

BASES FOR THE LIFE CYCLE ASSESSMENT

What is a life cycle assessment?

A life cycle assessment is the recording and evaluation, as comprehensively as possible, of the environmental impacts of one or several product systems based on all the basic material and energy flows. The term "product systems" here encompasses products, systems, procedures and behaviours. By structuring complex, interacting substances and impacts, the LCA creates a concise information basis on which to make environment-focused decisions.

There are various reasons, application cases and motives for doing an LCA: for example a process, product or service is in need of optimisation to environmental criteria, the environmental compatibility of a material or product requires assessment, or environmental criteria need to be included in a planning and design process.

The results of LCAs serve to show up weak spots, improve a product's environmental characteristics, aid decisions on acquisition and purchasing, foster environmentally friendly products and procedures, compare alternative behaviours, or justify recommendations for action. They can be used as a work aid, a monitoring tool or an aid to decision-making, and provide an effective means of environmental prevention.

An LCA assesses the material and energy flows which impact a selected set of indicators (e.g. potential global warming potential). Any other environmental effects, such as hazards to health or ecosystems, detrimental effects on biodiversity etc., and factors relating to technical masonry matters, as well as economic or social factors, do not come into consideration in an LCA and should be assessed using complementary methods, such as expert opinions, risk analysis, etc.

Life cycle assessment methods [ÖNORM EN ISO 14040ff]

Procedure

Today, there is widespread international consensus about LCA procedure. The standards ISO 14040 and ISO 14044 (in Austria: ÖNORM EN ISO 14040 and EN ISO 14044) provide the framework:

- ISO 14040 Environmental management - Life cycle assessment - Principles and Framework
- ISO 14044 Environmental management - Life cycle assessment – Requirements and Guidelines

The assessment is done in four clearly distinct phases:

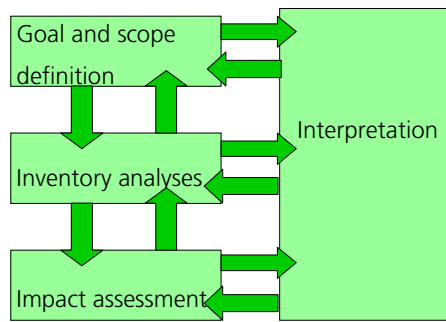


Diagram 1: The LCA assessment is done in four phases 1. Goal and scope definition, 2. Inventory analysis, 3. Impact assessment, 4. Interpretation. The results of each phase may have repercussions on the previous phase. For example, the inventory analysis may show that no data are available for calculating a chosen indicator. In this case, the assessment method specified in the goal and scope definition will have to be changed accordingly.

A critical examination by an internal or external expert should also be conducted in the case of LCAs the results of which are used to justify comparisons.

Goal and scope definition

General goal and scope definition

The goal and scope definition is a crucial phase which prepares the ground for the further progress and outcome of an LCA. Knowing who is aiming to have a controlling influence on which system and the interest in doing so (to which purpose) is of fundamental importance in an LCA. The goal and scope definition phase therefore consists in defining the subject matter (objects of study), the target group and the content of which the latter is to be notified. A variety of background circumstances, such as a need to provide explanations and information about the product, analyse weak spots, achieve environmental optimisation, provide policy advice or advertise may play a role here. Possible target groups for the assessment may be consumers, entrepreneurs, artisans, trade unionists, politicians or scientists. When defining the subject matter, the objects of study are stipulated in precise terms (e.g. "thermal insulation systems for façade insulation available on the Austrian market").

Once the background factors, target groups and purpose of the LCA have been set out and the actual objects of study chosen, it is time to define the functional unit, as well as the structural, spatial and temporal limits ("system boundaries") of the study [Deilmann 2000]

Scope

In defining the **subject matter**, the objects of the study, such as opaque (conventional) thermal insulation materials which are available on the Austrian market, are stipulated in precise terms. The **goal and scope**

definition phase consists in defining the target group and the content of which the latter is to be notified. For example, the purpose of the study might be to show insulation manufacturers ways of optimising the production process and to aid consumers in deciding which product to choose. Note that in LCAs, it may be necessary to adapt different aspects of the scope when collecting the data in order to achieve the defined goals. The important thing is to document this.

