

Partnerships for better
innovation support



A Review of LCA Methods and Tools and their Suitability for SMEs

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1. Introduction

This report has been compiled as part of the BIOCHEM project (www.biochem-project.eu) under work package 3 and forms deliverable 3.2.

Report Purpose

This report is intended to provide a background to Life Cycle Assessment (LCA) and an overview of the suitability of various LCA tools and methods to SMEs (Small and Medium-sized Enterprises) and the bio-based sector.

Who is it targeted at?

This report is aimed at those new to LCA and/or those wanting to select a suitable method or tool to perform LCA within their business.

It is written from the perspective of the chemistry-using industry wishing to implement bio-based approaches to new product development and needing to compare environmental impacts of new materials and processes with existing methods.

Life cycle thinking

Successful and sustainable innovation depends on having a clear understanding of the impacts and benefits of a product or service throughout the whole life cycle from the sourcing of raw materials to ultimate disposal at end of life. It is vital to consider all stages in the life cycle, not just the ones that are within company's factory gate.

For the chemicals and chemistry-using sectors there has been a long tradition of not worrying too much about where the materials come from and what happens to the product once sold to the end user. This is no longer acceptable as both policy makers and society at large demand more responsible product stewardship, which means thinking beyond the factory gate and understanding the full life cycle of a product or an activity. Besides, taking a life cycle approach makes business sense: it can help spot important risks to company, and equally importantly, it can help gain a market advantage by identifying opportunities for improving products and services.

There are five key stages in the life cycle of a product or service (Figure 1):

- **Raw materials** – sourcing the materials required for the product or service
- **Production** – converting raw materials and assembling the products
- **Distribution** – getting the product to the end user
- **Use** – where the end user derives the direct value from the product or service
- **End of life** – what happens when the end user has finished with the product or service.



Figure 1 Stages in the life cycle of a product

D3.2 Review of LCA Tools

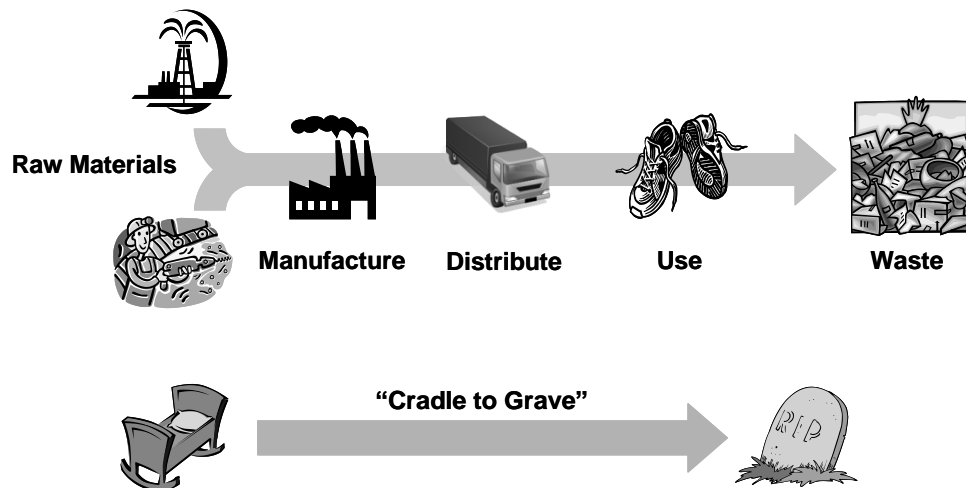


Figure 2 A 'cradle to grave' approach to analysing the life cycle of a product or service

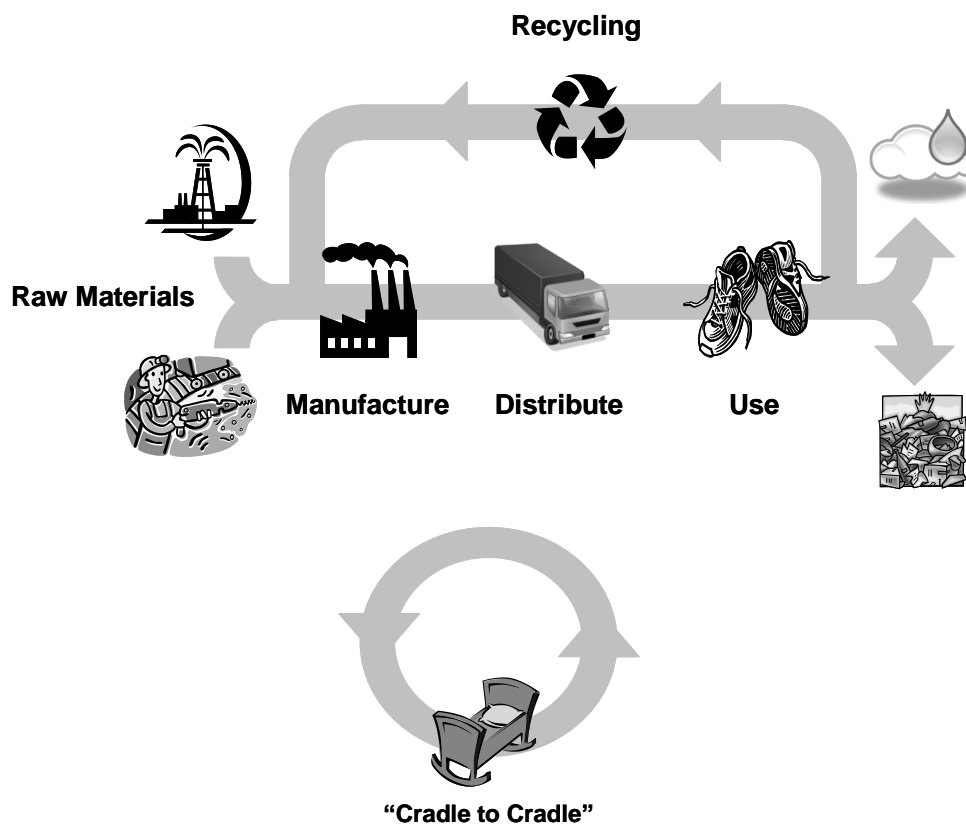


Figure 3 A 'cradle to cradle' approach to analysing the life cycle of a product or service

