14044: 2006, and the results and conclusions shall be accurately and completely reported without bias to the intended audience. It is essential that the LCA study is transparent and that there is sufficient detail to allow the reader to understand the choices made throughout the study and the reasoning during the interpretation. Third party reporting should also adhere to the additional requirements stipulated in ISO 14044, in order to make the LCA studies transparent and comparable, so that the report shall cover:

1. general aspects;
2. goal of the study;
3. scope of the study;
4. description of the system boundaries;
5. key assumptions and data sources;
6. life cycle inventory analysis;
7. life cycle impact assessment;
8. life cycle interpretation; and
9. critical review.

9.2 Critical review

The critical review process can be carried out by:

- internal or external expert review; and/or
- project steering committee; and/or
- other relevant interested third-parties.

In accordance with ISO 14040 and ISO 14044: 2006 the critical review process shall ensure that:

- methods used to perform the LCA are consistent with ISO 14040 and ISO 14044: 2006 and scientifically valid;
- the data used is appropriate to achieve the goal and scope of the study;
- the interpretations are consistent with the limitations identified in the goal and scope; and
- there is consistency and transparency throughout the study report.

9.3 Inventory disclosure and transparency

Much of the value of LCA studies arise from the capacity to compare different farming practices and methods. However, a large portion of the data involved in LCA studies is likely to be confidential. In order to maximise the usefulness of the LCA results Table 4 illustrates the kind of high-level data that should be reported for LCA studies.

Table 4: Example of inventory to be collected and disclosed Source: (adapted from [5])

Parameters	Unit	Average (kg/t)	Average (kg/ha)
Inputs			
Energy			
Total	MJ		
Cultivation	MJ		
Processing	MJ		
Transport of chemicals	MJ		
General farm operations	MJ		
Waste management	MJ		
Water distribution	MJ		
Water			
Water for raw materials	ML		
Animal feed	ML		
Water for processing	ML		
Irrigation water			
Drinking water			
Greenhouse Gas			
Raw materials			
CO_2-e for cultivation and harvesting	kg CO_2-e		
Electricity	kg CO_2-e		
Diesel	kg CO_2-e		
Fertilisers	kg CO_2-e		
Pesticides	kg CO_2-e		
Manure management	kg CO_2-e		
CO_2-e for processing	kg CO_2-e		
CO_2-e for transport	kg CO_2-e		
Outputs			
Greenhouse Gas Emissions			
Waste water management	kg CO_2-e		
Livestock	kg CO_2-e		
On-field emissions (N_2O)	kg CO_2-e		
Manure management emissions (N_2O)	kg CO_2-e		

9.4 Confidentiality

The data may in some cases be aggregated over the life cycle or portions of it, so that competitive data is obscured. One method of doing this could be by combining processes along the life cycle under three major stages (the processes incorporated into each stage should be specified):

- pre-farm;
- on –farm; and
- post farm.

9.5 Accuracy

The level of accuracy of the results and impacts should be calculated and reported as a (+/-) percentage level. This will be derived from the sensitivity and uncertainty analysis discussed in section 8.

10. Summary

This report has proposed a methodology for the application of LCA in selected Australian primary industries. The methodology is consistent with internationally recognised standards and methodologies. It is anticipated (and encouraged) that the methodology will be refined through application and case studies, and extended to other agricultural industries.

10.1 Sharing LCA data and outputs

This report has stressed several principles in the application of the methodology, in particular transparency and openness. For Australian agricultural LCAs to be applied successfully and accurately, and for the practice to become widespread and easier in application, there is a need for the sharing of data and cooperation amongst industry sectors. There are several options for data sharing amongst primary industries:

- through openness, transparency and high quality reporting in publications (therefore facilitating data sharing);
- through the Australian Life Cycle Inventory Database Initiative (AusLCI); and
- a proposed database to be developed, and overseen by CSIRO. The database should be consistent with AusLCI, which links CSIRO's extensive library of information, particularly on biofuels, with academics, RDCs, state agencies, companies, libraries and international groups. AusLCI is currently unfunded, and could be developed into a data library for LCA for industries.

10.2 Greenhouse Friendly and eco-labelling opportunities

The proposed methodology is designed to lay appropriate foundations so that the studied product can more easily become compliant with environmental labelling schemes, such as ISO 14025 (Environmental labels and declarations - Type III environmental declarations - Principles and procedures) and Greenhouse Friendly. The methodology is also in line with product category rules for preparing an environmental product declaration (EPD). An EPD is defined as quantified environmental data for a product with pre-set categories of parameters based on the ISO 14040 series of standards, but not excluding additional environmental information.

Although this methodology lays appropriate foundations for EPDs the impact categories used for EPDs are more extensive and therefore further data and impact categories would be required.

Appendix 1: Terms

(As per International Standards, ISO 14044 [2])

allocation - partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems

biogenic carbon sources - refers to carbon from life processes, including animal exhalation and plant absorption through photosynthesis. The absorption of carbon dioxide by plants is not included as sequestration because considered neutral, in that it is anticipated that this will be shortly returned to carbon dioxide.

comparative assertion - environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function

completeness check - process of verifying whether information from the phases of a life cycle assessment is sufficient for reaching conclusions in accordance with the goal and scope definition

consistency check - process of verifying that the assumptions, methods and data are consistently applied throughout the study and are in accordance with the goal and scope definition performed before conclusions are reached

co-product - any of two or more products coming from the same unit process or product system

critical review - process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment (NOTE 1 The principles are described in ISO 14040:2006, 4.1. NOTE 2 The requirements are described in this International Standard.)

cut-off criteria - specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study

data quality - characteristics of data that relate to their ability to satisfy stated requirements

evaluation - element within the life cycle interpretation phase intended to establish confidence in the results of the life cycle assessment (NOTE Evaluation includes completeness check, sensitivity check, consistency check, and any other validation that may be required according to the goal and scope definition of the study)

functional unit - quantified performance of a product system for use as a reference unit

impact category - class representing environmental issues of concern to which life cycle inventory analysis results may be assigned

impact category indicator - quantifiable representation of an impact category (NOTE The shorter expression "category indicator" is used in this International Standard for improved readability)

input - product, material or energy flow that enters a unit process

interested party - individual or group concerned with or affected

life cycle - consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal

life cycle assessment - compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

life cycle inventory analysis - phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle

life cycle inventory analysis result - outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment

life cycle impact assessment - phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product

life cycle interpretation - phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations

output - product, material or energy flow that leaves a unit process (NOTE Products and materials include raw materials, intermediate products, co-products, and releases.)

process energy - energy input required for operating the process or equipment within a unit process, excluding energy inputs for production and delivery of the energy itself

product flow - products entering from or leaving to another product system

product system - collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study

sensitivity check - process of verifying that the information obtained from a sensitivity analysis is relevant for reaching the conclusions and giving recommendations

system boundary - set of criteria specifying which unit processes are part of a product system (NOTE The term "system boundary" is not used in this International Standard in relation to LCIA)

uncertainty analysis - systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability (NOTE Either ranges or probability distributions are used to determine uncertainty in the results)

unit process - smallest element considered in the life cycle inventory analysis for which input and output data are quantified

transparency - open, comprehensive and understandable presentation of information

waste - substances or objects which the holder intends or is required to dispose of (NOTE The definition is taken from the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal* (22 March 1989) but is not confined in this International Standard to hazardous waste)

Appendix 2: LCA Workshop Minutes

Workshop objectives

- To review and finalise the draft report, *Methodology for Agricultural Life Cycle Assessment in Australia*, produced for stakeholders by URS
- To coordinate interested parties with RIRDC in a collaborative submission to DAFF's call for projects relating to LCA and Climate Change.

