Basic Concepts on Ecodesign

Unit 4: Life Cycle Assessment and Costs

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On completion of this unit a learner will:

– Know the Life Cycle Assessment and the associated costs.
– Know methodologies, tools and data sets applied to perform the Life Cycle Assessment.

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4.1 Definition of Life Cycle Assessment

Life Cycle Assessment (LCA) is one of the most used methodologies to improve the environmental behaviour of products, processes and activities.

According to the standard ISO 14040[1], Life Cycle and "Life Cycle Assessment" are defined as:

- "Life Cycle": consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources, to final disposal.

- "Life Cycle Assessment": a technique to determine the potential environmental aspects and impacts associated to a product, service or process, with a compilation of the system inputs and outputs; the assessment of the potential environmental impacts associated to those inputs and outputs; and the interpretation of the results from the inventory and impact stages related to the objects of study.

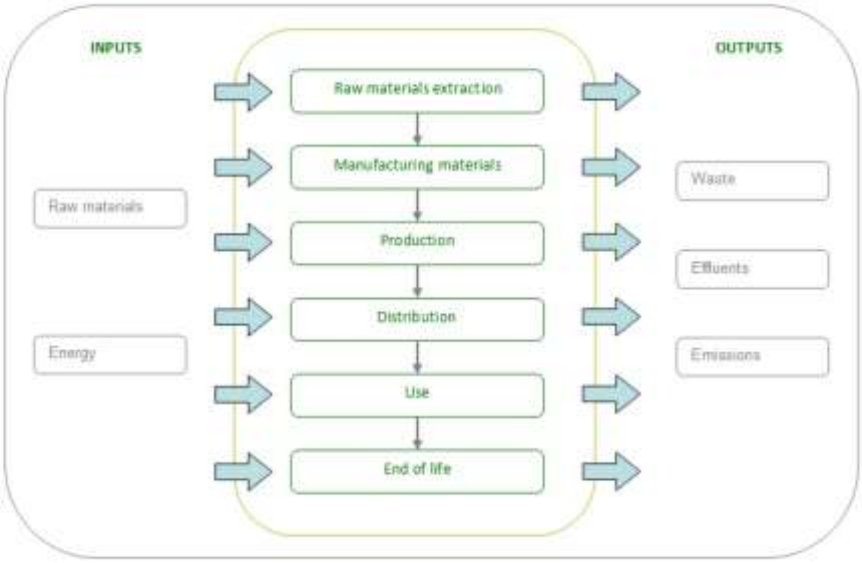

Figure 1. Life Cycle stages

LCA includes the entire product's life cycle, process or activity, taking into account the extraction and processing of raw materials, production, transport and distribution, use, reuse and maintenance, recycling and final disposal stages.

[1] ISO 14040:2006. Environmental Management. Life Cycle Assessment. Principles and framework.

When the LCA is developed according to the standards ISO 14040[1] and ISO 14044[2], the LCA is generally focused on the consumption of resources and the environmental impacts generated.

Currently, the European Platform on Life Cycle Assessment (EPLCA) -launched with the aim of promoting work and the LCA implementation in the industry as well as in administration- is working to standardise a methodology and the data treatment, so that all LCAs have the same tools.

In 2012 the Institute for Environment and Sustainability (IES) of the European Commission's Joint Research Centre (JRC), in cooperation with the Commission Directorate General for the Environment, published the "ILCD Handbook" (International Reference Life Cycle Data System) with the aim of providing common techniques, tools and sources of information as a reference for developing LCA. The work is essentially the "ILCD Handbook" (standard ISO 14040 user guide, reporting, etc.) and the "ILCD Data Network" (reference data sets development).

Benefits of the Life Cycle Assessment of a product, process or activity:

- It provides information about the negative environmental impacts, from a holistic approach comprising every Life Cycle stage, not only the manufacturing process itself. It offers a clear image of the actual consequences.
- It is helpful to take decisions and actions to reduce and to remove negative environmental impacts. It promotes product development and design with a better environmental performance.
- It is helpful to avoid that an implemented solution to an environmental problem of a certain stage generates an even worse problem in another stage of the cycle.
- It is the technical support of Ecodesign and "Eco-labelling". Integrated (not only) in the marketing strategy of the product, it helps making known that environmental criteria have been taken into account during the design.
- LCA is an instrument not only for environmental protection and preservation of natural resources, but also for cost reduction and the improvement of the competitiveness of a company.