Life cycle thinking is sometimes referred to as a 'cradle to grave' approach as it follows a product or a service from sourcing of primary materials ('cradle') to ultimate disposal of waste ('grave'); see Figure 2 for an illustration. A related term 'cradle to cradle' refers to designing product so that they can be easily reused or recycled at the end of their useful life (Figure 3). This helps to use resources in a more sustainable way as well as to avoid waste at the end of life. Therefore, a sustainable approach to design of products is vital, as the whole life cycle of a product and its

subsequent impacts are determined at this stage. For more detail, consult the “Sustainable Design Guide” available within BIOCHEM.

Life cycle thinking enables us to identify both threats and opportunities in the life cycle of the product or service; to understand the tradeoffs between the impacts at different stages of the life cycle, and to communicate the challenges and options to others.

It is also useful in finding out where in the life cycle the major impacts arise as a starting point for discussing where the innovation targets could be set. The following are some examples of most intensive life cycle stages for different sectors and products:

- *Raw material intensive product*

Most of the impact is created by the materials contained in the product. This includes consumption of energy and waste generation in producing the raw materials, as well as social impacts such as disturbance of local communities to access minerals. Typical high impact materials would include virgin metals, natural extracts such as perfume ingredients, and energy intensive materials such as bricks and concrete. Electronic and electrical equipment are typical of products in this category.

- *Manufacturing intensive product*

Processing the raw materials during manufacture causes the greatest impact through energy consumption, waste production, and health and safety issues. Typical manufacturing intensive products use materials which undergo extensive processing during the production process, or which produce large volumes of waste. Examples include many consumer durables and chemicals.

- *Distribution intensive product*

The overall impact is dominated by the system of distribution. This category includes products which are transported over long distances, are heavy and use of a lot of packaging. Examples include fresh, out-of-season vegetables.

- *Use intensive product*

Impacts in the use phase dominate the life cycle. Products with high durability and which go through many cycles of use are found in this category. Examples include automobiles, dishwashers and laser printers.

- *Disposal intensive product*

These are products where the main impact comes at end of life. Products including hazardous materials are often expensive and difficult to dispose of safely. Batteries are an example of this class.

Life cycle assessment

Life cycle thinking can be translated into quantitative measures of sustainability. Some examples of such measures, considering the three pillars of sustainability (environmental, social and economic) are illustrated in Figure 4.

Environmental sustainability can be quantified on a life cycle basis by using Life Cycle Assessment (LCA). LCA is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product or a service throughout its life cycle.

By taking into account the whole life cycle of an activity along its supply chain, LCA enables identification of the most significant impacts and stages in the life cycle that need to be targeted for maximum improvements. This helps to avoid the shifting of environmental burdens from one stage to another, as would be the case if the production process alone was considered.

D3.2 Review of LCA Tools

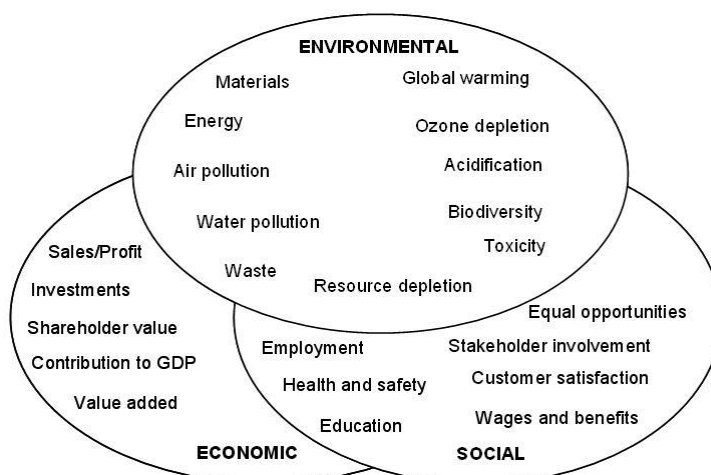


Figure 4 *Some sustainability issues in the life cycle of a product or service (Azapagic and Stichnothe, 2010)*

A key concept within LCA is the unit of service (“functional unit”). The unit of service is a convenient measure of what is actually being delivered to the user. For an automobile, the unit of service could be a passenger kilometre, or for a ball-point pen a kilometre of writing. For an adhesive, it could be 1 cm² of bonded materials at a defined strength, or for a photocopier one A4 copy at 5% coverage. For paint, the unit of service could be defined as coverage of 1 m² of surface and durability over 5 years. By focusing on the benefit that the user receives, the unit of service allows us to compare products and services to deliver that benefit in very different ways.

The LCA methodology is explained in greater detail in Section 2; other LCA-related methods are discussed in Section 3.

LCA methods and tools for bio-based products

There are no methods or tools that are entirely designed for assessing the life cycle impacts of bio-based products. The degree of suitability for this sector depends on the databases available and inclusion of factors particular to bio-based materials, e.g. land-use change. This report attempts to assess existing, widely available LCA methods and tools and also critique their ease of use by SMEs.

