Report for the Australian Renewable Energy Agency

Literature Review for Establishing a National LCA Approach for Australian Bioenergy

By Edge Environment and Life Cycle Strategies, in consultation with Prof. Annette Cowie and Meo Carbon Solutions GmbH

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Contents

1 Bioenergy and Life Cycle Assessment (LCA)

Bioenergy is increasingly used to help meet greenhouse gas (GHG) and renewable energy targets. Australia's bioenergy industry currently uses a range of biomass resources, including bagasse, landfill gas, wood waste and black liquor, energy crops, agricultural products and municipal solid waste. Traditionally, mainly woody biomass has been used for bioenergy, but more recent technologies have expanded the potential resources to those such as agricultural residues, oilseeds and algae.

A variety of conversion pathways can be used to convert biomass into downstream products and bioenergy, including anaerobic digestion, hydrothermal liquefaction, pyrolysis, combustion, transesterification etc. The choice of pathway and technology depends on the type of biomass material and desired bioenergy and/or co-product outcome. Some processes can be relatively simple, like growing, harvesting and burning wood for heat generation. Other complex processes, like algae production for transport fuels, require a controlled growing environment using specific microalgae species, and the algae are then processed to separate the oils which are refined into biofuels (State Government of Victoria, 2015).

The modes of use of bioenergy and biofuels are varied, including transportation and aviation fuel, stationary electricity production, process heat used in manufacturing. The range of by-products/process wastes include biochar, glycerine and ash.

Life cycle assessment (LCA) has emerged as an approach to quantify and account for environmental impacts in a product life cycle and has served regulatory and permitting needs for decades (Taylor & McManus, 2013). When a tool was needed, LCA was a logical choice, and it now forms a core component of several biofuels policy instruments, including:

- EU Renewable Energy Directive
- UK DfT Renewable Transport Fuel Obligation
- US EPA Renewable Fuel Standard
- California Air Resources Board's Low Carbon Fuel Standard.

Originally focused on accounting for current or past impacts on existing projects, LCA is becoming forward looking to assess future impacts of a more consequential nature. The methods are evolving as LCA is asked to answer fundamentally different questions (McManus M. et al., 2015). Because heavy use of LCA in bioenergy decision-making entered from the climate discourse, most of the emphasis thus far has been on GHG emission balances. However, as engagement with broader sustainability standards has grown, the metrics space has begun to broaden to include social and ecosystem impacts amongst others. Although a conceptually simple tool, it can become challenging in practice (McManus & Taylor, 2015).

Specific challenges for applying LCA for comparisons and decision-making regarding bioenergy projects and products include accounting for the broad range of possible biomass resources, conversion pathways and possible uses and markets for co-products. Additionally, a challenge for applying LCA relates to appropriately encompassing and accounting for the broad range of relevant environmental and sustainability-related metrics and results relevant to answering the questions asked from the LCA.

2 Project Context

Edge Environment and Life Cycle Strategies are pleased to be working with ARENA to establish a National LCA Approach for Australian Bioenergy (the Project). The purpose of the Project from the initial scope is to develop a standardised methodology and guidance for funding proponents to ARENA. The aim of the LCA methodology is to:

- Guide more effective decision-making by providing a 'level playing field' benchmark that enables ARENA to compare funding application and completed projects against each other, taking into account multiple feedstocks, conversion platforms and co-products.
- Support 'due diligence' by ensuring the projects ARENA supports are able to deliver a net benefit in terms of, for example, GHG footprint, land use changes (LUCs), social impacts and energy balance.
- Manage the potential for reputational risk inherent in funding projects that may involve environmental and/or social sensitivities (that may often be quite geographically specific), and which go beyond carbon intensity alone.
- Providing clarity about the proportion of a given bioenergy/biofuel project that directly relates to the output of renewable energy (versus co-products).
- Understanding where the innovation gaps/opportunities/'hot spots' lie in terms of the technical maturation of novel pathways and approaches.
- Provide a platform for more informed techno-economic evaluation of projects.

In an effort to draw on world's best practice, reduce duplication of methods and increase national and international consistency, the Project is beginning with a literature review to establish how current LCA standards and methodologies can inform the development of an ARENA methodology and guidelines.

3 Scope of the Review

The scope of the literature review is for the development of LCA guidance for bioenergy systems. The focus of the review is on:

- Relevant Australian and international legislation.
- Methodologies, schemes, guidelines and standards which have a direct bearing on the development of the ARENA biofuels and bioenergy LCA methodology guidance.

The review does not focus on, for example individual bioenergy LCA studies or specific research topics under development.

4 Methodology

The literature for the review was identified from the initial stakeholder and expert consultation process, insight from the authors and an online key word search. Key documents that have direct relevance on significant aspects of the ARENA LCA guidelines were shortlisted and summarised.

Although the focus of the review is on the identified key documents, the review includes a number of generic methodologies, guidelines and standards, not specifically developed for bioenergy systems, as well as a few more noteworthy initiatives and schemes in the bioenergy domain.

The literature was reviewed and presented by the anticipated key topics of the LCA guidelines, as determined by the authors. The key topics were refined and restructured during the review to reflect the content of the literature.

5 Relevant legislation

5.1 Australian legislation

Known previously as the Mandatory Renewable Energy Target, the **Renewable Energy Target (RET)** has been in operation since 2001, first legislated through the *Renewable Energy (Electricity) Act 2000*. The RET does not include biofuels or bioenergy that are not used to generate electricity (e.g. energy used in transport) – the initial aim was to source two per cent of the nation's electricity generation from renewable sources. In 2009, this was increased to ensure renewable energy made up the equivalent of 20 per cent of Australia's electricity (41,000 GWh). The latest amendment to the RET was through the *Renewable Energy (Electricity) Amendment Act 2015*. The most significant change was to reduce the target from 41,000 to 33,000 GWh. Another 2015 change relevant to the Project is the reinstatement of biomass from native forest wood waste as an eligible source of renewable energy, including the same safeguards that were in place prior to removal of this source from eligibility in late 2011 (basically assuring that only forestry co-products are used). The RET was also split into two separate schemes, the Large-scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES). Under the RET, accredited renewable energy power stations are entitled to create Large-Scale Generation Certificates (LGCs) based on the amount of eligible renewable electricity they produce above their baseline.

The **National Greenhouse and Energy Reporting (NGER) Scheme** was introduced in 2007 to provide data and accounting in relation to GHG emissions and energy consumption and production (Australian Government, 2007). The NGER Scheme provides a single national reporting framework for energy and emissions reporting. The primary purpose of the NGER Scheme is to help account for Australia's national GHG accounts, as required, and to report National Inventory Reports to the UN Framework Convention on Climate Change (UNFCCC) and track against commitments to the Kyoto Protocol. For this purpose, the NGER Scheme focuses on measuring energy consumption from facilities rather than taking a complete life cycle approach. For example, the Australian Greenhouse Accounts and National Inventory Reports to the IPCC separate industry sector GHG emissions and emissions from Agriculture, Forestry and Other Land Use (AFOLU), as required by the UNFCCC. For the purpose of the Project, a more comprehensive LCA approach is required, accounting for upstream feedstock and land use impacts associated with bioenergy and biofuel production systems.

The **Carbon Farming Initiative (CFI)**, officially the *Carbon Credits (Carbon Farming Initiative) Act 2011* (Australian Government, 2011), was introduced as a legislated offsets scheme. The CFI allowed farmers and land managers to earn carbon credits by storing carbon or reducing GHG emissions on the land. These credits can then be sold to people and businesses wishing to offset their emissions. The CFI was amended in 2014 to establish the **Emissions Reduction Fund (ERF)**. The ERF builds on the CFI, expanding coverage to encourage emissions reductions across the economy. The objective of the ERF is to help achieve Australia's 2020 emissions reduction target of five per cent below 2000 levels by 2020. The Government has provided $2.55 billion to establish the ERF. Currently, the ERF does not include a methodology for calculating GHG savings from bioenergy and biofuel projects, other than one for landfill gas.

5.2 International legislation

Looking overseas, there has been significantly more legislation created to incentivise the increased production of bioenergy and biofuels. The following are the most relevant pieces of international legislation for the assessment of bioenergy and biofuels.

EU Renewable Energy Directive

The EU Renewable Energy Directive (RED) is included in the 'key document' section below (see section 6.6).

US EPA Renewable Fuel Standard

The Renewable Fuel Standard (RFS) program was created under the Energy Policy Act of 2005 (EPAct), which amended the Clean Air Act (CAA). The Energy Independence and Security Act of 2007 (EISA) further amended the

CAA by expanding the RFS program. EPA implements the program in consultation with U.S. Department of Agriculture and the Department of Energy.

The RFS program is a national policy that requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil or jet fuel. The following targets exist under the RFS:

- Biomass-based diesel must meet a 50% lifecycle GHG reduction
- Cellulosic biofuel must be produced from cellulose, hemicellulose, or lignin and must meet a 60% lifecycle GHG reduction
  Advanced biofuel can be produced from qualifying renewable biomass (except corn starch) and must meet a 50% GHG reduction

Renewable (or conventional) fuel typically refers to ethanol derived from corn starch and must meet a 20% lifecycle GHG reduction threshold

The RFS uses the GREET model to determine GHG reductions for biofuel and bioenergy pathways (see section 9.1).

California Air Resources Board's Low Carbon Fuel Standard (LCFS)

The California Air Resources Board Low Carbon Fuel Standard (LCFS) directive calls for a reduction of at least 10 percent in the carbon intensity of California's transportation fuels by 2020. These reductions include not only tailpipe emissions but also all other associated emissions from production, distribution and use of transport fuels within the state. Therefore, California LCFS considers the fuel's full life cycle, also known as the "well to wheels" or "seed to wheels" efficiency of transport fuels. The LCFS is a mix of command and control regulation and emissions trading, as it will use market-based mechanisms that allow providers to choose how they will reduce emissions while responding to consumer demand.

The LCFS uses an adapted version of the Greenhouse and Regulated Emissions and Energy use in Transportation (GREET) model (CA GREET 2.0) to calculate the GHG savings from biofuel pathways (see section 9.1).

