

# **Lifecycle assessment (LCA)**

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# Life cycle assessment (LCA)

Philipp Schepelmann ([philipp.schepelmann@wupperinst.org](mailto:philipp.schepelmann@wupperinst.org))

## 1 Introduction to LCA

Lifecycle assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a product (ISO 1996). As a systematic tool, LCA analyses and assesses environmental impacts over the entire lifecycle of a product. LCA involves tracing out the major stages and processes involved over lifecycle of a product/process/system covering raw materials extraction, manufacturing, product use, recycling and final disposal, identifying and quantifying relevant environmental impacts at each stage. LCA aims to facilitate a systems view in product and process evaluation (Joshi 2000) and can be considered as one of the major approaches in the field of industrial ecology (Udo De Haes 2002).

LCA comprises the compiling of an inventory of relevant inputs and outputs of a product or system, the evaluation of the potential environmental impacts and the interpretation of the results.

Lifecycle assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes and emissions released to the environment, and to evaluate opportunities to achieve environmental improvements (SETAC 1991).

According to SETAC (1993, p.7) ‘the prime objectives of carrying out a LCA are:

- to provide a picture as complete as possible of the interactions of an activity with the environment
- to contribute to the understanding of the overall and interdependent nature of the environmental consequences of human activities; and
- to provide decision-makers with information which defines the environmental effects of these activities and identifies opportunities for environmental improvements.’

LCA provides information to manufacturers, suppliers, customers, policy-makers and other stakeholders, it can be used for general information purposes, but also for specific production and consumption oriented improvements e.g. process optimization, product comparison, product policies and ecolabelling.

<b>Government</b>	<b>Private sector</b>
LCAs support strategic choices regarding environmental performance of product, energy, transport, building and agriculture policies	LCAs support strategic decisions regarding use of resources, processes, waste management, etc.
LCAs are a platform for exchanging environmental information, e.g. for covenants or permits	LCAs provide information for (re)design of products and processes
LCA supports ecolabelling	LCAs are used for internal communication, e.g. for setting up an environmental management system and codes of practice
LCA can be used to make consumers aware of their environmental behaviour	LCAs can contribute to external communication to e.g. costumers, consumers and governments

## 2 Methodology of LCA

Full LCA methodologies are codified in the ISO standard series 14040 (ISO 1996). Carrying out an LCA consists of four main phases (ISO 1996, SETAC 1993, Wenzel et al. 1997, Frankl & Rubik 2000):

### First phase: Goal and scope definition

Clearly defining goal and scope of an LCA is of crucial importance in order not to provide confusing results and misleading interpretations (Frankl & Rubik 2000). Thus, the following questions should be considered:

- What is the purpose of the LCA?
- What is the spatial and temporal scope of the LCA?
- What are the functional units to be assessed?
- Who is the target group?
- Which decisions must the LCA support?
- What is the extent of these decisions?

Which product/solution is to be assessed, and which alternatives to be compared?

### Second phase: Inventory analysis

The inventory analysis phase accounts for input and output flows of materials, energy, water and pollutants. This phase's reliability affects the complete assessment. Therefore it is necessary to follow the precise standards for data collecting, calculation procedures, allocation rules etc., i.e. SETAC (1993) and ISO (1996). Two key questions are to be answered:

What is the system to be assessed (defining systems)?  
What are the system's boundaries?

### Third phase: Impact assessment

The impacts assessment phase implies the selection of impact categories, classification and characterisation of environmental impacts based on the inventory analysis, regarding goal and scope. The impacts assessment procedure is codified in ISO standard 14042, though the impacts are often context-specific and can thus hardly be generalised (Frankl & Rubik 2000). The identification of impact categories depends on the goal of the particular LCA. General impact categories are resources depletion, human health as well as ecological and global impacts. These impacts are operationalized by specific impacts such as global warming, ozone depletion, acidification or eutrophication. In the characterisation phase, the impacts are analysed, quantified and calculated, requiring scientific knowledge about load-response relationships. For that purpose, the inventory data needs to be analysed by modelling approaches, like the use of equivalency factors (e.g. ozone depletion potential) or toxicological data.

### Fourth phase: Interpretation

The interpretation phase organises the results of the inventory analysis and impact assessment in a comprehensible way in order to handle them by decision makers. The findings allow a global view on the lifecycle of products and/or processes. With respect to the goal and scope of the study conclusions and recommendations may be formulated (Frankl & Rubik 2000).