Functional unit

In the first phase, the functional requirements of the objects of study are defined (e.g. "thermal insulation" for insulating materials). Here, the objects of study must fulfil identical purposes or render identical service. It is usually difficult to define the functional requirements, as most products are multifunctional (e.g. thermal insulators may be heat and sound-insulating). A physical unit is then assigned to the functional requirement (e.g. "thermal resistance" in the case of thermal insulators). The process chains or product lines are examined up to the moment when the functional requirements are achieved. Only then it is meaningful and possible to make a comparison. For example, it is not meaningful to compare the energy and material assessments for the manufacture of 1kg of insulating material. Rather, you need to refer to the functional unit, e.g. thermal resistance in $\text{m}^2\text{K/W}$.

System boundaries

The system to be analysed is delimited by a precisely defined model (system boundaries). The system boundaries encompass the structural (also: "objective"), spatial and temporal limits of the model

First of all, the **structural boundary** delimits the life cycle phases which are under investigation.

System boundary

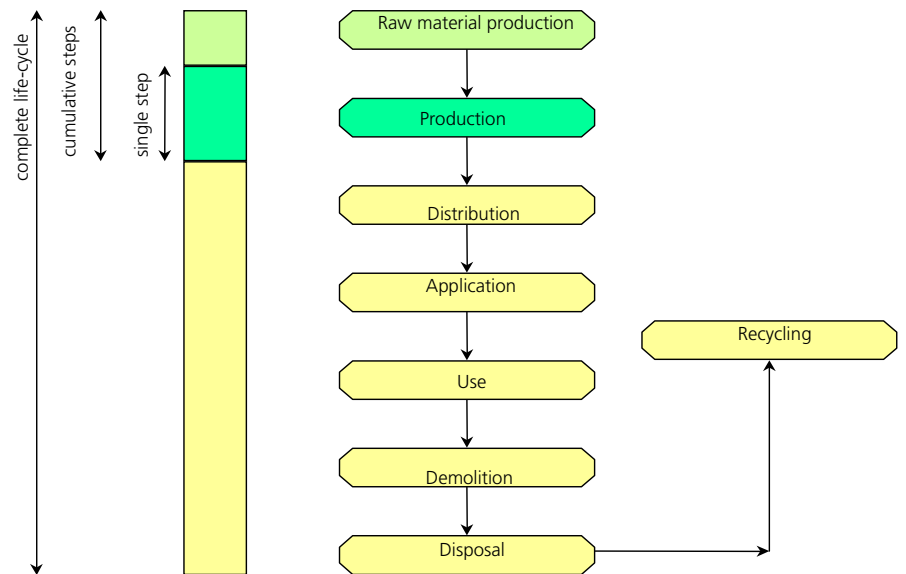


Diagram 2: Simplified diagram of the life cycle of a building material to demonstrate the three types of investigation applied in life cycle assessments: single step, cumulative steps, complete life cycle.

Depending on where the system boundaries lie, one of the following three types of investigation is conducted:

- Single step – based on one single step without taking the previous and subsequent steps into account (e.g. production only).
- Cumulative steps – based on all material flows up to a defined point in time or a defined state, usually until the end product is ready for shipping.
- Complete life cycle – encompasses all the phases in the life cycle of the product. In this type of assessment, different scenarios of use and disposal have to be defined, as inputs and pollution downstream of the manufacturing process have to be taken into account. The longer the life, the more difficult prediction becomes.

Next, the aspects and indicators of the individual phases of a product's life which are to be examined are determined.

The **spatial boundary** may be in terms of a factory, a national boundary, or global, for example. Product-related boundaries are usually based on national data.

The temporal boundary must be defined for the following issues

- the period of data collection
- the useful life of the product
- the period of observation of impacts

Data

Data may be collected at the place of production. They may be taken from published sources, or be calculated on the basis of such. All data categories may contain a mixture of measured, calculated or estimated data.

