LCA – Life Cycle Assessment

Prof. Paulo Ferrão
**Definition of LCA** according to ISO 14040:

LCA is a technique [...] compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory and impact phases in relation to the objectives of the study.
LCA Stages and characteristics
• Two procedural LCA Standards
  - ISO 14044 - Requirements and guidelines (2006)
• Replaced:

• Others LCA ISO standards
  - ISO 14048 - Data documentation format (2002)
  - ISO 14049 - Examples of application of ISO 14041 to goal and scope definition and inventory analysis (2000)
Normative References

• Other standards with relevance to LCA
  – PAS 2050 – GHG accounting of product systems

• Important aspect of LCA ISO norms
  – LCA cannot be certified, as in ISO 14001
  – LCA is a relative methodology due to its nature
  – Recommendations and guidelines are goal and scope dependent
Structure of a Process-based LCA Model
Life cycle assessment terminology (ISO 14040:2006)

- Elementary flows (e.g. resource extractions) – input flows
- Elementary flows (e.g. emissions to air) – output flows

Economy-environment system boundary

Functional unit

Product system
• Circularity effects in the economy must be accounted for: cars are made from steel, steel is made with iron ore, coal, steel machinery, etc. Iron ore and coal are mined using steel machinery, energy, etc...
• **Goal and scope** – in which the reasons for the study, the intended audience, the functional unit, etc. are defined.

• **Inventory** – in which the data describing the system is collected and converted to a standard format to provide a description of the physical characteristics of the system of interest.

• **Impact assessment** – in which the physical flows are translated into potential environmental impacts.

• **Interpretation** – in which the results are evaluated and interpreted in context of their significant, uncertainty, etc.

• **Improvement** – in which the system is modified in some way to reduce or ameliorate the observed environmental impacts.
Fundamental concept always associated

Product /Service: Functional Unit
The **functional unit** describes the primary function(s) fulfilled by a (product) system, and indicates how much of this function is to be considered in the intended LCA study.

It will be used as a basis for selecting one or more alternative (product) systems that can provide these function(s). The functional unit enables different systems to be treated as functionally equivalent and allows reference flows to be determined for each of them.

Having defined the functional unit, the amount of product which is necessary to fulfill the function shall be quantified. The result of this quantification is the **reference flow**.
• **Life cycle perspective**
  - Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided.

• **Environmental focus**
  - Address the environmental aspects and impacts of a product system. Economic and social aspects and impacts are, typically, outside the scope of the LCA. Other tools may be combined with LCA for more extensive assessments.

• **Relative approach and functional unit**
  - Relative approach, structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit.

According with ISO 14040(2006)
• Iterative approach
  – Approach within and between the phases contributes to the comprehensiveness and consistency of the study and the reported results

• Transparency
  – Due to the inherent complexity in LCA, transparency is an important guiding principle in executing LCA, in order to ensure a proper interpretation of the results

• Comprehensiveness
  – Considers all attributes or aspects of natural environment, human health and resources. By considering all attributes and aspects within one study in a cross-media perspective, potential trade-offs can be identified and assessed.

According with ISO 14040(2006)
• **Some advantages**
  - Holistic view
  - Assessment of global and regional environmental impacts
  - Adds objectivity to impact assessment
  - Provides information for improvements, communication, etc.
  - LCA is an evolving methodology (e.g. databases, impact assessment, etc.)

• **Some limitations**
  - LCA is a model of a complex reality, thus a simplification of reality
  - Scope dependent
  - Data availability
  - Could be time consuming, depending on the scope and objectives
  - Not a triple bottom assessment (social and economic assessment, typically out)
When LCA could be useful?

- **Internally**
  - Compare environmental impacts of different products with the same function
  - Compare a product environmental impact with reference to a standard
  - Identify the most environmentally most dominant phases in a product life cycle
  - In eco-design, identify opportunities for improvement
  - Help the company internal strategy definition

- **Externally**
  - Marketing
  - Information and education
  - Lobbying
  - Labeling purposes
When LCA should not to be used?