UK DfT Renewable Transport Fuel Obligation

The Renewable Transport Fuel Obligation (RTFO) in the United Kingdom is a requirement on transport fuel suppliers to ensure that 5 percent of all road vehicle fuel is supplied is from sustainable renewable sources by 2010. The RTFO is aimed at helping bring the UK into line with European Union RED. The RTFO only covers biofuels used in the transport and non-road mobile machinery (NRMM) sectors.

6 Key Documents

The following are a list of six key documents which have a direct bearing on the development of the methodology and guidance for ARENA biofuels and bioenergy LCA. A brief description of each document to provide context to the comparison undertaken later in the review is provided in Table 1 below:

- ISO 14044:2006 – Environmental management – Life cycle assessment – Requirements and guidelines (ISO, 2006)
- ISO/TS 14067 – Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication (ISO, 2013)
- PAS2050 – Publicly Available Specification 2050 – Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (BSI, 2011)
- Product Environmental Footprint (PEF) Guide (European Union, 2013)
- ISO 13065 – Sustainability criteria for biofuels (ISO, 2015)
- European Union (EU) Renewable Energy Directive (RED) (European Union, 2009)[1].

While these key documents are referred to constantly throughout this literature review, others in the scientific literature, and specifically the following, have been reviewed and referred to:

- UNEP/SETAC Life Cycle Initiative (including Guidelines for Social-LCA, life cycle impact assessment (LCIA), land use impacts and biodiversity)
- Round Table on Sustainable Biomaterials (RSB)[2]
- ILCD Handbook
- International Energy Agency (IEA) Bioenergy
- European Commission Joint Research Centre (JRC)
- ISO 14046 – Environmental management – Water footprint – Requirements and guidelines.

Table 1. General information for key documents

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU Directive on Renewable Energy (RED)
Developer	ISO	ISO	British Standards Institution	European Commission	ISO	European Commission
Geographical scope	Global	Global	Global	Global	Global	Europe
Product scope	All products and services	All products and services	All products and services	All products and services	Bioenergy production	Bioenergy production
Status	Standard	Technical specification	Publicly Available	Legislation	Standard	Legislation

[1] Amended by (European Union (2013) and European Union (2015).

[2] While RSB is only one of several biomass certification schemes, it is the most comprehensive and was therefore most relevant for comparison with LCA standards for scope coverage. Other certification schemes include the Dutch “NTA 8080- Sustainability criteria for biomass for energy purpose”.

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU Directive on Renewable Energy (RED)
			Specification (PAS)[3]			
Year published	2006	2013	2008 (updated 2011)	2013	2015	2009 (amendments 2013 and 2015)

6.1 ISO 14044

ISO 14044 is the original standard on requirements for LCA. It represents a hard fought consensus developed between 1996 when ISO 14040 – Principals and Guidelines for LCA was published and 1999, when a third of the three requirements standards (14041, 14042 and 14043) representing inventory impact assessment and interpretation stages of LCA, respectively, were then merged into a single standard (14044) in 2006. What this means is the consensus developed in this standard is now more than 15 years old, but being the first and about LCA in the most general sense, it forms the backbone of almost all the standards and guides which have followed. Most standards developed after 14044 have built on it to become more specific in methodology or to be applied to a particular sector or environmental aspect.

6.2 ISO/TS 14067

ISO/TS 14067 is a technical specification, which was originally intended to be published as an international standard (ISO, 2013)[4]. It is closely aligned with ISO 14044 with a specific scope more clearly defined around the calculation of carbon footprints, which in LCA terms are the cumulative GHG emission results, and also on what could be reported as a carbon footprint. It has direct relevance to the bioenergy method and guidelines, with the carbon cycle being integral to the benefits of biofuel production. Being completed in 2013, it is more up to date than 14044, but for consistency it does not contradict 14044 in areas of LCA methodology. ISO/TS 14067 gives detailed guidance about what should and should not be included in a product carbon footprint, and how the carbon footprint results should be reported.

6.3 PAS 2050

PAS 2050 was first published in 2008 with an update released in 2011 (BSI, 2011). It was the first standard to specifically address GHGs and methodological guidance for the calculation of carbon footprints. It was an innovative standard aimed at producing an implementable method, which could be applied in a labelling context, and was widely used in the early years of carbon footprinting. Being a British Standard (as opposed to an international standard or a European standard) it could go much further in developing and be a more prescriptive methodology in a relatively short time. It included impacts from direct land use change (dLUC) based on national averages for different land types and countries.

6.4 PEF Guide

The European Commission (EC) Joint Research Centre (JRC) released a draft version of the Product Environmental Footprint (PEF) Guide in 2012, and in April 2013 the final PEF Guide was established through the EU Commission

[3] PAS provides a sponsored and fast route to standardisation, but does not have the same status as a standard.

[4] ISO/TS 14067 is up for another vote in 2016 where it will either become a full-fledged standard, remain a technical specification or be revoked. Given increasing uptake in the use of ISO/TS 14067 it seems unlikely that it will be revoked.

Recommendation on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations (European Union, 2013). This communication also established the Organizational Environmental Footprint (OEF) Guide based on a common LCA methodology. The PEF Guide builds on an earlier EU methodology called the International Life Cycle Inventory Database (ILCD) Handbook (European Commission JRC IES, 2010). The PEF Guide is comprehensive and quite prescriptive in nature and covers all products and services (not only bioenergy). While prescriptive, the PEF Guide is designed to be used as an overarching set of calculation rules on which specific PEFCRs are based for the calculation of product footprints. A PEF study may not be used for comparative assertions unless it is based on a PEFCR. PEFCRs are currently in the pilot stage of development and no PEFCR is currently planned for bioenergy or biofuels.

6.5 ISO 13065

ISO 13065 was published as an international standard in September 2015 and specifies principles, criteria and indicators to facilitate the assessment of environmental, social and economic aspects that can be used to evaluate and compare bioenergy production and products, supply chains and applications (ISO, 2015). Environmental criteria include GHGs, water, soil, air, biodiversity, energy efficiency and waste. ISO 13065 also refers to four groups of social criteria including human rights, labour rights, land use rights and LUC as well as water use rights.

Criteria are mostly addressed with qualitative and descriptive indicators, apart from GHG emissions, quantified and reported in accordance with ISO/TS 14067 and energy efficiency.

The scope of the document is much broader than the proposed ARENA methodology and guidelines. However, the GHG footprint section, which is the only life cycle calculation described in the standard, is useful as it applies ISO/TS 14067 in the specific context of bioenergy.

6.6 EU Renewable Energy Directive (RED)

The EU RED, published in April 2009 (European Union, 2009), establishes an overall policy for the production and promotion of energy from renewable sources in the EU. It requires the EU to fulfil at least 20 per cent of its total energy needs with renewables by 2020 – to be achieved through the attainment of individual national targets. All EU countries must also ensure that at least 10 per cent of their transport fuels come from renewable sources by 2020 (European Comission, 2016). The EU RED is supported by a calculation and methodology, which is required to be completed before the fuel can be counted by countries towards the renewable fuel targets. This methodology is very prescriptive and has evolved over time as new fuels come about and new data becomes available. The methodology is scientifically conservative in that it requires a high degree of international acceptance for calculation approaches and data sources, and is in many parts simplified to make it workable for different countries and fuel producers to use. This is a useful benchmark for the ARENA LCA methodology.

The EU has defined a set of sustainability criteria, both environmental and social, embedded within the RED legislation (European Commission, 2010) that ensure the use of biofuels (used in transport) and bioliquids (used for electricity and heating) is done in a way that guarantees real carbon savings and protects biodiversity. The RED also refers to socials impacts such as availability of foodstuffs at an affordable price, labour rights and land use rights. Only biofuels and bioliquids that comply with the criteria can receive government support or count towards national renewable energy targets. To be considered sustainable, biofuels must achieve GHG savings of at least 35 per cent in comparison to fossil fuels. This savings requirement rises to 50 per cent in 2017. In 2018, it rises again to 60 per cent, but only for new production plants. All life cycle emissions are taken into account when calculating GHG savings. This includes emissions from cultivation, processing and transport.

7 Review by Topic Area

7.1 Elements related to LCA Scope

7.1.1 Functional unit

The 'functional unit' provides a common basis for comparison of results in any LCA study. The main issue with the definition of the functional unit is defining at what point along the production process the functional unit is set. A fuel LCA can be defined to encompass the production of 1 litre or 1 MJ of fuel, and it may extend to the point of combustion of the fuel or it may even go through to defining the intended *purpose* of combustion, which may be delivery of heat or transport services.

Generic LCA standards provide some guidance about how the functional unit shall be described, while the bioenergy-specific standards provide a specific example of the functional unit. In the RED, the GHG calculation has a specific functional unit being an energy metric (i.e. 1 MJ) of fuel combusted in a vehicle. The RSB GHG calculation methodology specifies the functional unit as 1 MJ of finished biofuel product with results published on a lower heating value (LHV) at 0 per cent water (RSB, 2012). The IEA Bioenergy Task 43 recommends that to define a functional unit to make a comparison, the function needs to be precisely defined (e.g. a MJ of steam and a MJ of electricity have different exergy content and do not provide the same function) (IEA Bioenergy Task 43, 2015). For systems producing electricity from biomass, it is more relevant to use a functional unit of unit electricity produced at the power station (Schmidt & Brandao, 2013). Table 2 gives a comparison of the requirements for the functional unit from the key documents.

Table 2. Functional unit comparison from key documents

ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
Shall be consistent with the goal and scope of the study Clearly defined and measurable	Aligned with ISO 14044	Very little information and guidance given	Aligned with ISO 14044	Depends on goal and scope of GHG project. A delivered/declared unit is to be used when the assessment does not cover a full life cycle	Functional unit is 1 MJ of fuel delivered distributed and combusted in Europe

For the ARENA methodology, it would be useful to differentiate a declared unit for a partial LCA (e.g. for bio crude production only), and a functional unit to apply in the instance where the LCA needs to continues through the full life cycle to include combustion of the biofuel or bioenergy source. The preference would be for the latter as it allows a fair comparison against competing conventional energy sources and other bioenergy sources.

7.1.2 System boundary and cut-off rules

The system boundary describes the life cycles stages and unit processes that should be included in any LCA. The system boundary description may include where the system begins (e.g. at farm production), where it ends (e.g. at fuel combustion in the vehicle), and by listing the processes which will be included in the boundary (e.g. crop production, transport and fuel conversion). Consistency of system boundaries is critical for comparability of studies and to ensure the most relevant processes from a product system are included.