The LCA is the base for sustainable consumption and production, the technical support of:

– Ecodesign.

[2] ISO 14044:2006. Environmental Management. Life Cycle Assessment. Requirements and guidelines.

– Carbon footprints (GHG emissions), hydro, environmental, etc.

– Eco-labelling type I (Ecolabel, etc.) y type III (Environmental Product Declaration -EPD).

– GPP: Green Public Procurement.

4.2 Life Cycle Assessment Stages

Every document included in the "ILCD Handbook", mentioned above, are in line with international standards for the Life Cycle Assessment, which are the following:

- ISO 14040:2006. Environmental Management. Life Cycle Assessment. Principles and Framework.
- ISO 14044:2006. Environmental Management. Life Cycle Assessment. Requirements and Guidelines.

According to these standards, LCA main stages are four:

- STAGE 1: GOAL AND SCOPE DEFINITION.
- STAGE 2: INVENTORY ANALYSIS.
- STAGE 3: IMPACT ASSESSMENT.
- STAGE 4: INTERPRETATION.

When the cost analysis is required, an additional stage is added:

- STAGE 5: LIFE CYCLE COSTING ANALYSIS.

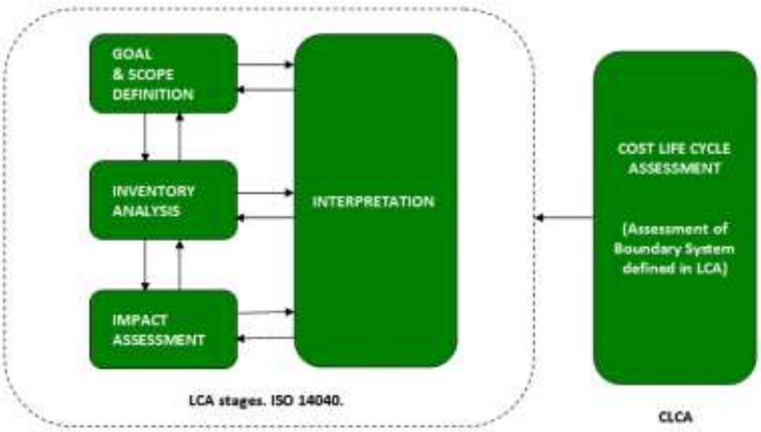

Figure 2. Life Cycle Assessment stages

The LCA stages are described in the subsections below.

4.2.1 Stage 1: Goal and Scope Definition

4.2.1.1 LCA Stage 1 Objective

At this stage the following are defined: aim of the study, reason for undertaking the study, target audience and the description of the chosen system -functional unit, system boundaries, data quality requirements, stated hypothesis, assessment methods, selecting impact categories, etc.

LCA may be applied to a product, process or activity.

4.2.1.2 Basic Concepts on LCA

Two basic concepts for understanding LCA are: “functional unit” and “system boundary”.

Functional unit

The “functional unit” is the reference unit to measure the performance of the product inputs and outputs. Its function must be identified and quantified in order to compare different products or systems.

The “functional unit” is selected to compare and define the level of detail. A functional unit may be related to the potential use of the product or it may be an actual physical unit.

The “functional unit” allows working in a manner corresponding to alternative systems for its comparison.

Functional unit examples:

- Two different products cannot be compared, but its service can, which is the case of two packages for a liquid, e.g. milk. The packages are made of glass and HDPE respectively. The functional unit is “the distribution of a certain amount of milk” (e.g. 100,000 litres or another quantity).
- When the two products belong to the same category, e.g. two chairs, the functional unit for the study of each product is “a chair”.

System boundaries

The system boundaries determine which unitary processes must be included in the LCA. Those processes will be determined considering factors such as: assessment application, stated hypothesis, exclusions, required quality data, economical limitations, etc.