- Compare environmental impacts of totally different products
- It is not a substitute for location dependent assessments (e.g. EIA – Environmental Impact Assessment), but is complementary
- The same thing for risk analysis
• Goal and scope

• Inventory analysis

• Impact assessment

• Interpretation
Goal and scope definition
LCA step 1
Goal and Scope Definition
• Goal Definition

  - The purpose of the analysis
  - The intended use of the results
  - The study stakeholders
• Scope definition
  – Product system to be studied
  – Functions of the product system or, in the case of comparative studies, the systems
  – Functional unit
  – System boundary (process included)
  – Allocation procedures
  – Methodology of impact assessment, impact categories selected and subsequent interpretation to be used
  – Data requirements (temporal, spatial and technological coverage)
  – Assumptions
  – Limitations
  – Initial data quality requirements
Scope definition

- Type of critical review, if any
- Type and format of the report required for the study

The scope should be sufficiently well defined to ensure that the depth and detail of the study are compatible and sufficient to address the stated goal.

- Nevertheless, the initial goal and scope definition (LCA step 1) is to be revised interactively, according with intermediary and final results, as well with choices made during the LCA (e.g. allocation made in specific process).

- Document, Document, Document...
### System boundaries cut-off rules

- **Cut-off rules (system boundaries)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>% of total mass  (e.g. 5%)</td>
<td>Materials and energy</td>
</tr>
<tr>
<td>2</td>
<td>% of Energy</td>
<td>Excluding capital goods</td>
</tr>
<tr>
<td>3</td>
<td>% of environmental relevance</td>
<td>Including capital goods</td>
</tr>
</tbody>
</table>

Best!
But how to do it? In this stage we still have no result...
LCA Step 2
Inventory analysis

Life cycle assessment framework

Goal and scope definition

Inventory analysis

Impact assessment

Interpretation
• **Inventory Analysis**
  
  – The inputs and outputs of all life-cycle processes have to be determined in terms of material and energy.

  – Produce a process tree or a flow-chart classifying the events in a product’s life-cycle which are to be considered in the LCA, plus their interrelations.

  – Next, start collecting the relevant data for each event: the emissions from each process and the resources (back to raw materials) used.

  – Establish (correct) material and energy balance(s) for each process stage and event.
Example of a simplified material/energy balance

<table>
<thead>
<tr>
<th>Resources</th>
<th>Atmospheric emissions</th>
<th>Water emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectric energy</td>
<td>CO2 748000.0 g</td>
<td>Residual water 1.7 m3</td>
</tr>
<tr>
<td>Natural gas (vol)</td>
<td>SOx 2690.0 g</td>
<td>Cl 63900.0 g</td>
</tr>
<tr>
<td>Uranium</td>
<td>NOx 2310.0 g</td>
<td>Inorganic subst. 39500.0 g</td>
</tr>
<tr>
<td>Process water</td>
<td>VOC 1640.0 g</td>
<td>Suspension solids 5030.0 g</td>
</tr>
<tr>
<td>Glass cullet</td>
<td>Dust 1300.0 g</td>
<td>Sulphates 627.0 g</td>
</tr>
<tr>
<td>Sand</td>
<td>CO 787.0 g</td>
<td>Oils 283.0 g</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>Metane 781.0 g</td>
<td>VOC 74.0 g</td>
</tr>
<tr>
<td>Lime stone</td>
<td>HCl 67.9 g</td>
<td>Metallic ions 59.3 g</td>
</tr>
<tr>
<td>Rock salt</td>
<td>Pb 44.6 g</td>
<td>NH4+ 29.3 g</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>Ammonia 38.2 g</td>
<td>Ba 24.3 g</td>
</tr>
<tr>
<td>Coal</td>
<td>HF 15.8 g</td>
<td>Fe 23.6 g</td>
</tr>
<tr>
<td>Rock</td>
<td>metals 4.2 g</td>
<td>Al 20.3 g</td>
</tr>
<tr>
<td>Anthracite</td>
<td>CxHy aromatic 3.8 g</td>
<td>N tot 9.9 g</td>
</tr>
<tr>
<td></td>
<td>N2O 2.0 g</td>
<td>COD 9.6 g</td>
</tr>
<tr>
<td></td>
<td>Benzene 1.9 g</td>
<td>CxHy aromatics 7.8 g</td>
</tr>
<tr>
<td></td>
<td>Ni 0.4 g</td>
<td>Nitrates 6.3 g</td>
</tr>
</tbody>
</table>
• **Data collection**
  - Energy inputs, raw material inputs, ancillary inputs, other physical inputs
  - Products, co-products and waste
  - Emissions to air, discharges to water and soil
  - Other environmental aspects

