LIFE CYCLE ASSESSMENT (LCA) OF BIOENERGY PRODUCTS AND PROJECTS

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ARENA

Report for the Australian Renewable Energy Agency

Method and guidance for undertaking life cycle assessment (LCA) of bioenergy products and projects

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GLOSSARY

Term	Definition (including source)
Advancing Renewables Programme	A program run by ARENA to support a broad range of development, demonstration and pre-commercial deployment projects that have the potential to lower the cost and increase the use of renewable energy technologies in Australia in the long term (ARENA, 2016).
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 (ISO 14040).
Australian Renewable Energy Agency (ARENA)	Independent agency of the Australian federal government, established in 2012 to increase the competitiveness of renewable energy and increase its supply in Australia. (ARENA, 2016).
Bioenergy	Energy derived from biomass (ISO 13065). Note: The term bioenergy includes solid, liquid and gaseous fuels derived from biomass.
Biogenic carbon	Carbon derived from biomass (ISO/TS 14067).
Biomass	Material of biological origin excluding material embedded in geological formations and material transformed to fossilised material, and excluding peat (ISO/TS 14067).
Carbon dioxide equivalent (CO2 eq., CO2 e)	Unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide (ISO/TS 14067).
Carbon footprint	Sum of greenhouse gas emissions and removals in a product system, expressed as CO2 equivalents and based on a life cycle assessment using the single impact category of climate change (ISO/TS 14067).
Characterisation factor	Factors derived from a characterisation model are applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator (ISO 14040).
Commercial Readiness Index (CRI)	A tool that project proponents may want to use when considering their projects and ARENA will use to measure the 'commercial readiness' of renewable energy solutions (ARENA, 2014).
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 (ISO 14040).
Cutoff 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 (ISO 14040).
Declared unit	A unit used in place of the functional unit when the study does not include a 'cradle to grave' scope (ISO 13065).
Determining product	A determining product of an activity is defined as a product for which a change in demand will affect the production volume of the activity. It is also sometimes called a ''reference product'' (e.g. in ecoinvent terminology) (Consequential-LCA, 2015).
Direct land use change	Change in human use or management of land within the product system being assessed (ISO/TS 14067).
Fossil carbon	Carbon which is contained in fossilised material (ISO/TS 14067).
Functional unit	Quantified performance of a product system for use as a reference unit (ISO 14040).
Global warming potential (GWP)	Characterisation factor describing the radiative forcing impact of one mass-based unit of a given greenhouse gas relative to that of carbon dioxide over a given period of time (ISO/TS 14067).

Term	Definition (including source)
Greenhouse gas (GHG)	Natural or anthropogenic gaseous constituent of the atmosphere that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the earth's surface, the atmosphere, and clouds (ISO 13065).
Impact category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned (ISO 14044).
Impact category indicator	Quantifiable representation of an impact category (ISO 14044). See Table 4 for description of environmental impact categories and indicators relevant to this methodology and guidelines.
Indirect land use change	Change in the use or management of land that is a consequence of direct land use change, but which occurs outside the product system being assessed (ISO/TS 14067).
Investment Plan	A plan documenting the focus areas for financial support provided by ARENA, as well as ARENA's current investment priorities (ARENA, 2015).
Land use change	A change in human use or management of land.
LCA Commissioner	Entity or individual proposing the project to ARENA, contacting or commissioning the professional or firm carrying out the study/life cycle assessment.
LCA practitioner	Professional carrying out the study/life cycle assessment.
Life cycle assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040).
Life cycle impact assessment (LCIA)	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 (ISO 14040).
Life cycle inventory (LCI)	Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (ISO 14040).
Multi-functionality and co-products	Refers to a process that creates multiple products or functions. Products often thought of as waste can also be thought of co-products if they provide some function or value.
Process optimisation LCA	Proof of concept LCA updated once a project is in system test and small scale commercial trial, when commercialisation begins.
Proof of concept LCA	LCA study undertaken on bioenergy project during early technology development.
System boundary	Set of criteria specifying which unit processes are part of a product system (ISO 14040).
System expansion	Recommended ISO 14040 method for avoiding allocation. This is done by 'expanding the product system to include the additional functions related to the co-products' (ISO 14044), note also that Annex H in 13065 gives guidance on application of system expansion.
Technology Readiness Level (TRL)	A scale used by ARENA to assess the technological development of a project, separate to but overlapping with the early stages in the Commercial Readiness Index (ARENA, 2014).

1 INTRODUCTION

The Australian Renewable Energy Agency (ARENA) was established to make renewable energy solutions more commercially-competitive and to increase their supply in the Australian marketplace. ARENA helps fund and share information about renewable energy projects.

ARENA requires proponents to deliver a life cycle assessment (LCA) report in relation to all funded bioenergy and biofuels projects, unless a waiver has been applied (as per ARENA's existing Investment Plan – http://arena.gov.au/funding/investment-focus-areas/).

1.1 Objectives of the method and guidance

This method has been developed to support ARENA applicants in undertaking LCA studies of the proposed technologies. The main audience for this document is LCA practitioners. The aim of the LCA method is to:

- Provide bioenergy proponents with insights into the environmental benefits and risks across the full life cycle of bioenergy products/projects.
- Guide more effective decision-making by providing a 'level playing field' benchmark that enables ARENA to compare projects against conventional generation or fuel options.
- Support 'due diligence' by ensuring the projects supported by ARENA are able to deliver a net benefit in environmental terms e.g. greenhouse gas (GHG) footprint or energy balance.
- Understand where the innovation gaps/opportunities/"hot spots" lie in terms of the technical maturation of novel pathways and approaches.
- Enable knowledge sharing, including:
  - Provide a solid basis for communication of project impacts and benefits to the community.
  - Provide analyses with robust comparability to non-biofuel alternatives that are functionally similar.
  - Provide high quality LCA outputs for independent scrutiny by other LCA experts, academics, non-government organisations (NGOs) etc.

The objectives of the method do not currently include social and socio-economic impacts, given that existing ARENA-specific and other regulatory assessments and mechanisms already cover these aspects.

The objective does not explicitly align with other Australian Government schemes and standards, such as the National Greenhouse and Energy Reporting scheme and the National Carbon Offset Standard, but does take them into consideration wherever these are consistent with published LCA standards. Adherence to these ARENA guidelines does not imply compliance with other Australian Government or State government schemes or standards.

The Australian Renewable Energy Agency (ARENA) was established to make renewable energy solutions more commercially-competitive and to increase their supply in the Australian marketplace.

1.2 Foundation standards used in development of the method and guidance

The method is built on international standards surrounding LCA, GHG (greenhouse gas) assessment and bioenergy assessment, primarily:

- ISO 14040 – Environmental management – Life cycle assessment – Principles and framework describes the principles and framework for life cycle assessment.
- ISO 14044 – Environmental management standard – Life cycle assessment, Requirements and guidelines is an important standard, and the underpinning original standard on requirements for LCA.
- ISO/TS 14067 – Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication is a technical specification for calculation of carbon footprints of products, which are the cumulative GHG emissions across a product life cycle. It is relevant to quantifying the total GHG emissions of a bioenergy product.
- ISO 13065 – Sustainability criteria for bioenergy provides valuable guidance for Bioenergy projects, in particular the section on GHG methodologies, assessment and comparisons.

The ISO 14040 and ISO 14044 standards are the overarching standards for LCA, while the ISO/TS 14067 is a newer standard and provides additional detail on carbon accounting approaches and ISO 13065 provides some specific guidance on bioenergy systems. The aim of this method is to provide a tailored and workable solution for Australian bioenergy, so strict adherence to these standards is not essential, but any departures from these standards will be noted and justified.

1.3 Stakeholder engagement process

A process of stakeholder engagement was undertaken to elicit feedback on technical aspects of this Method and Guidance as well as its practicality and achievability. The stakeholder engagement:

- Included over 125 individual stakeholders through various activities such as semi-structured interviews, a survey, a webinar, email correspondence and presentations at relevant conferences. The survey was also sent to all individuals/organisations registered through ARENA's online subscription service.
- Included organisations from all states as well as national and international organisations. Organisations engaged included Bioenergy Australia, Biofuels Association of Australia, CSIRO, Department of Environment, Clean Energy Regulator, QANTAS, Virgin Australia, WWF and RMIT University.
- Included individuals from associations (and membership based organisations), government, NGOs and community organisations, industry (producers and users of bioenergy), consultant organisations and academic sectors.

