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ARENA LCA Guidelines for Bioenergy Projects

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

Australian Government
Australian Renewable Energy Agency

ARENA

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Glossary

Term	Definition
Australian Life Cycle Assessment Society (ALCAS)	Professional Association for Life Cycle Assessment in Australia http://www.alcas.asn.au
Allocation	Partitioning of 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 Carbon Credit Units (ACCUs)	One ACCU represents one tonne of carbon dioxide equivalent (t CO_2e) that would have otherwise been released into the atmosphere. Generated from eligible ACCU Scheme projects. These are tradeable financial products to incentivise carbon abatement activities (Clean Energy Regulator, 2025a).
Australian Carbon Credit Unit (ACCU) Scheme	Australia's national scheme to encourage people and businesses to run projects to reduce emissions or store carbon. Projects can encompass technology or transition in practices (Clean Energy Regulator, 2025b).
Australian Renewable Energy Agency (ARENA)	Independent agency of the Australian federal government, established in 2012, to manage the government's renewable energy programs and to increase the supply and competitiveness of Australian renewable energy sources (ARENA, 2025a).
ARENA Funding Program	Refers to any program of funding outlined on ARENA's website https://arena.gov.au/funding
BAU (Business-as-usual)	Used for reference case to represent production processes in the absence of the implementation of bioenergy project.
Biogenic carbon	Carbon derived from biomass (ISO 14067).
Bioenergy	Energy derived from biomass (ISO 13065). Note: The term bioenergy includes solid, liquid and gaseous fuels derived from biomass.
Biomass	Material of biological origin, excluding material embedded in geological formations, material transformed to fossilised material, and peat (ISO 14067).
Carbon dioxide equivalent (CO_2 eq., CO_2e)	Unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide (ISO 14067).
Carbon footprint	Sum of greenhouse gas emissions and removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change (ISO 14067).
Carbon Offsetting and Reduction Scheme for	Global market-based scheme developed by the International Civil Aviation Organization (ICAO) to reduce emissions from international aviation through reporting and offsetting obligations (ICAO, 2025b).

Term	Definition
International Aviation (CORSIA)	
Characterisation factors	Factors derived from a characterisation model that 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 factor that ARENA use to measure the ‘commercial readiness’ of renewable energy solutions (ARENA, 2014).
Commodity approach	The commodity approach is used in these Guidelines to describe an attributional LCA calculation using energy allocation for co-products and calculating a footprint result only for the energy products of the Bioenergy scenario. This is the same approach used in CORSIA and EU RED III reporting standards.
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	In an LCA, it specifies the amount of material or energy flow, or the level of environmental significance associated with unit processes, or product systems, to be excluded from a study (ISO 14040).
Declared unit	In an LCA, is a unit used in place of the functional unit when the study does not include a ‘cradle to grave’ scope (ISO 13065).
Determining product	In an LCA, 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 (dLUC)	In an LCA, is the change in human use or management of land within the product system being assessed (ISO 14067).
European Emissions Trading Scheme (EU ETS)	A cap and trade system to reduce emissions by setting a limit in total emissions and allowing trading of emission allowances to incentivise reductions (European Commission, 2025a).
European Renewable Energy Directive (EU RED)	Establishes targets for increased renewable energy use and supporting coordination between European countries (European Commission, 2025b).
Fossil carbon	Carbon that is contained in fossilised material (ISO 14067).
FullCAM	Full Carbon Accounting Model (DCCEEW, 2025a)
Functional unit	Quantified performance of a product system for use as a reference unit in an LCA (ISO 14040).

Term	Definition
HEFA	Hydrotreated esters and fatty acid
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 14067).
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).
Guarantee of Origin (GO) Scheme	The Australian Government assurance scheme that is being developed to align with international practice in tracking and verifying emissions associated with certain products (Clean Energy Regulator, 2025c).
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 Appendix F for description of environmental impact categories and indicators relevant to this methodology and guidelines.
Indirect land use change (iLUC)	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 14067).
International Civil Aviation Organization (ICAO)	A United Nations agency to help member countries cooperate on global aviation standards and policies. ICAO supports the safe, efficient and sustainable development of international air transport (ICAO, 2025a).
IPCC	Intergovernmental Panel on Climate Change
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).
LCACP	Life Cycle Assessment Certified Practitioner
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).

Term	Definition
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).
Multifunctionality and co-products	Refers to a process that creates multiple products or functions. Products often thought of as waste can also be thought of as co-products if they provide some function or value.
NEM	National electricity market
National Greenhouse and Energy Reporting (NGER) Scheme	The Australian national framework for reporting greenhouse gas emissions, energy production and consumption for companies over certain thresholds. The data informs national GHG emissions, policy and program development and is administered by the Clean Energy Regulator (Clean Energy Regulator, 2025d).
Process optimisation LCA	Proof of concept LCA updated once a project is in system test and small-scale commercial trial, when commercialisation begins.
Project approach	The project approach is used in these Guidelines to describe a consequential LCA calculation where all products and services produced by the Bioenergy scenario are compared against a Reference scenario where the Bioenergy scenario does not exist. This is aligned to the ISO13065 standard on sustainability of Bioenergy scenarios.
Proof of concept LCA	LCA study undertaken on a bioenergy project during early technology development.
Proponents	Includes both applicants and ARENA funding recipients.
RED	Renewable Energy Directive
Safeguard Mechanism	The Safeguard Mechanism builds on the NGER Reporting Scheme to require large emitters to reduce their emissions in line with national targets (Clean Energy Regulator, 2025e).
SAF	Sustainable Aviation Fuel
System boundary	Set of criteria specifying which unit processes are part of a product system in an LCA (ISO 14040).
System expansion	Recommended ISO 14040 method for avoiding allocation in an LCA. This is done by expanding the system boundary to include the additional functions related to the co-products (ISO 14044).
TRL	Technology Readiness Level

1 | Introduction

1.1 Context

This report has been prepared for the Australian Renewable Energy Agency (ARENA), which supports the global transition to net zero emissions by accelerating the pace of pre-commercial innovation, to the benefit of Australia. ARENA's purpose is to support improvements in the competitiveness and supply of renewable energy by providing financial assistance and sharing knowledge, to accelerate innovation that benefits all Australians, and facilitates the achievement of Australia's greenhouse gas emissions targets.

The emission reduction potential is a key aspect of the value of renewable energy projects. For bioenergy projects, a Life Cycle Assessment (LCA) is the globally recognised methodology to assess this potential and overall environmental impact. ARENA requires the submission of LCA reports for all ARENA-funded bioenergy projects, unless an exemption is granted by ARENA. This ensures that ARENA can have confidence in the emissions reduction claims from ARENA supported projects.

To support ARENA proponents in undertaking LCA studies, the ARENA LCA Guidelines 'Method and guidance for undertaking life cycle assessment of bioenergy products and projects' were developed and published on ARENA's website in 2016. Since then, there has been substantial evolution in LCA and greenhouse gas (GHG) accounting guidance specific to bioenergy, LCA impact assessment methods, and the underpinning international standards for LCA. To incorporate these developments, the ARENA LCA Guidelines were updated in 2025.

Table 1: Versions of ARENA Guidelines

Edition	Authors	Subjects	Released
1st edition	Lifecycles and Edge Environment	First edition of the document	August 2016
2nd edition	Lifecycles (reviewed by Edge Impact, formerly Edge Environment)	Updated edition - increased alignment with international reporting frameworks and guidance on more recent LCA approaches.	August 2025

1.2 Objectives of the LCA Guidelines

The LCA Guidelines have been developed to support ARENA proponents in undertaking LCA studies of proposed bioenergy projects.

The objectives of the LCA Guidelines are to:

- Provide clear guidance to industry on ARENA's LCA requirements and expectations across the funding application and project phases.
- Establish a consistent framework to assess and compare the environmental performance of bioenergy projects — including emissions reduction potential — aligned with international standards and certification schemes.
- Define ARENA's sustainability and environmental impact expectations to support transparent project evaluation and portfolio-wide comparability.
- Support knowledge sharing by applying a standardised approach to communicate the environmental benefits of bioenergy projects, helping to build industry capability and inform future decision-making.

The scope of the ARENA Guidelines does not include social and socio-economic aspects, given that existing ARENA-specific and other regulatory assessments and mechanisms already cover these aspects.

The main target audience for this document include:

- ARENA bioenergy project proponents
- LCA practitioners
- Other stakeholders seeking a framework to assess the environmental impact of a bioenergy product or project.

1.3 Stakeholder engagement process

A process of stakeholder engagement was used to develop and refine the technical aspects of the ARENA Guidelines.

The first edition of these Guidelines involved extensive engagement with over 125 individual stakeholders across Australian national and state governments, community organisations, international bodies, industry and key organisations including Bioenergy Australia, the Commonwealth Scientific and Industrial Research Organisation, the Commonwealth Department of Environment, the Clean Energy Regulator, Qantas, Virgin Australia, the World Wildlife Fund and RMIT University.

The second edition sought feedback from a smaller pool of stakeholders to target those who had already engaged with the original Guidelines.

The key suggestions received by the stakeholders and how they have been addressed in the revised Guidelines are summarised in the table below.

Table 2: Summary of stakeholders' suggestions and their integration into the revised Guidelines

Suggestion	Integration into revised Guidelines
Increase alignment with international bioenergy reporting frameworks, in particular in the sustainable aviation fuel (SAF) sector	The revision of these Guidelines has, where available, integrated consistencies with international reporting frameworks such as the CORSIA and the EU RED III (see section 1.4).
Allow flexibility to accept LCAs calculated for other project requirements	The Safeguard Mechanism, and the NGER and ACCU schemes cannot be used to prepare LCA reports for ARENA because these methods differ in scope and reporting requirements. However, a number of international regulatory schemes can be used for the *Proof of Concept* LCA (see Appendix A).
Recognise incoming Australian reporting requirements, such as the Guarantee of Origin Scheme (GO Scheme)	Once finalised, the GO scheme will be recognised for the *Proof of Concept* LCA, as listed in the recognised schemes in Appendix A. The GO Scheme provides the mechanism for tracking and verifying the GHG emissions intensity of products including renewable electricity and hydrogen and will later expand to industries such as green metals and low carbon liquid fuels (DCCEEW, 2025b). The GO scheme is emerging, with rules and methodologies to be developed in 2025.

Suggestion	Integration into revised Guidelines
Review environmental impact indicators to increase consistency with other reporting frameworks	The reporting obligations on environmental impact categories have been streamlined to reduce burden on proponents and to increase consistency with other reporting frameworks (see section 2.8).
Provide further guidance and information on existing tools and methods	Appendices A-G provide detailed guidance and information on existing tools and methods (see appendices A-G).

1.4 Alignment with international standards

Language

This document 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).

The Guidelines also retain terminology from the international standards to identify different actors 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.

ISO standards

The Guidelines are built on international standards surrounding LCA, GHG 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 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 of bioenergy, in particular the section on GHG methodologies, assessment and comparisons.

The ISO 14040 and ISO 14044 standards are the overarching standards for LCA, while ISO 14067 is a newer standard and provides additional detail on carbon accounting approaches.

Sector-specific standards

A number of sector-specific standards have been referenced to create alignment with current best practice in the assessment and certification of fuels.

Specifically, an alignment has been sought, where possible, with:

- the Renewable Energy Directive (RED) III from the EU; and
- the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) guidelines from the International Civil Aviation Organization (ICAO).

The alignment with these standards helps reduce potential duplication of LCA activity by proponents and should give good alignment between results from the ARENA Guidelines and industry standards.

1.5 LCA types and reporting requirements

ARENA-funded bioenergy project proponents are required to develop an LCA across three stages with differing reporting requirements, as summarised in Figure 1.

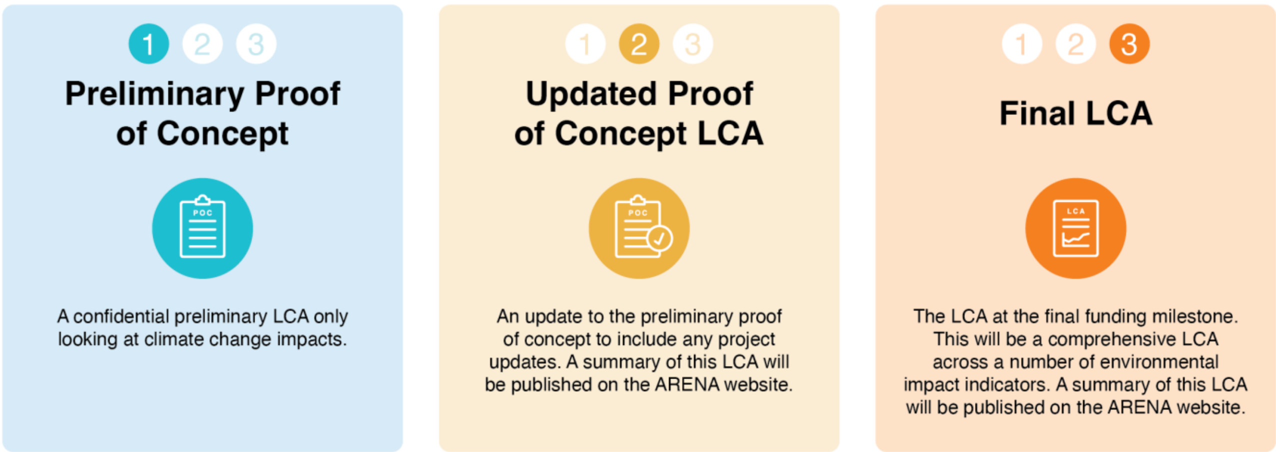


Figure 1: LCA reports to be submitted for ARENA-funded bioenergy projects.