The possible "system boundaries" of a LCA are:

- Cradle to Gate: a partial product's life cycle, from the extraction of raw materials, transformation and manufacturing entry, up to the manufacturer's gate.
- Gate to Gate: a partial product's supply chain that includes only the processes carried out on a product within a specific organisation or site (inputs and outputs).
- Cradle to Grave: a product's life cycle that includes raw material extraction, processing, distribution, storage, use, and disposal or recycling stages (end of life).
- Cradle to Cradle: a specific kind of cradle-to-grave, where the end-of-life disposal step for the product is a recycling process.

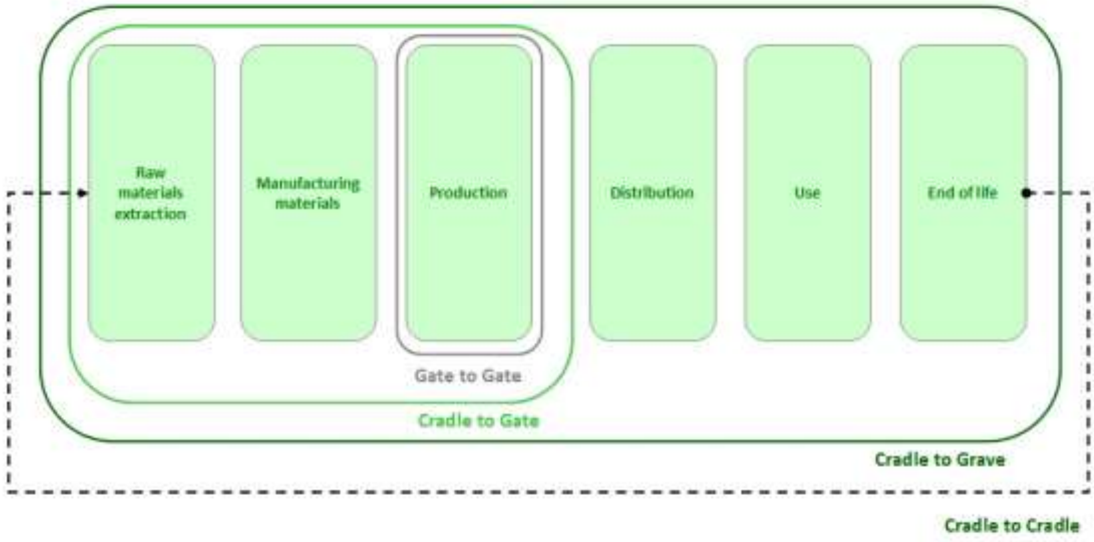

Figure 3. System boundaries of a LCA

4.2.2 Stage 2: Inventory Analysis (LCI)

4.2.2.1 LCA Stage 2 Objective

At this stage the necessary data is collected for the environmental assessment of the product, process or activity upon the basis of this method.

Data collection implies a great work, on the one side, knowledge of the materials and their origin, processes, consumed energy, transportation, etc.; and on the other side, the data quality and its availability. When data cannot be directly collected, it may be extracted from "external or internal data sets", some of them are mentioned in section 4.2.2.2.

The validation of inventory data must be carried out on an ongoing basis to review whether they are representative and valid. This will have a considerable impact to obtain a good LCA.

Mass and energy balance is the main method to perform life cycle inventory.

The inputs and outputs of the defined system are identified and quantified for the LCA, i.e. the environmental "aspects" related to the functional unit.

"Inputs" and "Outputs" examples:

-Inputs: water, energy and fuel consumption, materials and consumables, etc.

-Outputs: water effluents, waste, emissions, etc.

In Unit 6 of this course (Environmental Aspects of an Organisation) identification and quantification of environmental aspects are addressed in more detail.

4.2.2.2 Sources of Information for the LCI (Data Sets)

There are several sources of information for the drafting of the life cycle inventory. Those must be reliable sources.

Well-known sources and the typology of data presented are:

- ECOINVENT (Switzerland): data on electricity, energy sources, transportation, industrial materials, agricultural products and processes, waste treatment, etc. Its source of information is the Swiss Federal Office for the Environment.
- IDEMAT (Netherlands): data on industrial materials, energy and transportation.
- TEAM (France, United Kingdom, USA, Italy, Japan): data collected from the multinational consulting PWC related to waste treatment, electronical products, etc.
- BUWAL 250 (Switzerland): data reemissions related to energy production and diverse production processes, transportation and waste.
- ETH-ESU (Switzerland): data on fuel production and importation, electricity production and marketing, emissions derived from primary energy extraction, mineral resources extraction, raw materials and materials production.

