# The Method of Life Cycle Assessment (LCA)


## Summary

The LCA is a standardized method which allows the integral record, quantification and evaluation of the environmental damages connected with a product, a procedure, or a service in the context of a given question. Integral survey means the consideration of all steps preceding and following the procedure (Striegel, 2000). The structure of such an LCA is described in the DIN/ISO 14040 (and following) standard series. At first, it is necessary to define the objective and frame of the survey. Secondly, the inventory analysis has to be drawn up. Here, the streams of material and energy of the respective process steps are recorded in relation to a quantity concerning the benefit (benefit unit) under consideration of certain rules. In a third step, the impact assessment can be started after the completion of the factual balance. This impact assessment serves the identification, summation and quantification of the potential environmental effects of the examined systems and provides essential information for the subsequent interpretation that follows in a fourth step. Here, the results of the mass and energy balance and impact assessment are summarized, discussed and evaluated with reference to the objective. In order to draw conclusions, recommendations for action and decisions with reference to the question can be considered apart from the pure results. The same is true for subjective elements like moral concepts, technical feasibility as well as sociopolitical and economic aspects.


## Background

The scientific method of life cycle assessment allows quantifying environmental damages caused by products, procedures, or services. “Here, it serves the comparison of the environmental effects of two or several different products, product groups, systems, procedures, or behaviour, and supports the disclosure of weak spots, the improvement of the products’ environmental properties, the comparison of alternative behaviour patterns and the reasons for action recommendations” (German Federal Environment Agency, 1992). Initially, the instrument of LCA was developed with the aim of achieving the maximum quantification of a product’s entire life. The first comparative system analyses of products – above all beverage packaging – were started already around 1970 in the US and Germany. Even then, topics like raw materials, energy demand, emission and waste disposal were still important and thus in the focus of the integral balancing. At that time, the first steps to evaluate determined material streams with regard to their environmental effects had already been taken. However, their meaningfulness was not further developed before the 1980s (German Federal Environment Agency, 1996). After years of advancement, a broadly recognized framework methodology for LCA is available since 1997 (ISO/EN/DIN 14040, 1997). In the meantime, agreements concerning clear definitions of individual parts, i.e. the definition of the goal and scope of the balance as well as the inventory analysis (ISO/EN/DIN 14041, 1998) could be achieved due to intensive international standardization

efforts. Other parts, like the impact assessment (ISO/EN/DIN 14042, 2000) or the evaluation (ISO/EN/DIS 14043, 2000), are still actively discussed.
The method of LCA can be used not only for products but in principle also for technical processes (Burgess and Brennan, 2001, Curran, M.A. 2000), albeit there are no standardized guidelines yet. The sections of the LCA are described in the following chapters (see fig. 2). Before, however, the idea of the integral view behind the method is shortly expounded.

## Integral Consideration

The basic idea of the life cycle assessment method is the recording of all streams of material and energy that are connected with a product, a process, or a service. The entire life of products or product systems is considered “from the cradle to the grave”. That means that not only the environmental effects at the production plant are recorded, but also the entire manufacture of the product, from the exploitation of the raw materials over the distribution, the use and consumption up to and including the utilization and disposal. This extensive approach is important because statements about advantages and disadvantages of products or procedures can be distorted if the consideration is too narrow. With the help of the integral view, procedures as well as products can be optimized to their scientific minimum. This reflection is illustrated for the field of chemical reactions by the following graphic and its explanation.