1.5.1 Proof of Concept LCA

Purpose

The purpose of the *Proof of Concept* is:

- For ARENA's benefit, to:
  - ➢ Support the assessment of merit of the proposed project in relation to emissions reduction.
  - ➢ Provide confidence that technologies produce renewable energy with favourable overall GHG balances.
  - ➢ Give insights into the climate change advantages and risks associated with technologies.
- For ARENA program proponents' benefit, 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.

Accepted schemes

For *the Proof of Concept* LCAs, ARENA will accept existing LCAs undertaken for recognised certification schemes listed in Appendix A, subject to the following:

- The system boundary is consistent (see Section 2.4 for further information).
- The calculations provided are appropriately referenced.
- The proponent can provide additional information when requested.

To use an LCA assessed under a different reporting or certification scheme, the proponent shall ensure that all requirements of the *Proof of Concept* report are met, as outlined in 3.

Any concerns or variations with the methods for preparing the *Proof of Concept* LCA using a different reporting scheme should be discussed prior to submission with ARENA.

Delivery time

A *Proof of Concept* LCA is to be submitted as part of an application for ARENA funding (*Preliminary Proof of Concept* LCA) and should be updated and resubmitted with the first funding milestone (*Updated Proof of Concept* LCA).

Accessibility

While the *Preliminary* and *Updated Proof of Concept* LCAs will be kept confidential, proponents are required to prepare a public summary of the *Updated Proof of Concept* LCA to share with the broader industry the emission reduction opportunities associated with the bioenergy solution investigated in their projects. The summary of the *Updated Proof of Concept* LCA will be published on the ARENA website.

All non-sensitive information should be included within the public summary report. Any confidential information does not need to be disclosed. Any uncertainties around the public reporting requirement should be discussed with ARENA.

Content

The minimum content required for *Proof of Concept* LCAs is outlined in Table 3.

Table 3: Content required for Proof of Concept LCAs

Topic	Confidential report (Preliminary and Updated *Proof of Concept LCA*)	Public Summary of Updated *Proof of Concept LCA*
Goal of the Study	✓	✓
LCA approach (see section 2.2) or a reference to approved external standard used for the LCA	✓	✓
Summary of carbon footprint results* relative to reference scenario	✓	✓
Documentation of the main assumptions and project parameters	✓	✓
Discussion of the results	✓	✓
Explanation of how this information may be used to improve the project going forward	✓	

* Other environmental impact categories are not relevant for the purposes of the *Proof of Concept* LCA.

Critical review

External consultants are recommended but not required to prepare the *Proof of Concept* LCAs.

1.5.2 Final LCAs

Purpose

The purpose of the *Final* LCA is:

- For ARENA's benefit, to:
    - Provide a benchmark on the GHG performance.
    - Manage risks from other environmental impacts.
    - Help to communicate project benefits.
    - Provide insight into the commercial challenges and learnings from the new innovations and what has inhibited the technology from reaching deployment, if the project does not progress.
- For ARENA program proponents' benefit, to:
    - Provide scenario assessment of alternative technologies and management options.
    - Give 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.

Accepted schemes

The *Final* LCA shall comply with ISO 14044 and follow the guidelines included in this document. The schemes listed in Appendix A cannot be used to develop the *Final* LCA.

Delivery time

The *Final* LCA shall be submitted as part of the final funding milestone.

Accessibility

While the *Final* LCA will be kept confidential, proponents are required to prepare a public summary of the *Final* LCA to summarise the LCA results and to share with the broader industry the emission reduction opportunities associated with the bioenergy solution investigated in their projects. The summary of the *Final* LCA will be published on the ARENA website.

All non-sensitive information should be included within the public summary report. Any confidential information does not need to be disclosed. Any uncertainties around the public reporting requirement should be discussed with ARENA.

Content

The minimum content required for the *Final* LCA is outlined in Table 4.

Table 4: Content required for Final LCAs

Topic	Confidential report	Public Summary
Goal of the Study	✓	✓
Explanation of how any learnings of the *Proof of Concept* LCA were used to progress the project	✓	✓
LCA approach (see section 2.2) and rationale	✓	✓
Functional unit and reference flow (see section 2.3)	✓	✓
System boundary (see section 2.4)	✓	✓
Multifunctionality and allocation (see section 2.5)	✓	✓
Reference scenario and benchmarking (see section 2.6)	✓	✓
Cutoff criteria (see section 2.7)	✓	✓
Results on all environmental impact categories (see section 2.8)	✓	✓
Temporal aspects of the LCA (see section 2.9)	✓	✓
Inventory analysis (see section 2.10)	✓	
Land use change (see section 2.11)	✓	✓
Treatment of fossil, biogenic and atmospheric carbon (see section 2.12)	✓	
Emission factors and their sources, conversion factors (yields)	✓	
Data sources and quality assessment	✓	
Documentation of main assumptions and project parameters	✓	✓
Documentation of calculations	✓	
Discussion and interpretation	✓	✓
Explanation of how this information may be used to improve the project going forward	✓	

Critical review

A peer review by a certified LCA consultant is required for the *Final* LCA. This is to enhance the robustness of reporting to ARENA and reporting to stakeholders linked with the publication requirements.

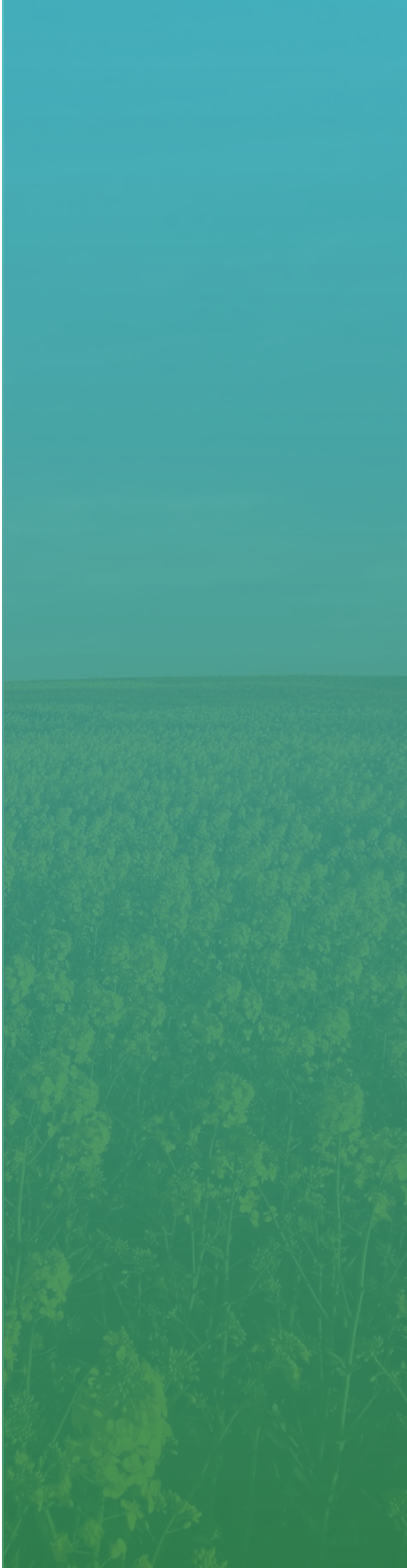
1.5.3 Summary of key differences between different types of LCA

The key differences between *Proof of Concept* (*Preliminary* and *Updated*) and *Final* LCAs are listed in Table 5.

Table 5: LCA requirements

Type of LCA	Delivery time	Are external schemes accepted?	Is a public summary required?	Is a critical review required?
***Preliminary Proof of Concept* LCA**	Funding application	Yes – see Appendix A	No	No, but recommended
***Updated Proof of Concept* LCA**	First funding milestone	Yes – see Appendix A	Yes	No, but recommended
***Final* LCA**	Last funding milestone	No	Yes	Yes

2 | Guidance and requirements for undertaking an LCA



2.1 Goal of the study

Overview

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

Requirements

This section shall document:

- the goals of the study, including the rationale for the ARENA funding
- what Technology Readiness Level (TRL) and Commercial Readiness Index (CRI) the technology has currently reached (See Appendix B for definitions of TRL and CRI)
- the audience for the study.

Guidance

Example study goals for a *Preliminary Proof of Concept* LCA, an *Updated Proof of Concept* LCA and a *Final* LCA are provided in Table 6.

Table 6: Example study goals for each type of LCA report

LCA report	Example study goals
Preliminary *Proof of Concept* LCA	*The goal of the LCA is to estimate the potential carbon footprint benefits of converting waste from woody weed removal in NSW to biocrudes suitable for conversion to sustainable aviation fuel. The project is at a TRL level 5 and is seeking ARENA funding to support further development. The audience for the study will be ARENA and an internal technology development team.*
Updated *Proof of Concept* LCA	*The goal of the LCA is to estimate the carbon footprint and best product mix between biochar for agriculture and biocrude for sustainable aviation fuel, using gasification of woody weeds from and management activities in western NSW. The project is at a TRL level 5 as has received ARENA funding to support further development and optimisation.* *The audience for the study will be an internal technology development team and ARENA.*
***Final* LCA**	*The goal of the LCA is to assess the potential environmental impacts and benefits of a pyrolysis plant in western NSW processing biomass from the region for use in production of sustainable aviation fuel. The project has reached TRL level 9/CRI level 2 with the assistance of ARENA funding.* *The audience for the study will be ARENA, investors, potential customers and the broader public.*

2.2 LCA approach – Commodity versus Project approach

Overview

There are several different approaches to calculating the environmental impacts or benefits of a bioenergy scenario. This document provides guidance on two approaches allowable to meet the ARENA requirements.

1. Commodity approach: The default approach in these Guidelines focuses on the bioenergy product output alone and partitioning off any other products using co-product allocation. In these Guidelines we refer to this as the *commodity approach.*[1] The commodity approach has been chosen as the default approach to provide greater comparability between projects and for consistency with other reporting frameworks.
2. Project approach: An alternative approach is to focus on all products and services from a bioenergy project and how these displace existing products and services. In this document we refer to this as the *project approach.*[2] The project approach is provided as an alternative to demonstrate the benefits from a more complex system and account for environmental impacts beyond the individual product analysis.

Commodity approach

Figure 2 shows the *commodity approach*, where the bioenergy product is assessed by taking an energy allocated share of upstream impacts and carrying these through into the footprint of the bioenergy product. This is then compared to the fossil-based equivalent reference scenario.

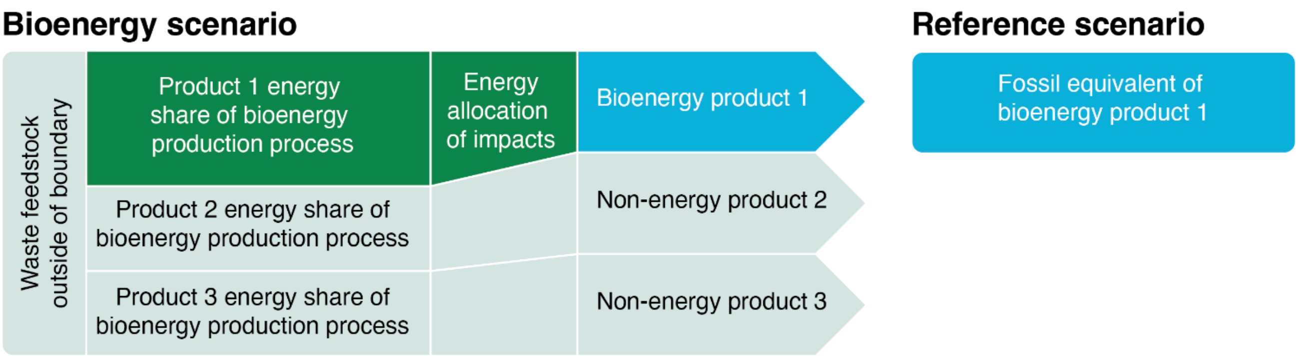


Figure 2: Description of the commodity approach applied to a bioenergy LCA study

Project approach

Figure 3 shows how the *project approach* calculates the total impact of the bioenergy project and compares these impacts to the functionally equivalent fossil-based sources of those products and services.