4.2.3 Stage 3: Life Cycle Impact Assessment

4.2.3.1 LCA Stage 3 Objective

At this stage the inventory is translated into possible indicators of environmental impact related to the environment, human health and the disposal of natural resources.

Life cycle inventory data are converted in environmental.

4.2.3.2 Stages of the Life Cycle Impact Assessment

There are 3 stages:

1. Classification of impact categories. (Mandatory).
2. Characterisation or "modelling" of inventory data. (Mandatory).
3. Normalisation, grouping and weighting. (Optional).

Classification of impact categories:

There is a wide array of environmental impact categories and the choice of a certain one in the carried out LCA depends on the aim of the study, the profile and the accuracy for the required results. Data are assigned to each impact category according to the expected environmental effect. A substance must be considered in each and every category if it contributes to several impact categories.

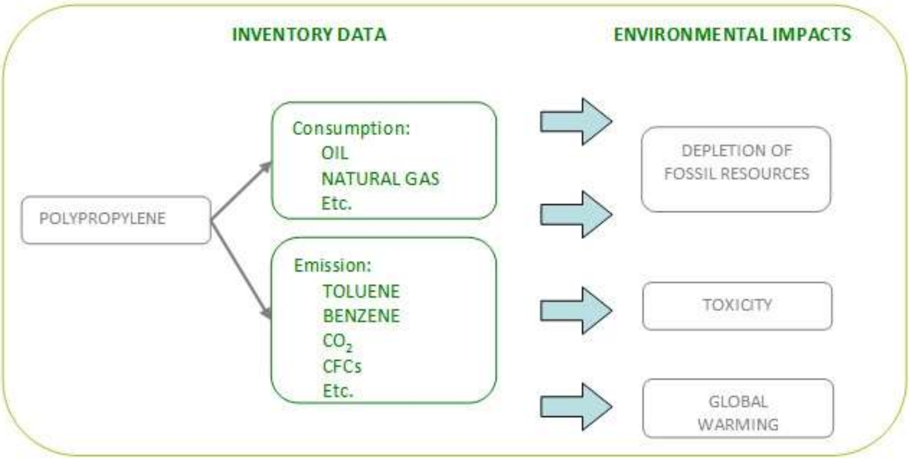

Figure 4. Example of impact categories associated to polypropylene

The following table displays impact categories defined by the Society of Environmental Toxicology and Chemistry (SETAC).

Table of impact categories according to SETAC

ENVIRONMENTAL IMPACT CATEGORIES		Reference unit	Characterisation factor
Global warming	Phenomenon observed in temperature measurements which shows on average an increase in the terrestrial atmosphere and oceans temperature during the last decades.	Kg. Eq. CO_2	**Global Warming Potential (GWP)**
Use of energy resources	Energy consumed in the collecting of raw materials, manufacturing, distribution, use and end-of-life of the assessed element.	MJ	**Quantity consumed**
Ozone depletion	Negative effects under the protection capacity of the ozone layer against ultraviolet radiation from the sun.	Kg. Eq. CFC-11	**Ozone Depletion Potential (ODP)**
Eutrophication	Excessive growth of algae population due to the artificial enrichment of river water and reservoir as a consequence of the massive use of fertilisers and detergents. This generates a high consumption of the oxigen of the water.	Kg. Eq. de NO_3	**Eutrophication Potential (EP)**
Acidification	Loss of the soil and water neutralising capacity as a consequence of the sulphur and nitrogen oxides unloaded into the atmosphere returning to the surface as acids.	Kg. Eq. SO_2	**Acidification Potential (AP)**
Raw material consumption	Consumption of materials extracted from the nature.	Tm	**Quantity consumed**
Photochemical oxidant formation	Formation of precursors from photochemical pollution. Natural sunlight impacts on those precursors, causing the formation of a series of compounds known as photochemical oxidants (e.g. Ozone-O3).	Kg. Eq. C_2H_4	**Photochemical Oxidant Formation Potential (POFP)**

Characterisation or “modelling” of inventory data:

Once every substance in the inventory is assigned, using the classification, to one or more environmental impact categories, their value is compared with regard to the reference substance of such category.