The feedback from the stakeholder engagement process was used to improve the practicality of the Method and Guidance.

1.4 How to use this document

This document provides requirements and recommendations for undertaking LCA studies of proposed bioenergy technologies. It adopts common language used in international standards, with the following verbal forms used:

- 'shall' indicates a requirement.
- 'should' indicates a recommendation.
- 'may' indicates a permission.
- 'can' indicates a possibility or a capability.

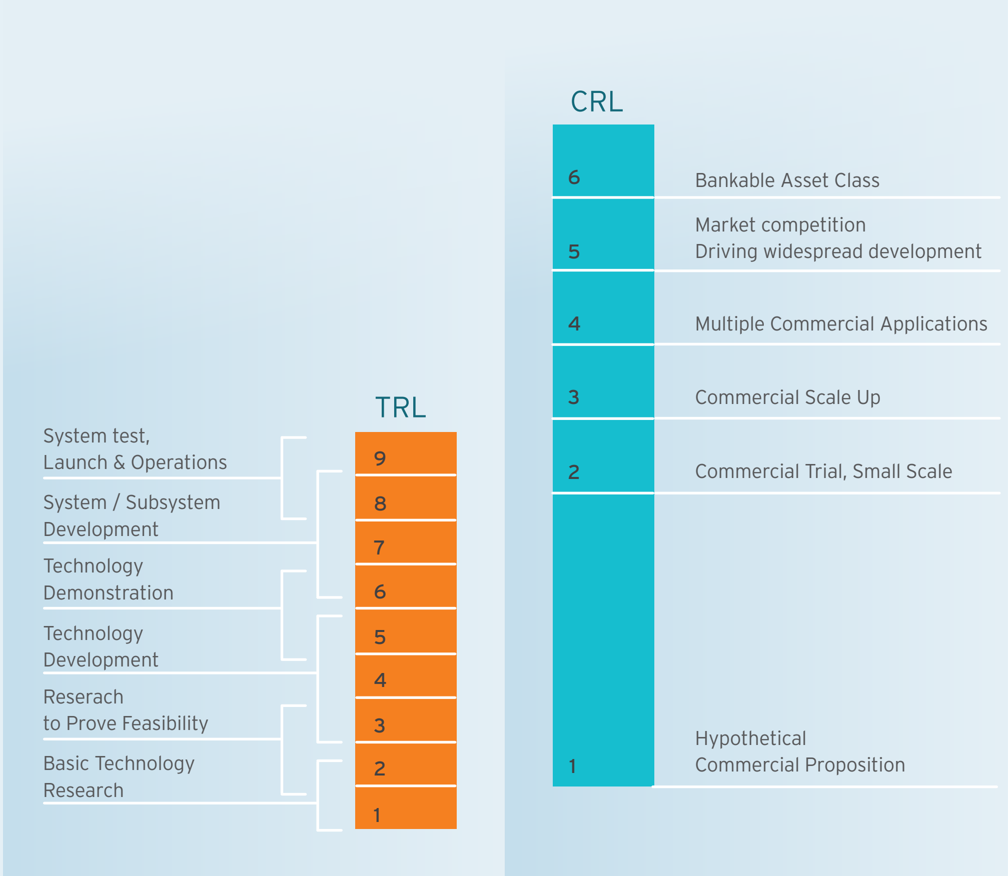
Further details can be found in the ISO/IEC Directives, Part 2 (ISO/IEC, 2011).

In addition to requirements and recommendations, this document also provides guidance for undertaking the LCA – which is solely for information purposes. We have retained terminology from the international standards to identify different players in the process including the LCA commissioner of the study (the person or organisation who requests the study to be undertaken) and the LCA practitioner (the person or organisation who undertakes the study). These may be one and the same when organisations undertake their own LCA studies.

1.5 How to assess the technical and commercial readiness of projects

ARENA classifies renewable energy projects using two overlapping scales relating to Technology Readiness Level (TRL) and Commercial Readiness Index (CRI), as per the Advancing Renewables Programme Guidelines (see Figure 1 below). In order to be elgible for funding under the ARP, applicants must be able to demonstrate that they are at a minimum TRL of 4.

Figure 1 – Technology Readiness Level (TRL) and Commercial Readiness Index (CRI). Source: (ARENA, 2014).

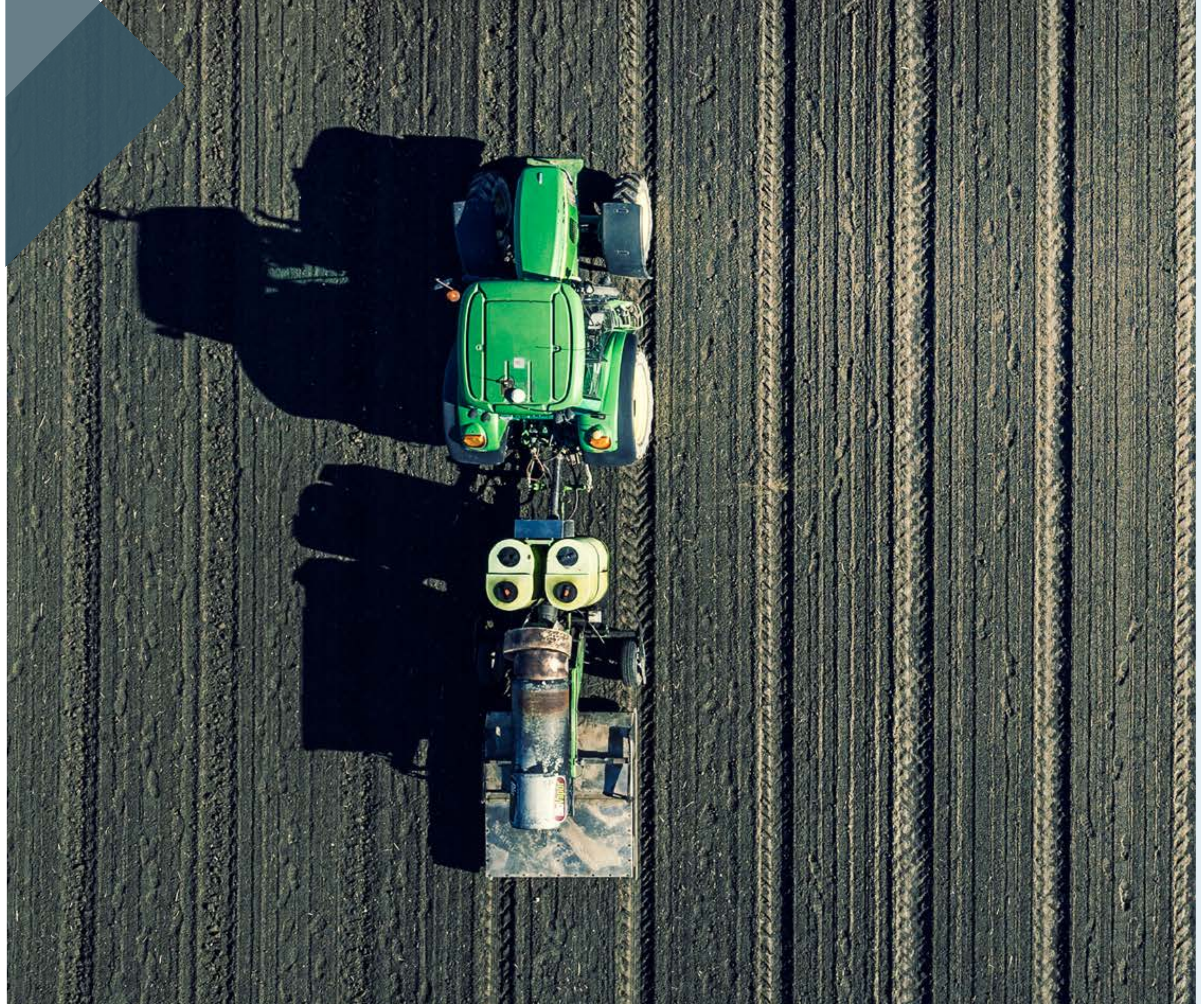


In order to be elgible for funding under the ARP, applicants must be able to demonstrate that they are at a minimum TRL of 4.

As per our Investment Plan, ARENA requires an LCA study to be undertaken for all bioenergy and biofuel projects.