As a basis for a decision-making processes considering environmental aspects, the LCA results point out various options for improvements and supports other environmental concepts, tools and systems (e.g. ecolabelling, environmental management system) (Fawer 2001).

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To interpret the results of LCAs 'confidence limits' are indispensable from an ecological and an economic perspective. If these limits show a wide range of uncertainty the ecologic benefits of an investment become questionable. In this case the results can lead to misjudgements (Schaltegger 1996).

## 3 Process of LCA

Basic procedure of an LCA can be outlined as follows:

- Record the interactions of a system with its environment (input and output view),
- Assessment of single environmental effects (e.g. greenhouse effect, acid rain),
- Point out options for improvements.

## 4 Review of LCA

### 4.1 Evaluation results of LCA

LCA is an established environmental management tool for assessing environmental impacts of products, especially since the 1990s (Frankl & Rubik 2000). LCA makes product lifecycles transparent and reveals environmental priorities for action. The stakeholders are provided with relevant information about material and energy flows in order to decide for different options.

LCA is useful in nearly all stages of the policy process, especially in the recognition of a problem.

Of the three pillars of sustainability LCA addresses foremost the environmental topics particularly well, although only selected aspects are covered. Despite its use in 'consumer interests' (e.g. ecolabelling) and 'governance and participation', LCA is not suitable to cover the social topics. LCA is furthermore not suitable to cover the economic topics, but by combining LCA with lifecycle costing (LCC) 'economic impacts' on micro level may be covered partially. LCA can be used to reveal investment potentials for clean technologies in a company.

Depending on the LCA, executing an LCA requires extensive data mining and is thus time intensive and costly. The technical equipment needed to carry out the assessment is limited to usual PC equipment and dedicated LCA software.

The LCA impact assessment has reached a high level of sophistication and it is characterized by various assumptions, which critically determined the results of an LCA. Although the application is complex and requires extended experience, the essence of what the tool does is rather easy to understand.

The steps to be taken are generally standardised, but the specific operations to get results may be rather extensive because of specific production conditions, insufficient data availability and/or heterogeneous data quality. With respect to uncertainties error calculations ought to accompany the calculation routines in order to prove the reliability of results. Many LCA carried out in the past suffer from the lack of error specifications. Therefore, the LCA needs high expertise. The LCA results aim to be transparent and comprehensible. There is a lot of practical experience with applying LCA. LCA can reveal material and energy flows that primarily affect the (environmental) performance of a product or process. Thus, LCA is required to obtain an ecolabel and helps to implement environmental management systems (EMA, EMS, ISO 14000, EMAS etc.). The geographical resolution and coverage of LCA studies is limited to the scope of the inventory data and may refer to 'Western Europe' or only to a certain product produced by a single plant. The LCA results are often on a relatively high level of aggregation, though the LCA uses input data of varying level of detail.

## 4.2 Experiences with LCA

The first examples of environmental assessments of products were carried out on packaging and published at the end of the 1960s and the beginning 1970s in the USA, focussing primarily on energy and resource requirements of waste (Wenzel et al. 1997). In the 1980s in several European countries LCAs were used to compare beverage packagings (BUS 1984, Lundholm & Sundström 1985, Franke 1984). Since then, interest in LCA has grown strongly, and a growing number of different and increasingly complex products and systems have been successfully assessed. Today there is also a large variety of LCA software and databases available, e.g. packaging, food, detergents, chemicals, cars, building materials, textiles and electronics.

Several LCAs carried out in the past proved to be unreliable because of inaccurate or missing data elaboration during the inventory phase (Ayres 1994). In particular there was a lack of systematic verification methods, which have only recently been introduced in some databases. To tackle these problems, several attempts have been started (Frankl & Rubik 2000). The work of the Society of Environment Toxicology and Chemistry (SETAC) and others is still ongoing. Currently there is a comprehensive framework how to carry out an LCA by the International Standardisation Organization ISO (ISO 14040 to 14049).

Depending on the different interests of commissioning actors in society, the focus of LCA varies. Authorities may use LCA, for instance, in work on product related aspects of environmental action plans and in environmental labelling of products (Wenzel et al. 1997). Companies may use them in product development, environmental management and marketing. Consumer organisations may use them in counselling consumers.