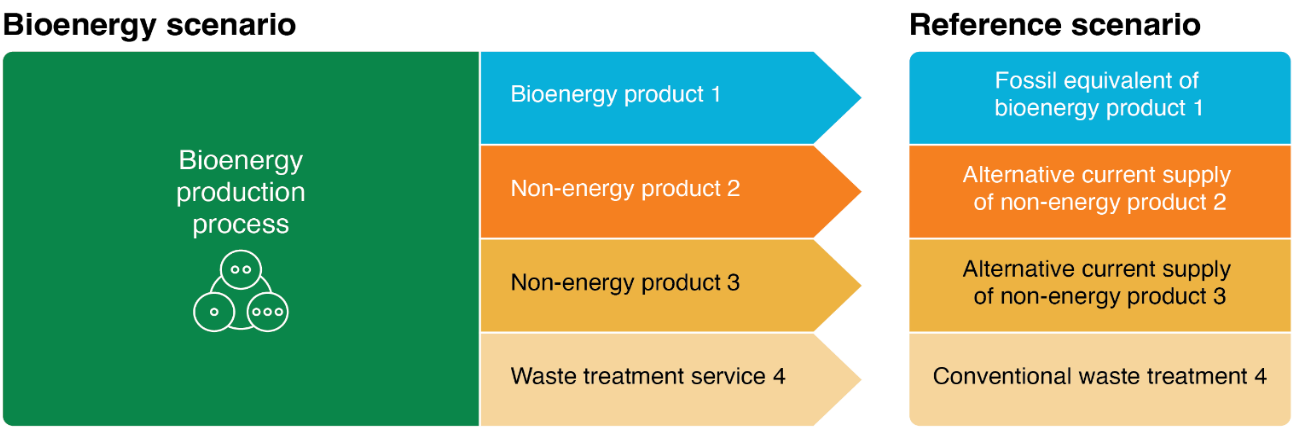


Figure 3: Description of the project approach applied to a bioenergy LCA study

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[1] In LCA this is also referred to as the attributional approach.
[2] In LCA this is also referred to as the consequential approach. This term is not used in these Guidelines as consequential LCA also involves other modelling choices which are out of scope.

Requirements

Under these Guidelines, the type of approach taken will affect the definitions of the functional unit, system boundary, multifunctionality approach and reference scenarios. Specific requirements differentiating the *commodity approach* and *project approach* are provided in the sections that treat these aspects (Sections 2.3, 2.4, 2.5 and 2.6).

All proponents shall use the *commodity approach* to calculate the bioenergy LCA, providing a value easily comparable across projects and consistent with major certification programs. In addition, all proponents have the option to also calculate the LCA based on the *project approach*, but this is strongly recommended only for projects with greater than 20% by mass of non-energy by-products.

In public summaries of the LCA, proponents can choose to use the *commodity approach* or both approaches to present the impacts and benefits of their project.

Guidance

The *commodity approach* is best suited to projects with mostly energy products (i.e. a biofuel refinery producing SAF and renewable diesel) and is well aligned with other bioenergy certification approaches such as CORSIA and EU RED III. These energy products are more easily compared to the fossil fuel reference scenario.

For projects with valuable co-products that are not energy related (e.g. animal feed from biofuels from processing forestry residues), the *commodity approach* may underestimate the full project benefits from the additional co-products. Therefore, the *project approach* is best suited to more complex bioenergy projects with multiple outputs including energy products, non-energy products and waste treatment services (such as utilising waste streams that otherwise require treatment). The results are based around a more complex functional unit and are more difficult to compare to other biofuel/fossil fuel reference scenario.

2.3 Functional units and reference flow

Overview

The ‘functional unit’ is the quantified output of the energy system. It provides a common basis for comparison of results in any LCA study. For the default *commodity approach*, the functional unit is the production and utilisation of 1 unit of energy typically being 1 MJ of thermal energy or 1 kWh of electrical energy.

In ISO 14040 the term ‘reference flow’ refers to the specific processes that fulfill the functional unit for each specific option assessed in the LCA. This is not the same as the term ‘reference scenario’, which, in these Guidelines, refers to the business-as-usual (BAU) product system that meets the functional unit in the absence of the bioenergy system.

For the bioenergy scenario, the functional unit is fulfilled by the bioenergy production and combustion (i.e. its reference flow) and this is compared to the corresponding reference flow of the reference scenario, which is typically the production and combustion of a conventional fossil fuel-based system. An example is provided in Table 7.

Table 7: Example of a functional unit and reference flows using the commodity approach

Project’s functional unit	Bioenergy scenario – reference flow	Reference scenario – reference flow
1 MJ aviation fuel production and combustion	1 MJ SAF combusted	1 MJ kerosene combusted

The functional unit in the *project approach* is expanded to contain all the products and services that are provided by the bioenergy scenario. This will include at least one bioenergy product but may include multiple energy and/or non-energy products and/or waste treatment services. The contents and scale of the functional unit is set by the reference flows of the bioenergy scenario. The BAU reference scenario needs to match these functions and services as closely as is possible.

For example, for an aviation fuel produced from canola oil using hydrotreated esters and fatty acid (HEFA) processing, the products would include the biofuel itself, co-products from canola pressing (canola meal), and co-products from HEFA processing (propane and naphtha) as shown in Figure 4 (a) bioenergy scenario. Each of these products is expressed in the functional unit so that it covers both the biofuel product and the reference scenario version of the product. Table 8 shows how the functional unit is scaled to be equivalent to 1 MJ of biofuel production and the proportions of other products and services produced when making 1 MJ of bioenergy. An equivalent group of products and services then needs to be defined for the reference scenario.

Table 8: Example of a functional unit and reference flows using the project approach for canola processed to aviation fuel

Project's functional unit	Bioenergy scenario – reference flow	Reference scenario – reference flow
1 MJ aviation fuel production and combustion	1 MJ SAF combusted	1 MJ kerosene combusted
12 g of equivalent high-protein animal feed	12 g canola meal with 26% protein content	10 g soybean meal with 30% protein content (quantity adjusted to account for higher protein content)
5 g of propane production and consumption	5 g bio-based propane	5 g refinery-based propane
2.1 g of naphtha production and consumption	2.1 g bio-based naphtha	2.1 g refinery-based naphtha

The reference scenario shows how each of these product flows are matched from the existing producers, as shown in Figure 4 (b). The choice of which producers of each product group to select is based on which one is most likely to be affected with the introduction of the new supply from the bioenergy system. This is referred to as the marginal supplier[3] and this can be difficult to determine and may vary by region and over time, so some level of simplification maybe required. In the case of the high-protein animal market, there are many other co-products that are excluded as they cannot adjust to meet demand because they can only change product level when the determining product from which they are a co-product increases. For example, people will not eat more fries so a product system can create more used cooking oil. Lupins are an important part of the animal feed market but are lacking in some key nutrients. Soybean meal is a key source of animal protein, and can increase its production to meet demand, and is readily substitutable with canola meal (with some minor limitations). For other co-products such as propane and naphtha the selection is more straightforward, with one dominant production pathway from crude oil refining.

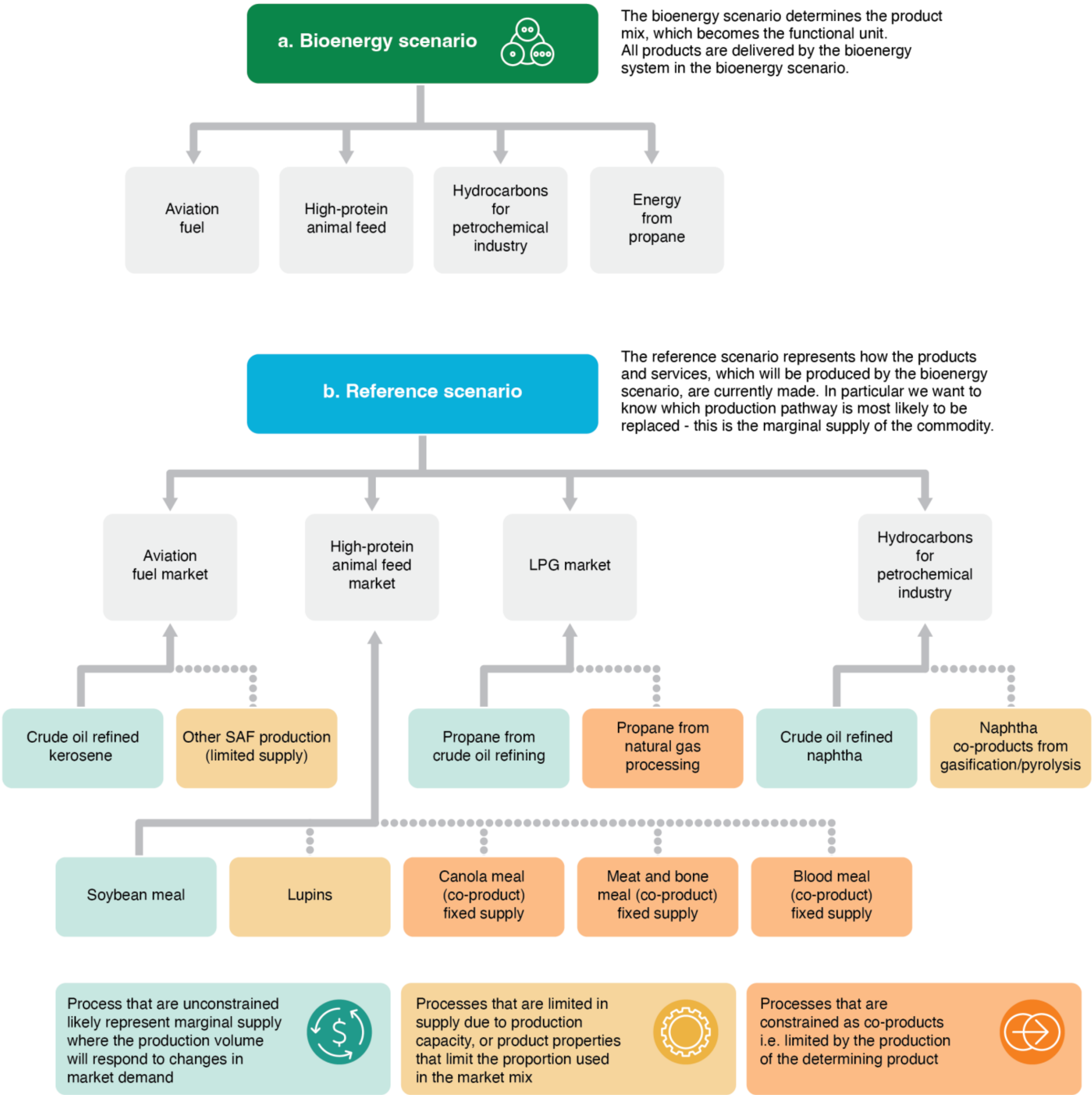


Figure 4: Matching bioenergy scenario products (a) with equivalent supply for the reference scenario (b)

Requirements

For the default *commodity approach,* the functional unit shall focus on the production of bioenergy so that it is comparable to the reference scenario. The functional unit shall be 1 MJ of thermal energy supply (or 1 kWh in the case of electricity). Any non-energy products are removed from consideration using the allocation procedure outlined in Section 2.5.

For the *project approach,* the functional unit shall include all products and services from the bioenergy scenario and should be scaled to 1 MJ of thermal energy supply (or 1 kWh in the case of electricity) with all other products and services being defined as the amount produced from the bioenergy scenario when it produces its 1 unit of energy.

Guidance

The definition of the functional unit should pay attention to the following:

- It needs to encompass all the options being covered in the study including the reference fuel/energy source. For example, the functional unit cannot be 1 MJ of biodiesel, instead, it needs to be 1 MJ of fuel combusted in diesel engines.
- It should be as specific as possible to help contextualise the use of the fuel. For example, if the fuel is fed into a natural gas network of the state gas grid, this regional requirement should be specified in the functional unit (e.g. production and combustion of 1 MJ of gas meeting natural gas standards from Victoria's gas distribution network).
- It should define the performance parameters. For example, if a biocrude is being produced, its energy content and key performance characteristics may need to be specified.

For the *commodity approach*, the functional unit is the production and use of 1 unit of energy in a specific context such as "the production and combustion of 1 MJ of aviation fuel" or "the generation of 1 kWh of electricity exported to the NSW grid".

For the *project approach,* attention needs to be paid to the quality parameters of each co-product. For example, if the bioenergy project produces animal feed as a co-product, the protein and energy content of the feed may both be important. Finding a single comparable conventional feed source may be difficult and a combination of other conventional feeds may be required to match the nutritional value of the feed co-product. In some circumstances the bioenergy co-product may need to be blended with other products before it becomes comparable with a conventional product. In these circumstances, additional blend material is added to the functional unit.