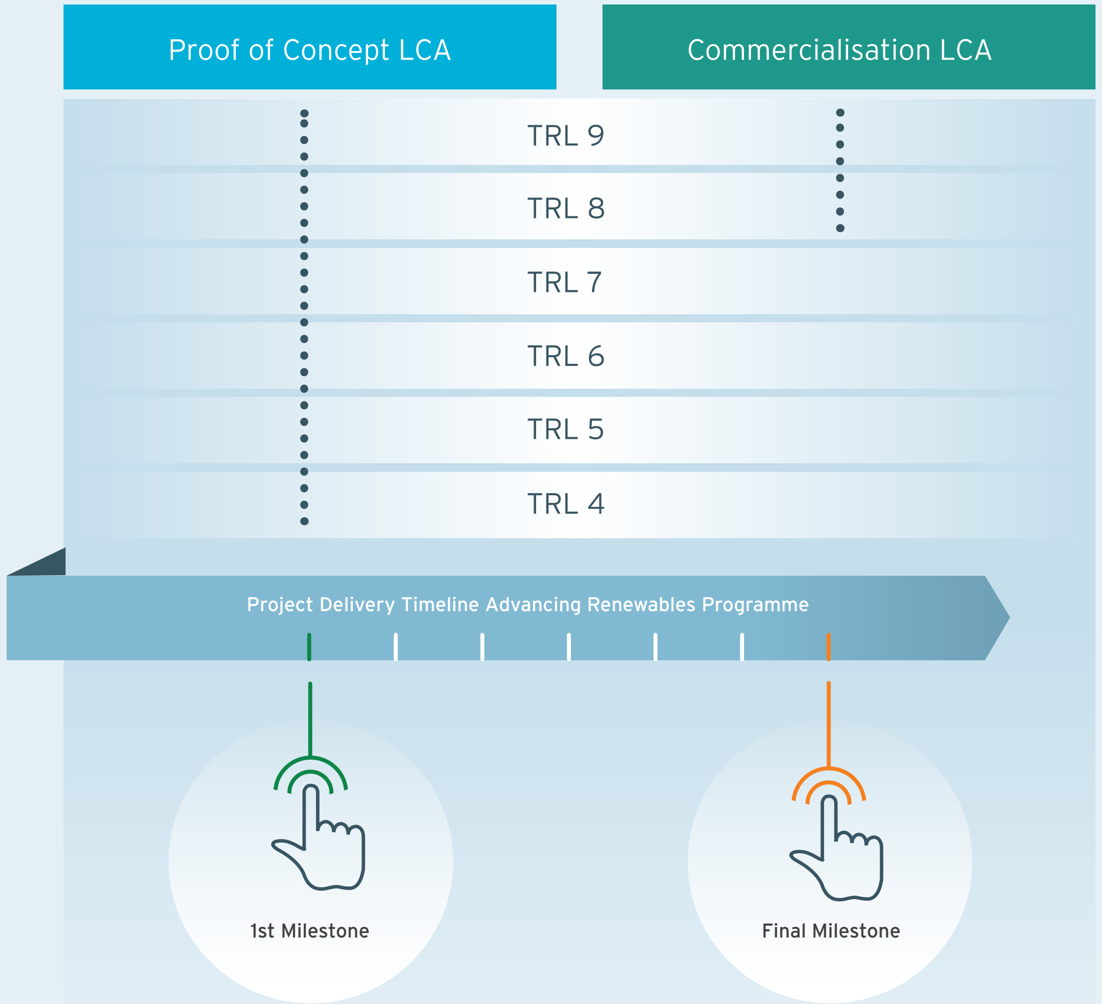
Specifically, this requires a high level **proof of concept LCA** to be delivered by the first funding milestone for all projects in these sectors, unless exemption has been granted by ARENA.

Projects rated at TRL 8-9/CRI 2+ must also deliver a more comprehensive LCA report, referred to as a **commercialisation LCA**, that is to be completed as a final milestone deliverable. In practice, this will build on the prior proof of concept LCA study that has been undertaken during the project inception stage.



1.6 When to develop an LCA study

Figure 2 – Timing of different LCA studies in relation to ARENA milestones



The purpose of a proof of concept LCA is:

For ARENA, to:

- Have confidence that technologies produce renewable energy with a favourable overall environmental impact profile, primarily in relation to embodied fossil energy and GHG balance.
- Acquire insight into environmental advantages and risks associated with technologies.
- For ARENA program participants, to:
- Provide insights into environmental challenges of different feedstocks and technologies.
- Create a level playing field comparison against current fossil fuel energy sources.
- Provide 'hot spot' analysis of environmental impacts and benefits to guide developments.
- Support knowledge sharing obligations associated with an ARENA funding agreement.

The purpose of a commercialisation LCA is:

For ARENA, to:

- Obtain a benchmark on the fossil energy used, energy return on energy invested (EROEI) and GHG performance.
- Manage risks from other environmental impacts.
- Help to communicate project benefits.

For ARENA program participants, to:

- Provide scenario assessment of alternative technologies and management options.
- Provide a tool for understanding impacts along the supply chain.
- Provide evidence of sustainability performance of fuels, for prospective markets.
- Support knowledge sharing obligations associated with an ARENA funding agreement.

Specifying the goal of the study is a fundamental requirement of an LCA.

2.1 Goal of the study

Overview

Specifying the goal of the study is a fundamental requirement of an LCA. The goal of the study outlines the purpose of the study and, in doing so, identifies the audience for the study and a framework of key questions to be answered by the study.

In the context of this method, part of the goal is already defined by ARENA as outlined in the objectives section of this document. Simply put, the goal may be to meet the requirements of ARENA. There are, however, broader purposes of the LCA for LCA commissioners, some of which are outlined in Section 1.4 of this document.

Requirements

The LCA shall document the goals of the study including whether it is part of an ARENA funding requirement and what TRL/CRI level the technology has currently reached. The goal shall include the audience for the study.

Guidance

Example: study goals for a proof of concept LCA and a commercialisation LCA are as follows:

Example goal for proof of concept LCA

The goal of the LCA is to meet the requirements of ARENA and provide insights to environmental impacts of different feedstock options available to the project.

The audience for the study will be ARENA and an internal technology development team.

Example goal for commercialisation LCA

The goal of the LCA is to meet the requirements of ARENA and provide verified environmental performance data to investors and potential customers.

The audience for the study will be ARENA, investors, potential customers and the broader public.

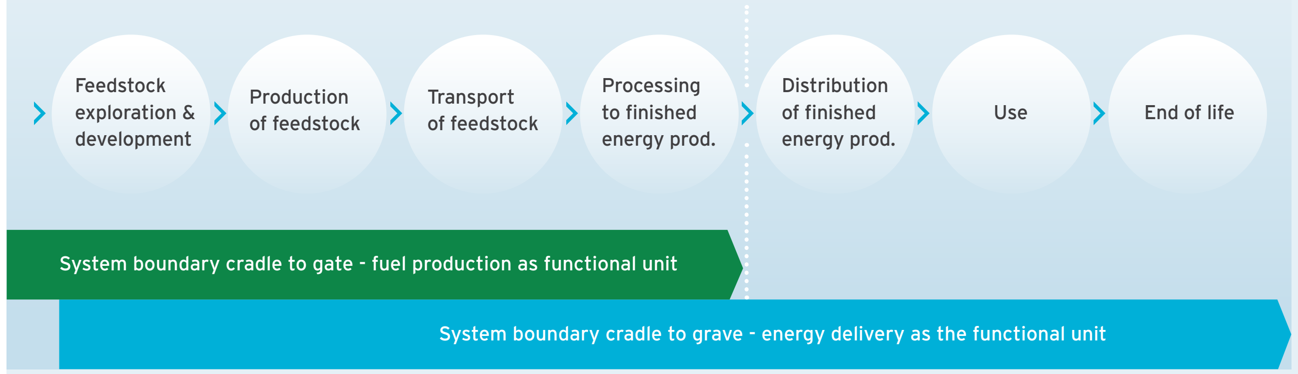
2.2 Functional units and system boundary

Overview

The 'functional unit' provides a common basis for comparison of results in any LCA study while the system boundary describes the processes to be included and excluded in the LCA. These two elements are closely linked because the definition of the functional unit will, in part, decide where the boundary is drawn. With bioenergy systems there are two potential ways to define the unit of comparison:

The production of equivalent quantities of fuel with a certain energy content (e.g. per MJ of fuel 'cradle to gate' or 'well to tank') or the production of equivalent quantities of service provided by the fuel or energy ('cradle to grave' or 'well to wheel'). An example of a functional unit for car transport is 1 km driven in a standard passenger vehicle. Figure 3 shows the two possible system boundaries.