Also affecting what is taken into account in an LCA study is what is referred to as the 'cut-off' criteria, which is a criterion for allowing exclusions from the study. This is typically done to make the LCA more manageable and to

consider only what is material to interpretation of the final result, which will be an important consideration for any ARENA project.

Note that the treatment of waste inputs can also be viewed as a decision for the system boundary, but is dealt with in this review under treatment of co-production. Table 3 gives a comparison for the system boundary and cut-off criteria requirements from the key documents.

Table 3. System boundary and cut-off criteria comparison from key documents

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
System boundary description	No specific boundary described	Same as for 14044	Shall include all of the product material life cycle processes	All processes linked to the product supply chain relative to the unit of analysis	Business-as-usual or projected future	From source to final energy (e.g. electricity from solid biomass)
Cut-off criteria	No threshold mentioned	No threshold mentioned	No threshold mentioned	Not allowed	Not mentioned	Immaterial flows can be excluded
Exclusions	Need to be documented	Need to be documented	Capital goods	Not allowed	Not mentioned	Capital goods/ Infrastructure

7.2 Elements related to LCA inventory

7.2.1 Use of primary data

Data quality is defined in ISO 14044 as the characteristics of data that relate to their ability to satisfy stated requirements of the LCA. Some standard and guidelines provide minimum requirements for data quality and/or documentation requirements to describe data quality. Data quality requirements are defined across different standards in the following classification. Table 4 shows the provisions in the different standards assessed. All recommend/require primary data for the main processes, but some standards view this as being the major contributing processes.

Table 4. Requirements for primary data

ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
Primary data should be used for processes that contribute most of the mass and energy flows	Primary data should be used for processes owned by the enterprise undertaking the assessment	Primary data should be used for processes owned by the enterprise undertaking the assessment	Specific data shall be obtained for all foreground processes and background processes where appropriate[5]	Business-as-usual or projected future (incorporating anticipated changes)	Measured data from survey or on-site data collection is preferred

[5] However, in case generic data is more representative or appropriate than specific data (to be justified and reported) for foreground processes, generic data shall be also used for the foreground processes.

ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
in the systems being studied					

7.2.2 Selection of secondary data

While primary data is specified in many guides as recommended (should be used), in reality many LCA studies cannot access primary data for a variety of reasons. For ARENA applicants the most important of these will be that modelled precedents do not yet exist for new and emerging technologies. Even where suppliers and technologies are well known, time, confidentiality and practicality may dictate that data collection from these sources would be impractical or impossible. Table 5 shows that secondary data is expected to be used in some part of all studies, with the main focus being on documentation and justification of what is being used. PAS 2050 and the PEF are very explicit about specific data source, or types of data source, which are preferred.

Beyond these standards we can look at other LCA guidance in Australia such as the Green Building Council Australia and Infrastructure Council of Australia tools, which give preference to Australian LCA data (e.g. AusLCI).

Table 5. Guidance and specification of secondary data

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
Guidance of use of secondary data	Data used in the study should document data requirement	Secondary data selection shall be documented and justified	Secondary data in compliance with PAS should be used in preference to other data	All generic data shall fulfil the data quality requirements specified in the PEF document	Secondary data should only be used for inputs where the collection of primary data is not possible or practicable	National statistics and referenced papers required
Preference for specific secondary sources	None	None	National government, official UN publications, and peer reviewed publications are preferred over secondary data from other sources ILCD data base in consideration for future revision of this PAS	Data developed in line with the PEF requirements International Reference Life Cycle Data System (ILCD) Data Network; ELCD database.	Secondary data may include literature data, calculated data, estimates or other representative data. Use of secondary data shall be documented and justified	3rd party certification tools used. ecoinvent and BioGrace tools are amongst accepted sources of emission factors for upstream impacts

7.2.3 Data quality requirements

Data quality is defined in ISO 14044 as the characteristics of data that relate to their ability to satisfy stated requirements of the LCA. Some standards and guidelines provide minimum requirements for data quality and/or

documentation requirements to describe data quality. Data quality requirements are defined across different standards in the following classification. Table 6 provides a summary of data quality requirements in the key documents reviewed.

Table 6. Data quality requirements

ISO 14044	ISO/TS 14067	PAS2050: 2011	PEF Guide	ISO 13065	EU RED
Time-related coverage Geographical coverage Technology coverage Completeness Consistency Reproducibility Sources of data Uncertainty of data	Same as 14044	Same as 14044	Largely same as 14044	Refers to ISO 14044	No DQI measures included

7.2.4 Treatment of co-production

Co-production occurs where one activity (in LCA terms called a 'unit process') produces more than one usable and/or valuable output. When this happens, there is a problem of how to apportion the embodied impacts of the activity to the separate products. The apportioned impact may be relevant for co-products or waste used as feedstock, or for co-products and waste generated from the system assessed.

This topic had generated significant debate over many years in LCA. The options for dealing with co-production are presented in the ISO 14044 standard as

1a) avoidance of allocation through further subdivision of the co-producing system,

1b) avoidance of allocation by expanding the system expansion to include the co-product in the functional unit,

2) allocation based on the relationship of impacts to changes in production of each of the co-products, and

3) allocation based on other properties of the products which reflect the relationship between the co-products (e.g. mass, energy content, volume).

The hierarchy developed in ISO 14044 is used in most other standards, sometimes with additional specifications. In PAS 2050, this is that economic allocation is used when the first two options for dealing with co-production are not practical. ISO 13065 uses the same hierarchy by presenting them as three possibilities without any particular preference. The three ISO standards require the effect of the choice of allocation method to be demonstrated in a sensitivity analysis. Only the RED simplifies allocation of a single approach based on the energy content of each of the co-products.

Waste products, which are utilised to some extent, are similar to co-products because in some instances special rules are applied to their allocation. ISO 13065 is explicit in that the alternative fate of wastes used in biofuels should be considered, which is essential in a system expansion approach. The EU RED states that all wastes have no allocation of prior impact or alternative use, and it also has a list of specific materials which are deemed to be waste, regardless of the fact they may have a positive value and be recognised and co-products. Table 7 shows a comparison of the treatment of allocation between the key documents.

Table 7. Comparison of treatment allocation between key documents.

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
Co-products	Hierarchy as described above	Same as ISO 14044	Hierarchy from ISO 14044 with economic value specified as the allocation approach in step 3	Hierarchy described above with great description of the procedure	All elements of the hierarchy, but with no preference for any approach	Allocation based on energy content
Allocation of impacts to wastes	Additional guidance on open loop recycling		Additional guidance on use of waste	Additional guidance for waste flows	System expansion recommended	All wastes and residues carry no prior burden

One additional document, which has a bearing on the co-production approach, is the Global Guidance Principles for Life Cycle Assessment Databases (UNEP/SETAC, 2011). It presents a flow chart to illustrate the recommended treatment of multi-functional processes (see Figure 1). The important aspect to note from this guidance, compared to the ISO guidelines, is the further differentiation of co-products into combined production (where the relative amounts of co-products can be varied independently) and joint production (where the ratio of co-products is relatively fixed). This has implications as to how markets may respond to changes in production of the determining product. It effectively puts step 2 of the ISO hierarchy above step 1b, which is system expansion.

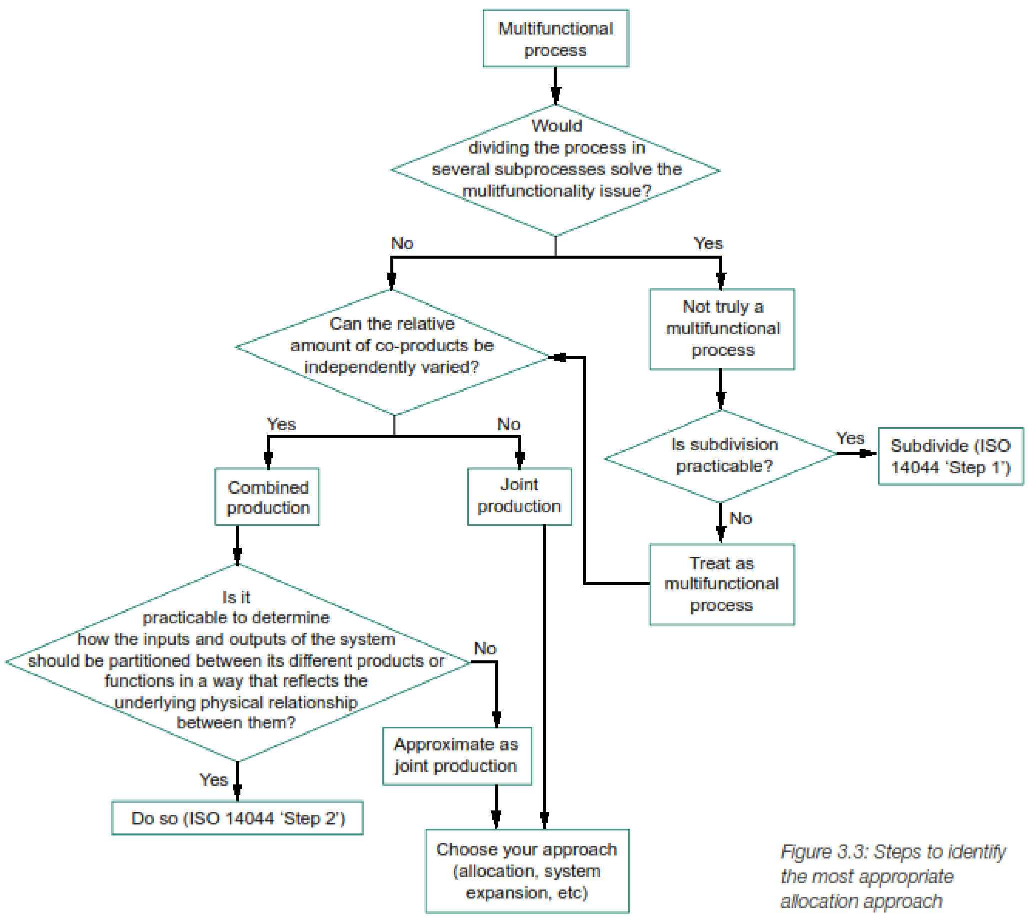

Figure 1. Steps to identify the most appropriate approach to modelling multi-functional processes (extracted from (UNEP/SETAC, 2011)

7.2.5 Modelling approach (attributional versus consequential)

The modelling approach used in LCA is often not recognised by practitioners, with decisions being more implicit than explicit. Over the past 20 years a distinction has been made in LCA between attributional and consequential modelling approaches.