Comparability and consistency of the base data are crucial for data quality. To obtain representative data, the following must be true:

- The processes being compared must be technically equivalent.
- Should generic data be used, their domain of validity must be specified and the source stated.
- The reference database and its comparability with the base data used must be stated.
- The geographical area of data collection must be stated.
- The data used must be up- to-date and correspond to an annual average for the reference year.
- It must be stated how gaps in the data are dealt with.
- The principal material and energy flows must be listed in full.

Life cycle inventory

Collecting and documenting the energy and material flows in a data record is called a life cycle inventory, or input/output analysis. The collected data are compiled into a standard data record with the following structure:

1. General information
2. Inputs
3. Outputs

Before raw materials are used in the factory, they usually undergo processes (upstream process chains) the material and energy flows of which also have to be taken into account in cumulative-step or complete life cycle assessments. By consequence, in the case of heating oil, for example, not only emissions caused by processing are assessed in the LCA, but also the impact on the environment of the extraction, processing and supply of the heating oil. The method of procedure in the life cycle inventory is therefore as follows:

The entire investigation period is subdivided into modules, after which the material and energy flows are entered for each module. Basically, there are two distinct types of data: firstly, the “background data” which describe general processes, such as transportation and supply of energy sources and, secondly, data describing the product or production-specific processes (“foreground data”) [Eyerer et al. 2000].

The foreground data records (=first-hand data, directly available) are in most cases available for the central production process (assessed factory or company); consequently, data availability is usually good for the

“factory assessment”. Outside this area of responsibility, and as the number of upstream products increases, it becomes more and more difficult to establish an inventory of a product’s life cycle. If these data are not directly available, databases may be used. Especially for general processes, such as transportation and supply of energy sources, there is in general no other alternative but to have recourse to databases.

Examples of databases or LCA software are:

- ecoinvent database v2.0, new version dated November 20, 2007 (<http://www.ecoinvent.org/de/aktuelles/datenbank-neuigkeiten/>)
- SimaPro 7 LCA software (<http://www.simapro.de/>)
- GEMIS - Global Emissions Model of Integrated Systems (<http://www.oeko.de/service/gemis/de/material.htm>)
- Gabi 4 Software System (<http://www.gabi-software.com/deutsch/gabi/gabi-4/>)

General information

The general information section contains the information which is required to precisely define the object of study.

Inputs

The inputs encompass raw materials (incl. adjuvants and working materials), energy, water and soil.

Some important categories of raw material are:

- Primary or direct raw materials: these are taken directly from the ecosphere.
- Indirect raw materials or ready-made products: these have already undergone processing prior to their use in the factory under investigation.
- Renewable resources: these are rapidly renewed in natural cycles.
- Secondary raw materials: these are renewed by means of recycling, or occur as co-products of processes.
- Feedstocks are the materials used to manufacture the product. Adjuvants are attributed to the product, but do not enter its material composition (e.g. formwork oils).

The starting point for analysis of **energy consumption** is the final energy requirement. From this, the primary energy source requirement (see indicators) is calculated based on the efficiency of the energy supply. Clean energy, such as solar power, is considered to be “free”. The use of natural energy sources is attributed to use of resources as if they were materials.

Outputs

The outputs include co-products (such as blast furnace slag from steel production), waste, emissions to air, water or soil, noise, waste heat and

nuclear radiation. Emissions into the environment (air, water, soil) as far as the system boundaries are called primary emissions. Intake by flora, fauna or humans is referred to as secondary impact.

Emissions to air should be counted either as back-up filter values or – in the absence of filters – as direct emissions (possibly as dust). The remaining filter dust is treated as waste.

As far as **emissions to water** are concerned, the system boundary depends on whether treatment is in-house or outsourced. In the case of in-house treatment, the emissions should be counted as back-up filter values at the point where they are channelled into rivers or streams.

Sewage sludge is attributed to the waste categories. When treatment is outsourced, the quantity of wastewater is first of all recorded at the factory boundary and, with the aid of transfer coefficients, converted into emissions into rivers and streams as a back-up filter value of the waste water plant, and into sewage sludge quantities.