Figure 3 - Diagram of 'cradle to gate' and 'cradle to grave' system boundaries.



Another consideration for the system boundary is the use of a threshold for including different processes, which is referred to in LCA standards as the cutoff criteria. This is used to simplify data collection and modelling in the LCA, allowing insignificant flows to be excluded.

There may be specific project types where capital equipment and infrastructure is significant and should be included. However, for the purpose of keeping the LCA practical and streamlined capital equipment and infrastructure may be excluded from most LCAs.

Note: the system boundary considerations to do with co-products and waste are described in Section 2.5 of this method.

Example – Biogas energy production from piggery waste

The functional unit of the energetic system producing biogas from piggery waste and use for power generation is the supply of 1 MWh of electricity to the grid.

Requirements

For commercialisation LCAs the system boundary shall be based on cradle to grave with the functional unit being the production of fuel and conversion to delivered energy. For proof of concept LCAs where the product is readily substitutable with the reference fuel, and data on, for example, combustion characteristics is not readily available, a declared unit may be used such as 1MJ of fuel produced excluding its conversion to energy, with the system boundary being from cradle to gate. The system boundary and functional units shall be documented in the LCA describing the processes that are included and excluded from the LCA.

The functional unit shall focus on the production of bioenergy so that it is comparable to the reference system. It is possible that some bioenergy projects have alternative options for utilisation, which lead to different end products (e.g. electricity or transport fuel). If this is the case the LCA will require multiple functional units.

A cutoff criterion based on mass and energy flows may be used to exclude minor flows from the system boundary; however, the effect of these exclusions should be assessed in the commercialisation LCA report. The cutoff for individual flows is 1 per cent and the cumulative contribution of the excluded processes should be less than five per cent.

The embodied impacts of capital equipment and infrastructure may be excluded from the LCA without further justification, except for:

- Production systems estimated to have an economic life of less than 10 years.
- Production systems requiring establishment of significant supporting physical infrastructure, such as dedicated roads, rail, pipelines and inter-modal change facilities.

For systems fitting either qualifier above, capital equipment and infrastructure shall be included at a scoping level in the LCA.

Guidance

The definitions of the functional unit appear trivial at times, but require particular attention to the following details:

- It needs to embrace all the options being covered in the study including the reference fuel/energy source.
- It should be as specific as possible to contextualise the use of the fuel.
- It should define the performance parameters but not the environmental objectives.

A list of functional unit examples for different bioenergy and biofuel scenarios is available in Appendix A.

The cutoff criteria requirements can be met by several pathways depending on the specific aspect or study, including drawing on comparable previous studies, engineering estimates, or even back-of-the-envelope calculations as a last resort, where appropriate.

2.3 Environmental impact categories

Overview

The environmental impact categories represent the differed classes or types of environmental impacts that are included in the study. They include quantitative characterisation models that link the inventory flows, for example 'carbon dioxide emission to air' or 'nitrate emissions to freshwater', to comparable environmental impacts with indicators, in this case global warming potential (GWP) and eutrophication respectively.

While many different facets of environmental science use environmental indicators, in LCA they are particularly challenging because they assess elementary flows and resulting environmental impacts from across the whole, often globally distributed supply chain, and for an extended timeframe – typically 100 years or more. It is important to assess and evaluate the LCA results being mindful of these challenges.

Note: the environmental impacts of bioenergy/biofuel can be wider than can be practically included in an LCA.

Requirements

- Impact categories for use in the LCA are:
- climate change
- fossil fuels resource depletion
- fossil fuel energy use (net calorific value)
- particulate matter formation
- eutrophication
- consumptive water use
- land use

In the proof of concept LCA, climate change, fossil fuel resource depletion and fossil fuel energy use shall be reported. The remaining indicators are recommended for inclusion at this stage, but are not compulsory. For a commercialisation LCA, all the categories listed above shall be reported.

Other indicators not listed above can be reported in the LCA, such as human toxicity, ecotoxicity, photochemical ozone formation, acidification and ozone layer depletion. At this stage, the recommendation is to not use external normalisation (scaled to for example per capita annual impact) and weighting (converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices) as no agreed approach is available for Australia and for applications of this methodology.

Characterisation models should be sourced from the Best Practice Guidance for Life Cycle Impact Assessment published by the Australian Life Cycle Assessment Society (ALCAS) (Renouf, et al., 2015), or as stipulated in Appendix B. Fossil fuel energy use is not defined by the ALCAS best practice guidelines so shall be calculated as the total net calorific value of fossil fuel energy (MJ of coal, gas and oil) used to obtain the delivered energy resource.

Guidance

Although the environmental impact assessment requirements for the proof of concept LCA can be met using relatively basic spreadsheet models, it is recommended that the practitioner start at this stage to develop the LCA model and inventory using LCA tools, with a view to gradually building and refining the model to inform decision-making and meet the requirements for the later commercialisation LCA. See Appendix C for examples of tools and resources available for LCA modelling.

2.4 Temporal aspects of the LCA

Overview

Most capital expenditures and investments in bioenergy systems are made on the basis of long-term operations and returns. One of the core benefits of LCA is to support decision-making by identifying trade-offs and potential burden shifts between the establishment of a bioenergy project/system, the operations, and end of life/de-commissioning environmental consequences.

Requirements and recommendation

The temporal scope of the LCA shall be documented. The timeframe for the LCA should be based on the economic timeframe for the proposed plant and equipment, which can be taken to be between 20 and 30 years.

The LCA should be undertaken without the effects of time, such as changes outside the project's control, including technology improvements, electricity grid changes, climatic changes, etc. The timing of emissions and removals shall be documented in the inventory. The effect of timing may be documented and reported separately.

Guidance

The economic timeframe for the proposed plant and equipment should be based on the real, expected service life, rather than based on other criteria such as warranty time periods.

The timeframes used for the LCA, overall and for individual components, shall be justified in the study.

Example – Biogas energy production from piggery waste

The anaerobic digestion pond, collection facility and biogas engine, as per the business plan, will begin operation 2 years after starting construction and are estimated to have an economic life of 25 years. The engine is expected to need replacement every 10 years.

25

Years of economic life. Biogas energy production from piggery waste

2.5 Multi-functionality and allocation

Overview

Multi-functionality or co-production, refers to a process that creates more than once useful product output. For example, sugar cane milling produces sugar juice (which is refined to sugar) and bagasse (which is mostly used for cogeneration of steam and electricity). The sugar refining produces raw sugar and molasses. It is an inherent part of the bio-economy where many products are based on co-products and or produce other useful co-products. Feedstocks which have often been thought of as waste are in LCA terms considered as co-products where the feedstock has established uses and/or markets.

Approaches to dealing with multifunctional systems is highly debated in LCA, however the ISO 14044 LCA standard established a procedure and this has been refined by UNEP/SETAC Global Guidance(UNEP/SETAC 2011) with more detail provided in the carbon footprint standard ISO 14067 (ISO, 2013). This detail of this is explained in Appendix D, however in summary:

- when it's possible to break down the multifunction process it should be broken into smaller units to avoid allocation, or
- when it's possible to describe the biophysical /causal relationships between inputs and emissions to the different products, this should be done (e.g. input of feed to sheep which goes to wool compared to meat.)

When this cannot be done there are two competing approaches for isolating the impacts from individual products from a coproducing process;

- The first involves providing a credit to the main product (e.g., raw sugar) equal to the alternative use of the co-product (e.g. molasses, which otherwise would be used as a stock feed supplement).
- The second is to apportion/allocate the impacts of the multifunction system such as (e.g. sugar refining) between the two products based on a common measure of value (e.g. economic value or energy content).

Requirements and recommendation

The allocation of impacts between individual products in multifunction processes shall follow the following hierarchy:

- subdivision of processes;
- allocation based on causal relationships of inputs and emission to output products;
- system expansion for joint production, and
- allocation based on energy content or economic value.

The effects of alternative approaches to multi-functionality should be demonstrated in the commercialisation LCA.

For waste used as a feedstock, the impacts associated with its handling and processing shall be included in the LCA. Furthermore, the alternative fate of that material (landfill, left on field) should be included in the calculation. For example, for rice hulls that are currently disposed of to landfill, a bioenergy process that collects them for use in energy production would include the avoided landfill impacts (e.g. avoided methane emissions and avoided carbon storage) in the system boundary.