2. LCA methodology

Standards and guidance

Life cycle assessment (LCA) is a system for collating and evaluating information on the environmental performance of a product, service or an activity across its full life cycle, from 'cradle to grave'. In international standardisation, ISO 14040 (ISO, 2006a) series promote LCA as a technique to better understand and address the possible environmental impacts associated with products (including services). ISO 14040 defines the principles and framework of life cycle assessment, and ISO 14044 (ISO 2006b) gives more detailed requirements and guidelines. This framework, however, leaves space for choices that can have impact on the results and the conclusions of the assessment. Therefore some additional guidance, namely the International Reference Life Cycle Data System (ILCD) Handbook, has been set up to provide further instructions on LCA (EC, 2010). The ILCD Handbook is based on the ISO 14040/44 standards and it aims to support consistency and quality assurance of LCA.

LCA procedure

According to ISO 14044, the methodological framework for LCA consists of four phases which are outlined in Figure 5. In addition to the methodological framework for LCA, ISO 14044 defines requirements for the reporting of the assessments and guidelines for the possible implementation of the critical review.

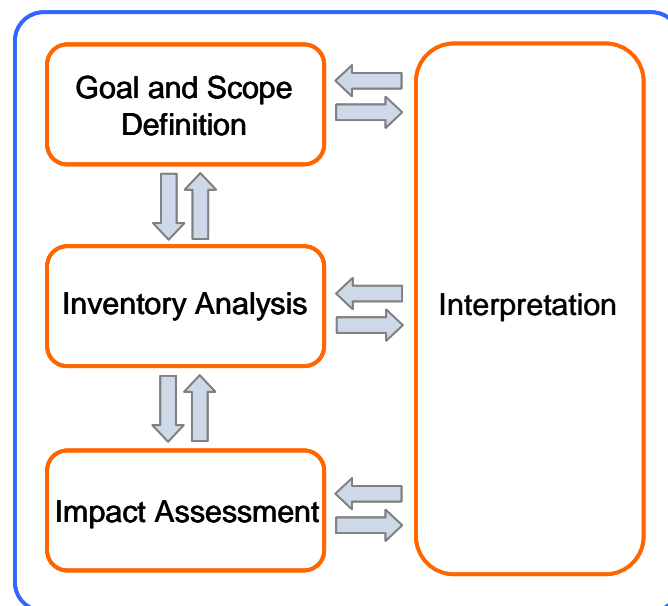


Figure 5 The methodological framework for LCA (ISO, 2006a)

1. Goal and scope definition

Defining the goal includes determining the reason for carrying out the LCA study, the intended audience, and the intended application while defining the scope involves setting the system boundaries and the level of detail.

2. Inventory analysis

The second phase of the LCA, the life cycle inventory analysis (LCI) phase, deals with collecting the necessary data to meet the objectives of the LCA study by inventoring the input and output

data of the studied system. Possible data sources include for example measurements on the production site, existing databases and bibliographic research.

3. Impact assessment

The purpose of the third phase of LCA, life cycle impact assessment (LCIA), is to convert the LCI results into the related environmental impacts – effects on natural resource use, natural environment and human health.

The impact assessment phase has two mandatory steps: classification and characterisation. Classification of the LCI results involves dividing the LCI results into impact categories – e.g. global warming, acidification, and human toxicity. In characterisation, the potential impact of each emission or resource use is estimated, using certain scientific factors. For example, the impact of methane emissions on climate change is estimated using the factor of 25 kg CO₂ eq./kg of CH₄. The remaining two LCIA steps, normalisation and weighting, are optional. Normalisation puts the estimated impacts in an appropriate context, for example, by normalising them to the total impacts in a region or country over certain time. Weighting allows decision makers to indicate which impacts are most important to them by assigning weights of importance to each impact. This results in aggregation of impacts into a single environmental impact value (or eco-efficiency) and can aid decision making, particularly when comparing different alternatives on a number of different criteria.

There are various LCIA methodologies that can be applied. They can differ in the impact categories they cover, in their selection of indicators, and in their geographical focus. The choice of the most suitable LCIA methodology is case-specific and the ILCD Handbook (EC, 2010) gives support on the selection of the appropriate methodology, providing further information on the main methodologies, including:

- CML 2002
- Eco-indicator 99
- Ecological Scarcity Method (Ecopoints 2006)
- EDIP97 and EDIP2003
- EPS 2000
- IMPACT 2002+
- LIME
- LUCAS
- ReCiPe
- TRACI
- MEEuP

4. Interpretation

The final phase of the LCA procedure is a life cycle interpretation, where the results of an LCI and LCIA are summarised and discussed to provide a basis for conclusions, recommendations and decision-making, depending on the goal and scope definition.

Carbon and water footprinting

As climate change has received a lot of attention, one impact category of LCA, climate change/global warming potential, has become more popularly known as 'carbon footprint'. A carbon footprint analysis describes the amount of greenhouse gas (GHG) emissions caused by a product, service or an activity over its entire life cycle. There are various methodologies and guidance for carbon footprinting. An example is PAS 2050:2008 (Publicly Available Specification), issued by the British Standards Institution (BSI, 2008). A number of other methodologies are under development, including the ISO 14067 and the World Resource Institute methodology (WRI, 2011).

Another impact category that is gaining importance is water usage, generally referred to as 'water footprint'. Currently, there is no agreed methodology on water footprinting and data are scarce. More information on water footprinting can be found in Jeswani and Azapagic (2011).