1. Welcome

Simon Winter, Research Manager, RIRDC's GLC Program, opened the workshop at 9.30am and welcomed participants, who included representatives from industry, state departments of primary industries and Federal Government departments, independent consultants and university researchers (see Attachment 1).

The objectives of the workshop were outlined, as above.

Tom Davison, General Manager, RIRDC's National Rural Issues Portfolio, briefly explained the background of RIRDC's Life Cycle Assessment (LCA) project. Development of a LCA methodology for agriculture was identified as an opportunity for collaborative investment at a meeting of RDCs in 2007.

RIRDC, Australian Pork Ltd, Sugar R&D Corporation, Meat & Livestock Australia, Australian Chicken Meat Federation, Cotton R&D Corporation and Dairy Australia provided funding for RIRDC Project PRJ-002940, Developing Agreed Life Cycle Assessment methodologies.

S Winter asked workshop participants to introduce themselves and to:

- identify their expectations from the workshop
- indicate their interest in participating in a collaborative submission to DAFF on Climate Change.

2. Industry need for a draft methodology

Bruce Edgerton, Australian Pork Ltd, gave a brief presentation on APL's interest in LCA outcomes. The Pork industry's interest in LCA is being driven by the reality of climate change factors and partly by international trade requirements for Australia to account for the resource use and emissions of its export products.

3. Overview of process undertaken and presentation of results

Venky Narayanaswamy and Steve Harris discussed development of the URS draft methodology. The methodology is based on a synthesis of an extensive literature review, and presents a standardised framework for use across primary industries to analyse resource uses and emissions across the life cycle of a product. It can be used to identify key areas of greenhouse gas (GHG) emissions, energy use and water use to increase environmental and economic performance. An agreed method for accounting and reporting on water use in agriculture has not been established, and URS's LCA methodology has proposed one.

4. Discussion of gaps/issues to be resolved

The scope of the methodology includes GHG emissions, energy and water use for the whole of the life span of animals and plants. Participants broke out into three groups for discussion on gaps or issues to be addressed in a revised methodology.

Table 1: Scope of water use and determining boundaries of (meat) production

Water: LCA has no established method for water use accounting or determining quality of water extracted. Proportion of rainfall utilised by product or crop, pumped water, reticulated water. Capacity utilisation: hectares of pasture consumed to grow animal or left unutilised but owned.

Boundary: farm level (pasture). 2000 not consistent with NCHS (1970). Quality of water in and out not being considered: cross referencing to ANZECC quality guidelines; water quality to be considered as part of mid-point impact assessment. **Allocation**: mass allocation should be stated explicitly; consistency in allocation methods application; economic allocation is quick and good, but needs to be sensitised in interpretation. Economic allocation: last three years value (average); systems expansion: where data available and cost/time effective

Functional unit: make comparable between products (kg of live weight at the farm gate; kg of primary processed meat at the process gate; kg of saleable meet at point of purchase [including packaging], need to determine production systems and generation boundaries

Product systems: production herd: how far to go back in the upstream life of animals, eg reproduction

Table 2: Scope of water use and LCA case studies

Case studies: need for hands on studies: land use sequestration; what's not going to work for intended goal/use; methodology to suggest accounting methods; LCA as tool to improve efficiencies; LCA needs to include economic values which will influence change; accreditation/reporting purposes; need to reach agreement on what's in/out; machinery and infrastructure included – building, lubricants; water – maximising use of salinity.

Water: using soft water to model water need for plants; evaporation; water use and quality in/out; renew-ability of water source: how to consider/report.

Table 3: Gaps in LCA Methodology

Define goals: why use LCA? To assess primarily greenhouse gas and water use, inform research and development direction; assure marketing.

Boundaries: from cradle to fork development of product, including downstream impacts of products

Functional units: goals of what need to do at farm and regional level; tied to goal of LCA

Tools for LCA: include scenario testing with normal KPI of each industry. Use scenarios of KPIs to determine which has greatest GHG impact.

Data: link to functional units; due to variability impacts (drought etc) modelling could be the way to proceed. Data must be 'representative' of system.

Allocation: allocation must happen as most farms varied in production. Allocation on dollar basis. Farm data must be a true representative of cradle to fork production

Additional discussion

PAS 2050 is the UK Carbon Trust methodology that meets ISO standard for greenhouse emissions (but does not include energy or water use). It is the common European certification model. The URS LCA methodology is compliant with PAS 2050. PAS 2050 also has a communication standard. Participants agreed that LCA should have a communication standard as well, developed collaboratively by industries.

Table 5: LCA Workshop Participants - 22 August 2008

Name	Organisation
Greg Bender	Abbott Innovation
Rowena Hodges	ACIL Tasman
Jacqueline Baptista	AECL
Bruce Edgerton	Australian Pork Ltd
Jeff Gilbert	Australian Carbon Certificates
Kerry Collien	Australian Carbon Certificates
Elisa Heylin	Chicken RDC
Bruce Pyke	Cotton RDC
Sandra Eady	CSIRO
Neil van Buuren	Dairy Australia
Bill Slattery	Department of Climate Change
Kevin Wilkinson	DPI Victoria
Steve Wiedemann	FSA
Peter Watt	FSA
Martin Blumenthal	Grains RDC
Ian Johnsson	Meat and Livestock Australia
Geoff Beecher	NSW Dept Primary Industries
Regina Fogarty	NSW Dept Primary Industries
Annette Cowie	NSW DPI (State Forest, NSW)
Francisco Javier Navarro	Queensland University of Technology
Venky Narayanaswamy	URS
Steve Harris	URS
David Michael	Wondu Business Technology Services
Tom Davison	RIRDC
Simon Winter	RIRDC
Alison Saunders	RIRDC
Helen Moffett	RIRDC

Appendix 3 – Examples of Data Sources

Table 6: Data sources and quality for a sugarcane study

(source [11])