Guidance

Identify all multi-function processes in the bioenergy LCA. For each input process coming from multi-function processes do the following:

- Check if any of the multi-function processes can be broken into smaller subsystems to avoid the need for allocation.
- Identify if the co-product being used in the bioenergy system is the determining product. If it is, a substitute should be identified for each non-determining co-product. The substitutes are then subtracted from the impacts of the co-producing system.
- If the process being used is a non-determining co-product, a substitute for this material is identified and this should be used as the impact for supplying the co-product.
- If the process being used is a utilised waste product, the benefits and impacts of diverting it from its current waste treatment, should be added to the bioenergy system.

If the output of the bioenergy system includes co-products the following would need to be implemented:

- Identify what products will be displaced by the co-products and provide an environmental credit to the bioenergy system, equal to these displaced products.

See Table 6 for examples of co-production and the replacement products to be used, and Table 5 for a list of products considered to be wastes.

2.6 Inventory analysis

Overview

LCA inventory is typically divided into foreground data (also called specific, site specific or primary data) and background data (also called generic or secondary data). The foreground data are often associated with activities directly under control of the economic operator undertaking the study.

The scope and quality of the data used for the inventory modelling and analysis are limiting factors for the environmental impact assessment (see section 2.3). Conversely, even with high quality data on for example soil salinization, invasive species or odour, there may not yet be methods available for assessing and including such impacts in LCA.

Requirements

For this guidance, site specific data should be used where available or when they can be derived from modelling, taking account of site specific factors.

Generic data may be used for upstream processes and for any processes where site specific data are not available. The use of generic data in this second instance should be documented and justified. In relation to multi-functionality – generic data that do not follow the same approach to allocation of co-products (for example AusLCI database based on economic allocation) can be used. However, where an allocation method has been used and the allocated product represents a significant contribution greater than five percent (5%) of any indicators used in the LCA, its allocation should be adjusted to be consistent with this method.

Guidance

The following list includes data bases and sources may be used to complete the inventory analysis, considering best fit to geographical location and technology used for the respective processes:

- AusLCI database published by ALCAS (AusLCI, 2016).
- ecoinvent 3 published by the ecoinvent Centre (2016).
- GaBi Databases published by thinkstep (2016).
- US Life Cycle Inventory Database published by the National Renewable Energy Laboratory (2016).
- Default combustion emission factors (e.g. NOX, SOX, particulates), following published resources such as the National Pollution Inventory's emission estimation technique manuals (National Pollutant Inventory, 2014) or GREET factors for GHGs and combustion emissions (Argonne National Labatory, 2016).

Information about LCA software and database resources can be found in Appendix A.

2.7 Reference system and benchmarking

Overview

The life cycle environmental performance of bioenergy systems needs to be compared against a reference baseline that serves as a benchmark for comparison. The underlying rationale is that the renewable energy will displace a proportion of the dominant energy sources and fuels in the market, which are currently principally fossil fuels. More specifically the ARENA renewable energy projects aim to enable investment in renewable energy production capacity which will offset existing capacity from non-renewable alternatives, or investment in future non- renewable energy production capacity.

Requirements and recommendation

The results of bioenergy and biofuel studies shall be compared to a reference system, which represents a scenario where the specific bioenergy under study is not produced. What this translates to is that bioenergy displaces the long term least competitive supplier into the specific market (assuming the market demand for the energy system is not affected by the new production, and that market demand in not growing faster than the increasing supply from the bioenergy system). For example, electricity fed into the national electricity market (NEM) may offset conventional coal based supply.

ISO 13065 describes two different reference systems:

1. Business as usual.
2. Projected future.

The business as usual option should be used as the default reference system. As an optional element, the results could be presented against a projected future reference system.

The system boundary for the reference system shall be the same as that used for the bioenergy system.

Guidance

Appendix A provides a list of common reference systems that are comparable with current bioenergy systems. All the reference systems are included in the AusLCI database.

2.8 Land use change (LUC)

Overview

ISO/TS 14067 (ISO, 2013) defines dLUC as a change in the use or management of land within the product system being assessed. The dLUC impacts may comprise only the carbon emissions and sequestration resulting from carbon stock changes in biomass, dead organic matter, and soil organic matters, evaluated in accordance with the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

The iLUC definition is based on ISO/TS 14067 (ISO, 2013), described as a change in the use or management of land as a consequence of direct LUC, but which occurs outside the product system being assessed. Due to a lack of consensus on methods for evaluation of indirect effects and uncertainties in modelling and attribution, quantitative assessment of GHG effects of iLUC is subject to significant uncertainty and with no clear agreement on calculation methods.

Requirements

The carbon dioxide emissions from direct LUC shall be calculated for land use activities in the project based on the IPCC Tier 1 approach. This approach examines the change in default carbon storage in the land use prior to the bioenergy project to that after the bioenergy project and amortises this over 20 years.

The scale of the direct land use to be assessed will vary by project with some projects having specific landholding which can be assessed to other sourcing from a region, and others from national markets. The scale of LUC calculations shall be consistent with the expected source area.

iLUC is not required to be calculated and reported at this stage due to a lack of an agreed approach.

Guidance

Calculation of direction land-use change is a difficult calculation especially when feedstocks come from different regions, which may vary from year to year. The calculation approach at a national level for land use change is also dependent on other activities outside the crop of interest (total expansion of crops is allocated across all crops with expanded their production in a given year). For this reason, its suggested that a default land use change calculator such as "Direct Land Use Change Assessment Tool" published by Blonk Consultants (2016) be used.

Blonk Consultants. (2016). Direct Land Use Change Assessment Tool, http://www.blonkconsultants.nl/direct-land-use-change-assessment-tool/?lang=en

2.9 Treatment of fossil, biogenic and atmospheric carbon

Overview

When inventorying carbon dioxide (CO2) emissions in LCA, a distinction is made between molecules of biogenic and fossil origin. Biogenic carbon is that which originates from biomass, while fossil carbon originates from geological fossil fuel reserves (oil, coal and gas). In LCA, the term biogenic carbon is used to refer to solid carbon contained in products and waste streams, as well as carbon in GHGs (i.e. CO2 and methane), which are emitted from biogenic material. Atmospheric carbon is carbon held in the atmosphere, which can be absorbed by biomass through photosynthesis. This process is referred to as 'biogenic uptake' of CO2.

In the greenhouse gas reporting frameworks there is a general assumption that the uptake of carbon dioxide into biomass and emissions from biomass are in balance. This is referred to as the 'biogenic carbon neutrality assumption'. This assumption is not made in this method, in line with ISO 14067, but rather needs to be demonstrated as part of the carbon balance in the inventory. A major advantage of tracking the carbon flows across the life cycle is that it better represents where the carbon is absorbed and where it is released. For example, rather than showing wood combustion emitting no carbon dioxide, as is shown in the Australian NGA factors, it will show a carbon absorption at the wood production stage and a carbon emission at the point of combustion.

Requirements and recommendation

All flows of carbon between different carbon pools (atmosphere, fossil, biosphere) shall be included and documented separately in the inventory. These include emission from:

- GHG emissions and removals arising from fossil and biogenic carbon sources and sinks;
- GHG emissions and removals occurring as a result of dLUC; and
- GHG emissions and removals from soil carbon change, if not already calculated as part of LUC.

Table 2 shows the naming convention used for different carbon flows in the life cycle inventory. It includes methane and carbon monoxide because these are part of any carbon balance.

Table 2 – Carbon related flow descriptions

Direction of flow	Inventory name	Example
Input from nature	Carbon dioxide, in air	Carbon absorbed during growth of biomass
Output to nature	Carbon dioxide, biogenic	Emission from combustion or degradation of biomass
Output to nature	Carbon dioxide, fossil	Emission from combustion of diesel fuel
Output to nature	Carbon dioxide, land transformation	Net emission from soil carbon change due to land use activity
Output to nature	Methane, biogenic	Emission of methane from biogas production facility
Output to nature	Methane, fossil	Emission of methane from natural gas distribution.
Output to nature	Carbon monoxide, biogenic	Emission of carbon monoxide from wood combustion.
Output to nature	Carbon monoxide, fossil	Emission of carbon monoxide petrol combustion.

The impact of fossil carbon emissions and that from carbon uptake and emissions from biomass should be included and reported separately in the LCA results – as required by ISO/TS 14067.

Guidance

LCA practitioners should make sure that the effects of carbon dioxide uptake during the biomass growth stage, emissions from LUC and subsequent biogenic carbon emissions from combustion are included in the LCA results.