Solid waste quantities are put into categories and recorded under the “cradle to gate” system boundary. These form the basis for an analysis aimed at estimating the long-term hazard using the mass of waste. Again, the resulting soil, water and air pollution caused by waste is determined from the waste treatment with the aid of transfer coefficients.

The energy output in the form of waste heat, nuclear radiation and noise is not recorded in most cases because of the low-quality data available for building materials.

A link also has to be made between the output flows and the subsequent processes which neither enter the environment by direct means nor flow into another product life cycle. Basically, this means disposal by waste management procedures.

Impact assessment

From a scientific point of view, estimating the impact represents the greatest challenge. Here, the material and energy flows recorded by the inventory are attributed to environmental impacts. The procedure for establishing this impact estimation generally comprises the following steps [CML 2001]:

1. Classification: The results of the inventory analysis are attributed to a concise number of impact categories
2. Characterisation: The attributed substances are quantified and weighted within the impact categories (impact potential method).

The general methodological and scientific requirements for impact estimations are still being developed.

The table below shows the impact categories and their respective units.

Environment categories	Unit
Global warming	kg CO ₂ equivalent

Acidification	kg SO ₂ equivalent
Formation of photooxidants	kg ethylene equivalent
Stratospheric ozone depletion	kg CFC 11 equivalent
Eutrophication	kg PO ₄ equivalent

Table: Environment categories and their respective units

Substances may be attributed to several impact categories: For example, nitric oxides must be attributed to acidification and to the formation of photooxidants.

There will be a more detailed discussion of the individual environment categories after the Interpretation section.

Consumption of energy resources in the form of primary energy in MJ does not come into the impact classification according to Heijungs, as it is a resource quantity (cause).

Interpretation

Interpretation is carried out at the end of this procedure. For the purposes of interpretation, the indicators are interpreted within the framework of a model. Basically, there are two different approaches:

- The low-level aggregation method
- The high-level aggregation method

Low-level aggregation

Low-level aggregation strives to conflate the interpretation criteria into what is known as an "environmental profile". Frequently, the results for the individual indicators are then also normalised and then placed side by side with one another as having equal importance. Usually, a discussion is then held and the results interpreted.

The advantage of low-level aggregation is first and foremost its transparency and ease of comprehension. However, low-level aggregations do not generally lead to clear decisions for or against and, given the frequent complexity of the environmental profile, require the decision-makers to form their own opinion, in which all too often one "evil" has to be weighed against another. Decisions based on environmental profiles can therefore often be extremely political.

High-level aggregation

With high-level aggregation, the environmental criteria from a wide variety of environmental media, recorded in different units of measurement, are conflated and presented in one or a small number of absolute measures for interpretation. For this, a number of widely differing environmental pollution types have to be weighted, set in relation to one another and, subsequently, correlated to a single basis for interpretation. In general, the environmental interaction of individual

factors is extremely complex however, and cannot be explained in terms of simple linear relationships of cause and effect.

Conflation of the different impacts of a product or process on the environment makes the information in a high-level aggregation extremely dense. The particular appeal of the high-level aggregation procedure thus resides in its clear rating as “good” or “bad”, or “better than X” or “worse than X”.

Some examples of high-level aggregation procedures are the O13 index, the BUWAL Ecopoints system and the Sustainable Process Index (SPI).

Environment categories

Primary energy consumption

Primary energy consumption (PEC, also primary energy content or requirement) is the overall consumption of energy resources required to manufacture a product or a service. Primary energy consumption therefore also includes the energy used to obtain the raw materials or energy loss through waste heat, for example. It is divided into energy from non-renewable resources (oil, natural gas, lignite and coal, nuclear power) and energy from renewable sources (biomass, hydroelectric power, solar energy and wind energy). The primary energy consumption is calculated from the highest calorific value of all the energy resources deployed.