Traditionally, LCA was used to answer specific questions that are directly attributable to the life cycle of a product in the existing technological and economic climate (Sanchez, et al., 2012; Sanden & Karlström, 2007). This is now known as 'attributional' LCA. LCA's newer, undisputedly important task is to help to anticipate future impacts, so as to influence and evaluate policy options as part of governance for sustainability in energy, emerging technology and resources. This is consequential LCA and allows impacts to be considered in a wider, even global, context of producers and consumers (Nuffield Council on Bioethics, 2011). This more 'consequential' approach is considered to be the appropriate method for policy-makers (Brander, Tipper, Hutchison, & Davis, 2009). However, this expansion has been proven to be challenging and, in some cases, controversial.

Attributional LCA (also referred to as an accounting or descriptive approach) products attempt to provide information on what portion of global burdens can be associated with a product (and its life cycle). For inputs to processes the actual supplier (or if this is not available an average of suppliers) will be used. Step 3 of the co-production hierarchy described in the last section is based on an attributional approach.

Consequential LCA modelling (sometimes referred to as change-oriented approach) attempts to provide information on the environmental burdens that occur, directly or indirectly, as a consequence of a decision (usually represented by changes in demand for a product). The system expansion approach in the last section is based on a consequential modelling approach.

However, co-production in not the only modelling decision which is affected by the choice of consequential or attributional modelling approaches. The way supply chains are modelled in these two approaches is very different. In consequential modelling the supply of inputs is based on the marginal supply, which supplier and technology will actually increase production to meet a change in demand. It may not be the actual supplier providing the input, but it may be that a supplier from another region has the capacity and competitiveness to change their production. For example, Australia exports 75 per cent of its beef production – so, if Australians eat a small amount of additional beef is this likely to change the production of beef in this country? Probably not, as production levels are not driven by domestic demand, but more by global demand represented by global prices. The marginal supplier of beef would draw from the region that produces additional beef to make up for the shortfall from Australian exports, which occurs due to higher domestic production.

In terms of guidance available in the standards and LCA guidance documents available there is very little advice on how to conduct consequential LCA, and when consequential LCA may be relevant or preferred over the attributional approach. This is because the idea of attributional and consequential approaches was not articulated when the LCA standards were written, and it is also a subtle and somewhat complicated subject.

The main guidance for the use of consequential analysis comes from (Weidema B P, 2012) and from (European Commission JRC IES, 2010), which pre-dates the PEF Guide. The ILCD Handbook distinguished different decision contexts from micro-level choice, meso to macro-level decisions and accounting-based LCA. The use of the attributional approach is suggested for micro-level and accounting LCA studies. For meso- and macro-level decision-making, some form of consequential assessment is suggested.

7.2.6 Treatment of fossil and biogenic carbon

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 a biological source, 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. While carbon stored in fossil reserves can only be released into the atmosphere, biogenic carbon can either be removed (e.g. through photosynthesis) or released into the atmosphere (e.g. through biomass burning).

Under the UNFCCC Kyoto Protocol, biogenic CO_2 emissions and removals associated with bio-based products (e.g. timber or biofuels) are not accounted for in the energy and waste sectors. Carbon stock changes associated with bio-based products are, instead, intended to be accounted for in the Agriculture, Forestry and Other Land Use (AFOLU) sector (Brandão , et al., 2013). While this is suitable for the purpose of compiling National Inventory Reports, the exclusion of these biogenic carbon flows carried on into early product-based LCA and carbon footprinting studies and has led to significant questions over the failure to account for biogenic carbon emissions, especially for biofuels (e.g. see (Searchinger, et al., 2008), (Cherubini, et al., 2009)).

The overarching LCA standards, ISO 14040 and ISO 14044, give no provision for the treatment of fossil and biogenic carbon. In 2008, it was PAS2050 that first required that biogenic carbon emissions from dLUC be included in the carbon footprint of products. Furthermore, it was required that fossil and biogenic carbon emissions be reported separately. Amongst others, the European Commission ILCD Handbook and subsequent PEF Guide adapted a similar requirement for the inclusion and separate reporting of biogenic carbon. In 2013, ISO/TS 14067 was released as the first ISO document to deal with the treatment of biogenic carbon in LCA and carbon footprints. ISO 13065 and the EU RED give no guidance for the separate treatment of fossil and biogenic carbon, although it is implied that the net impact of the biogenic carbon balance be accounted for with requirements to address climate impacts from LULUC.

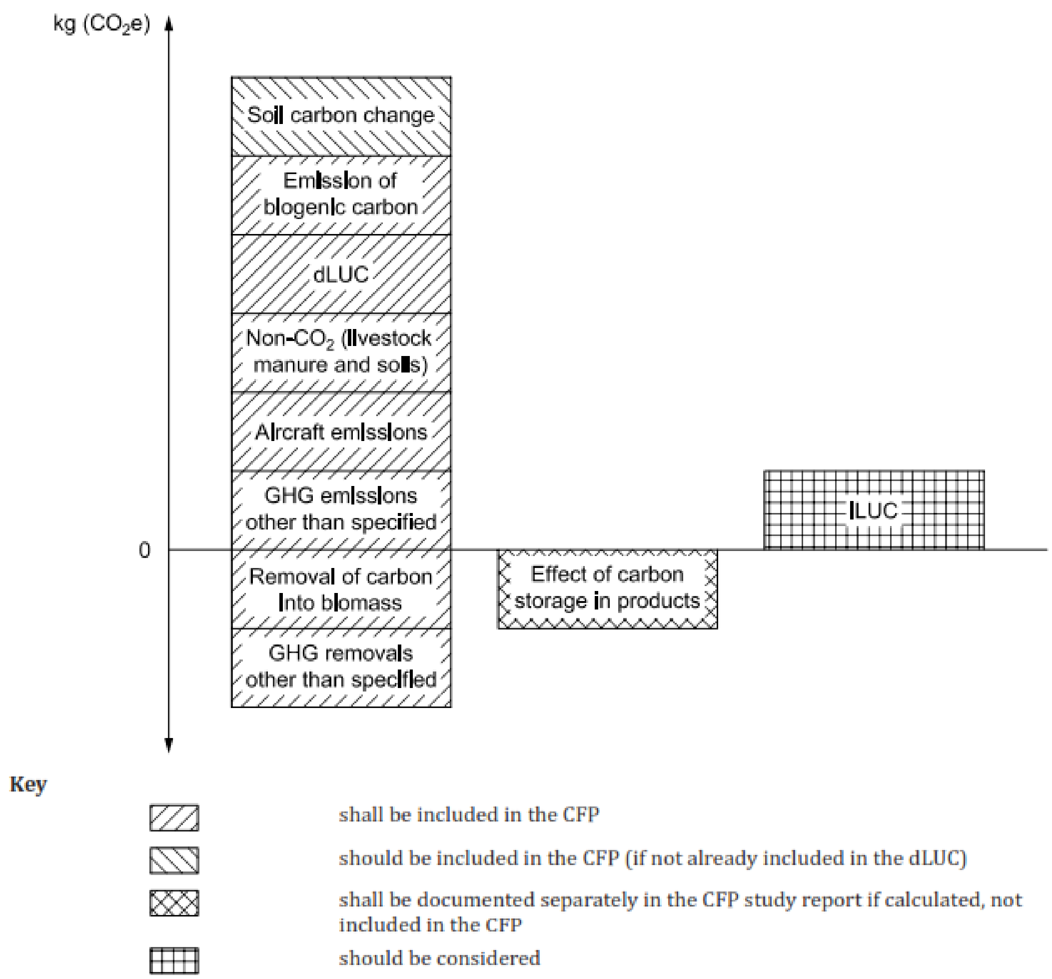

Figure 2. Illustration of the specific components of the carbon footprint of products as defined in ISO/TS 14067 (ISO, 2013).

Timing of uptake and emissions

For bioenergy based on annual or short rotation crops, the biogenic CO_2 emitted during combustion of any fuel is quickly reabsorbed by biomass regrowth. When a forest stand is harvested and used for bioenergy, the carbon emitted was sequestered several years before harvest and will take several years to be sequestered again (if the forest regrows). For long rotation forests there will be a significant discrepancy between the uptake and emission of carbon into the atmosphere. Taking a forward looking perspective, the decades it may take for the forest to regrow may result in a short-term increase in GHG emissions until the carbon is reabsorbed.

A 2013 review into *Carbon Accounting of Forest Bioenergy* conducted by the European Commission Joint Research Centre (JRC) indicated that "the use of stem-wood from dedicated harvest for bioenergy would cause an actual increase in GHG emissions compared to those from fossil fuels in the short-and medium term (decades), while it may start to generate GHG savings only in the long-term (several decades to centuries)", while GHG savings in the short term were achievable with forest residues, thinnings and salvage logging (JRC, 2013). A 2013 IEA Bioenergy document *On the Timing of Greenhouse Gas Mitigation Benefits of Forest-Based Bioenergy* noted that "the design of the GHG accounting framework has a strong influence on the calculated GHG savings", for example, the definition of the "without bioenergy" reference scenario against which the bioenergy scenario is evaluated is critical (Cowie, Berndes, & Smith, 2013). The final recommendation from IEA Bioenergy was that "it is important to consider the entire forest landscape and the wide range of conditions within which forest bioenergy systems operate, long term as well as short term effects and climate objectives, and the interactions between human actions and forest growth". A 2014 European Commission Directorate-General Energy (DG ENER) project *Review of Literature on Biogenic Carbon and Life Cycle Assessment of Forest Bioenergy* (Matthews, et al., 2015) also concluded that the LCA methodology, goal and scope had a large bearing on the results, with discrepancies between projects applying attributional and consequential LCA given as one example.