ASPECT		DATA SOURCE	DATA QUALITY RATING [a]
FOREGROUND PROCESSES			
Cane growing	Cane yields	Industry statistics (Australian Sugar Yearbook, 2006)	(1,1,1,1,1)
	Fuel use	Farm survey data (Antony 2004a,b,c, Hardman 2002 and Dent et al., 2003)	(2,4,1,1,1)
	Machinery and infrastructure utilisation	Estimates based on discussion with industry personnel	(5,2,1,1,1)
	Fertiliser use	Farm survey data from Canegrowers (2001)	(1,1,1,1,1)
	Pesticide use	Farm survey data from Canegrowers (2001)	(1,1,1,1,1)
	Transport distances for fertilisers / pesticides	Estimates based on discussion with industry personnel	(5,1,1,1,1)
	Water use	Farm survey data from CAES Environmental Audit (2004)	(1,1,1,1,1)
	Energy for irrigation	Generic estimates from Holden et al. (1998)	(3,1,1,1,1)
	Field emissions to air		
	Nitrous oxide (N_2O) from denitrification	Published APSIM modeling data (Thorburn et al., 2004)	(2,1,1,1,1)
	Nitrogen oxide (NO_x) from denitrification	Published APSIM modeling data (Thorburn et al., 2004)	(2,1,1,1,1)
	Ammonia (NH_3) from volatilisation	Published experimental data (Denmead et al., 1990)	(1,4,1,1,1)
	Emissions from pre-harvest burning of cane	Estimates from Australian Greenhouse Office (2005)	(4,1,1,1,1)
	Field emissions to water		
	Nitrogen via surface runoff	Not yet available	NA
	Phosphorous via surface runoff	Published estimates from Bloesch et al. (1997)	(3,1,3,1,1)
	Pesticide	Published estimates from Simpson et al. (2001)	(2,1,1,1,1)
	Nitrate via leaching	Published APSIM modeling data (Thorburn et al., 2004)	(2,1,1,1,1)
Harvesting	Fuel use	Industry survey data from industry personnel	(1,1,1,1,1)
	Machinery and infrastructure utilisation	Estimates based on discussion with industry personnel	(5,2,1,1,1)
Transport	Modal haul-down and distances	Industry survey data (Hildebrand 2002)	(1,1,1,1,1)
	Cane rail infrastructure	Light Railway Research Society of Australia	(1,1,1,1,1)
BACKGROUND PROCESSES			
Cane growing inputs	Fertilisers:		
	Urea	Australian inventory database	(4,3,3,4,2)
	Diammonium phosphate	Production data for Phosphate Hill operation (WMC Hudson 2005)	(1,1,1,1,1)
	Ammonium sulphate	Australian inventory database	(3,4,4,4,4)
	Potassium chloride	Australian inventory database	(3,4,4,4,4)
	Agricultural lime ($CaCO_3$)	Australian inventory database	(2,1,1,1,1)
	Pesticides	Australian inventory database	(3,4,3,4,4)
Machinery and infrastructure	Tractor production	Ecoinvent database	(2,3,4,4,4)
	Harvester production	Ecoinvent database	(2,3,4,4,4)
	Shed production	Ecoinvent database	(2,3,4,4,4)
	Railway rolling stock production	Ecoinvent database	(2,3,4,4,4)
Transport operations	Tractor / harvester operation	Australian inventory database	(2,2,2,2,2)
	Truck operation	Australian inventory database	(2,2,2,2,2)
	Vehicle operation	Australian inventory database	(2,2,2,2,2)
	Cane rail operation	Australian inventory database	(2,3,2,2,4)
	Shipping	Australian inventory database	(2,2,2,2,2)
Energy inputs	Diesel	Australian inventory database	(2,2,2,2,2)
	Fuel oil	Australian inventory database	(2,2,2,2,2)
	Natural gas	Australian inventory database	(2,2,2,2,2)
	Coal	Australian inventory database	(2,2,2,2,2)
	Electricity	Australian inventory database	(2,2,2,2,2)
Materials	Steel	Australian inventory database	(2,2,2,1,2)
	Timber	Australian inventory database	(2,2,2,2,2)
	Concrete	Australian inventory database	(2,2,2,2,2)
	Gravel	Australian inventory database	(2,2,2,2,2)

Appendix 4: System Boundary Diagrams

The following pages below show system diagrams for each of the agricultural sectors covered by this LCA methodology. Each diagram shows the functional unit choice for each of the system boundary choices. The diagrams illustrate the input resources energy use, water use and GHG emissions data that would need to be collected for the stages included in the study. See section 4 for further information.

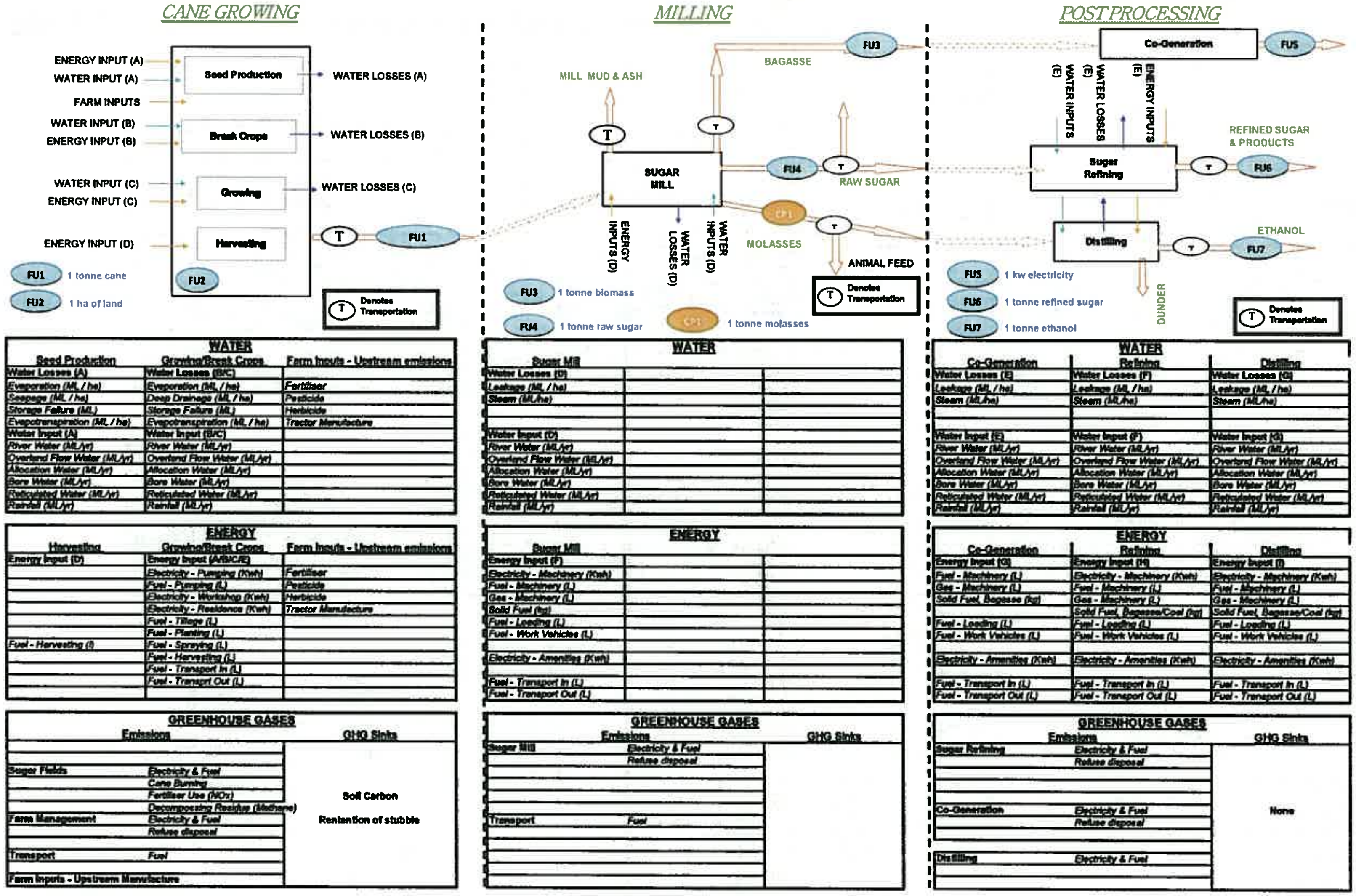


Figure 2: System boundary diagram for sugar lifecycle (developed by FSA Consulting)