Global warming potential, GWP

Global warming potential, or GWP, describes the contribution made by a trace gas to the greenhouse effect relative to carbon dioxide. For each greenhouse gas, an equivalent amount of carbon dioxide is calculated in kilograms. This enables their direct impact on global warming to be expressed as a single impact indicator; to do so, the global warming potential of an emitted gas i (GWP_i) is multiplied by the mass of the gas m_i in kilograms:

$$GWP = \sum_i GWP_i \cdot m_i$$

Global warming potential can be determined for various time horizons (20, 100 or 500 years). A shorter integration period (span of time during which the input signal is sampled and the average value calculated) of 20 years is crucial for predicting short-term changes due to an exacerbated greenhouse effect, as can be expected for land. This means that it can be used if the temperature rise is to be limited, for example, to 0.1°C per decade. By contrast, longer integration periods of 100 and 500 years are appropriate for evaluating the long-term rise in ocean levels and serve, for example, to weight the greenhouse gases by limiting the total anthropogenic temperature rise to, say, 2°C.

Greenhouse gases	GWP 20 in kg CO ₂ eq.	GWP 100 in kg CO ₂ eq.	GWP 500 in kg CO ₂ eq.
Carbon dioxide CO ₂	1	1	1
Methane CH ₄	56	21	6.5
Dichlormethane	31	9	3
Trichlormethane	14	4	1
Tetrachlormethane*	2000	1400	500
HFC R 134 a	3400	1300	420
HFC R 152 a	460	140	42
HCFC R 141 b ²	1800	630	200
HCFC R 142 b ²	4200	2000	630
Sulphur hexafluoride SF ₆	16300	23900	34900
Laughing gas N ₂ O	280	310	170

Table: Trace gases which contribute to the greenhouse effect and their respective GWP_i coefficients. Source: [CML 2001]; GWP values for gases marked with * date from 1994.

Acidification potential (AP)

Acidification is caused mainly by the interaction of nitric oxides (NO_x) and sulphur dioxides (SO₂) with other constituents of the air. These gases can be converted in the space of just a few days into nitric acid (HNO₃) and sulphuric acid (H₂SO₄) – both substances which are instantaneously soluble in water – by means of any number of reactions, such as combination with the hydroxyl radicals (OH* radicals). The acidified water droplets then precipitate as acid rain. Unlike the greenhouse effect, acidification is a regional, not a global, phenomenon. Sulphuric and nitric acid may also be deposited dry, in the form of gases proper, or as constituents of microscopic particles. There is increasing evidence that the dry deposits cause as many global environmental problems as the wet ones.

Knowledge of the impact of acidification is still only fragmentary. One of the clearly attributed consequences is the acidification of lakes, rivers and streams, which is decimating fish stocks in terms both of quantity and diversity. Acidification can have the effect of mobilising heavy metals, which then become available to plants and trees. Moreover, acid deposits may play a role in the observed damage to forests. Over-acidification of the soil can impact the solubility and thus the availability to plants of nutrients and trace elements. Corrosion on buildings and outdoor art works is another consequence of acidification.

The unit of measurement for the tendency of a constituent to acidify is the acidification potential, AP. It is expressed as an impact indicator in the same way as GWP:

$$AP = \sum_i AP_i \cdot m_i$$

Below are the average “European acidification potentials” of selected substances:

Substance	Average European AP factors in kg SO ₂ eq. for Switzerland
Sulphur dioxide SO ₂	1.2
Nitric oxides (as NO ₂)	0.5
Ammonia NH ₃	1.6

Table: Acidification potentials of selected substances. Source: [Huijbregts 1999].

Photochemical ozone creation potential (photosmog, summer smog)

Photosmog in towns and their immediate vicinity is caused by the formation of photooxidants in the lower troposphere. This refers to the mixture of harmful, highly reactive gases which forms when sunlight comes into contact with anthropogenic emissions (especially nitric oxide compounds and hydrocarbons from car exhausts). The more highly reactive gases react within the space of a few hours close to the source of the emissions, while the less reactive constituents may spread before forming oxidants. Ozone is the principal product of this photochemical reaction and is also the chief cause of smog-related ocular irritation and respiratory problems, as well as of damage to trees and crops. The photochemical ozone creation potential (POCP) refers to the propensity of a substance to form photooxidants (summer smog). The photochemical ozone creation potential is measured in relation to the reference substance ethylene.