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

2.4 System boundary

Overview

The system boundary describes the processes to be included in and excluded from the LCA. It also describes the scope of the LCA and the boundary between different product systems.

For the default *commodity approach,* the system boundary is cradle to grave including all stages from feedstock production, fuel production, and distribution to ultimate combustion as shown in Figure 5 (a). In the *commodity approach* wastes are outside the system boundary and for co-products only a portion of the upstream production impacts are included based on the energy share allocation. The co-products created by the bioenergy system are removed from the system allocation based on energy content.

The system boundary for the *project approach* is shown in Figure 5 (b) and includes the management of wastes and the input and output of by-products and co-products. The description of the system boundary for the bioenergy scenario using the project approach is less complex than the reference scenario, which may be complicated as the energy and products will come from different production systems (this is exemplified in Figure 7).

Note that for energy systems, the end of life is usually at the point of combustion or shortly after if there are waste treatment processes associated with the combustion.

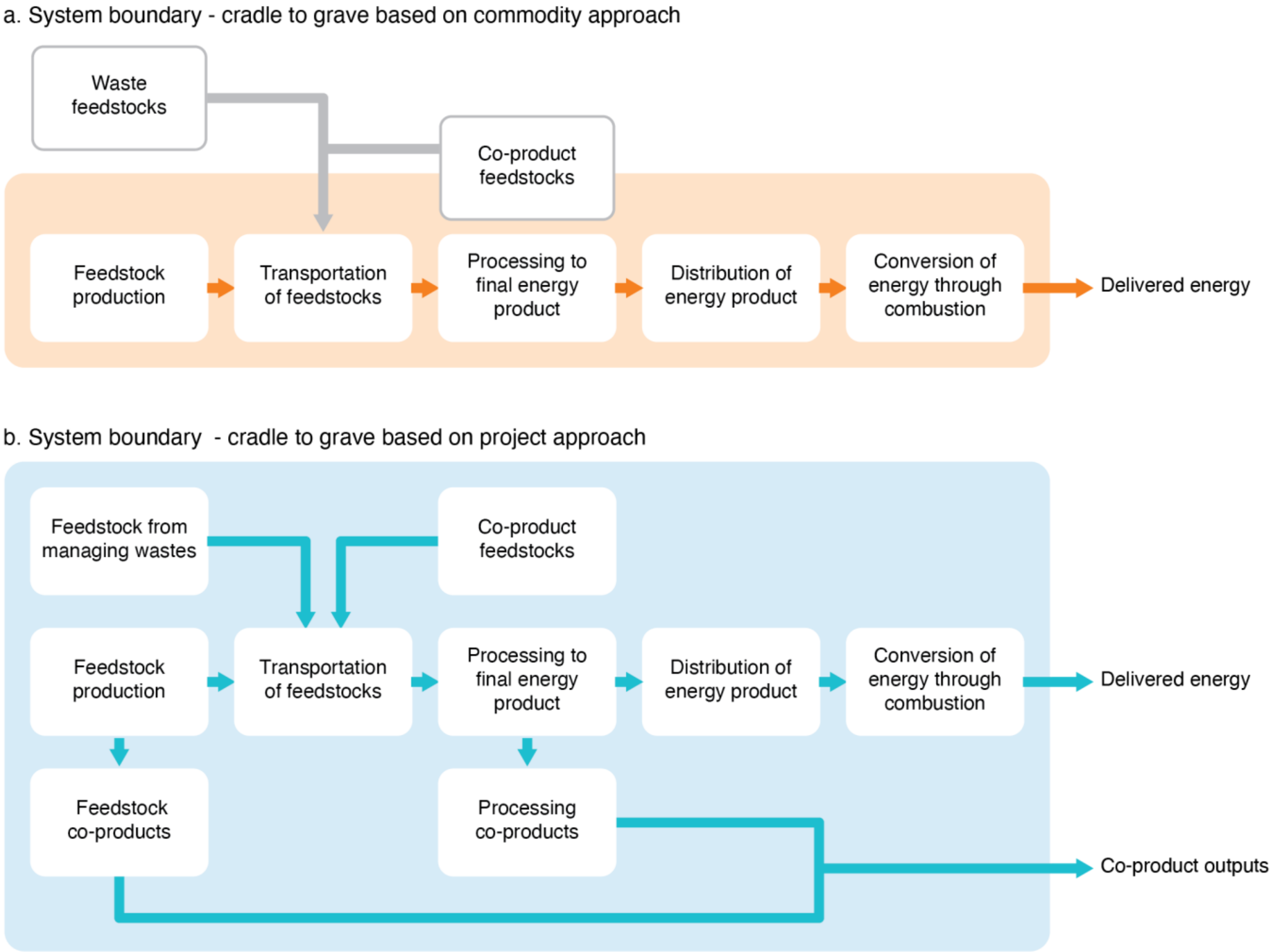


Figure 5: Cradle to grave system boundary diagram for (a) commodity approach and (b) project approach

Requirements

For the default *commodity approach*, the system boundary shall include all life cycle stages, cradle to grave, with the functional unit being the production of fuel and conversion to delivered energy. For products for which the end use is not clear, a common usage scenario shall be chosen and justified.

For the *project approach*, the system boundary shall be consistent with the *commodity approach* but include the life cycle stages of all products within the system.

Guidance

Following on from the example of the canola-based SAF project described in 2.3, the system boundary using the *commodity approach* could be represented as in Figure 6 with a single product supply chain, where any co-products are removed from the system based on energy content allocation (represented by the arrows' width). Note that the reference scenario system boundary shows a similar allocation based on the energy content of co-products.

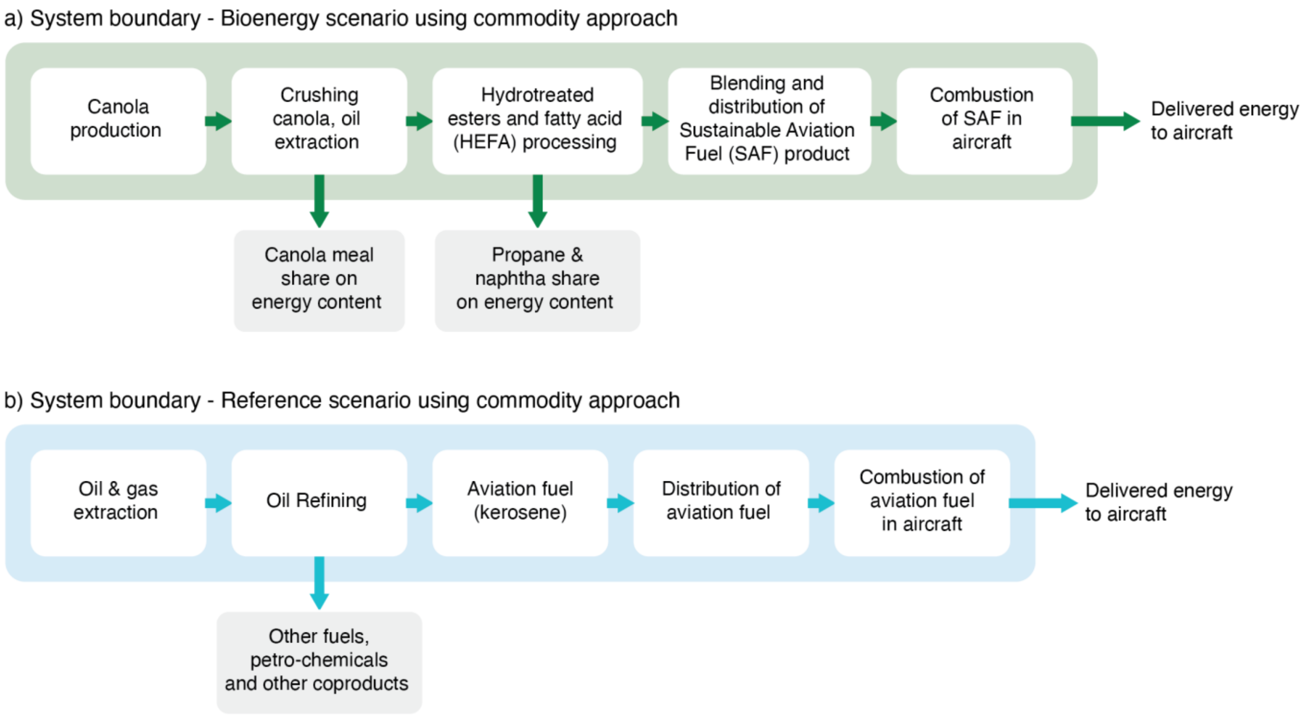


Figure 6: Example of system boundaries for (a) canola-based SAF with three co-products and (b) reference scenario, using the commodity approach

A system boundary using the *project approach* is shown in Figure 7 for both the bioenergy and reference scenarios. The bioenergy scenario based on SAF from canola is represented by one supply chain producing the SAF and three co-products. The reference scenario requires four separate supply chains to meet the same demands using conventional products (noting that, in this case, three of these are different versions of crude oil refining).

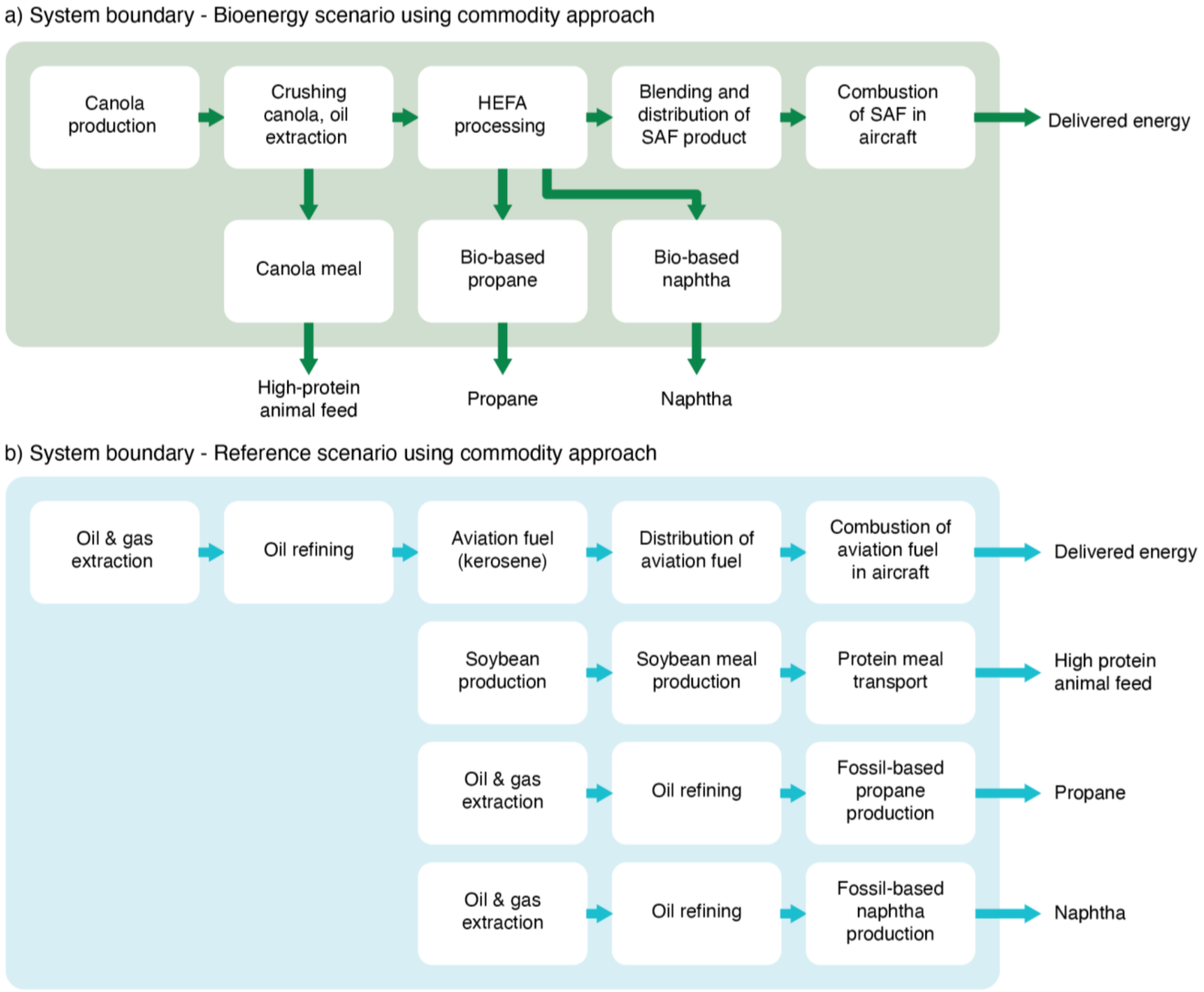


Figure 7: Example of system boundary for (a) canola based SAF with three co-products and (b) corresponding reference scenario, using the project approach

2.5 Multifunctionality and allocation

Overview

Multifunctionality, or co-production, refers to a process that creates more than one useful product output. The examples in Section 2.3 illustrate this process: the canola oil production produces a co-product of high-protein animal feed and the HEFA processing produces aviation fuel as well as co-products of propane and naphtha.