Carbon storage

Carbon storage refers to biogenic carbon stored in biomass and/or bio-based products during the service life or in landfill at end of life. Due to the short lifetime of bioenergy and biofuel products, the calculation of climate change impacts from carbon storage is not of major concern. PAS2050 first provided a formula for carbon temporarily stored, or emissions temporarily delayed, in product systems to be taken into account in global warming potential (GWP) calculations and required that this impact be reported in a supplementary figure. Carbon stored beyond the 100-year time horizon (commonly used for GWP calculations) was treated as carbon permanently stored and therefore the benefit of carbon storage beyond 100 years was included in the product footprint. More recent environmental footprinting guidance has required that carbon storage (even beyond 100 years) not be included in the default footprint results. The PEF Guide and ISO/TS 14067 both require that carbon storage not be included in the default footprint, but allow for it to be reported separately as an additional figure. Table 8 gives a comparison for the treatment of carbon and carbon storage from the key documents.

Table 8. Treatment of carbon and carbon storage comparison from key documents

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
Treatment of biogenic carbon emissions	No provision	Removals and emissions shall be reported separately for both fossil and biogenic sources	Both carbon emissions and removals are included in the assessment (man-datory)	Removals and emissions shall be reported separately for both fossils and biogenic sources	No provision	'Biogenic carbon' not referred to, but carbon emission from carbon stock changes included
Treatment of carbon storage	No provision	Carbon storage not included in the default carbon	Not included in default footprint. Any	Not to be considered in calculation of the PEF for the	No provision	No provision

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
		footprint. May be reported separately	impact of carbon storage is included in the inventory, but must also be recorded separately	default impact categories, unless otherwise specified. In a supporting Product Category Rules (PCR)		
Timing of emissions	No provision	Optional – calculation method given	Optional – calculation method given	Optional – ISO/TS 14067 method referred to	No provision	No provision

7.2.7 Land use and land use change (LULUC)

Agriculture and forestry, like other human activities, use land and at the same time these activities influence the land they use through, for example, good management practices. Land use is an important aspect of the life cycle of bioenergy and biofuels. Land use has two aspects (land occupation and land transformation) and these can both have positive or negative effects on, for example, biotic production potential, biodiversity, ecological soil quality, soil carbon content, soil erosion and fresh water availability. Land use is associated with physical, as well as often chemical, impacts on the soil and therefore on its fertility or production potential. While all production systems will require a certain amount of land, it has been the production of food, feed and fibre, which has traditionally required a great area. With the emersion of the biofuel and biomaterial economies in recent years, there is an additional stress on finite land resources. The term land use and land use change (LULUC) is used by the IPCC to refer to both the occupational and transformation impact of land use.

To quantify LULUC a distinction is generally made using the following reference flows:

— land occupation is measured in area [m^2] times time [m^2 x a]

— land transformation is measured in area [m^2].

7.2.7.1 Reference system for land use

A 2015 article on defining the "land-use baseline", including authors from IEA Bioenergy Task 38, concluded that a baseline is required to separate the studied parts of the techno sphere from natural processes and to describe the impact of land use on ecosystem quality, such as carbon sequestration and biodiversity (Solmakallio, et al., 2015).

ISO 14044 gives little guidance on how to define the reference land use system when calculating LUC impacts. The following specific approaches are available:

- PAS2050 and ISO14067 offer no direct guidance on establishing a land use reference system. In general, these standards refer to the IPCC methodology, which is based on using stable (current state) carbon stocks of a defined land use system as a reference.
- The PEF Guide refers to the EU Commission Decision 2010/3751 on guidelines for the calculation of land carbon stocks in the EU RED (European Commission, 2010). Commission Decision 2010/3751 gives detailed guidance on how to classify land use types and gives default values for carbon stocks to use.
- ISO 13065 states that the reference system may be defined as:
    - "Business-as-usual": continuation of current practice based on historic data.

- "Projected future": incorporating additional variables such as anticipated changes (see ISO 13065 6.2.2 for more detail).

Beyond calculating LUC impacts, the UNEP/SETAC Life Cycle Initiative recommends that a reference system of *relaxation to potential natural vegetation* (natural regeneration) be used in attributional LCA to quantify land use (occupation) impacts (Koellner, et al., 2013). This is supported by Solmakallio, et al. (2015), concurring that the most coherent baseline for human-induced land-use in attributional LCA is natural regeneration".

Modelling natural regeneration in practice requires assumptions as to how land will recover, or *rebound*, to a natural state without human intervention. Natural regeneration for the land-use baseline could arguably be thought of as a "projected future" in the ISO 13065 standard.

The mentioned IPCC land use change methodology (used for UNFCCC National Inventory Reporting) uses a zero-change baseline to measure and report changes in carbon stocks. This approach is arguably more straight forward but does not separate changes in carbon stocks brought about by human or natural interventions.

The options for the ARENA guidelines include broadly:

- ISO 13065 "Business-as-usual" reference system,
- ISO 13065 "Projected future" reference system, or
- IPCC zero change baseline.

7.2.7.2 Direct land use change (dLUC)

dLUC refers to the immediate transformation impact of shifting between land uses for a specific area of land. ISO 14044 gives no provision for the inclusion or assessment of LULUC impacts, direct or indirect. PAS2050, PEF Guide, ISO/TS 14067, ISO 13065 and EU RED all require that the IPCC method is used to account for GHG emissions from dLUC occurring within 20 years of land occupation, with carbon emissions from carbon stock changes from LUC amortised over 20 years (i.e. rather than one single year being responsible for the dLUC impact, the burden is spread over 20 years). While not explicitly referring to land use impacts, ISO 13065 also has prescriptive criteria to ensure that impact on biodiversity and soil quality are minimised (there are impacts that are closely related to land use).

7.2.7.3 Indirect land use change (iLUC)

iLUC refers to the displacement of land through land competition, whereby a secondary LUC is caused at another site (e.g. deforestation of tropical rainforest). There is currently no agreed scientific method to characterise iLUC in coherence with the modelling principles of LCA. iLUC is excluded from PAS2050 and the PEF Guide, while ISO/TS 14067 states that iLUC should be included once and internationally agreed method has been established. ISO 13065 does not cover any indirect land use impacts. To begin with, the RED did not cover environmental impacts from iLUC, although it was noted that the Commission should "develop a concrete methodology to minimise greenhouse gas emissions caused by indirect land-use changes".

The RED was amended in 2015 by Directive 2015/1513 to include a requirement that provisional mean values for iLUC GHG emissions are reported, with an associated range derived from a sensitivity analysis. Annex VIII from Directive 2015/1513 gives default values for indirect GHG emissions caused by different feedstocks.

Table 9 gives a comparison for LUC requirements from the key documents.

Table 9. Land use change comparison from key documents

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
Direct land use change	No provision	IPCC method to be used. To be accounted for when occurring	IPCC method to be used. To be accounted for when occurring	IPCC method to be used. To be accounted for when occurring	GHG emissions and GHG removals associated with	Carbon stock changes accounted for in line with

	ISO 14044	ISO/TS 14067	PAS2050:2011	PEF Guide	ISO 13065	EU RED
		within 20 years. GHG impact amortised over 20 years	within 20 years. GHG impact amortised over 20 years	within 20 years. GHG impact amortised over 20 years	a process causing changes in carbon stocks compared to the reference land use	IPCC method, referred to as "land use change"
Indirect land use change	No provision	iLUC to be included once internationally agreed method has been established	iLUC is excluded	Not included for the time being	Not included	Default values for iLUC impact given for certain feedstocks (2015 amendment)

7.3 Elements related to impact assessment

When it comes to impact assessment, ISO 13065 is most relevant due to the refined scope in addressing biofuels and specific biofuel issues and impacts. However, in terms of LCIA, ISO 13065 offers little guidance on quantifiable indicators other than GHG emissions (for which is recommends to follow ISO/TS 14067). A recent European standard for LCA of bio-based products (EN 16760) states that "the impact assessment methodologies for a number of impact categories often considered as particularly relevant for biomaterial systems (e.g. land use, water use, soil degradation and biodiversity are not sufficiently developed to satisfy some or all of the given criteria). This applies to midpoint and end point approaches which include or build on these same categories" (CEN, 2015). While this standard does not apply to biofuels, the approach to environmental impact assessment is relevant due to bio-based materials and biofuels being based on the same biomass production systems. For these impact categories of concern (i.e. land use, water use, soil degradation and biodiversity), which are not sufficiently developed for use in LCA, EN 16760 states that these shall still be considered in the assessment and interpretation through, for example, "evidence of accepted good practice and/or conformance with accepted sustainability criteria".

The ILCD Handbook Recommendations for Life Cycle Impact Assessment in the European Context gives a good comparison of a wide range of environmental indicators for use in LCA (JRC, 2011). This document included recommendations for specific methods at both the midpoint and endpoint level, with a classification according to their quality into three levels: "I" (recommended and satisfactory), "II" (recommended but in need of some improvements), or "III" (recommended, but to be applied with caution). Building on this work, the UNEP-SETAC Life Cycle Initiative has launched a flagship project to provide global guidance and build consensus on environmental LCIA indicators (Jolliet, et al., 2014). The recently developed Australian Life Cycle Assessment Society (ALCAS) *Best Practice Guidelines to Life Cycle Impact Assessment in Australia* (Renouf, et al., 2015) build on these studies and offer specific guidance for which specific environmental indicators are most appropriate for use in the Australian context.

Beyond assessing GHG emissions, the approach of applying good practice requirements and/or sustainability criteria is that taken in ISO 13065, the EU RED legislation and the RSB, while ISO 14044 and the PEF Guide focus on a more holistic range of environmental indicators.

7.3.1 Environmental indicators

ISO 14044 does not specify compulsory indicators, but does specify that indicators should relate to the product system under study and be based on models that have international acceptance, and they should not overlap or double count the same impact.

ISO 13065 gives guidance for environmental indicators specifically relevant for biofuels, and it refers to seven environmental criteria: GHG emissions, water, soil, air, biodiversity, energy efficiency and waste. Most indicators related to these criteria are qualitative, except GHGs and energy efficiency. GHG emission indicators refer to grams of CO_2 per delivered unit or energy delivered. Energy efficiency refers to MJ energy input per MJ energy delivered (or its inverse). Other criteria refer to the description of procedures applied to identify potential impacts and measures to address water quality, soil quality and productivity, air emissions, etc. One indicator for each criteria refers to the value and trends of key parameters or metrics used to measure the effect of addressing the impacts identified. Results of tests, measurements or evaluation should be derived from methods (e.g. ISO standards, ASTM standards), data from competent bodies or government authorities, or through other practicably appropriate means.