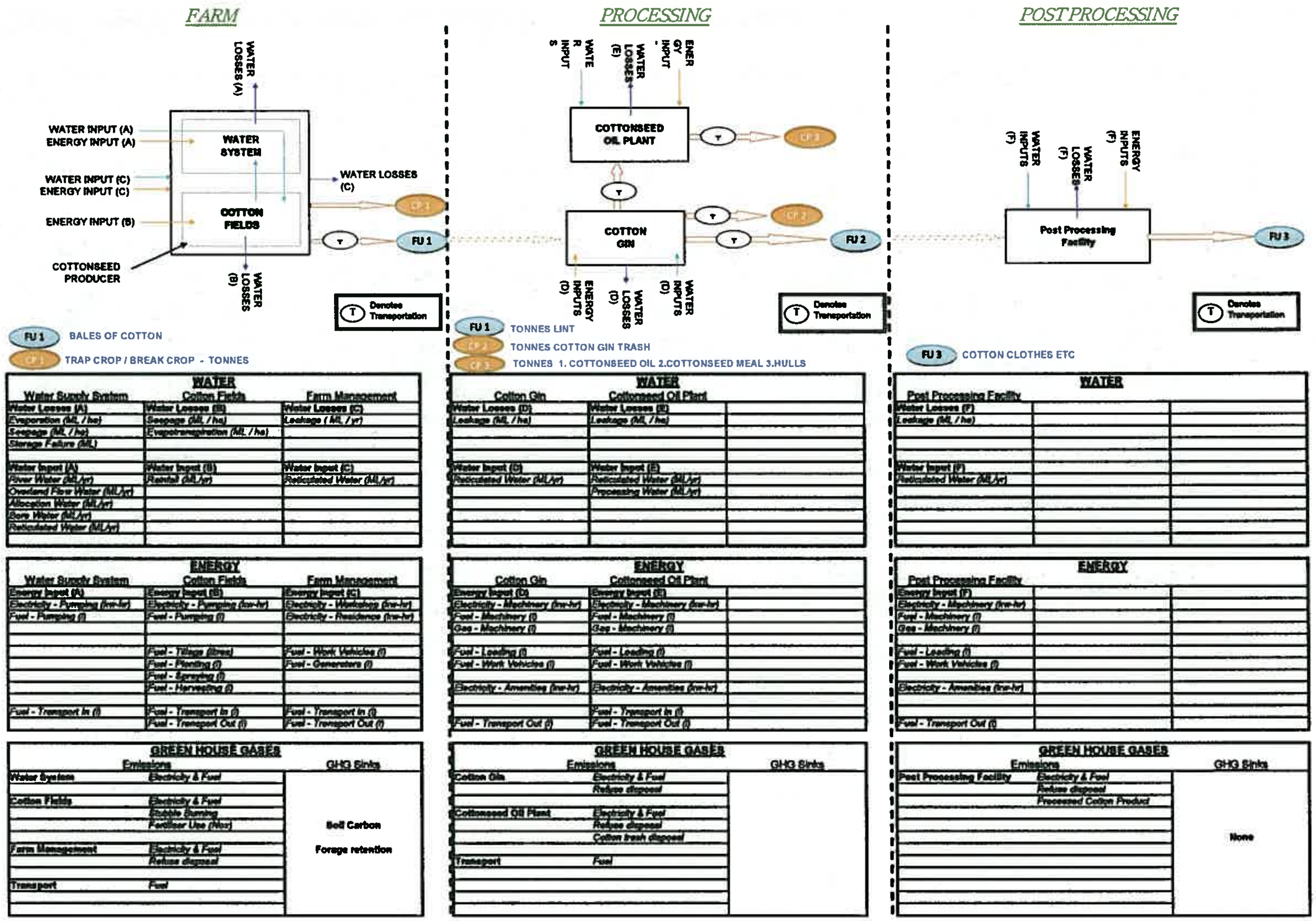


Figure 3: System boundary diagram for cotton lifecycle (developed by FSA Consulting)

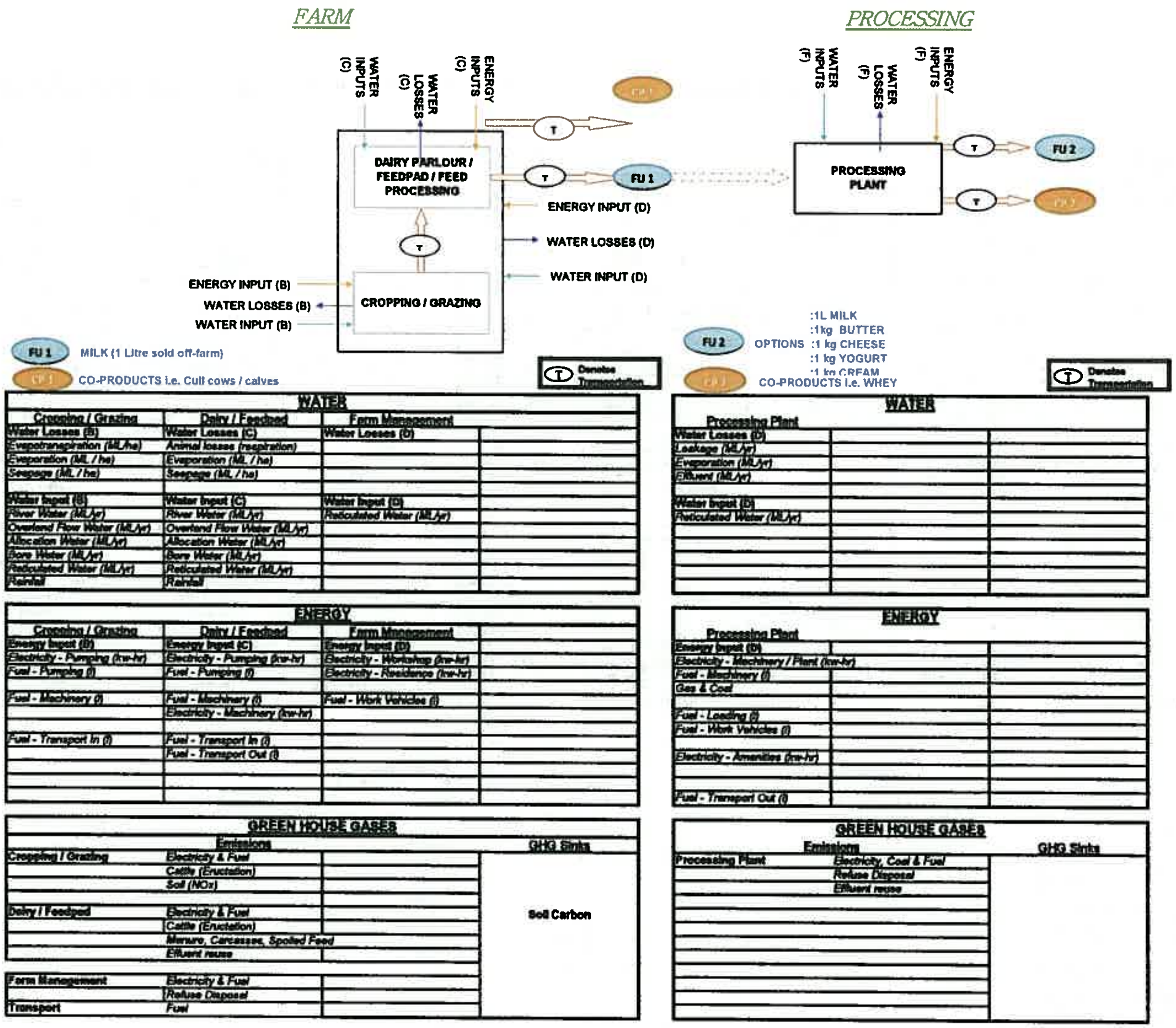


Figure 4: System boundary diagram for dairy lifecycle (developed by FSA Consulting)