The approach taken in this method to include all biogenic and fossil fuel flows means that practitioners will need to ensure that carbon adsorption in biomass system and re-emissions at each part of the supply chain are included. It also means that carbon balance is required after any allocation applied to inventory data (see section 2.5). Note that AusLCI and ecoinvent already balance carbon emissions after the application of allocation. Practitioners will also need to ensure that the impact assessment method used for calculating climate change impacts has the appropriate biogenic and atmospheric emission flows included (see section 2.3).

Results will be used to fulfil knowledge sharing obligations, as well as benchmark against fossil energy incumbents to ensure that a 'net benefit' is being delivered.

2.10 Reporting requirements and transparency

Overview

The LCA results and conclusions are intended to guide improvement in bioenergy projects funded by ARENA. It is important to ARENA that these results be transparently communicated with interpretation of the most important environmental aspects of the project as well as recommendations for improvements. The LCA results will be used by ARENA to fulfil its knowledge sharing obligations as well as benchmarking against fossil energy incumbents to ensure that a 'net benefit' is being delivered by the projects that we support.

Requirements

A summary report with LCA results shall be provided to ARENA for both the proof of concept LCA and commercialisation LCA.

The summary report submitted to ARENA shall, at a minimum, include the following:

- Goal and scope
- Summary of LCA results;
- Documentation of the main assumptions and the calculation approach;
- Discussion and interpretation; and
- Explanation of how this information will be used to improve the project going forward.

The proof of concept LCA background reporting should include the following heading structure and information as a guide:

- Goal of study;
- Functional unit, reference flows and reference system;
- System boundary and cutoff criteria applied;
- Inventory of inputs and outputs;
- Emission factors and their sources, conversion factors (yields);
- Data sources and quality assessment;
- Documentation of assumptions and calculations;
- Results;
- Discussion and interpretation; and
- How this information will be used to improve the project going forward.

The commercialisation LCA must include an ISO 14044 compliant background report.

Guidance

Information pertaining to confidential and/or commercially sensitive information may be excluded from the summary reports but should be included in an LCA background report if required to meet the requirements of an ISO 14044 compliant LCA report. A non-disclosure agreement may be used for the critical review process, if the report contains any sensitive information.

2.11 Critical review

Overview

Critical review of LCA studies improves the quality and independence of the LCA. The critical review in particular focuses on the appropriateness of data used, assumptions made in relation to the goal, and scope of the study. It also checks whether the conclusions from the LCA can be supported by the presented results.

Requirement

An ISO 14044 compliant critical review of the commercialisation LCA shall be undertaken.

The LCA practitioner conducting the critical review shall meet one of the following requirements:

- have at least five years of professional experience in the field of LCA;
- have been involved in at least five peer reviewed LCA studies; or
- be a Life Cycle Assessment Certified Practitioner (LCACP) – administered by ALCAS or the American Centre for Life Cycle Assessment.

Guidance

Although not a strict requirement, it is recommended that the LCA practitioner conducting the critical review has experience and knowledge of bioenergy and the relevant technologies included in the LCA.

Although it is useful for the LCA practitioner conducting the critical review to have a good overview and knowledge of the Australian market, local knowledge may be traded off against bioenergy and technology specific expertise.

A list of ALCAS Certified Practitioners can be found here: http://treasurer40.wix.com/lca-certification#!certified-practioners/cdbr

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A APPENDIX A
FUNCTIONAL UNITS AND REFERENCE FUELS FOR COMPARISON IN LCA

The choice of reference fuel is based on long term projections on what the renewable technologies will be replacing. For liquid fuels the dominance of gasoline and diesel in their respective sectors, makes it easy to identify them as the reference fuel. While there could be an argument that the imported fraction of fuels could be the reference, there is no evidence that imported fuels are less competitive than domestic production. In relation to electricity that has many contributing technologies (each filling a different market niche) ARENA's Advancing Renewables Program aims to increase the supply of renewable energy in the Australian marketplace while reducing the cost, thereby reducing reliance on fossil fuels and responding to policy pressures to achieve lower emission outcomes. Consequently, conventional coal-based electricity generation is taken to be the reference fuel against which baseload electricity generation is compared.

Table 3 - Reference fuels and functional units for different bioenergy systems

Bioenergy fuel source	Output (electricity, heat, transport fuel, other)	Region/application	Reference fuel	Functional unit
Biomass (e.g. air dry wood, stacked newspaper, dried animal manure, cereal straw), biogas (from municipal solid waste, waste water, anaerobic digestion of organic material)	Combustion for electricity, baseload	Qld, NSW, Vic., SA, Tas. – within national electricity market	Conventional coal electricity supply in NEM	Production of 1 kWh of electricity supplied to the National Electricity Market.
		WA	Electricity (black coal) WA	Production of 1 kWh of electricity supplied to WA grid
		NT	Electricity (gas)	Production of 1 kWh of electricity supplied to NT grid
		Remote locations	Electricity diesel generated	Production of 1 kWh of electricity supplied in remote location
	Heat	Steam to industrial application	Steam from natural gas	Supply of 1 GJ of steam at specific pressure
		Hot water	Hot water from natural gas	Supply of 1 m3 of hot water at specific temperature
Biogas (anaerobic digestion of organic material) used to make BioCNG	CNG supply for transport		CNG from natural gas	Supply of 1 GJ of CNG
Biogas (from municipal solid waste, waste water, anaerobic digestion of organic material)	Gas supply	Vic.	Natural gas, Vic.	Supply of 1 GJ of natural gas in Vic.
		NSW	Natural gas, NSW	Supply of 1 GJ of natural gas in NSW
		Qld	Natural gas, Qld	Supply of 1 GJ of natural gas in Qld
		SA	Natural gas, SA	Supply of 1 GJ of natural gas in SA
		WA	Natural gas, WA	Supply of 1 GJ of natural gas in WA
		Tas.	Natural gas, Tas.	Supply of 1 GJ of natural gas in Tas.
		NT	Natural gas, NT	Supply of 1 GJ of natural gas in NT
Biomass (e.g. straw, paper waste, wood and wood waste)	Pellets	Cement kiln	Coal combustion cement kiln	Combustion of 1 GJ of solid fuel in cement kiln
		Industrial boiler	Coal use in boiler	Combustion of 1 GJ of solid fuel in industrial boiler
		Fire wood	Combustion fire wood in slow combustion stove	Combustion of 1 GJ of solid fuel in slow combustion stove
Oilseed crops, canola, sunflower, soybean etc.	Biodiesel	Diesel (standard)	Low sulphur diesel, average Australian supply	Supply and combustion of 1 GJ of fuel in compression ignition engine based in Euro IV compliant heavy vehicle
Ethanol production from molasses, grains, lignocellulosic materials	Bioethanol	E10 blend with gasoline RON 92	Gasoline, RON 95, average Australian supply	Supply and combustion of 1 GJ of fuel in spark ignition engine based in Euro IV compliant light vehicle
Bio-oil, syngas or biomethane (from e.g. wood residues, municipal solid wastes etc)	Advanced/ renewable/" drop-in" biofuels including diesel, aviation kerosene and heavy fuel oil	Functionally equivalent to fossil-oil derived fuel product (chemically identical, fully miscible)	Petroleum product mix from fossil crudes	Production of petroleum products produced from 1 tonne of biocrude input

B APPENDIX B
EXPLANATION OF ENVIRONMENTAL INDICATORS

Table 4 - Impact assessment categories and characterisation models retained in this LCA.