The scope of PAS2050 and ISO/TS 14067 only includes GHG emissions, and therefore climate change is the only impact to consider and the IPCC GWP is to be used as an indicator.

ISO 14046 is an international standard for water footprinting, but unlike ISO/TS 14067, no detailed guidance is given for any specific indicator (i.e. GWP) and what is to be included and excluded in a water impact assessment. ISO 14046 allows for the communication of a single indicator water footprint (e.g. water scarcity footprint, water availability footprint, water degradation footprint), but a full "water footprint profile" comprises of several indicators relating to a comprehensive water impact assessment. Unlike ISO/TS 14067, ISO 14046 adherence for water impact assessment is not required by ISO 13065, the PEF Guide or the RSB. EN 16760 states that "there is no current international acceptance for any single model assessing the impact of water use".

Based on the ILCD Handbook, the PEF Guide refers to 14 midpoint categories to be used. Unless otherwise specified in the PEFCR, impacts may be excluded. These are shown in Table 10 and their relevance to bioenergy and biofuel LCA is explained.

Table 10. Impact categories included in the ILCD Handbook Recommendations (2010)

Impact category	Support in key documents	Relevance to bioenergy and biofuel
Climate change	Very strong	Purpose of biofuels/bioenergy is to avoid associated GHG emissions – therefore crucial that biofuel/bioenergy projects prove a GHG reduction compared with fossil fuels
Ozone depletion	Non-existent	Indirectly relevant
Ecotoxicity for aquatic fresh water	Weak (indirect – water quality)	Upstream biomass growth associated with bioenergy and biofuel systems may involve the use of toxic pesticides, which can leach into freshwater
Human toxicity – cancer effects	Non-existent	Indirectly relevant
Human toxicity – non-cancer effects	Non-existent	Indirectly relevant
Particulate matter/respiratory inorganics	Significant	Bioenergy and biofuels may be associated with higher emissions of particulate matter and respiratory inorganics from combustion
Ionising radiation – ecosystems and human health effects	Non-existent	Indirectly relevant
Photochemical ozone formation	Significant	Bioenergy and biofuel combustion may result in higher emissions of precursors to photochemical ozone and smog (e.g. aerosols)
Acidification	Weak (indirect, soil quality)	Bioenergy and biofuel combustion results in the emission of acidifying substances (e.g. NO_x, SO_2)
Eutrophication – terrestrial	Weak (indirect, soil quality)	Upstream biomass growth associated with bioenergy and biofuel systems may involve the use of fertilisers, which can leach into freshwater

Eutrophication – aquatic	Weak (indirect, water quality)	Upstream biomass growth associated with bioenergy and biofuel systems may involve the use of fertilisers, which can leach into freshwater
Resource depletion – water	Strong	Water is an essential resource for production of biomass.
Resource depletion – mineral, fossil	Strong	A key benefit of bioenergy and biofuel production is the avoidance of non-renewable fossil fuel depletion, however both mineral and fossil resources are required to produce biomass.
Land use	Very strong	Upstream biomass growth is associated with significant land use when compared with fossil fuels. This cause significant land use (occupational) and LUC impacts, which can be considered to be caused directly or indirectly caused by the product system

The EU Renewable Energy Directive refers to GHG emission savings, evaluated with an LCA method. It also takes into account land biodiversity value and land carbon stock. More broadly, sustainability criteria also include soil, water and air protection.

The UNEP-SETAC Life Cycle Initiative has developed a guideline to assess land use impacts in LCA (Koellner, et al., 2013). The framework gives a range of impact pathways from human intervention to impact on biodiversity and ecosystem services. The studied land use system is compared to a reference land use of relaxation to "potential natural vegetation", rather than the more common zero-change or business-as-usual carbon stock scenarios. This framework is difficult to implement as it involved modelling a hypothetical land use scenario, and this is not yet supported by any standards.

Table 11. Environmental indicators comparison from key documents

	ISO 14044	ISO/TS 14067	PAS2050: 2011	PEF Guide	ISO 13065	EU RED
Indicators – compulsory	Impact categories should be comprehensive and related to product system under study	Climate change, including LUC. All GHG emissions shall be reported	Climate change, including LUC. All GHG emissions shall be reported	14 mid-point impact categories, unless otherwise specified in the PEFCR	GHG, water, soil, air, biodiversity, energy efficiency, waste	GHG emission saving, land biodiversity value, land carbon stock
Indicators – optional	No provision	Supplementary figure to account for timing of GHG emissions, carbon storage and iLUC	No provision	Exclusion of certain impact categories is justified as specified in the PEF Guide	No provision	No provision

7.3.2 Social indicators

Very few of the documents covered in this literature review address both environmental and social indicators. Social impacts are addressed in two of the keys documents, but none of them provide a specific methodology or database for social assessment. They do not refer to Social-LCA (S-LCA) and focus on qualitative criteria to assess social risks and impacts.

ISO 13065 includes environmental, social and economic indicators that must all be addressed. The EU Renewable Energy Directive requires a report on the impact of increased demand for biofuel on social sustainability. The RSB refers to several principles regarding social indicators related to biofuel. It mentions that biofuel operations shall not violate human rights or labour rights, and shall promote decent work and the well-being of workers. It also refers to food security as well as land and water rights.

ISO 13065 refers to four groups of social criteria:

- Human rights
- Labour rights: forced labour, child labour, collective bargaining rights, working conditions
- Land use rights and LUC
- Water use rights: water availability in water-scarce countries.

The EU Renewable Energy Directive refers to socials impacts such as:

- Availability of foodstuffs at affordable price
- Labour rights
- Land use rights.

The RSB refers to a more comprehensive set of criteria, including:

- Human rights
- Labour rights
- Food security
- Land rights
- Water rights.

S-LCA is not suggested in key documents. The Guidelines for S-LCA of products (United Nations Environment Programme, 2009) is the only source addressing S-LCA. However, the Guidelines do not provide guidance for the use of a specific methodology or database.

To help screening for social hotspots, the Social Hotspot Database (SHDB) project was launched in 2009 by New Earth, a not-for-profit focused on information systems for sustainability (New Earth / Social Hotspots Database Project, 2016). The SHDB provides comprehensive and detailed information on supply chain human rights and working conditions available to everyone. A key aspect of the project has been to ensure that users have full transparent access to information about working conditions, impacts and global supply chains, as well as about the hundreds of sources and the methods used to characterise risks within the SHDB. However, the SHDB is arguably not in widespread use

The assessment of social risks through LCA is in an early stage, rapidly developing discipline with international best practice guidelines, but as yet no detailed protocols (Sevenster, 2015). Therefore, only limited and immature resources exist and very few practitioners are qualified to perform these studies.

Table 12. Social indicators comparison from key documents

	ISO 14044	ISO/TS 14067	PAS2050: 2011	PEF Guide	ISO 13065	EU RED
Indicators – compulsory	Not included	Not included	Not included	Not included	Human rights, labour rights and child labour, land use rights and LUC, water use rights	Availability of foodstuffs at affordable price, labour rights, land use rights,
Indicators – optional	Not included	Not included	Not included	Not included	Not included	Not included

7.3.3 Normalisation and weighting

The normalisation of category indicator results shows the magnitude of these results compared to a reference, usually done by dividing indicator values by reference values. A typical reference value might be the total or total per capita emissions of a particular GHG in a certain country in a certain year or other time period. The conversion of indicator results using factors based on value choices is called weighting. Depending on the weighting procedure, indicator results of different impact categories might be aggregated to a single figure. Since weighting is purely value-driven, weighting factors must be clearly communicated. Additionally, a sensitivity analysis showing how different weighting factors and methods influence the weighting results is recommended (IEA Bioenergy Task 43, 2015).

ISO 14044 states that weighting shall not be used for comparative assertions intended to be disclosed to the public, and weighting is not included within the ISO 13065 or RED frameworks. However, ARENA may wish to consider normalisation and weighting as a tool for screening for environmental hotspots. The UNEP-SETAC Life Cycle Initiative recommends that weighting is used in this way, stating “endpoint approaches are primarily useful to compare the respective importance of midpoints and put them in perspective based on common metrics – rather than aggregating results in a single number” (Jolliet, et al., 2014).

7.4 Elements related to reporting and review

Not all documents mentioned reporting requirements. ISO 14044 and the PEF Guide both mention the study report shall include, at a minimum, a summary, a main report including results, data, methods, assumptions and LCA interpretation, and an annex. Any additional supporting information can be included in a confidential report that shall contain raw data and confidential information. The content of the PEF reporting follows ISO 14044 requirements on reporting. This does not include any template for LCA. Table 13 gives a comparison of reporting requirements from key documents.

Table 13. Reporting and critical review comparison from key documents

	ISO 14044	ISO/TS 14067	PAS2050: 2011	PEF Guide	ISO 13065	EU RED
Practitioner qualification requirements	No provision	No provision	No provision	Minimum	No provision	No provision
Review requirements	Internal or external expert (or panel of interested parties), independent of the LCA (chairperson of the review panel)	No provision	No provision	Independent and qualified external review	No provision	No provision
Reporting	Results Data Choice of impact categories Methods (system boundary, unit processes) Assumptions Limitation	Results Data Methods Assumptions LCA interpretation	No provision	A minimum of a summary, a main report, and an annex, including specified elements. Additional supporting information can be included (e.g. confidential report)	Summarise results of the assessment along with a description of any bioenergy processes included in the assessment	Estimated impacts and net GHG emission savings Estimated demand and excess production of renewable energy

	ISO 14044	ISO/TS 14067	PAS2050: 2011	PEF Guide	ISO 13065	EU RED
Interpretation of results	The results of the LCI or LCIA phases shall be interpreted according to the goal and scope of the study. Sensitivity check of key inputs and outputs to be included	The results shall be interpreted according to the goal and scope, and also: - evaluate completeness, sensitivity and completeness - include conclusions, limitations and recommendations	No provision	- Assessment of the robustness of the PEF model - Identification of hotspots - Estimation of uncertainty - Conclusions, limitations and recommendations	No provision	No provision
Uncertainty analysis	The procedure is described qualitatively, but no prescriptive requirements given. Interpretation must give an idea of the uncertainty of the results	The interpretation shall include a quantitative and/or qualitative assessment of uncertainty, including the application of rounding rules or ranges	No provision	Minimum requirement is a qualitative description of the uncertainties of the final PEF results for both choice-related uncertainties and uncertainties of inventory data	No provision	No provision

7.4.1 Benchmarking against fossil fuels

Biofuels and bioenergy are usually viewed as alternative fuels to current (fossil) fuels used in the market. The extent to which a biofuel is an improvement is often therefore measured against an incumbent baseline product (or ‘functional equivalent’). While a comparison against a baseline fuel in important, setting goals for improvement can be difficult with many indicators involved. For biofuel, for example, land use will nearly always be higher than for fossil-based alternatives. There is also the issue of the timeframe for the baseline comparison. All of the current government schemes which provide credits for offsetting GHGs for alternative lighting and equipment installation base their predictions on current electricity impacts, despite the savings being spread over the next 10–20 years of grid electricity.