Environmental effects become units of the indicator using the “characterisation factors” for every chosen impact category. Thus, equivalent units are obtained, which may add to each other to measure the substances contribution to the impact category.

Normalisation, grouping and weighting:

These stages are not mandatory, their application depends on the LCA objective and scope.

- *Normalisation:* is the conversion of the characterisation results to neutral global units, dividing each one by a normalisation factor. Using these factors, the extent of the contribution to each impact category on the local environmental problem is depicted.

- *Grouping:* is the classification of impact categories in groups which encompass impact categories with similar effects.

- *Weighting:* is the conversion of the characterised values results to a common unit, which may add to each other (if the methodology includes a normalisation, then through the normalised values), and then multiplying them by the respective weighting factor. Subsequently, they all add up to obtain a total unique score of the system environmental impact.

At the last two stages, “characterisation” and “normalisation, grouping and weighting”, different methods may be applied to assess the life cycle impact. The chosen method will vary depending on the level of information required and the aim of the LCA (internal level, external level, product comparison, etc.). Some methods intend to define an environmental profile quantifying “midpoints”, which represent the many impact categories, some others try to assess “endpoints” on the environment.

Differences between impact assessment methods: “ENDPOINT” and “MIDPOINT”:

- “ENDPOINT”, assessment of the last environmental effect: final impact categories vary and affect directly to society. They are more relevant and accessible worldwide. Nevertheless, there is no scientific consensus, they are not fully elaborated.

- “MIDPOINT”, assessment of mid environmental effects: these categories are closer to environmental intervention. There are calculation models that better adjust to intervention in these mid environmental categories. They are the most used.

Main methodologies are displayed below for the “Life Cycle Impact Assessment”.

Table. Available methodologies for the life cycle impact assessment

Name	Country	Year	Observations
CML-IA	Netherlands	2001	Developer: Centre for Environmental Studies (CML), University of Leiden, 2001. Replaces the CML 1992 method. Includes: characterisation and normalisation.
Ecological scarcity 2013	Germany	2013	Developer: the "ecological scarcity" method, also known as Ecopoints or Umweltbelastungspunkte, is a monitoring of Ecological scarcity 2006 and the Ecological scarcity 1997 method, which was known as Ecopoints 97 (CH). Includes: characterisation, normalisation and weighting.
EDIP 2003	Denmark	2003	Developer: Institute for Product Development, Technical University of Denmark with five Danish firms. Includes: characterisation, normalisation and weighting.
EPD (2013)	Sweden	2013	Developer: the previous method was EPD (2008) and it is used to draw environmental product declarations (EPD), as it is explained in the website of the Swedish Environmental Management Council (SEMC) Includes: characterisation, normalisation and weighting.
EPS 2015d and EPS 2015dx	Sweden	2015	The methodology by default of EPS 2015 (Environmental Priotrity Strategies on product design) is a damage-oriented method, previously EPS 2000. Includes: characterisation, normalisation and weighting.

Name	Country	Year	Observations
ILCD 2011 Midpoint+	Europe	2011*	Developer: this is the revised and updated method of ILCD Midpoint 2011 (without "+") which may still be found in the Replaced folder. For this new version, normalisation factors were added according to "Normalisation method and data for Environmental Footprints, 2014, Lorenzo Benini, et al., Report EUR 26842 EN". Characterisation factors in the category "Land use" are updated based on "ERRATA CORRIGE to ILCD – LCIA characterisation factors" - Version06_02_2015 (v. 1.0.6) - "Lista de cambios en CF para uso del suelo desde v 1 0 5 a v 1 0 6_REVISED.xlsx". Includes: characterisation.
Impact 2002+	Sweden	2002	Developer: IMPACT 2002+, acronym of IMPact Assessment of Chemical Toxics, is an impact assessment methodology originally designed by the École Polytechnique Fédérale de Lausanne (EPFL), with up-to-date studies carried out by the research team themselves now under the name Ecointesys- life cycle systems (Lausanne). Includes: characterisation, normalisation and weighting.
ReCiPe 2016	Netherlands	2016	Developer: ReCiPe 2016 is an updated and extended version of ReCiPe 2008. As its precursor, ReCiPe 2016, includes midpoint (problem-oriented) and endpoint (damage-oriented) available for three different approaches (Individualist (I), Hierarchist (H), and Egalitarian (E)). Includes: Value choices, characterisation at average level, normalisation, damage assessment and weighting.