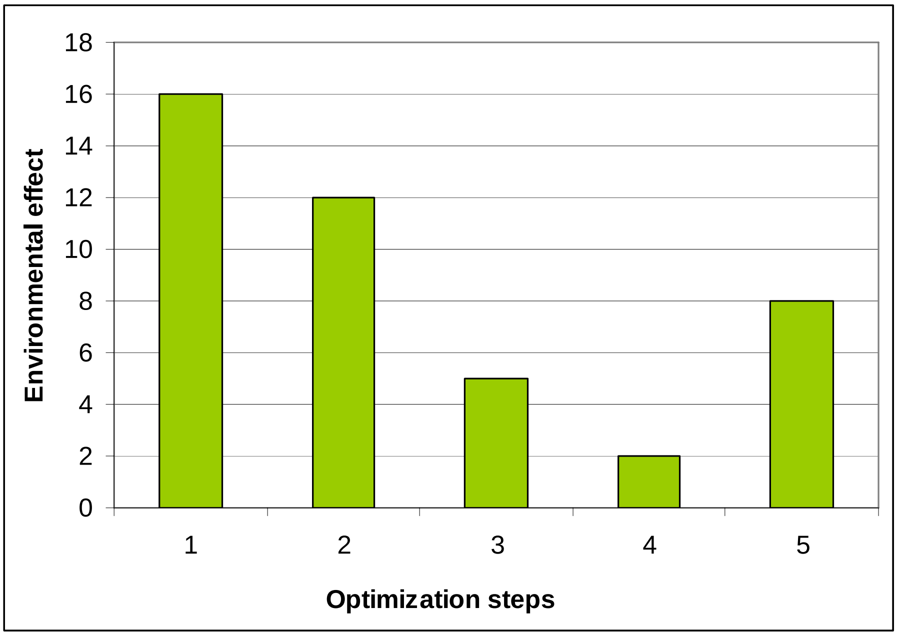


**Figure 1: Environmental damages of a reaction with/without optimization**

*Figure 1: The environmental effect of a reaction is summarized in column 1. If the reaction is fully considered, i.e. inclusive the precedent production steps of educts, auxiliary materials and energy, and if the solvent is changed in the pre-chain due to its high level of environmental damages, then the condition described in column 2 can be achieved. If all possible spheres are optimized, the scientific minimum of this reaction (column*

*3) is achieved and a further reduction of its adverse effects on the environment is no longer possible. Now the reaction must be clearly changed in order to reach an even lower level (i.e. column 4). An essential change (i.e. the use of catalysts or a change of the basic materials) could make this further minimum possible. Due to its complexity, the environmental damage always must be checked after an optimization, because it is also possible that a renewed increase of the environmental damages (for example column 5) occurs.*

## The Method

As already mentioned, the structure of and the demands on LCA are fixed in the DIN/ISO 14040 –14043 standards. According to these standards, the LCA is divided into four parts:

- Definition of the goal and the scope
- Inventory analysis
- Impact assessment
- Interpretation.

Subsequently, these four parts are discussed in detail.

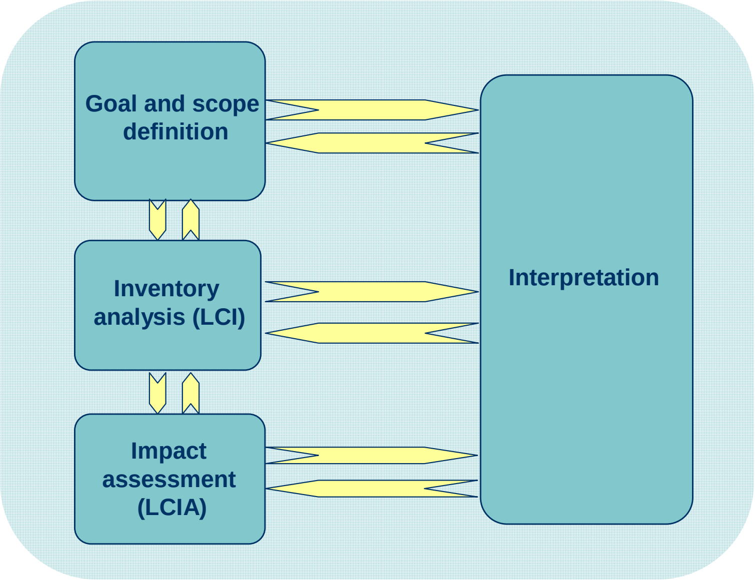


**Figure 2: Components of a LCA**

## Definition of the Goal and the Scope

The definition of the goal and the scope of the LCA study is crucial since this is the phase of essential determinations. According to the aims and the insight interest, the survey framework is defined and the demands on the further phases are determined. This may concern the intensity of the survey, the necessary quality of the data, the selection of the effect parameters with regard to the impact assessment, and the interpretive possibilities within the framework of the evaluation. Feedback results from the iterative character of the LCA. It has also to be decided whether and how an external report (critical survey) should be drawn up by a committee of experts as demanded by ISO 14040 for comparative studies that are intended for the public.