The main areas of the application of LCA within public environmental politics have been waste treatment options, means of transport, energy sources, and product's choice (Frankl & Rubik 2000).

Although there had been increasing expectations on the use and applications of LCA until the first half of the 1990, the instrument has developed a complexity (esp. the LCA impact assessment), which hampers a broad-scale regular application. Instead, LCA is usually applied for selected products of special concern.

## 4.3 Combinations of LCA with other tools

There is a wide range of lifecycle approaches and also many conventional analytical tools now developing along the lifecycle approach (Frankl & Rubik 2000). The various approaches for the environmental assessment of business activities follow concepts like environmental management systems, life cycle thinking or cleaner production and consumption.

In practice tools are not always applied in a standardised way but are often combined. The possible combinations and interactions of LCA include:

- Lifecycle costing (LCC) consists of an inventory and analysis of economic implication of environmental impact of a given product during its lifecycle. The term LCC has different meanings and can include the identifications of internal costs (for a company) and/or external/social costs.
- Material intensity per service unit (MIPS) presents a single aggregated number to describe the use of material and the impacts of the product (Schmidt–Bleek 1993). MIPS represents a screening method of LCA, focussing on the input side of the inventory and aggregating the results to three to five major categories: abiotic materials, biotic materials, soil/earth translocation, water extraction, and air input; this input is related to the use, utility, function or service of a product (Schmidt–Bleek 1993, Bringezu 1993, Schmidt–Bleek et al. 1996; Ritthoff et al. 2004).
- Substance flow analysis (SFA)
- Cost–benefit analysis
- Multi–criteria analysis. The assessment of selected impacts (e.g. greenhouse effects, ozone depletion etc.) may be subject to weighting and integration procedure in the MCA.
- Environmental impact assessment
- Environmental accounting

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- Environmental risk analysis and assessment
- Hazard assessment
- Environmental Management Systems (EMA, EMS, EMAS, ISO 14001 etc.)
- Economy-wide Material Flow Accounting. In a study for DG Environment, it was attempted to develop an indicator combining information on material flows with information on environmental impacts (Van der Voet et al. 2004). This indicator was called EMC, Environmentally weighed Material Consumption. It was applied for the 25 EU countries and 3 Candidate countries. Time series were made for the former EU-15 countries from 1990 – 2000, and for the newly accessed and candidate countries from 1992 – 2000. The results were compared with the DMC for the same countries and time period. This shed some light on the discussion with respect to the extent to which the DMC indeed can be regarded as a proxy for environmental pressure which it proved to be.

### 4.4 Strengths and limitations of LCA

LCAs have certain strengths and certain limitations. An overview is given in Table 1, based on ISO (1996), Frankl & Rubik (2000), Wrisberg et al. (2002), Fawer (2001), supplemented.

Table 1: Strengths and limitations of life cycle assessment.

Strengths and opportunities	Limitations and threats
LCA allows a cradle-to-grave approach. LCA can systematically address the environmental aspects of a product system from raw material acquisition to final disposal.	The degree of detail and time frame of an LCA may vary to a large extent, depending on the definition of goal and scope.  The possibility to select different allocations, system boundaries and recycling concepts leads to data inconsistencies, as well as double counting and omissions. Therefore, (further) standardisation of LCA after ISO is required.
	There is no scientific basis for reducing LCA results to a single overall score or number, since trade-offs and complexities exist for the systems analysed at different stages of their lifecycles.
LCA is comprehensive with respect to environmental interventions and environmental issues considered.	LCA is complex and hence data intensive.  With respect to data coverage in the inventory, all relevant material flows of the <u>Economy-wide Material Flow Analysis</u> (EMFA) should be included which is currently not the case. In this respect, current LCAs are by no means comprehensive.
LCA can help to avoid problem shifting from one stage in lifecycle to another from one sort of environmental issue to another and from one location to another.	LCA does not consider rebound and other social effects.
LCA can make explicit distinctions between science based information and value choices.	Only known and quantifiable environmental impacts are considered. Value choices can be hidden in allocation rules.
LCA is a flexible tool.	There is no single method for conducting LCA studies.
	The availability and quality of data is a big