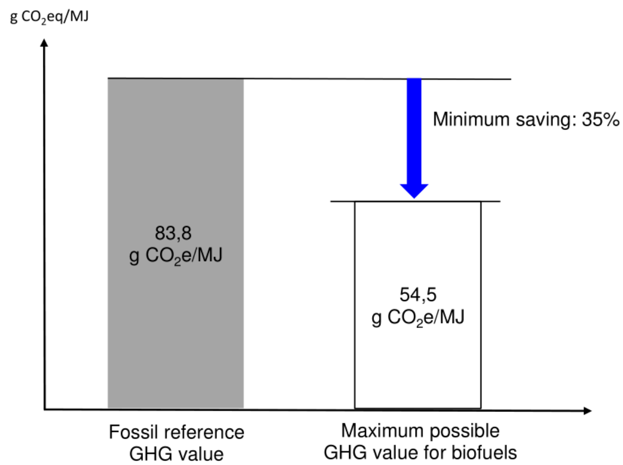

Figure 3: EU RED benchmark requirement

In the bioenergy area, benchmarks are used in the RED and have been set into regulation at 83.8g/MJ of fuel. Fuel which meets the reduction benchmark (currently 35 per cent going to 50 per cent in 2017) is counted as contributing to the total volume (measured by energy content) of biofuel required by the RED targets. An additional directive of the EU Fuel Quality Directive (FQD) takes all fuels into account and calculated a total decarbonisation of the fuel supply chain (not just biofuels). Its benchmark for fossil fuel production is, however, different to the RED being set at 95g/MJ.

The Roundtable on Sustainable Biomaterials GHG calculator uses a fossil fuel baseline. For bioelectricity systems, it will be necessary to also use an electricity (produced at power plant) baseline, which could be related marginal producers of baseload electricity, or could take and average of the grid.

8 Biofuel and biomass certification schemes

There are 19 voluntary biofuel and biomass certification schemes recognised by the European Commission as complying with the EU RED requirements (European Commission, 2016). They all comply with the RED requirements, but there are significant differences in terms of market relevance and additional sustainability criteria on top of the RED requirements. A 2013 report by WWF Germany compared the then 13 voluntary biofuel certification schemes approved by the RED (WWF, 2013). The report recognised the RSB as the “best performing scheme”. A similar report by IUCN Netherlands concluded that the RSB “covers more sustainability criteria, with greater detail, and with more breadth in terms of level of assurance” than any other of the voluntary scheme (IUCN, 2013). As the GHG calculation methodology is defined by the RED, there should be no differences amongst the certification schemes. A 2014 report funded by Airbus investigated the sustainable supply of Mallee jet fuel to Perth airport (Future Farm Industries CRC, 2014). In the absence of the newly developed biofuel standard (ISO 13065), the sustainability assessment methodology closely followed the RSB scheme, which Airbus and The Australasian Sustainable Aviation Fuel Users Group are committed to.

While the RSB may be the most comprehensive, it may not be the most appropriate for guiding the ARENA approach for LCA. Both the WWF and IUCN studies acknowledge that there is an additional burden, especially for small-scale producers, to meet assurance and chain of custody requirements for the schemes with broader coverage (e.g. the RSB). The International Sustainability & Carbon Certification (ISCC) System is the most widely used scheme for RED certification and is rated second by the WWF study. The approach of recognising 3rd party certification schemes has the advantage of being flexible, allowing timely implementation and only absorbing moderate admin capacity. However, over all the environmental and social criteria it is only GHG emissions that are covered with an LCA approach, and therefore these schemes offer little guidance for developing an LCA framework. ARENA may wish to consider a hybrid approach; whereby more qualitative reporting requirements are included in the framework to ensure that certain sustainability criteria are met.

Roundtable on Sustainable Biomaterials (RSB) Standard

The RSB is an independent and global multi-stakeholder coalition, which works to promote the sustainability of biomaterials. Originally focused on liquid biofuels, the RSB standard now includes other forms of bioenergy, as well as a number of bio-based products or bio-products that may result from the biofuels supply and production chains.

The RSB uses a variety of environmental, social and chain of custody compliance indicators for certification. An LCA-based assessment is only included for GHG emissions with the RSB GHG Calculation Methodology (RSB, 2012) and a 50% reduction in GHG emissions against a fossil fuel baseline is required for compliance. Other indicators are more qualitative and/or in the form of prescriptive requirements for certification. The RSB also refers to specific social principles such as human and labour rights, food security, and water and land rights. Social requirements are also predominantly qualitative.

The RSB offers certification to its Standard for Certification of Bio-Products (RSB, 2015). While the EU RED is a set of mandatory sustainability criteria for biofuels and bioliquids, the RSB offers a set of principles and criteria as the means for complying with the EU RED to gain market access. The RSB supports its Principles and Criteria for Sustainable Biofuel Production with a guidance document (data examples and sources), a number of standards for specific circumstances and tools to assist calculations. Standards can be selected for EU RED application or global application.

9 LCA-based tools used to assess biofuels

There are a number of full LCA software packages that can be used to assess the life cycle impacts of biofuels. These include commercial software programs, the most popular of which are SimaPro, GaBi and Umberto. OpenLCA is also an open source free LCA software program, but depending on data requirements its use may require the purchase of commercial LCA databases (e.g. ecoinvent and GaBi databases).

There are several simplified LCA-based tools used to specifically assess the environmental impact of biofuels, although most are high level and do not include a full assessment of environmental impacts (e.g. many focus only on GHG emissions). Since a great deal of detail and complexity can lie behind a simple result, this has introduced "a new set of challenges, including unexpected – or unrecognized – difficulties in comparing studies or results" (McManus & Taylor, 2015).

Most of the EU RED voluntary schemes for biofuel certification include their own GHG calculator (e.g. RSB GHG Calculator (RSB, 2012) and BioGrace), which are based on the EU RED requirements and should produce very similar results. Despite this, a direct comparison of the two tools found that GHG results varied by 20 to 35 per cent for the same biofuel production pathways (using the same input data) (Hennecke, et al., 2013), with significant variation found in N_2O production from N-fertilisers and GHG emissions LUC (varying by -14 to 49 per cent). Others have been developed in North America, namely GREET (Argonne National Labatory, 2016) and GHGenius (S&T Squared Consultants, 2004), and are based on mainly national data sources and legislative frameworks. Variation in GHG results can be considered to be even greater between European and North American-based tools.

9.1 GREET model

The GREET model was developed by the Argonne National Laboratory – a science and engineering research national laboratory operated by the University of Chicago for the US Department of Energy. The GREET model includes more than 100 fuel production pathways and more than 70 vehicle/fuel systems, including both conventional and renewable fuels. The model uses data from peer-reviewed literature but also allows for the user to edit or enter specific data for a project.

For a given vehicle and fuel system, GREET separately calculates the following:

- Consumption of total energy (energy in non-renewable and renewable sources), fossil fuels (petroleum, fossil natural gas, and coal together), petroleum, coal and natural gas
- Emissions of GHGs, calculated in CO_2 equivalents, primarily CO_2, CH_4, and N_2O
- Emissions of six criteria pollutants: VOCs, CO, NO_X, particulate matter (PM10 and PM2.5), and SO_X.

Analysis can be carried out from either "well to pump", or "well to wheel", taking into account the efficiency of different vehicle operations during the use of the fuel. While other non-GHG air pollutants are modelled in GREET, it is only GHGs for which impact assessment characterisation is included (Global Warming Potential assessed over 100 years). Other pollutants are simply given as flows to the air and would require to be input into an impact assessment method to assess other impact (e.g. acidification, photochemical ozone creation etc.).

The CA-GREET model is a California-specific version of the GREET life cycle model which is used to calculate GHG emissions under the California Low Carbon Fuel Standard (LCFS).

9.2 GHGenius

GHGenius is a spreadsheet-based model parameterised for Canada and has been expanded to model additional fuel pathways and scenarios. The model was developed by S&T Squared Consultants for Natural Resources Canada. GHGenius can calculate energy and emissions associated with conventional or alternative fuel production for the past, present and future (through to 2050). GHGenius can perform the LCA for specific regions (east, central or west) of Canada, the United States and Mexico, or for India as a whole. For Canada, it is also possible to model

many of the processes by province. It is also possible to model regions of North America. Data for the United States are sourced from the US Energy Information Agency, the US Census Bureau, and the US EPA AP 42 emission factors are largely used. Data for Canada are sourced from Statistics Canada, Natural Resources Canada, Environment Canada, the National Energy Board, the Canadian Association of Petroleum Producers and the Canadian Gas Association. Beyond CO_2, CH_4 and N_2O, GHGenius also includes CFC-12 and HFC-134a in the GHG assessment (not included in the GREET model). Other air pollutants included in the model are: CO, NOx, non-methane organic compounds (NMOCs), sulphur dioxide (SO2), and total particulate matter. As with GREET, these other pollutants are not assessed in an LCIA methodology, but are left as individual emissions.

9.3 BioGrace

The BioGrace project ran from 2010 to 2012 and was financed by the Intelligent Energy Europe Programme of the EU. The BioGrace projects aim at harmonising bioenergy GHG emissions calculations in Europe. The BioGrace model is a European life cycle model that evaluates European fuel pathways under the RED – it is one of the 19 voluntary schemes approved by the EU for RED compliance. The BioGrace GHG calculation tool includes the calculation of 22 biofuel system standard values (emissions factors) listed in Annex V of the RED, showing how the default values in Annex V.A and V.D of the RED were calculated.