It is expressed as an impact indicator in the same way as GWP.

$$POCP = \sum_i POCP_i \times m_i$$

Stratospheric ozone depletion (ODP)

The depletion of the stratospheric ozone layer is caused by the catalyst effect of halogens in specific climatic conditions. The increased amount of ultraviolet radiation penetrating to the earth’s surface raises the risk of skin cancer and cataracts. It also causes damage to crops and phytoplankton, which is at the bottom of the food chain in the oceans. Chlorofluorocarbons (CFC) are chiefly responsible for the depletion of the ozone layer in the stratosphere. In the lower atmosphere, these act in the same way as noble gases, and are thus completely non-toxic and inert. Being inert, they arrive in the stratosphere unaltered and are then split up by the strong ultraviolet radiation. The chloratoms which are released as a result have the ability to break down the ozone by acting as a catalyst for its conversion into normal atmospheric oxygen. Since catalysts speed up chemical reactions but emerge from the process

virtually unchanged themselves, one single chloratome can ultimately destroy many thousands of ozone molecules. Even if CFC emissions ended abruptly today, the ozone belt in the stratosphere would only return to today's level in another 40-60 years. Since early 1995, the production and use of CFCs has been strictly prohibited in the European Union. This prohibition affects only the most potent ozone destroyers, fully halogenated CFCs. Partly halogenated CFCs and HFCs (HCFCs and HFCs) are only prohibited in a few European countries (e.g. in Austria, where a transition period has been granted for HFCs). By looking at the dwell time and the forecast concentration of emissions, the ozone depletion potentials, or ODPs, were determined in relation to the substance CFC R 11 (trichlorfluoromethane). They are expressed as an impact indicator in the same way as GWP.

$$ODP = \sum_i ODP_{\infty,i} \times m_i$$

$ODP_{\infty,i}$ is the ozone depletion potential for gas i.

Substance	ODP in kg CFC R 11 eq.
CFC R 11	1
CFC R 12	0.82
CFC R 113	0.9
CFC R 22	0.034
Halon H 1211	5.1
Halon H 1301	12
HCFC R 141b	0.086
HCFC R 142b	0.043
1,1,1 trichlorethane	0.11
CH ₃ Br	0.37
Tetrachlormethane	1.2

Table: Ozone depletion potentials of various substances. Source: [WMO 1999]

Eutrophication (EP)

Fertilisation is the application of additional nutrients to soil and water in order to raise farming production. **Excessive fertilisation** can affect the environment in a variety of ways. For example, it can cause a shift in the diversity of the ecosystem. At present, eutrophication is calculated solely on the basis of substances which contain neither nitrogen nor phosphorous. The potential contribution of a substance to the production of biomass is expressed as in terms of eutrophication potential, EP. This is expressed as an impact indicator in the same way as GWP:

$$EP = \sum_i EP_i \times m_i$$

Substance	EP in kg PO ₄ ³⁻ eq.
Phosphate PO ₄ ³⁻	1
Ammonium NH ₄	0.33
Nitrogen N	0.42
Nitric oxides NO _x	0.13
Chemical oxygen demand COD	0.022

Table: Eutrophication potential of some substances. [Source Heijungs et al. 1992]

Note that with this definition, the nitrates which enter the ground water as a result of excessive fertilisation are not taken into account. These are attributed to human toxicity.

OI3 indicator

The OI3_{TGH} indicator has been developed to calculate environmental ratings for buildings.

In the OI3 procedure, each of the three environmental values “Non-renewable primary energy consumption” (PECnr), “global warming potential” (GWP)* and “acidification potential” (AP) is put onto a building measurement scale from 0 (a very “good” building) and 100 (a very “bad” building) (environmental indicator OI_{TGH}PECnr, environmental indicator OI_{TGH}GWP and environmental indicator OI_{TGH}AP) and then weighted to one-third

$$OI3_{TGH} = 1/3 OI_{TGH}PECnr + 1/3 OI_{TGH}GWP + 1/3 OI_{TGH}AP$$

The result for the OI3_{TGH} indicator of a building is a figure between 0 and 100. **For building materials and construction, the OI3 indicator is solely a computational aid and can also have a negative value.** Like other environmental indicators, the lower the value, the better it is.