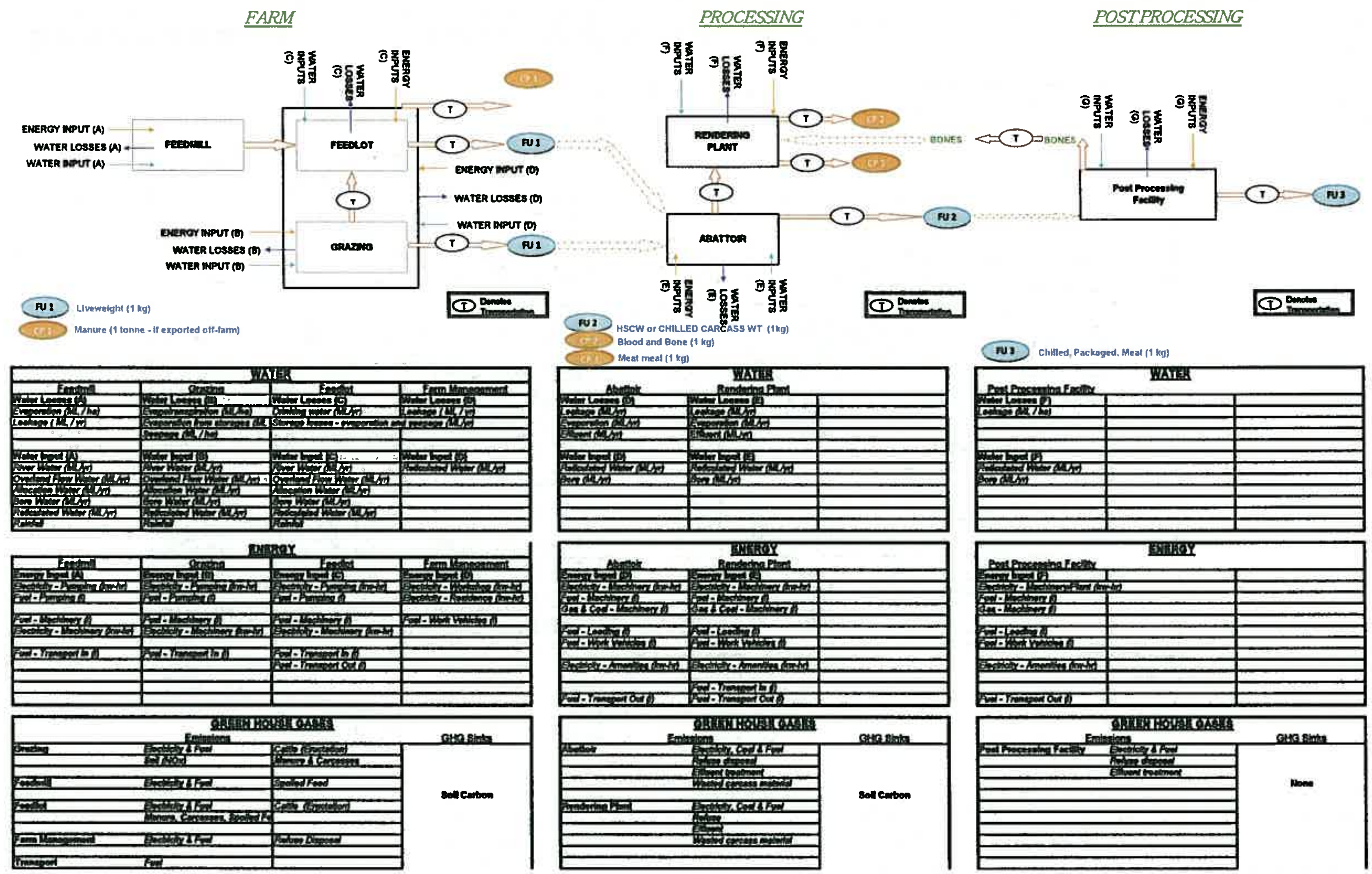


Figure 5: System boundary diagram for red meat lifecycle (developed by FSA Consulting)

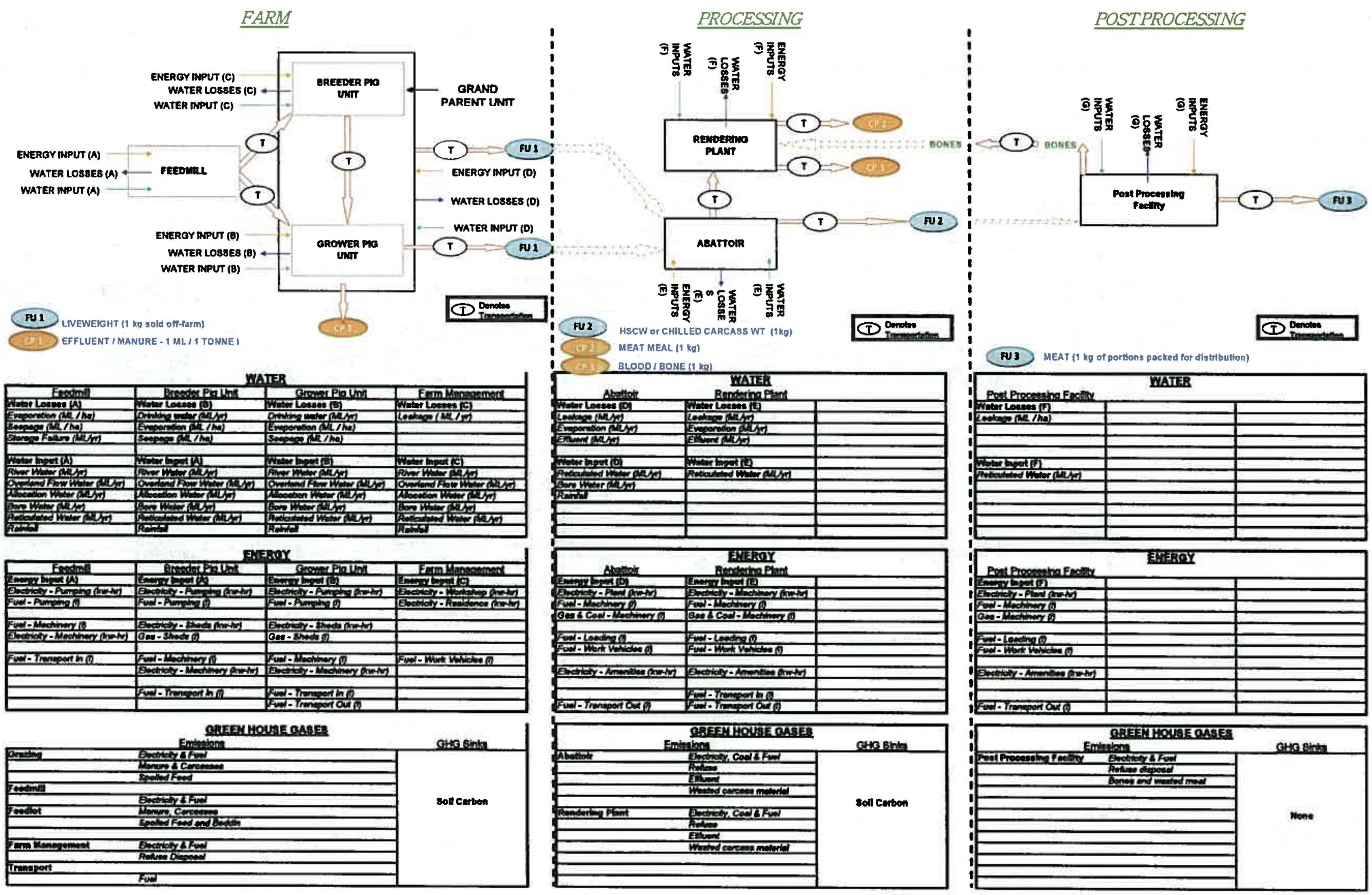
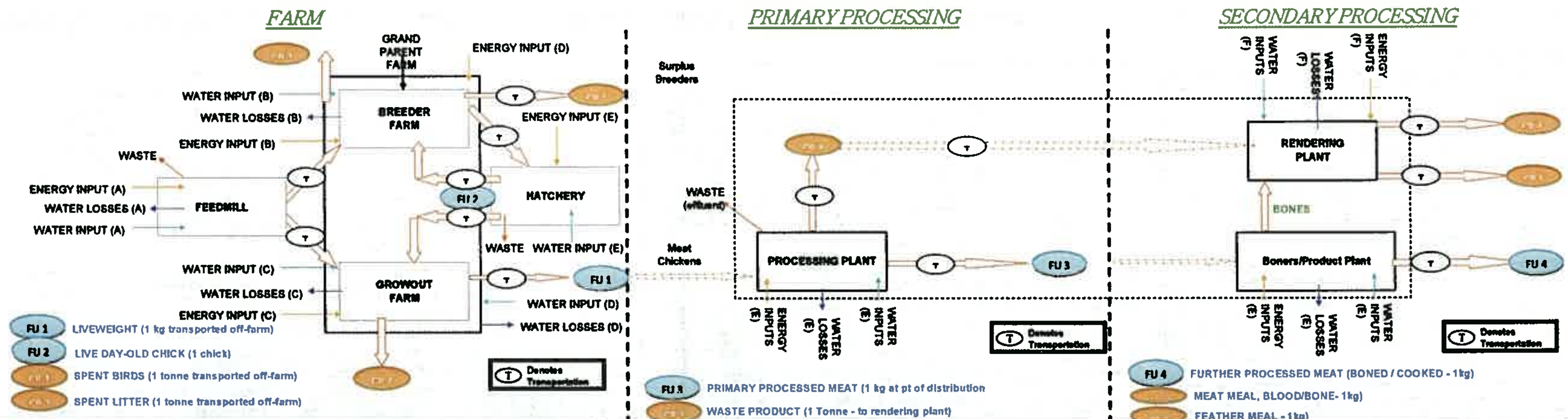