Co-products can also be inputs to bioenergy scenarios, such as molasses input to ethanol production. Additionally, many wastes or near-to-waste products are also used in bioenergy scenarios where the bioenergy scenario acts as a waste treatment service for the waste, such as starch waste used to make ethanol.

Approaches to dealing with multifunctional systems are highly debated in LCA, however the ISO 14044 LCA standard establishes a procedure that has been refined by UNEP/SETAC Global Guidance with more detail provided in the carbon footprint standard ISO 14067. The detail of this is explained in Appendix D, however, in summary:

- When it is possible to break the multifunction process, it should be broken into smaller units to avoid allocation.

- Or, when it is possible to describe the biophysical/causal relationships between inputs and emissions to the different products, this should be done (i.e. this can only be done when the ratio of co-products can be varied, for example fuel mixes produced by refineries).

When neither of these options can be done, there are two competing approaches for isolating the impacts from individual products from a co-producing process:

- The first is to apportion/allocate the impacts of the multifunction system (e.g. canola crushing) between the two products (e.g. canola oil and canola meal) based on a common measure of value (e.g. energy content or economic value) as proposed in the *commodity approach* of these Guidelines.
- The second involves expanding the system boundary to include the co-products, as proposed in the *project approach* of these Guidelines.

Requirements

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 emissions to output products
- allocation based on energy content for the *commodity approach* calculation
- system expansion to include all co-products[4] in the system boundary for the *project approach*.

The effects of alternative approaches to multifunctionality should be demonstrated in the *Final* LCA.

For simplicity, the *commodity approach* treats waste feedstocks and near-to-waste feedstocks as having zero impact. Near-to-waste feedstock includes products with inelastic supply and no value, which may result from by-products, residues from agriculture and forestry. Appendix E shows a list of feedstocks that can be treated as having zero impact.

When using the *project approach,* the alternative fate of the waste commodity shall be added to the reference scenario to balance the waste management service function. For example, if rice hulls are proposed to be used in a bioenergy process, but are currently sent to landfill, this landfill process should be added to the comparative reference scenario.

Guidance

The decision for choosing the allocation approach for these Guidelines is guided by the summary provided in Figure 8.

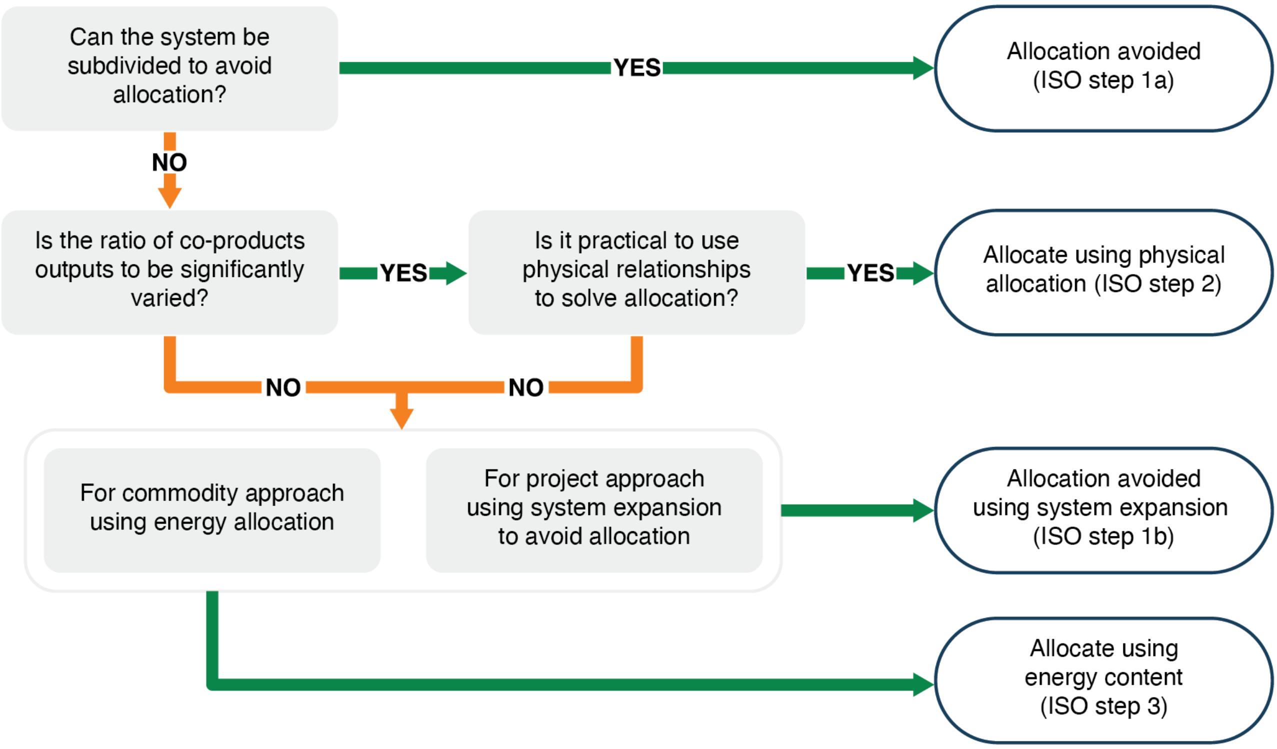


Figure 8: Decision tree for allocation approaches for ARENA Guidelines

All multifunction processes in the bioenergy scenario should be identified. For each input process coming from multifunction processes, the following should be done:

- Check if any of the multifunction processes can be broken into smaller subsystems to avoid the need for allocation.
- Determine if it is possible and practical to use the physical relationships between process inputs and co-product output and if so, consider using the physical allocation approach according to ISO 14044 step 2 in allocation hierarchy. An example would be how crude oil refineries alter the main output mix of products through different processing options.

If the feedstock input is a waste product or by-product:

- For the *commodity approach*
  - ➢ Check if it is an approved waste, residue or by-product (see Appendix E for guidance) and if so, its footprint is zero for the commodity approach.
  - ➢ If it is not on the approved list, use energy allocation to allocate upstream impacts between the feedstock and the other products coming from that system.
- For the *project approach*
  - ➢ Any impact for accessing the waste (additional transport or processing) is added to the bioenergy scenario.
  - ➢ For the reference scenario the current fate of the waste (waste management) and/or its use is modelled and added to the reference scenario.

If the output of the bioenergy scenario includes co-products, the following should be considered:

- For the *commodity approach* calculation, the system impacts should be allocated between the co-products based on their respective energy contents based on lower heating values.

- If the co-products contain significant (>20% by mass) non-energy products, or important waste treatment services, consider also undertaking the LCA using the *project approach* to better represent the non-energy value of the bioenergy project.

The approach taken to deal with multifunction processes can affect the results of LCA studies. When using allocation as the solution, the allocation key (e.g. energy content, mass or economic) can also affect the results. Energy content allocation is well suited to bioenergy co-products as it assigns emissions to co-products in proportion to their contribution to the total energy content of all the products, measured as the lower heating value. Lower heating value (or net calorific value) is the amount of heat released when the fuel is combusted without recovery of energy used to vaporise moisture in the fuel or the moisture formed from combustion. Gross or higher heating values include the recovery of energy from this vapour when it condenses (which is incorporated into some combustion technologies). If only a gross calorific value is found, and net calorific value can be calculated if the moisture content and hydrogen content of the fuel are known. The lower heating value is also distinct from digestible energy or metabolizable energy which represent the energy extractable from food by an animal. This latter value will typically be less than the lower heating value and thus should not be used.

However, for product systems with outputs that have other valuable properties (e.g. metal content, protein value), energy allocation may be an inaccurate allocation key as it will undervalue products with low energy even though they contain other desirable properties. For such product systems, the *project approach* outlined in these Guidelines is recommended as an additional calculation approach.

The default energy content values should be sourced from the most recently published National Greenhouse Account Factors (DCCEEW, 2024).

2.6 Reference scenario and benchmarking

Overview

The life cycle environmental performance of bioenergy scenarios 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, 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

The results of bioenergy LCA studies shall be compared to a reference scenario, 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 its specific market – assuming that the market demand for the energy system is not affected by the new production, and that the market demand in not growing faster than the increasing supply from the bioenergy scenario. For example, new renewable electricity supply into the national electricity market (NEM) may offset conventional fossil supply into the NEM.

ISO 13065 describes two different reference scenarios:

1. Business-as-usual (BAU)
2. Projected future

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

For the *commodity approach,* the reference scenario is the equivalent fossil fuel system.

For the *project approach,* the reference scenario is made up of the conventional/marginal supply of each of the products and co-product outputs in the bioenergy scenario. Additionally, for any co-product inputs used by the bioenergy scenario the alternative marginal supply of that product needs to be added to the reference scenario.

Where the bioenergy scenario product is electricity, the reference scenario shall be modelled using the residual electricity grid for the state(s) where the electricity is supplied.

Guidance

The marginal supply of a product is the supply that is most likely to vary with changes in demand. In the absence of other information, the average of current supply can be used as the marginal supply.

Appendix C provides a list of common reference scenarios that are comparable with current bioenergy scenarios.

2.7 Cutoff criteria

Overview

When building an LCA, there is a need to establish which processes and flows should be included. To manage this, a threshold for including different processes can be set, which is referred to, in the LCA standards, as the cutoff criteria. It 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 are 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.

EXAMPLE

APPLIED CUTOFF CRITERIA

The bioenergy plant burning biomass for energy has excluded the following items.

- Transportation of biomass with the site boundary (typically less than 1km) compared to feedstock transported over 100km to site (less than 1%).
- Minor shredding of biomass at forest collection site, which would normally be undertaken regardless of its use in facility.
- Maintenance materials and spare parts (<1% annual economic facility throughout).
- Cleaning chemicals used for cleaning reactions at end of week shut down (2 x 44 gallon drums per year) compared to biomass throughout of 1.2 million tonnes of biomass processed (<0.001% by mass).

The sum of these omissions is not expected to exceed 5% of the mass flow or climate change total of the product.

Requirements

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 final LCA report. The cutoff for individual flows shall be 1% and the cumulative contribution of the excluded processes should be less than 5%.

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. Significant supporting infrastructure would involve large-scale development that may extend beyond the project footprint and would be considered to be substantially larger infrastructure requirements than a typical factory and plant and equipment.

Capital equipment and infrastructure must be included in the final LCA for systems that meet either of the qualifiers mentioned above.

Modelling of the reference scenario should have the same infrastructure rule applied – being excluded when it is excluded from the bioenergy system and vice versa.

Guidance

The effort required for modelling the capital equipment should be commensurate with the scale of contribution it has to the final result. A detailed pipe-by-pipe description is usually not required and default infrastructure models from existing LCA databases may be sufficient to demonstrate the relative contribution from infrastructure to the overall project.

2.8 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 together into impact categories, for example ‘carbon dioxide emissions to air’ and ‘methane emissions to air’ are both linked to the climate change indicators.

While many different facets of environmental science use environmental indicators, in LCA they are particularly challenging because they assess elementary flows and their 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 with these challenges in mind.

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

Requirements

The impact categories for use in the LCA are:

- Climate change / carbon footprint
- Fossil fuels resource depletion
- Particulate matter formation
- Eutrophication
- Consumptive water use

- Land use.

In the *Proof of Concept LCA*s only climate change / carbon footprint should be reported. For example, to demonstrate carbon dioxide emissions to air:

The commodity footprint of biodiesel is 60 g CO_2e/MJ compared to the reference scenario of conventional fossil fuel diesel of 94 g CO_2e/MJ.

The remaining indicators are recommended for inclusion at this stage but are not compulsory. For the *Final* 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. 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 weightings based on value choices). Weighting is not allowed under the ISO 14044 standard for comparisons that are to be made public.

Characterisation models for each indicator are provided in Appendix F and the impact method is available on the AusLCI website (http://www.auslci.com.au).

Guidance

Although the environmental impact assessment requirements for the *Proof of Concept* LCAs 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 *Final* LCA. See Appendix G for examples of tools and resources available for LCA modelling.

2.9 Temporal aspects of the LCA

Overview

Most capital expenditures and investments in bioenergy scenarios 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/decommissioning environmental consequences.

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.

Requirements

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 accounting for 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.

2.10 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 is often associated with activities directly under the control of the proponent and can be collected directly. The background data is data needed to complete the LCA but will not be collected directly.

The scope and quality of the data used for the inventory modelling and analysis are limiting factors for the environmental impact assessment (see Section 2.8). Conversely, even with high-quality data on, for example, soil salinisation, invasive species or odour, there may not yet be methods available for assessing and including such impacts in LCA.