Indicator	Description	Characterisation model
GWP100	Measured in kg CO2 equivalents (kg CO2 e). This is governed by the increased concentration of those gases which, when present in the atmosphere, trap heat and lead to increasing global temperatures. Major greenhouse gases are carbon dioxide, methane and nitrous oxide.	IPCC 5th Assessment Report model based on 100-year timeframe (Myhre, et al., 2013)
Fossil energy (abiotic depletion, fossil fuels)	Measured in kg oil equivalent. Based on concentration of reserves and rate of de-accumulation.	All fossil energy carriers based on relative scarcity (Goedkoop, et al., 2009).
Photochemical ozone creation potential (PCOP)	Measured in kg of ethene equivalent. This is the measure of the potential of hydrocarbons and nitrogen oxides in the atmosphere to combine with sunlight to produce photochemical ozone, which has significant respiratory and other health effects.	(CML, 2016)
Eutrophication	Measured in phosphate equivalent. This indicator represents the growth of algae in freshwater and marine systems, which can significantly affect the environmental quality due to oxygen depletion.	Eutrophication potentials based on Heijungs, et al. (1992), which assumes both NĐ and PĐspecies contribute. (CML, 2016)
Acidification	Measured in sulphur dioxide equivalent. Acidification is a relevant impact for processes releasing NOx and SOx, acidic gases and ammonia. NOx and SOx, the species that tend to contribute most of acidification impacts, are released from the burning of fossil fuels in electricity, steam and heat generation.	(CML, 2016)
Particulate matter	Measured in particulate matter less than 2.5 microns. Particulate matter both primary and secondary are responsible for millions deaths globally each year.	Currently Humberts et al. (2011), until the recommended factors from Pelton Workshop, January 2016 are published by UNEP/SETAC.
Ozone depletion potential	Measured in CFC 11 equivalent. Ozone depletion leads to break down in ozone layer, leading to increases in skin cancers and other effects.	(CML, 2016)
Land use	Measured as kg soil organic matter (SOM) (kg C/m2/a). Land use: SOM based on changes in SOM, measured in (kg C/m2/a). Biodiversity impacts not covered by the data set. Mila i Canals et al. 2007.	ILCD with potential updated data based on LANDCARE funded project.
Consumptive water use	Measured as L H2O eq. global average water scarcity. Quantity of water extracted directly from the environment, thereby competing with environmental and other human requirements for water.	Method of Ridoutt & Pfister, (2010), with Water stress indices of Pfister et al. (2009)

C APPENDIX C LCA SOFTWARE RESOURCES

To model impacts for the process optimisation LCA, an LCA software program and access to life cycle inventory (LCI) databases will be required. The majority of LCA software packages are commercial and require a license fee, including SimaPro and GaBi. These include access to LCI databases, which require ongoing maintenance such as Australasian Unit Process LCI, ecoinvent and GaBi databases. There is also openLCA, which is a free open source software package offering both free and commercial LCA datasets. Quantis Suite offers both a commercial and free version, the free version with limited databases.

The Australian Life Cycle Inventory Database Initiative AusLCI datasets are free and are publicly available for use.

D APPENDIX D DEFAULT SUBSTITUTIONS TO BE USED IN SYSTEM EXPANSION IN MULTIFUNCTION SYSTEMS

Figure 4 describes the four options which are available for solving allocation in multi-function systems in the order of preference. In line with the recommendations from UNEP, option 2 has been moved ahead of system expansion as it is only applied to combined production where the production volume of different co-product can be varied.

Figure 4 - Description of options for solving allocation in multi-functional systems

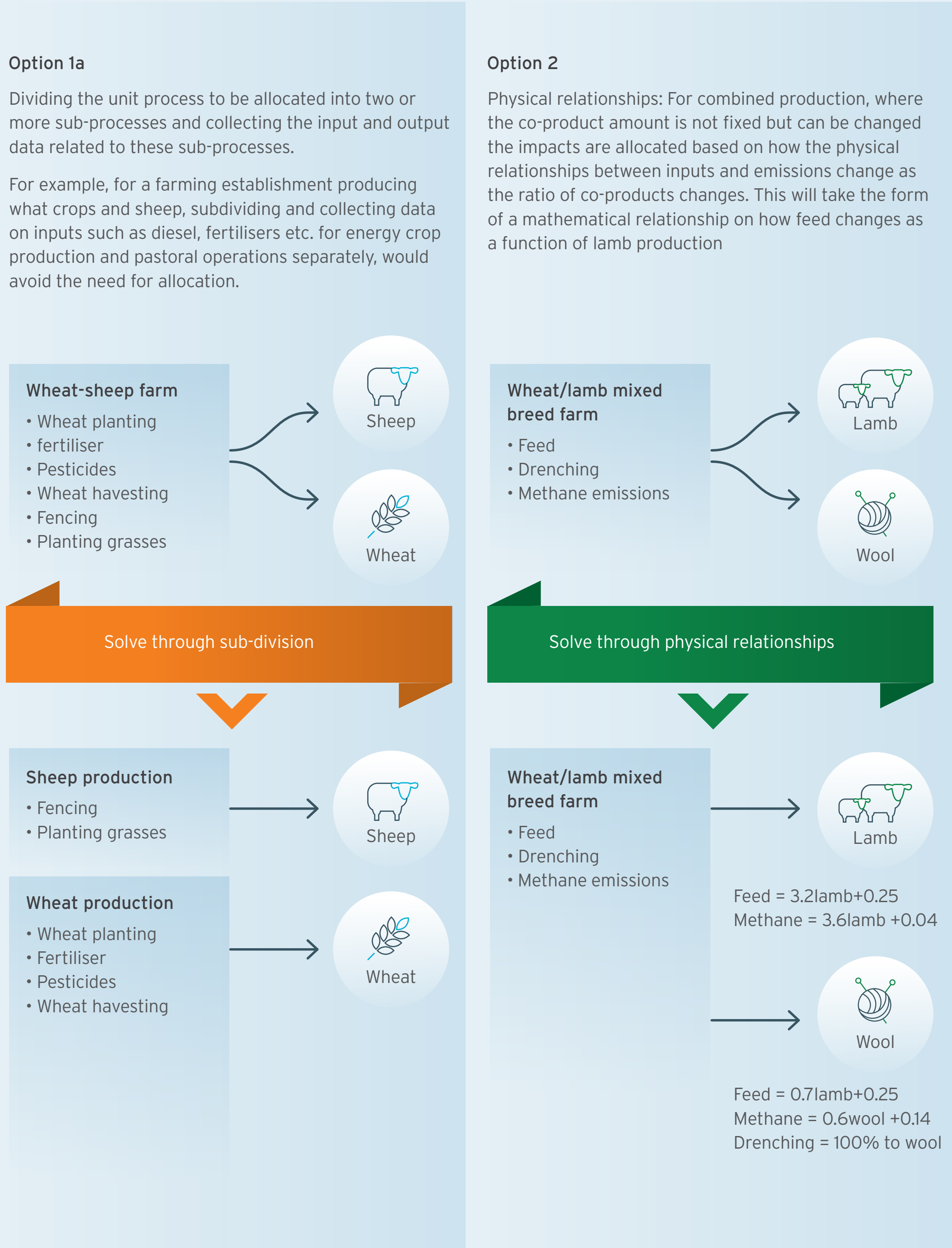


Figure 4 - Description of options for solving allocation in multi-functional systems