BEES	USA	2010	Developer: BEES, acronym of Building for Environmental and Economic Sustainability, a software tool developed for the National Institute of Standards and Technology (NIST). BEES combines a partial life cycle assessment and costing of construction materials in a single tool. Includes: characterisation, normalisation and weighting.
TRACI 2.1	USA	2012	Developer: Tool for Reduction and Assessment of Chemicals and other environmental Impacts (TRACI) is an independent software developed by the United States Environmental Protection Agency (EPA) specifically for the USA, which uses input parameters consisting in locations in the USA. Includes: characterisation, normalisation and weighting.

4.2.4 Stage 4: Interpretation of Results

At this stage the results of the two previous stages "inventory assessment" and "impact assessment" are interpreted according to the objectives and scope defined at the beginning.

Conclusions of the results assessment are registered, which allows to identify the LCA stages with the biggest environmental impact, and therefore may or must be improved. In case the aim of the study is to compare two products, the results may determine which one has a better environmental behaviour.

4.3 Assessment of Life Cycle Costing

The Life Cycle Costing (LCC) considers all costs, including the environmental impact during the entire life cycle, in the design and development stage of a product, process or activity.

A product, process or activity costs during the entire life cycle are easily visible, e.g. direct costs of raw materials, energy and labour. Nevertheless, other costs are less visible as the productivity loss due to generated waste, emissions, etc.

LCC includes every money flow related to a product during its entire life, combines economic with environmental parameters and is useful in the decision-taking process.

4.4 Software for the implementation of LCA and Assessment of LCC

The Life Cycle Assessment (LCA) is complex because it involves great analysis work, carrying out large calculations and the use of data sets. Help is needed for that purpose, therefore, the use of software tools for LCA is very extended. Some software tools already include a module to carry out the assessment of the Life Cycle Costing (LCC).

Software tools facilitate the study of the Life Cycle Assessment (LCA), specially the following stages: inventory, impact assessment and interpretation of results.

In the following table, SimaPro y GaBi -the most used software tools- are displayed.

Table. Software for the implementation of LCA

Name	Company	Description
SimaPro SimaPro	PRE-Consultants	Software specialised on LCA tools. Demos and support guides, and complete and varied data sets are available. It allows analysing complex products, breaking them down in their materials and processes.
GaBi thinkstep GaBi	Institute for Polymer Testing and Polymer Science (IKP) and the University of Stuttgart in collaboration with PE EUROPE GMBH	LCA tool. Products and systems, balance in inputs and outputs of emissions, materials and energy can be modulated and parameters modified at any moment. If offers end-of-life scenarios. It allows data exportation.
TEAM™	ECOBILAN PRICEWATERHOUSE COOPERS	Complete, flexible and powerful tool. It allows data insertion related to costs, flow charts, processes, etc. Data insertion is similar to GaBi. Life cycle parameters of a product can be modified at any moment. It allows end-of-life assessment and data exportation.
UMBERTO umberto	Ifu Hamburg GMBH	It offers great quality data and transparent results. It reflects the entire life cycle, inputs and outputs, flows between processes, etc. High flexibility with system boundaries. It also allows to study the economic cost life cycle. Data can be exported.
Eco-it	IHOBE	Tool specialised in LCA simplified software and Carbon Footprint (CF) for products. Specially recommended to product and package designers. Easy to handle.
Air.e LCA	Solid Forest	For LCA and Carbon Footprint. It may be applied to product or the organisation. Powerful graphical interface for the design of life cycle and process maps. It allows generation of verification and graphical reports automatically.

Open LCA	GreenDelta	Open source, free and multi-platform software for carrying out complete LCA. It is in development since 2006, characteristics can be modified to adapt to different needs because of its nature. It is LCA-oriented, but also allows carbon and water footprint. Wide array of databases.