10 Discussion and Recommendations

Note: The recommendations from the literature review herein, have been used in combination with stakeholder input and recommendations to inform the **Method and guidance for undertaking life cycle assessments of bioenergy products** document.

The literature review found that no one standard or guide existing today is likely to be able to fulfil ARENA's LCA requirement. ISO 14044 continues as the backbone of all LCA methods being developed and should remain so for ARENA. It does, however, need more detailed specification and guidance, being a generic standard for a broad range of applications and sectors (notably, this is relevant to any extension ARENA envisages for application of LCA methodology to assessment of other renewable energy technologies and projects).

ISO 13065 provides specific information and guidance about how to do an LCA based on GHG for bioenergy systems so is it in that sense the second most important document for requirement in the ARENA methodology. The core of the ISO 13065 GHG calculation requirements is that the ISO/TS 14067 methodology be used.

The Roundtable for Sustainable Biomass (RSB) offers a detailed GHG calculation methodology, but this dates back to 2012 before the publication of ISO/TS 14067 (2013) and ISO 13065 (2015), which should be considered more relevant. EN 16760 is only recently released but contains useful guidance for modelling biomass systems, such as agriculture and forestry, and has the advantage over ISO13065 of addressing multiple LCA indicators (CEN, 2015). However, as a European standard without much exposure so far it is not clear how widely it will be supported.

There are many other interesting and valuable documents coming out of IEA Task 38, and others which are forming the next generation of methodological approaches. It is our opinion, however, that ARENA needs to provide a methodology based on recognised approaches to ensure the reporting demands placed on successful ARENA applicants are not too onerous.

Preliminary recommendations, requiring further discussion and development, are:

- **Key document:** ISO 13065 is to be used as the primary guidance document, as it is a recent international standard, specifically focussing on sustainability criteria for bioenergy, with a suitable coverage of relevant issues for ARENA's assessments. A key limitation for the ARENA project is that ISO 13065 is not an LCA standard as such, so it needs to be complemented with specific LCA standards and methodological guidance.
- **Functional unit:** For the suggested ARENA approach, it would be useful to differentiate a declared unit for a partial LCA (e.g. for bio crude production or "well to pump") and a functional unit where the LCA continues through the full life cycle to combustion of the biofuel or bioenergy source ("well to wheel").

  The priority would be for the latter as it allows a fair comparison between competing conventional energy sources and other bioenergy sources (e.g. comparison of 1MWh of grid electricity, regardless of source).

  We anticipate the LCA guidelines will include a list of required declared/functional units and system boundaries per bioenergy project type. This will require careful consideration by ARENA and stakeholder input to ensure the list is comprehensive and manageable.
- **System boundaries:** The recommended system boundary is to include all processes linked to the product supply chain relative to the unit of analysis. This is arguably the default assumption for this type of LCA application.
- **Cut-off criteria:** For the purpose of keeping the LCA practical and streamlined, we propose to align with PAS 2050 and the EU RED and exclude capital equipment and infrastructure for the default LCAs. There may be specific project types where capital equipment and infrastructure is significant and should be included. The LCA guidelines should include a test or checklist to determine when capital goods and infrastructure should be included in the LCA.

- **Allocation:** For co-products used for the main feedstocks to bioenergy systems, and when producing usable co-products from bioenergy systems, substitution allocation should be used in line with the ISO 14044 hierarchy (i.e. consequential LCA). The challenge will be to ensure consistency between LCAs, e.g. to avoid projects selecting the most favourable substitution process/product. The guidelines need to be developed to ensure consistency using the substitution allocation approach. This will be challenging as substitution allocation needs to be kept up to date and aligned with current market conditions.

  Other aspects of consequential LCA such as marginal supply of inputs should not be stipulated, as this will create more confusion and work for practitioners. It is safer to avoid the terms consequential and attributional as they are broadly misunderstood in much of the LCA community.

  Where substitution is impractical, and for minor background flows, economic allocation can be used. As part of this, the alternative fate of by-products/waste needs to be included in any LCA as described in ISO13065 to properly reflect the impacts of new uses for low value material.

  The mixing of attributional and consequential methodology is not ideal from a purist's perspective, but it is arguably current "best" practice, and used for in the PEF methodology and for international Environmental Product Declarations (e.g. EN 15804).

- **Environmental impact assessment:** There is support in recently published standards to shortlist a set of environmental and social impacts most relevant to bioenergy. The existing EU RED framework can be useful for to cross-check that the range of relevant sustainability criteria are met for established biofuel supplies in Australia. The Australian LCA Society's Best Practice Guidelines for impact assessment should be followed as they provide specific details on methods and metrics, and to ensure alignment with regional best practice.

  Additionally, we recommend that proponents should:

  - Follow ISO/TS 14067 for the calculation of GHG emissions and climate impacts:
    - dLUC impacts included
    - iLUC use change excluded at this stage, but some comment on the risks of iLUC should be included in any LCA
    - Timing of emissions is not accounted for at this stage. The consideration of time-delayed emissions is relatively new, and there is no consensus on how to include in the standard LCA. Although relevant, it would be premature to include time-delayed emission adjustments in the ARENA LCA guidelines.
  - Refer to ISO 14046 for guidance on how to conduct water impact assessment, but ARENA will need to give more detailed guidance, as ISO 14046 does not deal with specific calculation methods.

  A smaller group of well-understood and interpreted impacts should be given preference over a large number of indicators which are poorly understood and relevant. The set of relevant impact categories include: Climate change, photochemical smog formation, airborne particulates and respiratory effects, acidification and acid rain, eutrophication and algae bloom, water resource depletion, land occupation and transformation, and eco-toxicity.

  For example, of the relevant impact categories, climate change and smog formation are better understood and underpinned by more robust scientific models than eco-toxicity and to some extent the effects and implications of land occupation and transformation on for example relevant biodiversity and ecosystems.

  This means that the ARENA Guidelines need to clarify which of the main impact categories and measurements should be reported against as mandatory items, and which are considered supplementary information to the LCA. This will require careful consideration since competing energy sources and

technologies will have strengths and weaknesses in different impact categories. Excluding or reducing the importance of a specific impact category will inevitably create 'winners and losers' in terms of LCA results.

Normalisation and weighting can be included and disclosed in line with the intended use of the LCAs by ARENA. Both normalisation and weighting can be very useful to focus the data collection and modelling on the key data/estimates/assumptions underpinning the LCA, and for stakeholders and decision-makers to interpret and focus on the most relevant parts of the LCA.

It should be noted that ISO 14040/44 is restrictive in the use of weighting of environmental impacts for comparative results disclosed publically.

- **Social impact/risk assessment:** Social-LCA is too immature yet to provide a relevant comparison between projects as required for ARENA's approach. There is not sufficient support for inclusion of LCA-based social assessment. Key social risks and impacts can still be accounted for as per, for example, ISO 13065, but it would not be LCA-based.

  A leading resource for S-LCA is the SHDB, which includes a comprehensive scope of social indicators/risks, but does not provide a very accurate differentiation for specific issues yet as it is only country and industry-specific.

  The lack of maturity of S-LCA means that ARENA needs to determine whether social impacts and risks shall be included using a qualitative, non-LCA based approach, albeit still informed by the ISO 13065 framework.

- **Benchmarking and hotspot analysis:** Benchmarking of the LCA will be highly relevant for ARENA to interpret and use the LCA for decision-making. Biofuels and bioenergy are usually viewed as alternative fuels to current fuels used in the market. The extent to which a biofuel is an improvement is often therefore measured against the current baseline.

  The areas of functional equivalence and normalisation are relatively well explored in LCA, and provide a suitable basis for defining LCA benchmarks and establishing which impact categories are significant/material for a project.

  Depending on how ARENA intends to use the LCA results for assessment and decision-making, the guidelines can be developed to include suitable functionally equivalent benchmark LCA impacts and normalisation factors per impact category. If the guidelines include benchmark impacts, these will need to be updated going forward as the electricity grid and/or fuel mix changes.

- **Resources for conducting the LCA:** Suggesting a hierarchy of data sources, including for example priority referencing of AusLCI and ecoinvent databases, will assist in creating more consistent background data treatment in different LCA studies and reduce uncertainty around the selection of upstream data by proponents.

  There is a significant risk in variation in GHG results for ARENA, allowing practitioners to use the different tools discussed. Hennecke, et al. (2013) note that a proponent can enhance the GHG performance of a biofuel by simply switching between two EU RED-approved calculation tools (BioGrace and RSB GHG calculator). Tools have also been developed with EU and North American-specific inventory data (e.g. for LUC and energy infrastructure).

  There is limited support in the literature for providing helpful guidelines for the use of LCA tools, databases, practitioner accreditations, etc. The most relevant examples are probably from current developments by national and international Green Building Councils. A suggested list of data sources for secondary material could be useful to keep some consistency in LCA application. This should be developed in collaboration/consultation with ALCAS directly, or ideally developed and maintained by ALCAS, to avoid creating a need for ARENA to keep the lists up to date.

  The ARENA guidelines will need to carefully consider which tools are endorsed. It may be worthwhile to engage with a number of key tool providers at the latter stages of the guideline development to seek

feedback on whether they comply, i.e. whether they are relevant for Australian projects/production and comoliant with ISO/TS 14067 for GHG calculations.

- **Quality assurance:** There is great value both to the proponent and the user of the LCA from having it independently reviewed. The approach to quality assurance should be developed in collaboration/consultation with ALCAS directly, or ideally developed and maintained by ALCAS, to avoid creating a need for ARENA to keep requirements and suitable professional accreditations up to date.

As a final remark and recommendation relevant to the forthcoming LCA guidelines for ARENA, drawing from Taylor and McManus' (2013) paper on the changing nature of LCA: bioenergy has contributed to the fastest era of both change and use in LCA's short history. The pace of LCA's adoption has meant that it is sometimes used to answer questions it cannot. LCA will only ever be as good as the data and assumptions it uses. It will also only ever be as good as the users of the results, in that any results must be used in the context for which they were developed.

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