• **Data calculation**
  - Validation of raw data
  - Relating data to unit process
  - Relating data to functional unit and reference flow

• **Intensive aspect** – constrains should be stated in the report (goal and scope)
• Allocation
  – Most industrial processes yield more than one product and they recycle intermediate or discarded products as raw materials
  – Examples:
    • Cow: milk, meat, leather
    • Salt electrolysis: chlorine, caustic soda and hydrogen

• What we are talking about is how to allocate environmental impacts for each product
  – As for the functional unit, “Good” allocation procedures are essential for an effective LCA study
  – Probably the most controversial aspect in LCA
• How to proceed?
  1. Avoid allocation in the first place
  2. Allocate impacts to the different products (allocation)

• Avoid allocation
  – By splitting the process in such a way that it can be described as two separate processes that each has a single output
  – Often this is not possible, for example wooden planks and saw dust are both an economic outputs of a saw mill, but one cannot split the sawing process into a part that is responsible for the saw dust and one that is responsible for the planks.
Avoid allocation

- Other option: Expand system boundaries
  - Inventory of alternative process that can produce the same product
  - Subtraction of the emissions from these process from the main output
  - When we don’t know the substitute process, we chose the worst case scenario - avoided product with less environmental impacts
• Allocation strategies:
  1. Use of physical causality (mass allocation, but energy could be also applied, e.g. incineration – electricity and heat), and if not possible
  2. Use other relationships (economic allocation)

<table>
<thead>
<tr>
<th></th>
<th>Mass allocation (mass percentage)</th>
<th>Economic allocation (added value allocation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wooden planks</td>
<td>60%</td>
<td>95%</td>
</tr>
<tr>
<td>Saw dust</td>
<td>40%</td>
<td>5%</td>
</tr>
</tbody>
</table>
When one of the outputs is waste, that should be taken that into account and the waste must be “discounted” from the allocation (unless it’s a sub-product).

**Economic allocation**
- Prices can fluctuate significantly (interferes in the analysis)
- Economic values are not always easy to obtain

It is always wise to perform a sensitivity analysis to know if the allocation method is relevant for the final result.
• Where no changes occur in the inherent properties of the recycled material, the allocation problem is avoided because the use of secondary material displaces the use of virgin (primary) materials
  – However, the first use of virgin materials in applicable open-loop product systems may follow an open-loop allocation procedure

• When changes occur in open-loop system, there should be allocation based on the following order:
  – Physical properties (e.g. mass), Economic properties, Number of subsequent uses of the recycled material

• How to do economic allocation?
  – Market value of the scrap material or recycled material in relation to market value of primary material
  – Ratio between waste (Product system 1 to recycling) or secondary material (recycling to Product system 2) prices, in relation with their sum. -> Who drives the market?
Impact assessment
Step 3 – Impact assessment