Figure 6: System boundary diagram for pig meat lifecycle (developed by FSA Consulting)



WATER – Farm

Breeder Farm / Feed Mill	Growout Farm	Farm Management	Hatchery
Water Losses (A)	Water Losses (B)	Water Losses (C)	Water Losses (C)
Evaporation (ML / ha)	Evaporation (ML / ha)	Leakage (ML / yr)	Leakage (ML / yr)
Seepage (ML / ha)	Seepage (ML / ha)		Cleaning (ML/yr)
Storage Failure (ML)	Storage Failure (ML)		
Water Input (A)	Water Input (B)	Water Input (C)	Water Input (C)
River Water (ML/yr)	River Water (ML/yr)	River Water (ML/yr)	River Water (ML/yr)
Overland Flow Water (ML/yr)	Overland Flow Water (ML/yr)	Overland Flow Water (ML/yr)	Overland Flow Water (ML/yr)
Allocation Water (ML/yr)	Allocation Water (ML/yr)	Allocation Water (ML/yr)	Allocation Water (ML/yr)
Bore Water (ML/yr)	Bore Water (ML/yr)	Bore Water (ML/yr)	Bore Water (ML/yr)
Reticulated Water (ML/yr)	Reticulated Water (ML/yr)	Reticulated Water (ML/yr)	Reticulated Water (ML/yr)
Rainfall	Rainfall	Rainfall	Rainfall

ENERGY – Farm

Breeder Farm / Feed Mill	Growout Farm	Farm Management	Hatchery
Energy Input (A,D,E)	Energy Input (B)	Energy Input (C)	Energy Input (C)
Electricity - Pumping (kw-hr)	Electricity - Pumping (kw-hr)	Electricity - Workshop (kw-hr)	Electricity - Pumping (kw-hr)
Fuel - Pumping (l)	Fuel - Pumping (l)	Electricity - Residence (kw-hr)	Fuel - Pumping (l)
Electricity - Sheds (kw-hr)	Electricity - Sheds (kw-hr)		Electricity - Incubators (kw-hr)
Gas - Sheds (l)	Gas - Sheds (l)		Gas - Incubators (l)
Fuel - Generators (l)	Fuel - Generators (l)		Fuel - Generators (l)
Fuel - Machinery (l)	Fuel - Machinery (l)	Fuel - Work Vehicles (l)	Fuel - Machinery (l)
Fuel - Transport In (l)	Fuel - Transport In (l)		Fuel - Transport In (l)
	Fuel - Transport Out (l)		Fuel - Transport Out (l)

GREEN HOUSE GASES – Farm

Emissions			GHG Sinks
Breeder/Hatchery	Electricity, Fuel & Gas		
	Manure, Carcasses, egg shell etc		
Feed Mill	Electricity, Fuel & Gas		
	Refuse Disposal		
Growout Farm	Electricity, Fuel & Gas		Soil Carbon
	Manure & Carcasses		
Farm Management	Electricity & Fuel		
	Refuse Disposal		
Transport	Fuel		

WATER – Primary Processing

Processing Plant		
Water Losses (D)		
Leakage (ML/yr)		
Evaporation (ML/yr)		
Effluent (ML/yr)		
Water Input (D)		
Reticulated Water (ML/yr)		

ENERGY – Primary Processing

Processing Plant		
Energy Input (D)		
Electricity - Machinery (kw-hr)		
Fuel - Machinery (l)		
Gas & Coal - Machinery (l)		
Fuel - Loading (l)		
Fuel - Work Vehicles (l)		
Electricity - Amenities (kw-hr)		
Fuel - Transport Out (l)		

GREEN HOUSE GASES – Primary Processing

Emissions		GHG Sinks
Processing Plant	Electricity, Coal & Fuel	None
	Refuse	
	Effluent treatment	
	Wasted carcass material	

WATER – Secondary Processing

Boners/Product Plant	Rendering Plant	
Water Losses (F)	Water Losses (E)	
Leakage (ML / ha)	Leakage (ML/yr)	
	Evaporation (ML/yr)	
	Effluent (ML/yr)	
Water Input (F)	Water Input (E)	
Reticulated Water (ML/yr)	Reticulated Water (ML/yr)	