LCA applications

LCA applications include product development and improvement, identification of more sustainable products or services, eco-labelling, policy making and marketing. Some of these applications are important for bio-based products as they can help to identify any environmental advantages over the fossil-based counterparts. For more information on product development and design, see the Sustainable Design Guide available within BIOCHEM.

LCA limitations

Limitations of LCA are related to the insufficient transparency of the results, which can hinder the utilisation of existing studies as a source of information and in comparisons. Moreover, LCA does not take into account the social and economic impacts during the life cycle of a product (even though the life cycle approach and its methodologies can also be applied to these aspects).

3. LCA-related approaches

A range of LCA approaches and methods can be used, depending on the intended application. This is illustrated in the graph below. In many cases this is dictated by the stage or maturity of the project development; the more developed the project, the more data is available to offer a quantitative estimate.

For the purposes of working with the BIOCHEM Sustainable Design Guide, the intended application is for design and innovation, so that the application of different tools is discussed in that context. Other LCA-related approaches can be found in Jeswani et al. (2010).

The approaches are discussed in order of decreasing sophistication and cost.

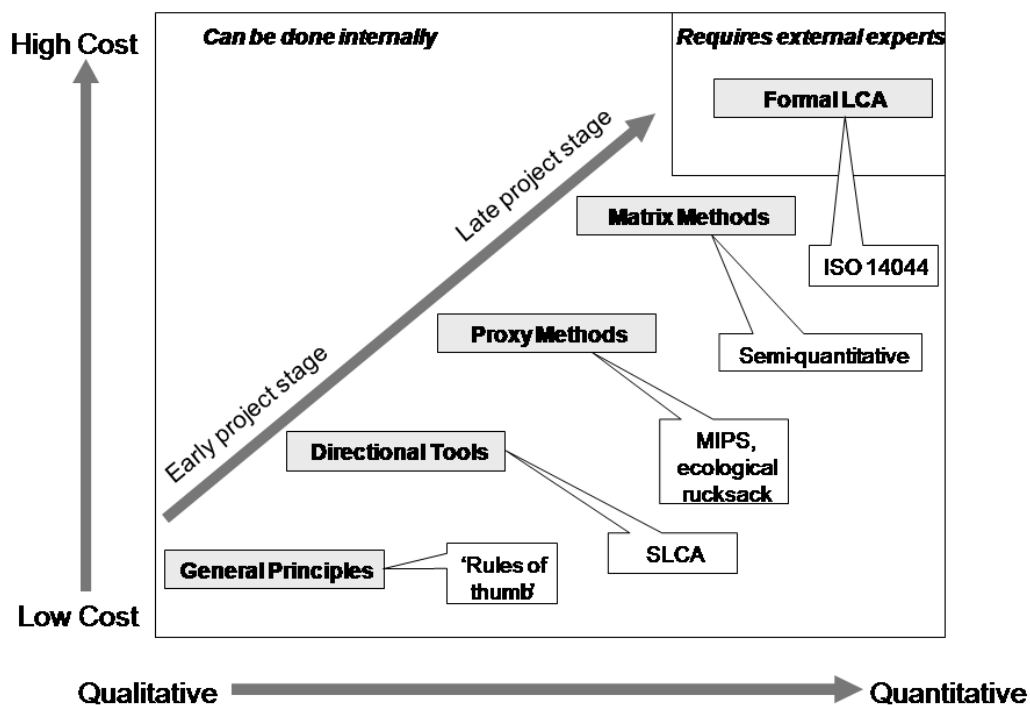


Figure 6 Different LCA tools and methodologies, depending on the intended application
 (CIKTN, 2009; also based on discussions with Chris Sherwin, Forum for the Future)

Life Cycle Assessment following ISO 14044

This is the “gold standard”, following an internationally accepted LCA methodology. It is most effectively used for existing products and processes and for policy-related questions. However, it is less suitable for screening innovation and design ideas due to its complexity and particularly high data requirements.

Matrix-based LCA

A more streamlined approach to LCA scores each stage of the life cycle for impact on a number of environmental indicators. Typical indicators include resource depletion, global warming potential, smog production, acidification, eutrophication, toxic waste production and biodiversity impact. Impact is estimated using a simple numerical scale. The completed matrix is used to focus attention on areas for improvement.

Proxy measures

Streamlined LCA methods are still too complicated for many applications. So proxy measures have been developed that use a single value to represent the environmental impact of a product or material. Examples include:

- **Embodied energy** - this is a commonly available indicator and works well for systems that are dominated by energy use, such as packaging and construction.
- **Material input per unit of service (MIPS)** - overcomes some of the issues of embodied energy by accounting for all material movements, but does not really discriminate between materials with different environmental risks. Ecological rucksack is a simple version of this that describes the amount of material moved from nature.
- **Ecological footprint** - measures the total land area that is required to support the production of the service, product or lifestyle. Most commonly used to communicate the impact of different life styles on the total amount of land required to support each society.
- **Eco-indicators** - an attempt to model a wide range of impacts that are then weighted against each other and summed into a single value. Because of the value judgments built into weighting the different impact categories, these are subjective measures of actual impact. An example method is the Eco-indicator 99 model, which has been used by designers and several LCA software packages support it (e.g. SimaPro and Gabi).

Directional tools

Very simple assessments can be used to identify areas of focus in innovation and to suggest directions to explore. One of the most useful of these is the Streamlined Life Cycle Assessment (SLCA) developed by the Forum for the Future and the Natural Step.