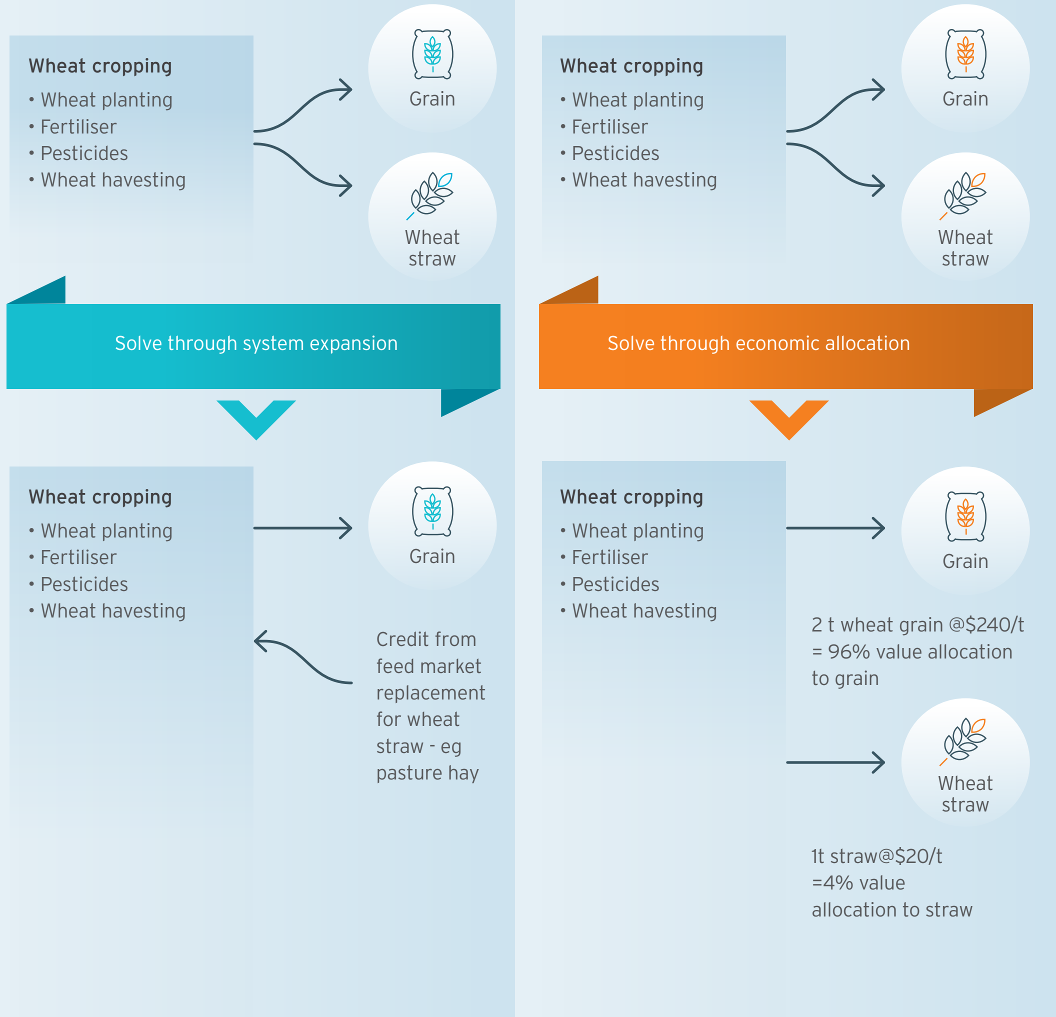
Option 1b

System expansion refers to the process of including the co-product into the system boundary and then removing it by providing a credit equal to the functional value of the co-product.

For example, consider what grain production would have straw as a co-product. The system boundary is expanded to include the low protein animal feed function (the main use of wheat straw). This function is then removed from the functional unit by subtracting an equivalent functional amount of pasture hay.

Option 3

Where physical relationships alone cannot be established as the basis of allocation, the inputs and emissions should be allocated between the co-products, based on other relationships between them such as the economic value of the co-products. Using the same example as system expansion of wheat and straw.



Note that the system expansion in option 1b above only provides a solution allocation of the main product. In system expansion there is a differentiation between the determining product, which is typically the most valuable product and the principle reason for the multifunction process existing, and the co-products, which do not affect the level of production, and are typically of much less value. Figure 5 is adapted from Weidema (Weidema, 2000) and describes how impact of the determining product is calculated compared with the co-product, for co-products that are fully utilised. The impact of the co-product is the impact of producing its market replacement. For example, if the market replacement for straw was pasture hay, then the impacts of using straw is equivalent to the production of additional pasture hay. For materials that are wastes or co-products not fully utilised they can be used without carrying any burden from the production system which produces them, but should be provided with a credit for avoiding their disposal impacts, if there are any.

Figure 5 – Formulae for calculating impacts of co-products using system expansion.

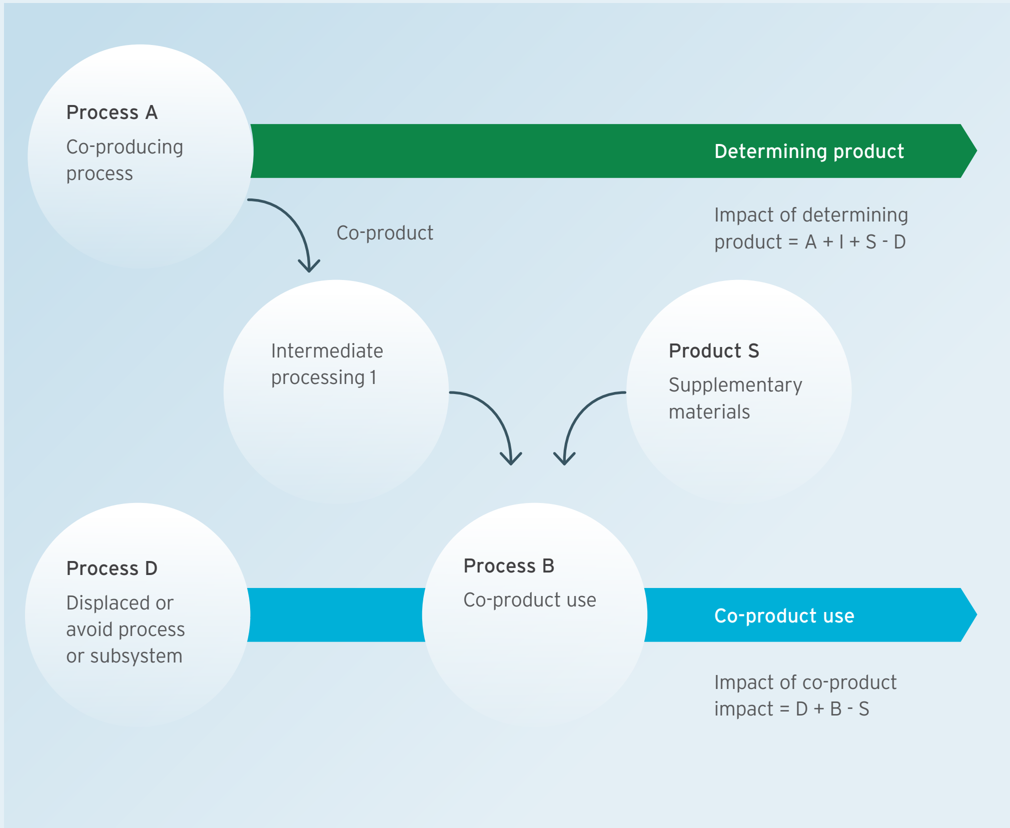


Table 5 lists a group of products which are considered to be true wastes that are not fully utilised and therefore are provided with a credit for avoiding their waste management impacts. Table 6 lists co-products that are fully utilised in the marketplace; therefore, any use of them is assumed to lead to a displacement of an alternate use. The substitution should be based as much as possible on observed competition between products. The substitutions suggested in Table 6 are indicative example but should be checked against the local situation.

Note that as markets develop a waste can transition to being a co-product and vice versa.

Table 5 - List of products considered to be wastes.

Process	Determining product	Waste product	Alternative fate
Sawmill operation	Timber	Sawdust	Landfill of sawdust. Possible in specific situations that alternate fate may be burning off.
Timber production system	Sawlog and pulplogs	Tops and branches	Currently largely left to degrade and in some circumstances may be burned off. Removal may have implication for soil carbon.
Sugar cane growing	Sugar cane	Cane trash	Left on field to degrade or incorporated into soil. Remove may have implication for soil carbon.
Grain production	Grain	Grain stubble	Left on field to degrade. Assume harvesting of straw does not compromise the soil stability benefits as stubble is simply cut lower than would normally be the case.

Table 6 – Co-production in the LCA foreground and the replacement products used.

Process	Determining product	Co-product	Substitution per kg co-product	Comment
Sugar refining	Sugar	Molasses	2.0kg Forage sorghum	Molasses is used in as stock feed in Australia. Alternative would be cassava starch used in Asia for feedstock to MSG which also uses molasses when its available.
Sugar refining with cogeneration from bagasse	Sugar	Electricity	Electricity from grid	
Starch production	Wheat starch	Starch waste	3.5kg Forage sorghum	Starch process waste is predominantly energy. Alternative would be cassava starch used in Asia for feedstock to MSG which also uses other starch waste when its available.
Ethanol from sorghum	Ethanol	Dried distillers grains and solubles (DDGS)	09 kg lupins and 0.25kg wheat	Need to balance protein and energy content of DDGS with crop mix
Ethanol from wheat	Ethanol	Dried distillers grains and solubles (DDGS)	09 kg lupins and 0.25kg wheat	Need to balance protein and energy content of DDGS with crop mix
Biogas production from organic waste treatment	Electricity	Waste disposal	Facultative treatment pond	The exact substitute might be site specific looking at the waste treatment processing being replaced by the biogas facility.
Beef production	Beef	Tallow	1kg Palm oil	Oils are traded internationally on oil and fats markets
Commercial and industrial fried food	Fried food	Used cooking oil	1kg Palm oil	Oils are traded internationally on oil and fats markets
Canola/rape seed oil production	Canola oil	Canola meal	3kg Lucerne hay -1.2 sorghum grain	The very high protein content of meal means that the offset of Lucerne supply to much energy which is they offset with sorghum grain.
Timber production	Timber	Wood chips/saw dust	1 kg pine production	

4 CONTACT INFORMATION

For more information on this method and guidance for undertaking life cycle assessments of bioenergy (including biofuel) projects and products, please contact:

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Report for the Australian Renewable Energy Agency

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ARENA