Requirements

Under this guidance, site-specific data should be used where available or where they can be derived from modelling, taking into account 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 multifunctionality – generic data that do not follow the same approach to allocation of co-products (e.g. 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 5%, of any indicators used in the LCA, its allocation should be adjusted to be consistent with this method.

Modelled electricity processes within organisation boundaries shall use a market-based approach as outlined in Chapter 7 of the National Greenhouse and Energy Reporting (Measurement) Determination 2008 (Clean Energy Regulator, 2025d). This includes the modelling of purchased green electricity where the appropriate life cycle inventory (LCI) data for renewables generation should be used, but especially for standard grid electricity supply, which should be modelled using the residual grid mix. The residual grid mix is the mix of electricity generated in a region after removing all the electricity generation that has been sold as green power or part of power purchase agreements.

Guidance

The LCA should prioritise databases and sources that are the best fit to the geographical location and technology used for the respective processes, sourcing data from the following in order of priority:

1. LCA databases
    - AusLCI database published by the Australian Life Cycle Assessment Society (ALCAS) (AusLCI, 2025)
    - ecoinvent 3 (Recycling cut-off version) published by the ecoinvent Centre (2025)
    - Agrifootprint (economic allocation version) (Blonk Agri-footprint BV,, 2022)
    - Sphera databases published by thinkstep (2025)
2. Previous LCA studies

3. Peer-reviewed scientific literature

There is no requirement on the data source, however practitioners should exercise discretion to use the best available data with appropriate data sources and justification, if necessary.

For electricity modelling, full LCI for residual electricity mixes are available for Australia in the AusLCI database and for some other regions in ecoinvent. Information about LCA software and database resources can be found in Appendix G.

2.11 Land use change (LUC)

Overview

ISO 14067 (2018) defines direct land use change (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).

EXAMPLE

dLUC INCLUSION

An ethanol facility is planning on sourcing sorghum from an area which includes 120 hectares of conversion of forest to cropping. Using the FullCAM model, the impact is 3.94t per hectare per year. The footprint of the land use change of 472t CO_2.

The indirect land use change (iLUC) definition is based on ISO 14067 (2018) and is described as a change in the use or management of land as a consequence of dLUC, 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 lacks any clear agreement on calculation methods.

EXAMPLE

iLUC INCLUSION

The ethanol facility also sources sorghum from 15,000 hectares of existing cereal cropping area. This additional demand will have the potential to induce land use change; however, this will be ameliorated by the supply of high-protein feed from dried distillers' grains and soluble (DDGS) which can reduce demand for other protein sources such as wheat. There is also potential to grow a proportion of the sorghum in place of fallows normally placed between existing wheat crops.

Requirements

The carbon dioxide impacts from dLUC shall be calculated for all land use activities within 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 compared to that after the bioenergy project and amortises this over 20 years. The scale of the dLUC to be assessed will vary between projects, with some projects having a specific landholding that can be assessed, to others sourcing from a broader region, and others from national markets. The scale of land use change calculations shall be consistent with the expected source area.

While there are some published iLUC values internationally, there is no agreed approach, despite there being a recognition that iLUC is an important issue. Bioenergy proponents shall discuss the potential for the project to lead to displacing land uses from within the bioenergy area to other areas in Australia or internationally. Secondly, proponents should present what strategies are being undertaken to reduce indirect effects of land use displacements within and outside the bioenergy project boundary.

dLUC and iLUC values included in background datasets should be excluded from the LCA but should be identified and included in the iLUC risk discussion.

Where applicable, the calculation for the *project* and *commodity approach* should be consistent.

Guidance

Calculating dLUC is difficult, especially when feedstocks come from different regions, which may vary from year to year. Land use change can be calculated directly using land clearing data and the consequent change in carbon stocks. This could be sourced from published values for above and belowground biomass and soil carbon stocks or can be modelled using a tool such as the Full Carbon Accounting Model (FullCAM).

2.12 Treatment of fossil, biogenic and atmospheric carbon

Overview

When inventorying carbon dioxide (CO_2) 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. CO_2 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 CO_2.

In the GHG reporting frameworks (Clean Energy Regulator, 2025d), there is a general assumption that the uptake of carbon dioxide into biomass and emissions from biomass are balanced. This is referred to as the 'biogenic carbon neutrality assumption' (Kouchaki-Penchah, et al., 2023).

The type of flows that are excluded when using the biogenic carbon neutrality assumption are shown in Figure 9.

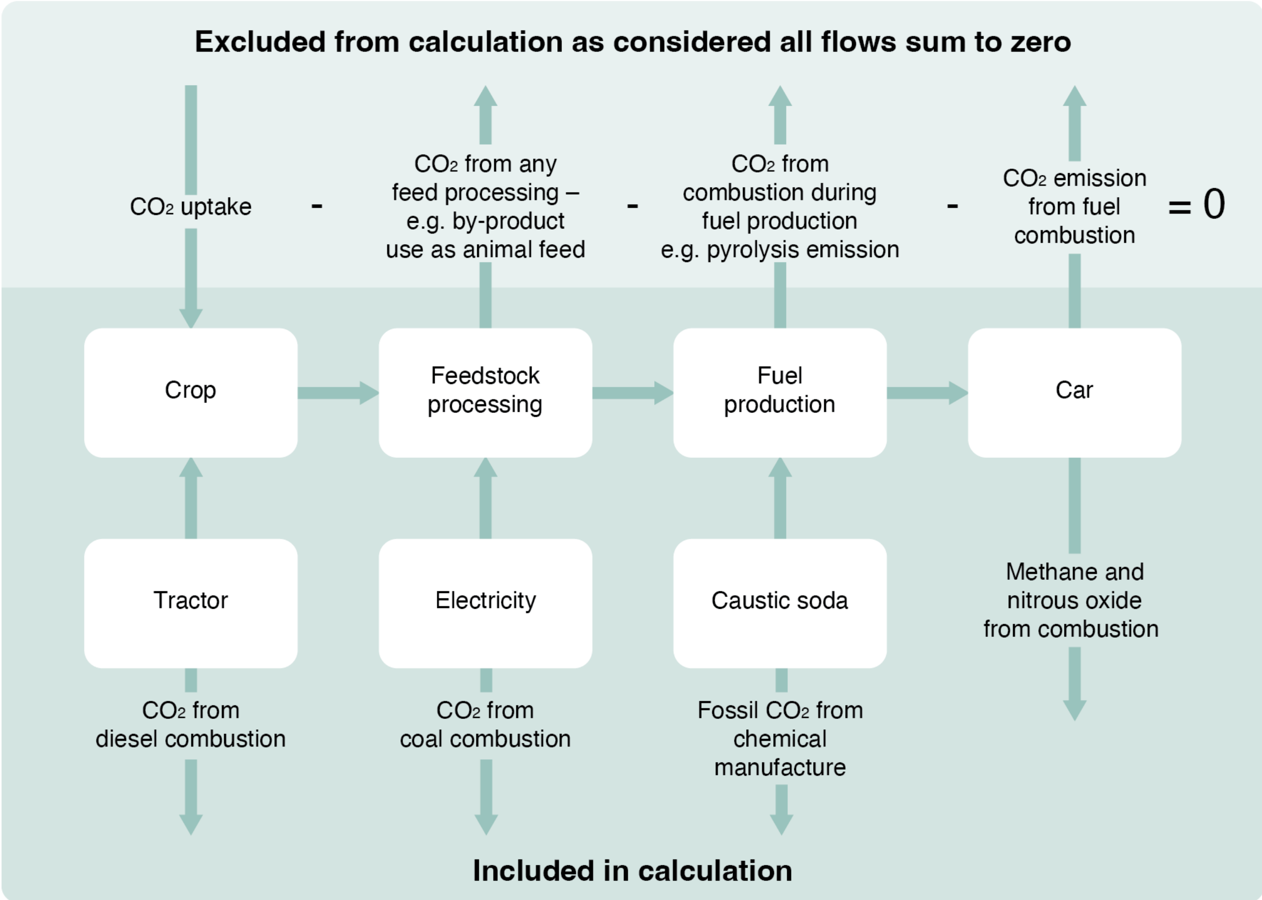


Figure 9: Description of which carbon flows are included and excluded when using the biogenic carbon neutrality assumption

Requirements

The LCA can be reported using the biogenic carbon neutrality assumption as long as all the biogenic carbon in output products is oxidised into CO_2 through combustion or degradation. If any output products contain un-oxidised biogenic carbon, or the biomass system includes changes in above or belowground carbon impacts, then a full biogenic carbon balance shall be used.

When a full biogenic carbon balance is used, all flows of carbon between different carbon pools (atmosphere, fossil, biosphere) shall be included and documented separately in the inventory. These include GHG emissions and removals:

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

The naming conventions used for different carbon flows in the LCI is shown in 9. These are used in the carbon balance and highlights the flows included when using the biogenic carbon neutrality assumption. It includes methane and carbon monoxide because these are part of any carbon balance.

Table 9: Carbon-related flow descriptions and inclusions

Direction of flow	Inventory name	Example	Full biogenic carbon balance	Biogenic carbon neutrality assumption
Input from nature	Carbon dioxide, in air	Carbon absorbed during growth of biomass	Included	Excluded
Input from nature	Carbon, organic, decrease in soil or biomass stock	Loss of soil carbon		
Output to nature	Carbon dioxide, biogenic	Emission from combustion or degradation of biomass	Included	Excluded
Output to nature	Carbon dioxide, fossil	Emission from combustion of diesel fuel	Included	Included
Output to nature	Carbon dioxide, land transformation	Net emission from soil carbon change due to land use activity	Included	Included
Output to nature	Carbon dioxide, to soil or biomass stock	An absorption of carbon dioxide into biochar or long-term soil carbon increase	Included	Included
Output to nature	Methane, biogenic	Emission of methane from biogas production facility	Included	Included
Output to nature	Methane, fossil	Emission of methane from natural gas distribution	Included	Included
Output to nature	Carbon monoxide, biogenic	Emission from combustion or degradation of biomass	Included	Excluded
Output to nature	Carbon monoxide, fossil	Emission from combustion of diesel fuel	Included	Included

Guidance

Using the biogenic carbon neutrality assumption simplifies the analysis of the LCA model but it relies on the correct identification of biogenic carbon emissions. If using the carbon neutrality assumption, when bio-based fuels are combusted, all carbon-related emissions should be identified as biogenic and not included in the carbon footprint calculation. Where the fuel is a blend, the biogenic carbon component of the fuel needs to be identified and the emissions from this component identified as biogenic while any fossil portion of the blend must be identified and treated as leading to fossil emissions.

If the LCA is going to complete a full biogenic carbon balance, practitioners will need to ensure that carbon absorption in the biomass system and re-emissions at each part of the supply chain are included. It also means that a carbon balance is required after any allocation is applied to the inventory data.

Note: 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.

For changes in soil carbon resulting from changes in land management, soil carbon stocks must be estimated using specified soil sampling methods in line with the Clean Energy Regulator guideline (Clean Energy Regulator, 2025f). This soil carbon change shall be reported separately and shall not be included in the default carbon footprint until the abatement is certified in accordance with the Clean Energy Regulator guidelines.

For biogenic carbon incorporated into stable carbon such as biochar, Puro.earth provides guidelines on this approach (Puro Earth, 2025). Biogenic carbon stored in biochar can be included in the default carbon footprint but shall be reported separately.

2.13 Critical review

Overview

Critical review of LCA studies improves the quality and independence of the LCA. The critical review focuses in particular on the appropriateness of the data used and the 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.

Requirements

An ISO 14044 compliant critical review of the *Final* 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; or
- have been involved in at least five peer-reviewed LCA studies; or
- be a Life Cycle Assessment Certified Practitioner (LCACP) – administered by ALCAS[5] or the American Centre for Life Cycle Assessment.

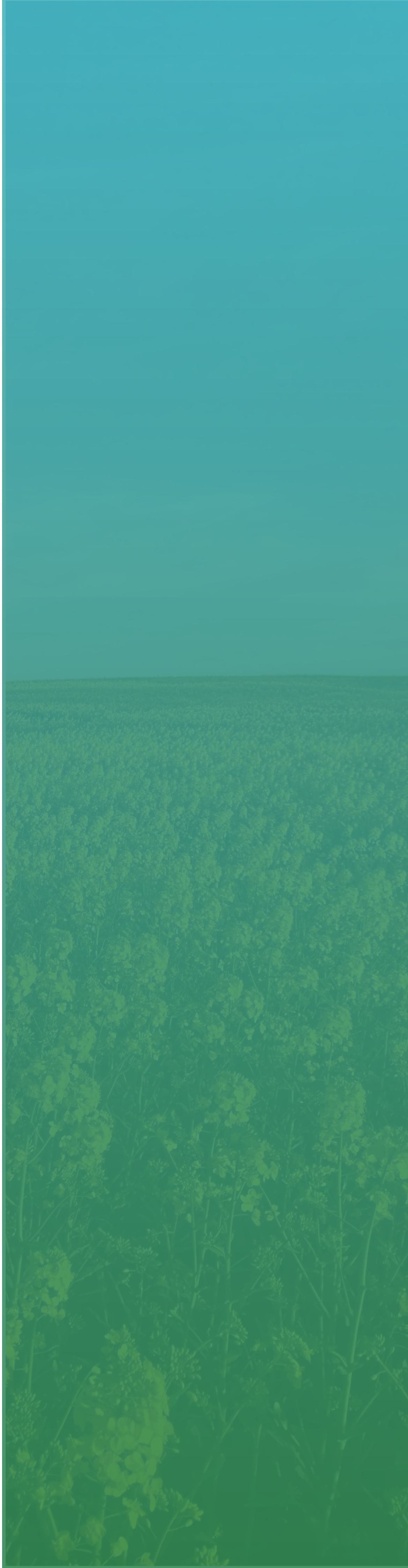
Guidance

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. The verification should adhere to the ISO 14071 guideline.