ENERGY – Secondary Processing

Boners/Product Plant	Rendering Plant	
Energy Input (F)	Energy Input (E)	
Electricity - Machinery (kw-hr)	Electricity - Machinery (kw-hr)	
Fuel - Machinery (l)	Fuel - Machinery (l)	
Gas - Machinery (l)	Gas & Coal - Machinery (l)	
Fuel - Loading (l)	Fuel - Loading (l)	
Fuel - Work Vehicles (l)	Fuel - Work Vehicles (l)	
Electricity - Amenities (kw-hr)	Electricity - Amenities (kw-hr)	
	Fuel - Transport In (l)	
Fuel - Transport Out (l)	Fuel - Transport Out (l)	

GREEN HOUSE GASES – Secondary Processing

Emissions		GHG Sinks
Boners/Product Plant	Electricity & Fuel	None
	Refuse disposal	
	Bones and wasted meat	
	Processed chicken product	
Rendering Plant	Electricity, Coal & Fuel	
	Refuse	
	Effluent	
	Wasted carcass material	

Figure 7: System boundary diagram for chicken lifecycle (developed by FSA Consulting)

Appendix 5: Water Availability Assessment Methods

Table 7: Surface water: sustainable yield - Surface water availability assessment methods

(Source [21])

	New South Wales
Sustainable yield	Rivers with estimated environmental flow rules in place: current yield.
Environmental water requirement	Where environmental flow rules have not been identified: the sustainable yield is the yield determined under the MDBMC Cap. The environmental flow requirement at each reporting location is the total flow in the river at that location for current Water Reform management and infrastructure conditions.
	Victoria
Sustainable yield	Surface water management areas located in the Murray-Darling Drainage Division: sustainable yield was assumed to be equivalent to the levels of average annual (also equivalent to developed yield) diversions available under the MDBMC cap. Surface water management areas located in southern Victoria: where environmental values could potentially be threatened by further allocations, the sustainable yield was limited to the allocation volume pending the outcome of detailed investigations of environmental water requirements. Remaining surface water management areas: the sustainable yield was assessed such that the degree of change to the natural flow regime is not ?unacceptable? as defined by a rating of 5 for the hydrology sub-index of the Index of Stream Condition.
Environmental water requirement	Difference between the total available water and the estimated sustainable yield. The total available water is determined as the sum of the mean annual flow, inflow from upstream catchments and cross catchment transfers that contribute to the available resource in the waterway.
	Queensland
Sustainable yield	Not determined
Environmental water requirement	Not determined
	Western Australia
Sustainable yield	Yields were reported by considering likely development scenarios and the application of management objective factors (including environmental water provisions) for individual sites.
Environmental water requirement	Not reported in technical report

South Australia

Sustainable yield	Defined as divertible yield, takes into account the environmental flow requirement.
Environmental water requirement	Fifty percent of median annual run-off (relating to farm dam development only).

Tasmania

Sustainable yield	Difference between annual median flow and the estimated environmental flow.
Environmental water requirement	Annual assessment of sustainable yield: 30% of the annual flow Critical Period assessment of sustainable yield: 40% of the summer flow (December-April) and 20% of the winter flow (May-November).

Northern Territory

Sustainable yield	Humid zone: 20% of divertible yield (median annual flow). Arid zone: 5% of divertible yield.
Environmental water requirement	Humid zone: 80% of divertible yield median annual flow). Arid zone: 95% of divertible yield.

Australian Capital Territory

Sustainable yield	Total water resource less environmental water requirements
Environmental water requirement	Environmental flows are based on the ACT environmental flow guidelines. Water supply catchments. Flows in rivers and streams below the eightieth percentile are environmental flows (protection of low flow). Flows above the eightieth percentile are available for diversion except for spawning flows. Remaining catchments. Ten percent of the flow volume in events above the eightieth percentile is assumed to be available for diversion. The remaining flow is allocated to the environment (protection of flushing flows).

Table 8. Groundwater: sustainable yield. Groundwater availability assessment methods. (Source [21])

	New South Wales
Sustainable yield methodology	Based on rainfall recharge, river recharge estimates and any other available information.
Groundwater dependent ecosystems	Nominal 30% of annual recharge is assigned to ecosystem maintenance (according to precautionary principle).
	Victoria
Sustainable yield methodology	Sustainable yield estimates are based on rainfall recharge, throughflow rates, well interference, sea water intrusion, river recharge/discharge, and numerical groundwater modelling (where available).
Groundwater dependent ecosystems	Environmental allowances for groundwater dependent ecosystems are made for each groundwater management unit according to conditions in that groundwater management unit. Systems included in the calculation include: river baseflow; wetlands; and marine and estuarine systems (in terms of saltwater intrusion limits only).
	Queensland
Sustainable yield methodology	Groundwater dependent ecosystems were included. Rainfall recharge, aquifer throughflow rates and extractions were used to determine the sustainable yield (or net recharge to aquifer).
Groundwater dependent ecosystems	None in sub-artesian aquifers. In the Great Artesian Basin where artificial ecosystems have developed around mound springs, groundwater dependent ecosystems are considered in the sustainable yield estimate.
	In some specific groundwater management units, groundwater dependent ecosystems have been considered, e.g. Sand Islands, Cooloola which is a heritage area. In these areas allowance has been made for cave and aquifer system and fauna.
	Western Australia
Sustainable yield methodology	Sustainable yield estimates are based on throughflow estimates, chloride analyses, rainfall recharge estimates and land use and determination of impact of land use on recharge.
Groundwater dependent ecosystems	Environmental allowance is made for each groundwater management unit according to conditions in that groundwater management unit. Basic allowance is 5% of total recharge. For significant wetlands it is approximately 40% of the total recharge, and for others it varies between 25-70% of total recharge. Groundwater dependent ecosystems allowed for in groundwater management units include terrestrial vegetation, river baseflow (Kimberley, Pilbara, Carnarvon), wetlands, cave and in aquifer systems, fauna (where known) and marine and estuarine systems.

South Australia

Sustainable yield methodology	In general no groundwater mining allowed, but there are some exceptions. Sustainable yield estimates are based on groundwater use, water level and salinity information, and recharge analyses. The recharge analyses included rainfall recharge estimates, lateral throughflow, chloride analyses and numerical groundwater modelling.
Groundwater dependent ecosystems	Groundwater dependent ecosystems allowed for include maintenance of mound springs in Great Artesian Basin.

Tasmania

Sustainable yield methodology	Rainfall recharge method used, with most of State assuming a 3% recharge rate.
Groundwater dependent ecosystems	None.

Northern Territory

Sustainable yield methodology	Based on rainfall - recharge as estimates. Northern areas: rainfall recharge rates of 0.2-5.0 ML/ha/yr; southern areas: rates of 0.02-2.5 ML/ha/yr were used.
Groundwater dependent ecosystems	50% of annual recharge assigned to groundwater dependent ecosystems

Australian Capital Territory

Sustainable yield methodology	Water balance method.
Groundwater dependent ecosystems	Nominal 90% of annual recharge due to lack of information on recharge and aquifer yields (using precautionary principle). Includes

Appendix 6: Default land use change values

GHG emissions arising from specified changes in land use for a selection of countries shall be as given in Table 9 (Source: PAS 2050).