### Definition of the goal

The concrete aims and the insight interest of the LCA have to be fixed in the process of defining the objective. Moreover, the clients and the target groups have to be named. If necessary, it has to be pointed out which role the LCA plays in the decision-making process and whether it is linked with further surveys (for example economics, technology, social matters). When communicating the results, it should be made clear for which questions the LCA is suitable and for which it is not.

### Establishing of the system boundary

The system boundary has to be determined according to the defined goals of the LCA. The available means, the temporal framework and the availability of the necessary data must be taken into account. In detail, the temporal, spatial, factual and technical spheres of recording, that is the intensity and scale of the balance, have to be determined. The system boundary marks the interface of the environment and other product systems. They also define which procedures are included in or excluded from the survey. With regard to the data acquisition, the scale, type (specific, average), and quality of the necessary data have to be determined.

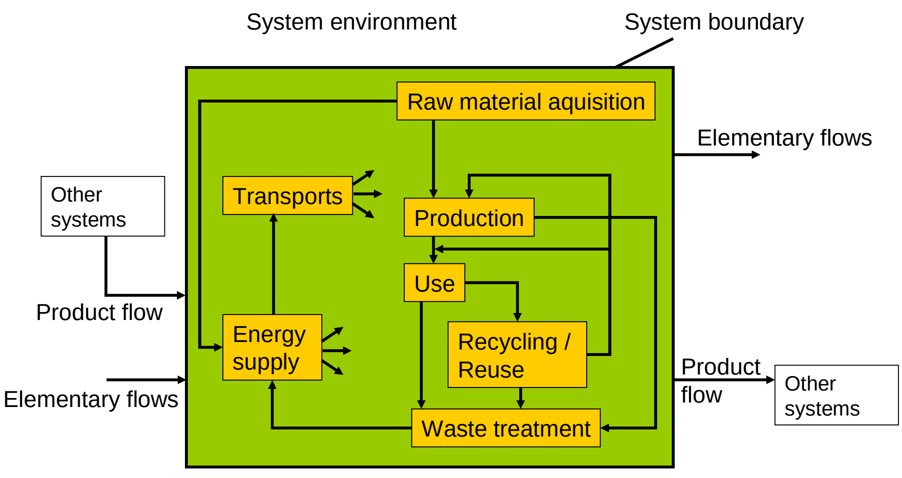


**Figure 3: Idealized illustration of a product system for life cycle inventory analysis**

Two problems emerge when the balance scope is established. First, the cut-off criteria and allocation procedures for coupling products have to be defined for the individual processes considered in the balance. Second, the functions of the examined systems as well as the functional unit have to be determined. Differences and possible restrictions of systems to be compared have to be documented.

**Cut-off Criteria**

In order to reduce the extent and complexity of the survey frame to a practicable degree, the balance scope is limited to a survey scale that fits the question properly. With the help of sensitivity analyses and performance criteria it is determined whether a material stream can be cut off. Among other things, the following criteria can be considered.

**Mass Criterion**

Only if the mass balance of a material stream in both the total input and output falls below a defined insignificance threshold, the manufacture of the material can be cut off.

**Energy Criterion**

Analogously, a material can only be cot off if its share in the total energy content of all input materials must fall below a certain insignificance threshold.