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 non-disclosure agreement may be used for the critical review process, if the report contains any sensitive information.

3 | References



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4 | Appendices

Appendix A – Accepted regulatory schemes for Proof of Concept LCA

These Guidelines allow for the use of LCA values calculated in accordance with the methodologies of the approved international regulatory schemes to meet certain requirements as outlined in Table 10.

Table 10: Accepted regulatory schemes to be used for Proof of Concept LCA

Standard	Administered by	Overview
Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) – Eligible Fuels (ICAO, 2024a)	International Civil Aviation Organization (ICAO)	For international aviation operators to recognise Sustainable Aviation Fuel (SAF) as part of the CORSIA obligations, the SAF must meet specific requirements on LCA, sustainability and traceability.
European Union Renewable Energy Directive (EU RED III) (European Commission, 2023)	European Commission & European Environment Agency, National Authorities	Biofuels and bioenergy products in the EU must comply with LCA requirements, land use change and environmental impacts.
Guarantee of Origin Scheme (GO Scheme) (Clean Energy Regulator, 2025c)	Clean Energy Regulator	The GO Scheme is the Australian Government assurance scheme to verify and track emissions of renewable and low emissions products. The GO Scheme's rules and methodologies are planned for development in 2025.
ISCC PLUS (ISCC, 2024)	International Sustainability and Carbon Certification (ISCC)	ISCC provides certification for biofuels meeting global sustainability standards with relevant requirements for LCA. This is a voluntary standard or applies to non-regulated markets.
RSB Global Fuels Certification (RSB, 2025)	Roundtable on Sustainable Biomaterials (RSB)	RSB provides certification for biofuels meeting global sustainability standards with relevant requirements for LCA. This is a voluntary standard or applies to non-regulated markets.
US EPA Renewable Fuel Standard (RFS) (U.S. EPA, 2025)	United States Environment Protection Agency (US EPA)	Fuel producers supplying to the US must calculate LCA to meet GHG requirements.
California Low Carbon Fuel Standard (LCFS) (CARB, 2025)	California Air Resources Board (CARB)	Fuel producers supplying to California must calculate LCA to meet GHG requirements.

Standard	Administered by	Overview
United Kingdom Renewable Transport Fuel Obligation (UK RTFO) / UK SAF Mandate (UK Department of Transport, 2025)	UK Department of Transport	Fuel suppliers to the UK must meet specific LCA and sustainability criteria for use in the UK.
International Maritime Organisation (IMO) – Net Zero Framework (in progress) (Marine Envrionment Protection Committee, 2024)	IMO	IMO has adopted LCA guidelines that are not yet mandatory but is working towards integrating within the GHG reduction frameworks.

Appendix B – Technology Readiness Level (TRL) and Commercial Readiness Index (CRI)

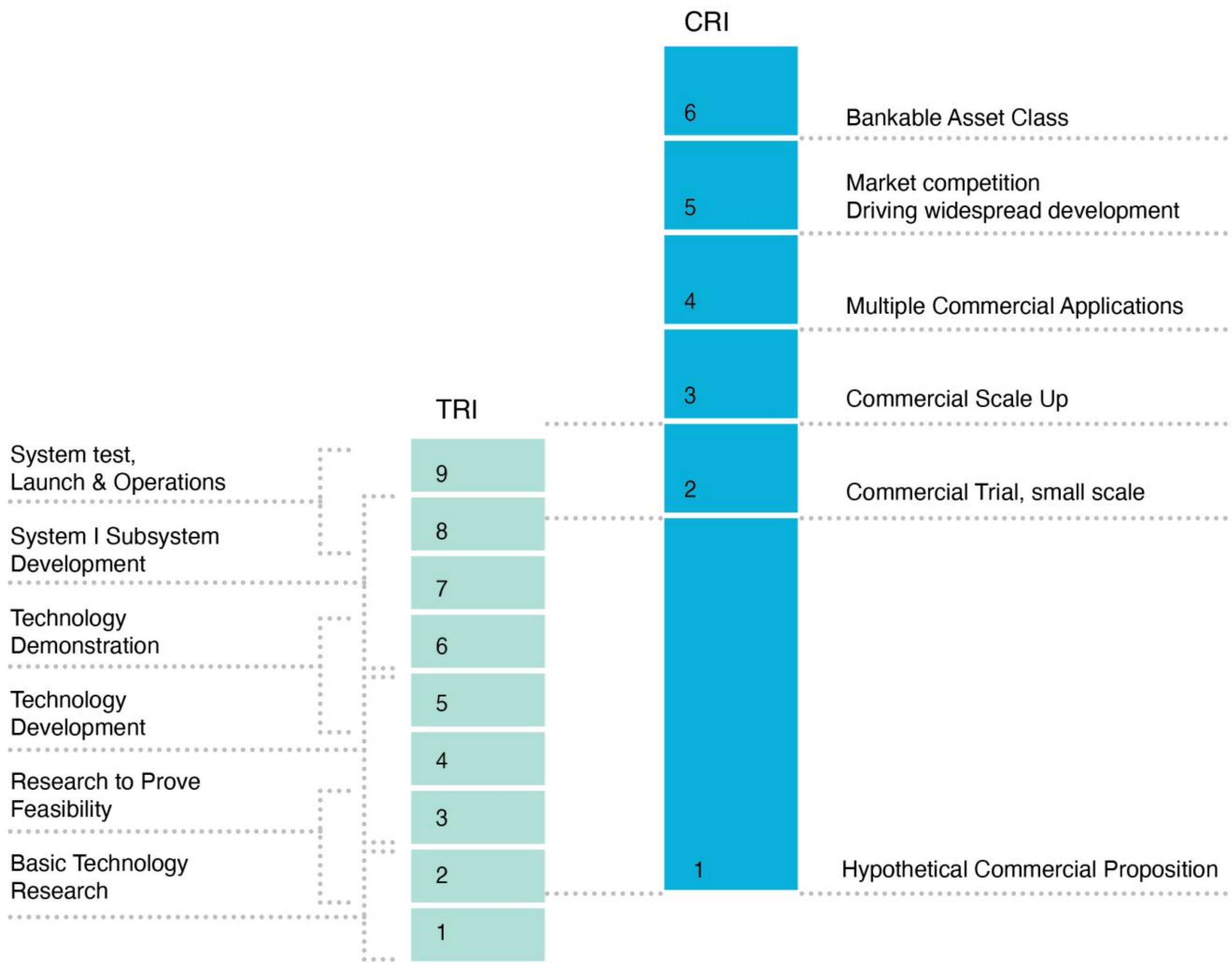


Figure 10: Technology Readiness Level (TRL) and Commercial Readiness Index (CRI). Source: (ARENA, 2014).

Appendix C – Examples of commodity and project approaches for different bioenergy projects

Table 11 provides illustrative examples of functional units and the associated reference flows for different bioenergy projects. All values on hypothetical and created to demonstrate the example and do not represent real world projects.

Table 11: Examples of commodity and project approaches

Example bioenergy scenario	Commodity approach	Project approach
Energy from waste using pyrolysis Feedstock of 50% municipal solid waste (MSW) and 50% forest residues. Assuming the product split for the pyrolysis unit is 60% bio-oil, 25% biochar and 15% wood vinegar.	**Functional unit** 1 MJ refinery feedstock converted to diesel and combusted	**Functional unit** 1 MJ refinery feedstock converted to diesel and combusted 9.6 g char 5.7 g animal feed supplement 58 g MSW management 58 g forestry waste management
	Bioenergy scenario – reference flow 1 MJ bio-oil converted to diesel in a refinery and combusted	**Bioenergy scenario – reference flow** 1 MJ bio-oil converted to diesel in a refinery and combusted 9.6 g biochar 5.7 g wood vinegar as feed supplement 58 g MSW treated through pyrolysis 58 g forestry waste treated through pyrolysis
	Reference scenario – reference flow 1 MJ crude oil imported to Australian refinery, converted to diesel and combusted	**Reference scenario – reference flow** 1 MJ crude oil imported to Australian refinery and converted to diesel and combusted 9.6 g coal char 5.7 g wood vinegar equivalent feed additive 58 g landfilled MSW 58 g forestry waste degradation on site
	Allocation Allocation is used to attribute its share of impacts to the bioenergy product (based on energy content). All waste feedstocks come with zero burden. The choice of diesel as the final product is based on a scenario choosing the most likely option/highest volume end product.	**Allocation** Allocation is not required.

Example bioenergy scenario	Commodity approach	Project approach
Biomethane from organic waste Assuming biomethane is produced by anaerobic digestion (AD) of commercial food waste with co-production of digestate and capture of CO_2 for industrial markets. Assuming 1,200 MJ of biogas (methane) per wet tonne of food waste.	**Functional unit** 1 MJ natural gas equivalent combusted **Bioenergy scenario – reference flow** 1 MJ biogas combusted **Reference scenario – reference flow** 1 MJ regional natural gas supply combusted **Allocation** Allocation is used to attribute its share of impacts to the biogas (based on energy content).	**Functional unit** 1 MJ natural gas equivalent combusted 0.85 kg food waste management soil conditioner with 0.004 kg N fertilisation 0.02 kg CO_2 **Bioenergy scenario – reference flow** 1 MJ biogas combusted 0.85 kg food waste management using AD 0.28 kg digestate from AD 0.02 kg CO_2 from biogas purification **Reference scenario – reference flow** 1 MJ regional natural gas supply combusted 0.85 kg food waste to composting 0.3 kg soil conditioner from compost 0.02 kg CO_2 from separation at natural gas wells **Allocation** In this example the compost from conventional aerobic composting and the output of the AD plant are assumed to be similar enough to be equivalent.
SAF from sugar mill residues Using sugar mill residues and hydrothermal liquefaction to convert into sustainable aviation fuel (SAF) and other low-carbon liquid fuels such as renewable diesel and low-sulphur marine fuels.	**Functional unit** 1 MJ aviation fuel combusted **Bioenergy scenario – reference flow** 1 MJ SAF combusted **Reference scenario – reference flow** 1 MJ kerosene jet fuel combusted	**Functional unit** 1 MJ aviation fuel combusted 0.4 MJ diesel combusted 0.24 MJ marine fuel combusted **Bioenergy scenario – reference flow** 1 MJ SAF combusted 0.4 MJ renewable diesel combusted 0.24 MJ low-sulphur bio-based marine fuel combusted **Reference scenario – reference flow** 1 MJ kerosene jet fuel combusted 0.4 MJ conventional diesel combusted 0.24 MJ conventional marine fuel combusted