It is a simple matrix (see Figure 7) of the stages of a product life cycle and four “system conditions” defined by the Natural Step as being critical to sustainability. Each cell in the matrix is filled in using a series of questions designed to be answered with a simple yes or no, and scored on a scale from good to bad. A quick SLCA can be carried out in a group discussion based on already available information.

Forum for the Future claims that benefits include:

- “Quicker and cheaper than a full LCA;
- Reveals approximately 80% of the impacts over the complete life cycle of any product within an afternoon’s workshop;
- Causes product teams to think systemically about a product and provides a way to judge whether or not an innovation is truly more sustainable or not;
- Communicates sustainability impacts to non-experts;
- Benchmarks progress towards full sustainability”.

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	RAW MATERIALS	PRODUCTION	PACKAGING AND DISTRIBUTION	USE AND PERIPHERALS	END-OF-LIFE
SC1: Scarce materials taken from the earth					
SC2: Man-made persistent materials					
SC3: Degradation of nature					
SC4: Meeting people's needs					

Good	Quite Good	OK	Quite Bad	Bad	Don't Know
All answers positive. System condition met.	Mostly positive responses. System condition mostly met.	Some positive responses. System condition on the way to being met.	Mostly negative responses. System condition mostly not met.	All answers negative. System condition not met.	Insufficient knowledge to make reasonable judgment.

Figure 7 The Natural Step SLCA (www.thenaturalstep.org/en/system/files/TNS-SLCA-tool.pdf)

General principles

General principles, common sense and rules of thumb can all be used to make a swift assessment of the life cycle impacts. For example, for most product and services energy costs dominate the overall environmental impacts. Thus, lower impacts can be obtained by:

- using low embodied energy materials;
- efficient manufacturing processes;
- reducing distribution costs;
- low energy use per functional unit (unit of service); and
- no complex clean up at end-of-life.

It may seem that this is a statement of the very obvious, but such simple life cycle thinking can have a powerful effect on design and should be a minimum baseline of understanding for all.

4. LCA tools

Tools for conducting LCA

There are various tools for conducting LCA or for supporting the different phases and applications of LCA. Several different tools have been developed for particular fields of industry. Only few free tools are available, one of them being CCalc (www.ccalc.org.uk). For most commercial tools, there is a free demo version available which can help decide on the suitability of the tool for a particular application. There are significant differences in the user-friendliness of the tools. Most tools include databases, although some are more comprehensive than others.

Table 1 includes a list of existing LCA-related tools. Some main characteristics of the tools are included, too, indicating e.g. the operating language, industrial sector and whether the tool is free or commercial. Most tools are tailored for experts, and only few cater for non-specialists and SMEs. An example is the CCalc tool, which has been developed specifically for such applications and within BIOCHEM is tailored for the bio-based sector.

D3.2 Review of LCA Tools

Table 1 Existing LCA tools

Tool name	Supplier	Supports LCI and/or LCIA*	Supports full LCA*	Language	Main database	Special area if any	Free?	If commercial, availability of free trials	Web page
AIST-LCA Ver.4	National Institute of Advanced Industrial Science and Technology (AIST)		Yes	Japanese	AIST-LCA database		No	No free trial available	http://www.aist-riss.jp/main/modules/product/software/nire.html?ml_lang=en
BEES 4.0	National Institute of Standards and Technology (NIST)		Yes	English	Bees database	Construction industry	Yes		http://www.nist.gov/el/economics/BEESSoftware.cfm
CCaLC Tool	The University of Manchester		Yes	English	CCaLC database including Ecolnvent database		Yes		http://www.ccalc.org.uk/index.php
Eco-Bat 2.1	Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud	Yes		French, Italian, English	Eco-Bat database	Construction industry	No		http://www.eco-bat.ch/index.php?option=com_content&view=frontpage&Itemid=1&lang=en
Ecoinvent waste disposal inventory tools v1.0	Doka Life Cycle Assessments (Doka Okobilanzen)	Yes		English	Ecoinvent database	Waste management	No	Yes	http://www.ecoinvent.ch/
EIME V3.0	CODDE		Yes	English	EIME database	Electrical, mechanical and electronic products	No	Yes	http://www.codde.fr/page.php?rubrique=20
Environmental Impact Estimator V3.0.2	Athena Sustainable Materials Institute		Yes	English	Own database	Construction industry	No	Yes	http://www.athenasmi.org/
eVerdEE v.2.0	ENEA - Italian National Agency for New Technology, Energy and the Environment		Yes	Italian, English	ENEA database		Yes		http://www.ecosmes.net/cm/index-EP
GaBi 4	PE International GmbH University of Stuttgart, LBP-GaBi		Yes	English	Gabi database		No	Yes	http://www.gabi-software.com/index.php?id=85&L=0&redirect=1
GEMIS version 4.4	Oeko-Institut (Institute for applied Ecology),	Yes		Spanish, Czech,		Energy, transport,	No		http://www.gemis.de/