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	problem, which still requires a lot of methodological and scientific work. It is unclear what to do, if data is missing and how to deal with (large) differences in different LCA databases.
LCA can be combined with other tools.	Decisions for actions in a company like risks, benefits and costs are not addressed by LCA.
The careful goal definition in LCA is a sound basis for the final evaluation.	The goal definition determines the result.
	Any LCA necessarily involves assumptions and subjective valuation procedures. Thus, great caution should be used in making environmental claims based on LCA.
Decisions based on LCA foster minimisation the use of materials and energy of existing processes; minimisation/avoiding effluents, air emissions and (hazardous) wastes of today 's factories; reducing immissions / impacts to employees (health).	<p>LCA does not directly consider future changes is technology and demand.</p> <p>LCA represents only part of environmental impacts.</p> <p>LCA only considers potential impacts.. It does not reveal actual (e.g. unknown) impacts on the state of the environment.</p>
LCA delivers a clear statement and intends to tell the ecological truth.	LCA may tend to aggregations with minor significance.
LCA can be considered as an indicator for success/improvement in a company.	LCA 's complexity is difficult to communicate.
LCA raises the environmental awareness in companies and helps identifying environmental priorities.	
The LCA approach intends to integrate life cycle thinking into business decisions (Joshi 2000). LCA supports environmental management systems.	
LCA may be useful for marketing of environmental objectives and products (ecolabelling). LCA can foster introducing and developing new environmental technologies and thus providing advantages in the market.	
LCA allows comparison of different enterprises (micro level), although it is difficult, unless they have similar production conditions.	
LCA allows comparison between related products over time considering a common indicator (e.g. land–use).	It is difficult to adapt the LCA tool for the analysis of complex products.
	LCA requires high expertise.
	<p>LCA is an extensive examination and thus time consuming and expensive.</p> <p>On the one hand, LCA tends to be beneficial in the case of mature products. Sine mature</p>

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processes have been optimized in the past, data is often available. On the other hand, new and emerging processes with considerable impacts could be modified from the start. But during the development phase, data on these processes are usually insufficient for preventive or precautionary action.
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### Imprecision and uncertainties:

In LCAs various sources of imprecision and uncertainties exist. The total error of an LCA can easily become larger than the calculated differences of ecological impacts of products and services. Most LCAs without error specification are regarded as unreliable (Schaltegger 1996). Results of LCA are mostly specific to one case and thus hardly to generalize.

For many substances no data are available. LCA often uses heterogeneous data from different sources. The necessary estimations and adjustment hold certain errors. Large errors are possible for the classification of LCA results. The valuation step is fuzzy, because it is based on vague models. Every method leads to a different value. Therefore a careful consideration of imprecision and uncertainties in LCA is necessary (Schaltegger 1996). There are sufficient mathematical methods available to define the maximum error limits and to avoid the misinterpretation of results.

The impact assessment phase (see section 3.2) is still under progress and requires methodological improvement. Yet, there are no generally accepted methodologies for consistent and accurate inventory data with specific potential environmental impacts (Frankl & Rubik 2000).

## 4.5 Research questions and challenges associated with LCA

How to combine LCA with other tools to obtain an added value for policy-making?

To which extent is the combination of LCA elements, e.g. impact assessment categories, with other tools, e.g. MFA, necessary for the generation of policy relevant and decision enabling information?

How could a less complex and more transparent LCA look like? Are there options for an "LCA light" (with many default values)?

How can LCA methods reveal trade-offs and uncertainties?

The European Platform on Life Cycle Assessment, a project of the European Commission, coordinated by DG JRC, IES in close collaboration with DG Environment, Directorate for Sustainable Development and Integration is supposed to meet the lifecycle related data and method needs of the Thematic Strategy on Waste Prevention and Recycling and the Thematic Strategy on the Sustainable Use of Natural Resources as well as of the Integrated Product Policy (IPP). Key purpose is to improve credibility and acceptance of LCAs; support the integration of lifecycle thinking into policy-making and decision-making processes with data, methods, and guidance. Key deliverables are expected to be LCI and LCIA data; methods and guidance; LCA information hub; expertise input to other EC services. (Source: <http://lca.jrc.it/>).

Furthermore, there is an emerging Coordinated Action for innovation in Life-Cycle Analysis for Sustainability (CALCAS). For more information on CALCAS, please contact [paolo.masoni@bologna.enea.it](mailto:paolo.masoni@bologna.enea.it)

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