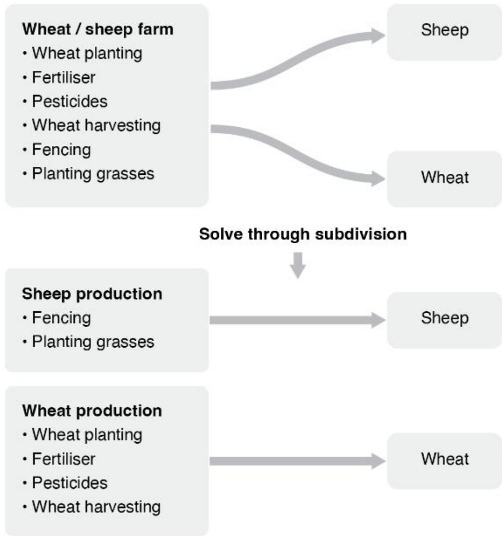
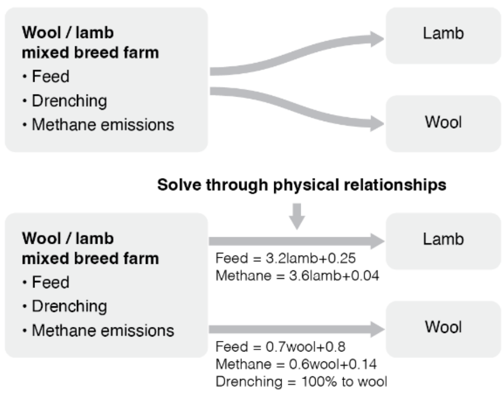
Example bioenergy scenario	Commodity approach	Project approach
	Allocation Allocation used to attribute its share of impacts to the SAF (based on energy content). All residues come with zero burden. **Note** A separate LCA could be calculated for 1 MJ of diesel or 1 MJ of marine fuel using the same energy-based allocation. The energy **allocation** approach allows each co-product to be dealt with independently.	**Allocation** Not required.
Biosolids gasification Using a gasification process on sewage sludge to provide biogas.	**Functional unit** 1 MJ equivalent natural gas combusted **Bioenergy scenario – reference flow** 1 MJ biogas combusted **Reference scenario – reference flow** 1 MJ regional natural gas supply combusted **Allocation** Allocation used to attribute its share of impacts to the biogas (based on energy content).	**Functional unit** 1 MJ equivalent natural gas combusted 10 mg char **Bioenergy scenario – reference flow** 1 MJ biogas combusted 10 mg biochar **Reference scenario – reference flow** 1 MJ regional natural gas supply combusted 10 mg coal char **Allocation** Not required.
Ethanol from molasses for vehicle fuel	**Functional unit** 1 MJ of fuel production and combustion in a gasoline engine **Bioenergy scenario – reference flow** 1 MJ bioethanol combusted in a petrol engine, blended as part of 10 blend	**Functional unit** 1 MJ of fuel production and combustion in a gasoline engine 4 g of potassium-rich soil conditioner 0.205 kg fermentation feedstock for monosodium glutamate **Bioenergy scenario – reference flow** 1 MJ of fuel production and combustion in a gasoline engine 4 g of bio dunder 0.205 kg of casava starch

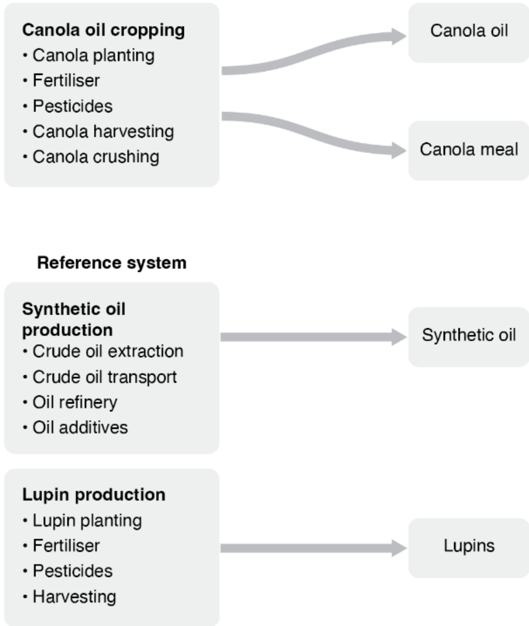
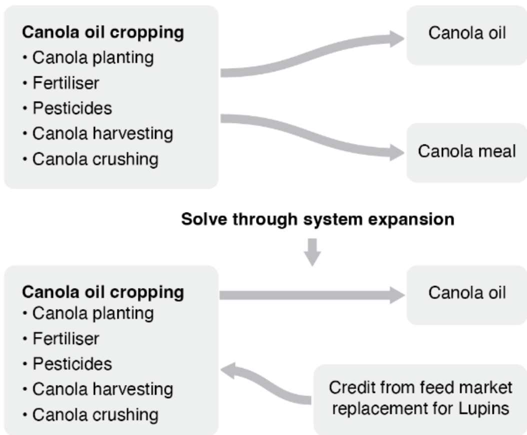
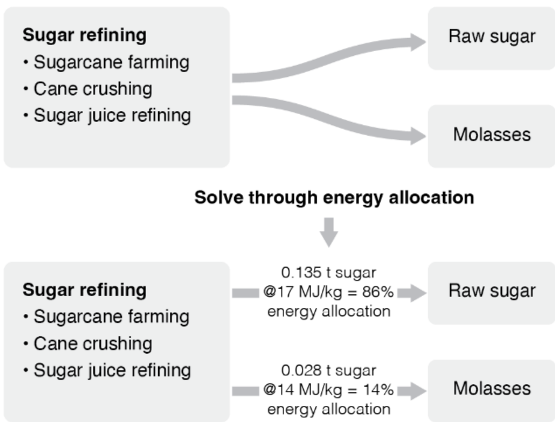
Example bioenergy scenario	Commodity approach	Project approach
	Reference scenario – reference flow 1 MJ gasoline combusted in a petrol engine **Allocation** Allocation is used to attribute its share of impacts to the biogas (based on energy content).	**Reference scenario – reference flow** 1 MJ gasoline combustion in a petrol engine 2.3 g potassium chloride 0.205 kg molasses **Allocation** Not required. **Note** As a co-product input the molasses in the Reference scenario is used as a fermentation input. In the Bioenergy scenario an equivalent feedstock needs to be added to account for the gap left by the molasses.

Appendix D – Explanation of methods to deal with co-production

Table 12 describes the five options for addressing allocation in multifunctional systems, presented in order of preference from ISO 14044. In line with the recommendations from the United Nations Environment Programme (UNEP), option 2 has been moved ahead of system expansion as it is only applicable to combined production where the production volume of different co-products can be varied. Option 1b system expansion is shown both with and without substitution of co-products. Note these Guidelines recommend option 3 for the *commodity approach* and option 1b1 for the *project approach*.

Table 12: Description of options for solving allocation in multifunctional systems (in order of preference from ISO14044)

Option	Solution description	Graphical representation
ISO 14044 Option 1a	Dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes separately. For example, for farming establishments producing wheat crops and sheep, subdividing and collecting data on inputs such as diesel, fertilisers, etc. for energy crop production and pastoral operations separately, would avoid the need for allocation.	
ISO 14044 Option 2	Physical relationships: for combined production, where the co-products amounts are not fixed but can be changed, the impacts are allocated based on how the physical relationships between inputs and emissions change as the ratio of co-products changes. This will take the form of a mathematical relationship on how feed and emissions change with the different ratios of wool and lamb production.	

Option	Solution description	Graphical representation
ISO 14044 Option 1b1	System expansion refers to the process of including the co-product(s) into the system boundary. This means that when comparing it to an alternative system the boundary is also expanded to meeting the same number of co-products. For example, canola oil production will have canola meal as a co-product. The system boundary is expanded to include the high-protein animal feed function (i.e. the main use of wheat straw). This function is also added to any system that is compared to the Bioenergy scenario. This is the method recommended for the *project approach* in these Guidelines.	
ISO 14044 Option 1b2	System expansion with substitution refers to the process of including the co-product(s) into the system boundary and then removing it by providing a credit equal to the functional value of the co-product. For example, canola oil production has high-protein meal as a co-product. The system boundary is expanded to include the high-protein animal feed function (i.e. the main use of canola meal). This function is then removed from the functional unit by subtracting an equivalent functional amount of pasture hay.	
ISO 14044 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 energy or economic value of the co-products. This is the method recommended for the *commodity approach* in these Guidelines.	

Appendix E – Waste, residue or by-product feedstocks

The list of feedstocks that can be classified as a waste, residue or by-product is extensive. Feedstocks that are classified as waste feedstocks in international reporting frameworks can be considered as having zero emissions from feedstock cultivation or production. The transport of the feedstock shall be included.

ARENA does not provide a 'positive list' but recommends proponents refer to international lists for guidance:

- Union Database for Biofuels (Europe) (European Commission, 2025)
- United Kingdom SAF Mandate and Renewable Transport Fuel Obligation (UK Department of Transport, 2020)
- CORSIA Eligible Fuels (ICAO, 2024b)

Figure 11 provides an overview of the assessment of the classifying feedstocks as waste, by-products, processing residues or co-products.

ARENA is providing a flexible approach and will follow international practice based on the approved schemes in Appendix A. There are differences between some international schemes. For example, CORSIA allows for certain by-products (e.g. beef tallow) and co-products (e.g. molasses) in the positive list. Where there is uncertainty on whether the feedstock is considered a waste, residue or co-product for the purposes of the bioenergy project, proponents are encouraged to engage with ARENA.

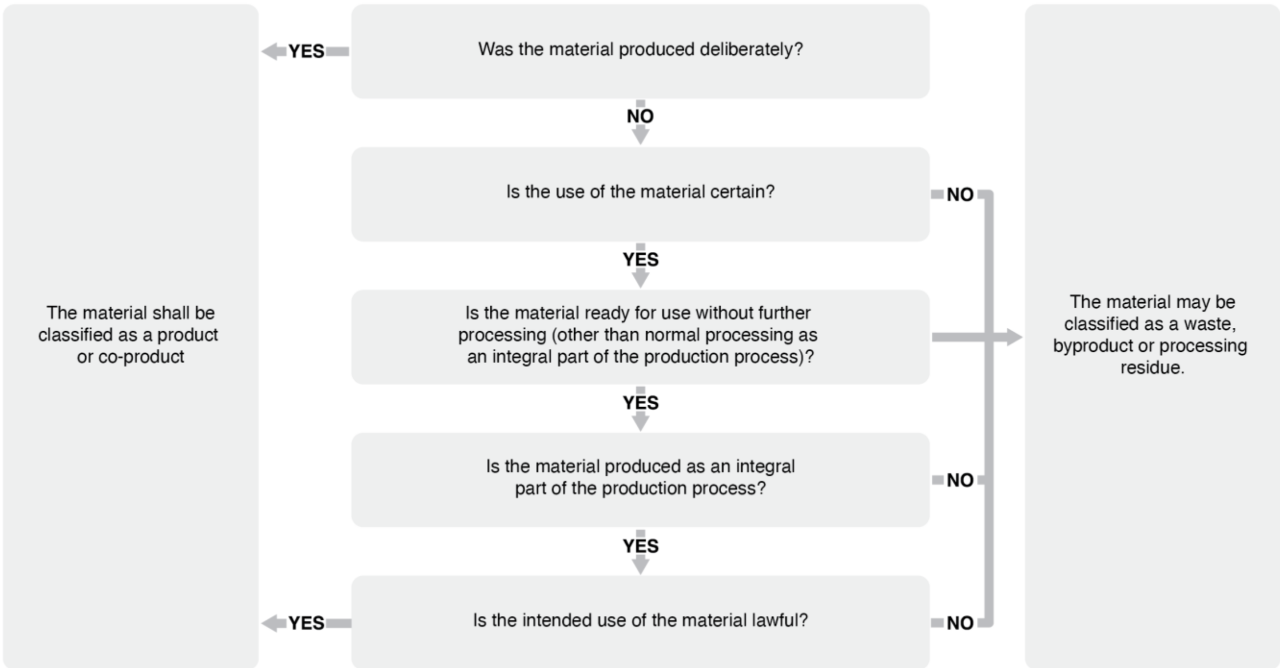


Figure 11: Process to determine feedstock classification adapted from RSB EU RED Standard for Advanced Fuels (wastes and residues) (RSB, 2025)

Appendix F – Explanation of environmental indicators

An overview of the environmental impact assessment indicators and characterisation models to be used for the calculation of the LCA is provided in Table 13.

Table 13: Impact assessment categories and characterisation models retained in this LCA

Indicator	Description	Characterisation model
Global Warming Potential 100 (GWP100)	Measured in kg CO_2 equivalents (kg CO_2e). This is governed by the increased concentration of greenhouse 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.	The model should be consistent with the most recent Australian National Greenhouse Account Factors (DCCEEW, 2024). At the time of this guidance publication, the factors applied are the IPCC 5th Assessment Report model based on a 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 deaccumulation.	All fossil energy carriers based on relative scarcity.
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.	Regionalised data from UNEP/SETAC GLAM (Payen, Cosme, & Elliott, 2021).
Particulate matter	Measured in particulate matter less than 2.5 microns. Considers particulate matter emissions that increased human disease incidence. Particulate matter is released to the atmosphere from incomplete combustions, aerosol gases and dusts.	Regionalised data from UNEP/SETAC Global Guidance on Environmental Life Cycle Impact Assessment Method (GLAM) (Fantke, et al., 2021).
Land use	Measured as kg soil organic matter (SOM) (kg C/m^2/year) Shows changes in SOM. Biodiversity impacts not covered by the data set.	Land use ecosystem services from GLAM (De Laurentiis, et al., 2024).
Consumptive water use	Measured as L H_2O eq. global average water scarcity. Quantity of water extracted directly from the environment, thereby competing with environmental and other human requirements for water.	AWARE consensus model from Water Use in LCA (WULCA) and GLAM (Boulay, et al., 2018).

Appendix G – 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 licence fee, including SimaPro and Sphera. These include access to LCI databases, which require ongoing maintenance such as Australian Life Cycle Inventory Database Initiative AusLCI, ecoinvent and Sphera databases. There is also openLCA, which is a free open-source software package offering both free and commercial LCA datasets.

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

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