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	Darmstadt Office			German, English		recycling and waste treatment			
KCL-ECO 4.1	VTT		Yes	English			No		http://www.vtt.fi/research/technology/sustainability_assessment.jsp?lang=en
LEGEP 1.2	LEGEP Software GmbH		Yes	English, German	LEGEP database	Construction industry	No	Yes	http://www.legep.de/index.php?AktivId=1125
LTE OGIP; Version 5.0; Build-Number 2092; 2005/12/12	t.h.e. Software GmbH		Yes	German		Construction industry	No		http://www.the-software.de/ogip/einfuehrung.html
OpenLCA	GreenDeltaTC GmbH		Yes	English			Yes		http://www.openlca.org
Qantis suite 2.0	Qantis		Yes	English	Qantis database		No	Yes	http://www.quantis-intl.com/software.php?step=fonct
REGIS 2.3	sinum AG		Yes	Japanese, Spanish, German, English	ecoinvent Data v1.3:		No	Yes	http://www.sinum.com/en/products/software/
SALCA-tools	Agroscope Reckenholz- Tänikon Research Station ART	Yes		German		Agriculture		Free for tool developers, project partners. Access can be negotiated case by case with the developers	http://www.agroscope.admin.ch/aktuell/index.html?lang=en
SankeyEditor 3.0	STENUM GmbH	Yes		English			No	Yes	http://www.stenum.at/en/?id=software/sankey/sankey-intro
SimaPro 7	PRé Consultants B.V.		Yes	E.g. Spanish, French, Italian, German, English	SimaPro database		No	Yes	http://www.pre.nl/
TEAM™ 4.5	Ecobilan - PricewaterhouseCoopers		Yes	English			(Yes)	Some versions free, others have demo available	https://www.ecobilan.com/uk_team.php
The Boustead	Boustead Consulting		Yes	English	The		No	Yes	http://www.boustead-

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Model 5.0.12	Limited				Boustead Model database				consulting.co.uk/
Umberto 5.5	ifu Hamburg GmbH		Yes	English	Umberto library		No	Yes	http://www.umberto.de/en/product/index.htm
USES-LCA	Radboud University Nijmegen	Yes		English		Toxic impacts between substances	Yes		http://www.ru.nl/environmentalscience/research/life_cycle/multimedia_toxic/
WRATE	UK Environment Agency		Yes	English		Municipal waste management systems	No	Yes	http://lca.jrc.ec.europa.eu/lcainfohub/tool2.vm?tid=197

* Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and Life Cycle Assessment (LCA)

LCA Databases

Various LCA databases are attached to the LCA tools and some can be used separately. There are both freely available and commercial databases.

Free databases

Terms of data usage differ from database to database, some require registration, some are not available for commercial purpose and others are delivered on author agreement only. Mainly “general data” is available, e.g. transport, energy, recycling and case studies from various industries. There is useful information available, but finding relevant information for selected uses can be extremely difficult. Formats may not be compatible with all the tools.

Table 2 lists freely available databases.

Table 2 Free LCA databases

Database name	Supplier	Languages	Special area, if any	Website
CCaLC database	The University of Manchester	English		www.ccalc.org.uk
CPM LCA Database	Centre for Environmental Assessment of Product and Material Systems - CPM	English		http://cpmdatabase.cpm.chalmers.se/
Eurofer data sets	EUROFER	English	Steel industry	www.eurofer.org
GEMIS 4.4	Oeko-Institut (Institute for applied Ecology), Darmstadt Office	Spanish Czech German English	Energy, transport, recycling and waste treatment	http://www.gemis.de/
Franklin Associates' Case examples	Franklin Associates	English		http://www.fal.com/projects.html
ILCD	European Commission	English		http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm
LC Data	Forschungszentrum Karlsruhe	German English	Energy, transport and end of life	www.lci-network.de
LCA_sostenipra_v.1.0	Universitat Autònoma de Barcelona (UAB)	Spanish Catalan English	biomass production (energy crops and forest biomass), wood use and recycling (energy and products), ecodesign, sustainable architecture, service systems and green chemistry	http://www.sostenipra.cat/
MFA_sostenipra_v.1.0	Universitat Autònoma de Barcelona (UAB)	Spanish Catalan English		http://www.sostenipra.cat/
PlasticsEurope Eco-profiles	PlasticsEurope	English	Polymers (main) and their intermediates	http://www.plasticseurope.org/plastics-sustainability/life-cycle-thinking.aspx
ProBas	Umweltbundesamt	German		http://www.probas.umweltbundesamt.de/php/index.php
US Life Cycle Inventory Database	Athena Sustainable Materials Institute	English		http://www.nrel.gov/lci/database/default.asp

Commercial databases

Commercial databases are often closely related with commercially available tools. The availability of data on some products is better than in the free databases. However, it is recommended to ensure before purchase that all required data are available. If not, extra data sets might cost significantly more than the data in the “basic” database. Only few commercial databases are specialised in chemicals or in bio-based materials. Table 3 lists commercial databases.

Table 3 Commercial LCA databases

Database name	Supplier	Free demo/trial available	Languages	Special area, if any	Website
DEAM™	Ecobilan - PricewaterhouseCoopers	No	English		https://www.ecobilan.com/uk_deam.php
EcoInvent Data v1.3	EcoInvent Centre	Yes	Japanese English		http://www.ecoinvent.org/
EIME V11.0	CODDE	Yes	Spanish French English	Selection of products	http://www.codde.fr/page.php?rubrique=20
esu-services database v1	ESU-services Ltd.	No	German English		http://www.esu-services.ch/index.php?id=104
GaBi databases 2006	PE International GmbH	No	Japanese German English		http://www.gabi-software.com/international/software/gabi-4/
Option data pack	National Institute of Advanced Industrial Science and Technology (AIST)	No	Japanese	Chemical production, iron & steel and waste management processes	http://www.jemai.or.jp/english/index.cfm
Sabento library 1.1	ifu Hamburg GmbH	No	German English	Enzymatic processes, cell cultures, and microbiological systems	http://www.sabento.com/en/demo/index.htm
SALCA 071	Agroscope Reckenholz-Tänikon Research Station ART	No (free to developers)	German English	Agriculture	http://www.agroscope.admin.ch/oekobilanzen/01198/index.html?lang=en
SimaPro database	PRé Consultants B.V.	Yes	English		http://www.pre.nl/simapro/inventory_databases.htm
sirAdos 1.2.	LEGEP Software GmbH	No	German	Construction	http://lca.jrc.ec.europa.eu/lcaifohub/database2.vm?dbid=128
The Boustead Model 5.0.12	Boustead Consulting Limited	No	English	Fuels, materials	http://www.boustead-consulting.co.uk/
Umberto library 5.5	ifu Hamburg GmbH	Yes	German English		http://www.umberto.de/en/product/index.htm

Suitability of tools and databases for biochemical industry

Table 4 outlines the applicability of the different tools to bio-based products by listing the comments received from the tool suppliers. Refer to Table 1 on the whether the tools are available free of charge or on a commercial basis.