Table 9: Default land use change values for selected countries

Country	Current land use	Previous land use	GHG emissions (t CO2e / ha/yr)
Argentina	Annual cropland	Forest land	17
		Grassland	2.2
	Perennial cropland	Forest land	15
		Grassland	1.9
Australia	Annual cropland	Forest land	23
		Grassland	2.2
	Perennial cropland	Forest land	21
		Grassland	1.9
Brazil	Annual cropland	Forest land	37
		Grassland	10.3
	Perennial cropland	Forest land	26
		Grassland	8.5
Canada	Annual cropland	Forest land	17
		Grassland	2.2
	Perennial cropland	Forest land	16
		Grassland	1.9
Finland	Annual cropland	Forest land	15
		Grassland	7.3
	Perennial cropland	Forest land	14
		Grassland	6.9
France	Annual cropland	Forest land	18
		Grassland	4.5
	Perennial cropland	Forest land	14
		Grassland	4.2
Germany	Annual cropland	Forest land	21
		Grassland	7.0
	Perennial cropland	Forest land	14
		Grassland	6.7
Indonesia	Annual cropland	Forest land	33
		Grassland	19.5
	Perennial cropland	Forest land	31
		Grassland	17.7
Malaysia	Annual cropland	Forest land	37
		Grassland	10.3
	Perennial cropland	Forest land	26
		Grassland	8.5
Mozambique	Annual cropland	Forest land	24
		Grassland	3.6
	Perennial cropland	Forest land	22
		Grassland	3.2
Pakistan	Annual cropland	Forest land	16
		Grassland	3.6
	Perennial cropland	Forest land	15
		Grassland	3.2
Poland	Annual cropland	Forest land	21

Country	Current land use	Previous land use	GHG emissions (t CO2e / ha/yr)
		Grassland	7.0
	Perennial cropland	Forest land	14
		Grassland	6.7
South Africa	Annual cropland	Forest land	26
		Grassland	1.6
	Perennial cropland	Forest land	25
		Grassland	1.2
Ukraine	Annual cropland	Forest land	18
		Grassland	6.2
	Perennial cropland	Forest land	18
		Grassland	5.8
United Kingdom	Annual cropland	Forest land	27
		Grassland	7.0
	Perennial cropland	Forest land	20
		Grassland	6.7
United States	Annual cropland	Forest land	17
		Grassland	1.9
	Perennial cropland	Forest land	16
		Grassland	1.5

References

1. ISO 14040. "*Environmental Management – Life Cycle Assessment – Principles and Framework*", International Standard, Second Edition, July 2006, pp.1-20.

2. ISO 14044. "*Environmental Management – Life Cycle Assessment – Requirements and guidelines*", International Standard, Second Edition, July 2006, pp.1-46.

3. ISO 14049. "*Environmental Management – Life Cycle Assessment – Examples of application of ISO 14041 to goal and scope definition and inventory analysis*", International Standard, First Edition, 2000-03-15, pp.1-43.

4. PAS 2050: "*Publicly Available Specification (PAS) – Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*", the British Standards working draft, 2008, pp. 1-47

5. Mourad. L.M, Coltro. L, et al. *"A Simple Methodology for Elaborating the Life Cycle Inventory of Agricultural Products"*. International Journal of LCA, Vol. 12(6), 2007, pp. 408-413.

6. Botha. T and H. von Blottnitz. "*A comparison of environmental benefits of bagasse-derived electricity and fuel ethanol on a life cycle basis*", Energy Policy, Vol. 34, 2006, pp. 2654-2661.

7. Cederberg. C and M. Stadig. "*System expansion and allocation in life cycle assessment of milk and beef production*", International Journal of LCA, Vol. 8(6), 2003, pp. 350-356

8. Thomassen. M.A, K.J. van Calker, M.C.J. Smits, G.L. Iepema, and I.J.M. de Boer. *"Life cycle assessment of conventional and organic milk production in the Netherlands"*, Agricultural Systems, Vol. 96, 2008, pp. 95-107.

9. Owen. JW. "*Water Resources in Life-Cycle Impact Assessment. Considerations in Choosing Category Indicators*". Journal of Industrial Ecology, Vol. 5, No. 2, pp. 37-54.

10. Harris S, and Narayanaswamy, 2008. *"Review of Australian and International Agricultural Life Cycle Assessment Examples"*. Report for the Rural Industries Research and Development Corporation, June 2008. Available online: http://www.rirdc.gov.au

11. Renouf MA, 2006. "*LCA of Queensland cane sugar lessons for the application of LCA to cropping systems in Australia.*" 5th Australian Conference on Life Cycle Assessment, Melbourne, 22-24 November 2006.

12. WBCSD, 2004. *"A Corporate Accounting and Reporting Standard."* World Business Council for Sustainable Development and World Resources Institute, March 2004. Available online at (last visited on 3rd October 2008): http://www.ghgprotocol.org/standards/.

13. Biswas WK, Barton L and Carter D, 2008. *"Global warming potential of wheat production in Western Australia: a life cycle assessment"*. Water and Environment Journal, 22, pp. 206-216.

14. Ginee JB et al, 2001. Life Cycle Assessment – An Operational Guide to the ISO Standards: Part 2A. Leiden University Report, May 2001. Available online at (last visited on 26/09/08): http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html

15. IPCC, 2001. *"The IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories"*. Available online (last visited 3rd October 2008): http://www.ipcc-nggip.iges.or.jp/public/gp/english/

16. ISO 14043:2000. *"Environmental management – Life Cycle Assessment – Life Cycle Interpretation."* International Standard, 2000, pp.1-30.

17. ABS, 2004. *"Water Account Australia: 2001-01"*. Available online (last visited 3rd October 2008)

18. NLWRA, 2001. *Australian Water Resource Assessment 2000 - surface and groundwater availability and quality*, a report of the National Land and Water Resources Audit (NLWRA). Available online at (last visited 3rd October 2008) : http://www.anra.gov.au/topics/water/pubs/national/ water_contents.html

19. Dairy Australia, 2003. *"Evaluation of the environmental performance of the Australian dairy processing industry using life cycle assessment"*. Final Report, June 2003, Editors Ross Nicol and Cathy Sage.

20. NLWRA, 2001. *"Water resources in Australia: A summary of the National Land and Water Resources Audit's Australian Water Resources Assessment 2000"*. Available online (last visited 3rd October 2008): http://www.anra.gov.au/topics/water/pubs/summary_reports/water_resources/ pubs/water-summary.pdf

21. ANRA, 2001. *"Water – Appendix 3. Water Availability Assessment Methods"*. Available online (last visited on 3rd October 2008): http://www.anra.gov.au/topics/water/pubs/national/water_app3.html

22. APSIM. *"Agricultural production systems simulator –fact sheet"*. Available online at (last visited 3rd October): http://www.apsru.gov.au/apsru/Products/APSIM/Apsim%20Fact%20Sheet.pdf

23. IPCC, 1996. *"IPCC Guidelines for National Greenhouse Gas Inventories"*. Available online at (last visited 3rd October): http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

24. DNDC. *"Welcome to DNDC"*. Website (last visited 3rd October 2008): http://www.dndc.sr.unh.edu/

Life Cycle Assessment Methodology for Australian Rural Industries

RIRDC Publication No. 09/028

This report proposes a Life Cycle Assessment (LCA) methodology for application in Australian rural industries. A standardised LCA methodology will improve the consistency of LCA reporting and greatly increase the value of results by enhancing their comparability. The report is targeted at Australian rural primary industries and associated stakeholders.

Life Cycle Assessment is a method to analyse resource uses and emissions across the life cycle of a product. It can systematically identify key areas to improve environmental and economic performance and can be applied to agricultural systems.

The LCA methodology will help primary industries to conduct LCA studies and prepare for any future requirements (either Australian and/or internationally) to account for resource uses and emissions.

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