**Allocation Procedure**

If coupling productions occur in the examined product system, allocations have to be applied. Coupling productions are production processes which, along with the planned product output, generate further products that can be used in other processes. The environmental effects caused by such a process have to be added proportionately to all coupling products of the process in accordance with a certain procedure. Waste is not a coupling product.

- If possible, allocations should be avoided.
- If it is impossible to avoid allocations, the inputs and outputs of the system have to be assigned to the different coupling products in a way that the basic physical relations are reflected. The allocation is not necessarily based on the mass criterion. Further physical criteria are applicable.
- If physical relations are not applicable or not sufficient, the allocation can take place on the basis of other relations, for example economic values. If several allocation procedures appear to be permissible, a sensitivity analysis must be carried out.

**Benefits and Functional Unit**

The benefits (or the functions) of the examined product systems have to be clearly determined. For quantifying the given benefit, a functional unit (i.e. one ton of product) must be defined which serves as a reference unit for all input and output streams and the potential environmental effects. When comparing different products or procedures, it is of particular importance that the criterion of the functional equivalence (similar properties and function of products i.e. beverage package for 1 litre of beverage) meets the considered systems. Only functionally equivalent systems can be compared! Differences in the environmental effects of alternative systems can be directly assigned to the products or procedures only if the function of the considered systems is equivalent.

## Inventory Analysis

In the inventory analysis, the material and energy flows are grasped and listed during their entire life. In a first step, process structures are modelled in order to have a basis for assembling data. The material and energy flows are determined as input-/output-sizes for every partial process with regard to the system boundary. By connecting all partial processes, the relations between the modules and the environment are represented, and the mass/energy balance is drawn up as the inventory of the total system. All material and energy streams which pass the system borders are listed as quantities in physical units. The data refer to the functional unit.

## Impact Assessment

The task of the impact assessment is the evaluation of the material and energy flows raised in the inventory analysis according to certain environmental effects. Thus, the impact assessment serves the recognition, summarization, and quantification of the potential environmental effects of the examined systems and delivers essential information for the evaluation.

Different committees still work on the development of the method. A first international consensus becomes apparent in the ISO DIN 14042, taking up the basics of the SETAC recommendations (SETAC, 1993). The individual steps of the impact assessment, i.e. definition of the effect categories, classification, and characterization, are expounded in the following.

In the framework of the “classification”, the material and energy flows examined in the inventory analysis are assigned to the environmental effects (effect categories) which have been fixed before. The following impact categories are usually included into a LCA:

- Global warming (GWP)
- (Stratospheric) ozone depletion (ODP)
- (Tropospheric) photochemical ozone creation (POCP)
- Acidification (AP)
- Eutrophication (NP)
- Human toxicity (HTP)
- Ecotoxicity (ETP)
- Land use

The impact categories describe potential effects on human and environment. Among other things, they differ according to their spatial references (global, regional and local effects). In principle, every environmental effect can be included into the survey, as long as the necessary data and a suitable model for the description and parameterisation of the effect are available. A material flow can be assigned to several environmental effects.

In the step “characterization”, the quantification of the assigned quanta takes place. With the help of equivalence factors, the different contributions of the materials are aggregated to an environmental effect and defined according to a reference substance. The flows listed in the inventory analysis are multiplied with the corresponding equivalence factors, and the individual contributions are summed up. The determined impact potential represents a measure for a possible environmental damage. The amounts of different impact potentials are not directly comparable with each other. In the course of the “standardization”, the result of the determined impact potential is related to an area-related reference value. A continuing aggregation of the impact categories to one or several indices is not carried out. The necessary evaluation of the individual criteria can only be derived from marginal individual criteria which are often not inferable in a scientific way. .

## Interpretation

The task of the interpretation step is the analysis of the results as well as the explanation of the meaningfulness and the restrictions. The essential facts, based on the results of the inventory analysis and the impact assessment, are to be determined and checked with regard to their completeness, sensitivity, and consistency of the results. The assumptions made in the phase of the goal and scope definition have to be considered. Based on this, conclusions have to be drawn and recommendations are to be made.

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