Bio-based products considered include bio-plastics, bio-lubricants, bio-surfactants, enzymes, and pharmaceuticals. Traditional bio-based products such as pulp and paper, wood products, bio-energy, and bio-fuels are excluded from analysis here.

Table 4 Bio-based features supported by the tools

Tool / database name	Supplier	Provider's comments on which aspects of bio-based products the tool covers	Website
BEES 4.0	National Institute of Standards and Technology (NIST)	Includes 230 building and construction products. Some of them are crop-based and some include bio-lubricant, bio-plastic, and bio-surfactant processes. One product is made from wheat straw (by-product)	http://ws680.nist.gov/bes
CCaLC Tool	The University of Manchester	The tool can be used to calculate the carbon footprint of any type of bio-products, provided the primary data are available. Secondary data are available in the databases within the tool. There are several case studies available within the tool related to bio-feedstocks and bio-products. Both 'business to 'business' and 'business to consumer' LCA studies can be conducted.	http://www.ccalc.org.uk
CPM LCA Database	Center for Environmental Assessment of Product and Material Systems - CPM	Single data might be available, and some tools, in particular the database structure can be useful	www.cpm.chalmers.se
Ecoinvent waste disposal inventory tools v1.0	Doka Life Cycle Assessments (Doka Okobilanzen)	Covers any (biomass) product, for which there is the necessary data (esp. elemental composition, degradability, heating value). Energy produced from end of life treatment is included in the model, and end of life modelling (esp. incineration and landfill, but also wastewater treatment)	http://www.ecoinvent.ch/
esu-services database v1	ESU-services Ltd.	In principle the database covers various aspects, e.g. -short-rotation wood -miscanthus -all types of food products -and food by-products -biogas production -gasification processes -waste water treatment, incineration or disposal processes Besides providing these ready available data on demand, the provider is specialized to investigate all types of products and processes on request of the customer	http://www.esu-services.ch/index
eVerdEE v.2.0	ENEA - Italian National Agency for New Technology,	Production processes of biomass-based chemicals and raw materials not implemented, but it can be done if data are	http://www.ecosmes.net/cm/index-EP

D3.2 Review of LCA Tools

	Energy and the Environment	available	
GaBi 4	PE International GmbH University of Stuttgart, LBP-GaBi	<p>PE can provide dedicated datasets on specialist bio-based products and processes. In a data-on-demand service, datasets include but are not limited to the following:</p> <p><i>Agriculture derived datasets to field edge / farm gate, for example:</i></p> <ul style="list-style-type: none"> - <i>Sugar/starch</i>: Sugar cane, Wheat, Potatoes, Rice plus many more. - <i>Fruit / Nuts / Vegetables</i>: Cashews, Peanuts, Apple plus many more. - <i>Fibre crops</i>: Sisal, Jute, Kenaf plus others. - <i>Oil / protein crops</i>: Sunflower, Rapeseed, Palm Oil, Jathropa plus many more. - <i>Animals</i>: Cattle, Pig, Chicken, Sheep plus many more. <p><i>Datasets on renewable materials:</i></p> <ul style="list-style-type: none"> - <i>Fibre products</i>: Cotton fibre, Kenaf fibre, Flax fibre plus others. - <i>Polymers/others</i>: Coutchuk/Latex (natural rubber), PLA, Cellophane plus many more. - <i>Bio-lubricants</i>: Rape oil, Sunflower oil, Castor oil plus many more. - <i>Bio-surfactants</i>: Tenside (Alcohol ethoxysulfates) - <i>Additives</i>: Yeast, Xylitol, Sorbitol plus others. <p><i>End of Life:</i></p> <ul style="list-style-type: none"> - Incineration Plants, Landfill, Composting plus others. 	http://www.gabi-software.com/
GEMIS	Oeko-Institut (Institute for applied Ecology), Darmstadt Office	GEMIS includes the feedstock provision stage for various annual and perennial crops. The provider is working in several national and EU projects to add life-cycles of selected biomaterials, and will have them included in a 2012 GEMIS database update.	http://www.gemis.de/
KCL-ECO 4.1	VTT	KCL-ECO is related to EcoData which is utilised only for consultancy work by the provider. Data is sold in entities case by case. The tool is compatible with ecoinvent database	http://www.vtt.fi/research/technology/sustainability_assessment.jsp?lang=en
REGIS 2.3	sinum AG	REGIS is by default delivered with ecoinvent data, but for specific inventory data additional suppliers can be addressed	http://www.sinum.com/en/products/software/
SALCAfarm and SALCAcrop	Agroscope Reckenholz-Taenikon Research Station ART	<p>SALCAcrop includes all kinds of agricultural crops (e.g. trees and grassland) but excludes forests and marine systems. It covers the biomass production, but not the processing. System boundary: farm gate</p> <p>SALCAfarm includes also animal products</p>	http://www.agroscope.admin.ch/oekobilanzen/index.html?lang=en
SimaPro	PRé Consultants B.V.	The main database, ecoinvent, has quite a range of bio-based materials. Another source of such data is the Danish food database	http://www.pre.nl/content/simapro-lca-software
TEAM™	Ecobilan - PricewaterhouseCoopers	A flexible tool enabling to model any system regardless of the industry or sector	https://www.ecobilan.com/uk_team.php

5. LCA needs of the bio-sector

Bio-based products

Bio-based products are derived from renewable resources, or biomass. Biomass encompasses all living and non-living organic material including crops, animal, agricultural and forestry waste. Biomass is a feedstock that is chemically rich but complex. Formed from sunlight, water, CO₂ and nutrients, biomass can be refined to substances such as starch, cellulose or oils which can be broken down into intermediate 'platform chemicals'.

Bio-based products can also be a result of the application of biocatalysts. These are biological products that are capable of catalysing a specific reaction. These can be in the form of isolated enzymes or the parent 'whole-cell' micro-organism (e.g. bacteria or yeast). All enzymes are proteins and tend to operate in aqueous systems at ambient temperature.

LCA issues for bio-based products

The main LCA issues for bio-based products are avoidance of fossil fuel resources and in most cases reduced global warming potential (greenhouse gas emissions). When carrying out an LCA of a bio-based product or comparing it with a fossil-derived product, it is important to consider the following issues:

Systems boundaries

The system boundary for an LCA study is determined by the scope of the study (see section 2). For bio-based products, it is particularly important that the system boundary includes agricultural activities and any change in land use for agricultural inputs. Consideration of end-of-life is also important because the choice of disposal determines whether waste materials can be used as a source of renewable energy, as 'carbon sinks', or potentially break down to green house gases with high global warming potential (e.g. methane in landfill).

For cultivated crops, the emission of nitrous oxide (N₂O) from soil can make a substantial contribution to the total greenhouse gas emissions. Evaluation of soil N₂O emissions is not straightforward due to the level of knowledge of this part of the nitrogen cycle. Currently, the IPCC (2007) approach is routinely used for these estimations.

Land use change refers to the effect on natural resource inputs and environmental outputs for the alternative use of the land if it had not been used to cultivate the biomass crop for bio-based product production. Permanent grassland or rainforest, for example, are significant stores of carbon and disturbing these can lead to a release of significant amount of carbon. Land is therefore considered an important carbon sink as well as a resource and the impact of displacement of crops must be considered. The latter has been critical in the arguments over the sustainability of biofuels.

Functional unit

As discussed in section 1, the functional unit is an important concept in LCA. For two LCAs to be directly comparable they must be based on the same functional unit which considers the actual function delivered by a product or service. Direct comparison on a mass basis for example is meaningless if the alternative products are used or disposed of in a different way or has a different lifetime.

Co-product allocation

Many processes involve the generation of more than one product and LCA allows for allocating or sharing of the impacts between these 'co-products'. This is typically needed for refinery products – from a petrochemical refinery and from a biorefinery. The use of co-product allocation method can have a strong effect on the LCA result. The different methods are (ISO, 2006b):

- **Substitution credits** - alternative products displaced by all co-products, apart from the main product, are identified and the impacts associated with the production of these alternatives are estimated and subtracted from those of the process under consideration so that the residual estimates comprise the LCA results for the main product (this approach is complicated to determine accurately but is reflective of real impact);
- **Allocation by mass** - in which total impacts are divided on the basis of the relative mass of each co-product produced by the process under investigation (this approach is easy to use but can be disproportionate in some cases, e.g. the main product is of low relative molecular weight);
Allocation by energy content - in which total impacts are divided on the basis of the relative energy contained by the amounts of co-products produced by the process under investigation (again a simple approach where the energy value is known but prone to misleading results); and
- **Allocation by price** - in which total impacts are divided on the basis of the relative values or price associated with each co-product produced by the process under investigation (another simple approach and based on demand but will change over time).

There is no universally-agreed choice for co-product allocation. The ISO 14041 Series standard recommends the above approaches in the order listed. PAS 2050 follows the similar approach, but excludes mass and energy allocation.

Examples of different allocation approaches in the bio-based sector can be found in the case studies included in CCaLC (www.ccalc.org.uk).

Summary

No universally agreed methodology exists but transparency on the above areas of variance in the use and reporting of LCA can help mitigate this. It is important that the methodology used is transparent and the full datasheet published so LCAs can be compared with confidence. It is important to provide the assumptions, sources of data and calculations. This can have consequences for the use of commercial software packages. Some of these are available under licence and incorporate extensive databases but cannot strictly provide complete transparency due to commercial restrictions. Other software packages that incorporate extensive databases are available as open source, thereby achieving greater transparency.

For more information on comparing LCAs on renewable chemicals, see BERR (2008).

6. Summary and future developments

As outlined in the previous sections, LCA is a powerful tool for helping the bio-based sector identify improvement opportunities in the supply chain and gain market advantage over the fossil-based products.

As also discussed in this report, there are many LCA methods and tools but none is tailored for the bio-based sector. Some difficulties in applying LCA in to bio-based products include the complexity of the methodology and lack of data.

In an attempt to bridge this gap, the BIOCHEM project is developing an LCA tool – Bio-CCaLC – that is tailored specifically for the bio-based sector and that will include appropriate databases, case studies and user guidance. Bio-CCaLC is building on the current CCaLC tool (www.ccalc.org.uk) and will be available free of charge. It is aimed at non-experts and SMEs. Training sessions will also be available on how to apply LCA and CCaLC in the bio-sector.

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