Life cycle assessment framework

- Goal and scope definition
- Inventory analysis
- Impact assessment

Interpretation

LCA step 3
Impact assessment

LCIA – Life Cycle Impact Assessment
LIFE CYCLE IMPACT ASSESSMENT

Mandatory elements

- Selection of Impact categories, category indicators and characterization models
- Assignment of LCI results (classification)
- Calculation of category indicator results (characterization)

Category indicator results, LCIA results (LCIA profile)

Optional elements

- Calculation of the magnitude of category indicator results relative to reference information (normalization)
- Grouping
- Weighting

Following ISO 14040
• Classification
  – The LCI results must be assigned to impact categories. For example CH₄ or CO₂ could be assigned to a impact category called “Climate change”

  – It is possible to assign emissions to more than one impact category at the same time. For example, SO₂ is simultaneously responsible for an impact on “Acidification” as well as in “Human health” or “Respiratory diseases”
• Characterization
  – Once the impact categories are defined and the LCI results are assigned to the impact categories, it is necessary to define characterization factors. These factors should reflect the relative contribution of an LCI result to the impact category indicator result.

  – For example, on a time scale of 100 years the contribution of 1 kg CH\(_4\) to global warming is 25 times as high as the emission of 1 kg CO\(_2\).

  – This means that if the characterization factor of CO\(_2\) is 1, the characterization factor of CH\(_4\) is 25. Thus, the impact category indicator result for global warming can be calculated by multiplying the LCI result with the characterization factor.
Characterizations factors for some GHG, according with IPCC, 2007. (Global warming potentials)

<table>
<thead>
<tr>
<th>Industrial Designation or Common Name (years)</th>
<th>Chemical Formula</th>
<th>Lifetime (years)</th>
<th>Radiative Efficiency (W m⁻² ppb⁻¹)</th>
<th>Global Warming Potential for Given Time Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>b1.4x10⁻⁵</td>
<td>1</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>See below</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>12</td>
<td>3.7x10⁻⁴</td>
<td>21</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>N₂O</td>
<td>114</td>
<td>3.03x10⁻³</td>
<td>310</td>
</tr>
<tr>
<td><strong>Substances controlled by the Montreal Protocol</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFC-11</td>
<td>CCl₃F</td>
<td>45</td>
<td>0.25</td>
<td>3,800</td>
</tr>
<tr>
<td>CFC-12</td>
<td>CCl₂F₂</td>
<td>100</td>
<td>0.32</td>
<td>8,100</td>
</tr>
<tr>
<td>CFC-13</td>
<td>CCl₃F</td>
<td>640</td>
<td>0.25</td>
<td>10,800</td>
</tr>
<tr>
<td>CFC-113</td>
<td>CCl₂FCCCl₃F₂</td>
<td>85</td>
<td>0.3</td>
<td>4,800</td>
</tr>
<tr>
<td>CFC-114</td>
<td>CClF₂CClF₂</td>
<td>300</td>
<td>0.31</td>
<td>8,040</td>
</tr>
<tr>
<td>CFC-115</td>
<td>CClF₃CF₃</td>
<td>1,700</td>
<td>0.18</td>
<td>5,310</td>
</tr>
<tr>
<td>Halon-1301</td>
<td>CBrF₃</td>
<td>65</td>
<td>0.32</td>
<td>5,400</td>
</tr>
<tr>
<td>Halon-1211</td>
<td>CBrClF₂</td>
<td>16</td>
<td>0.3</td>
<td>4,750</td>
</tr>
<tr>
<td>Halon-2402</td>
<td>CBrF₂CBrF₂</td>
<td>20</td>
<td>0.33</td>
<td>3,680</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>CCl₄</td>
<td>26</td>
<td>0.13</td>
<td>1,400</td>
</tr>
<tr>
<td>Methyl bromide</td>
<td>CH₃Br</td>
<td>0.7</td>
<td>0.01</td>
<td>17</td>
</tr>
<tr>
<td>Methyl chloroform</td>
<td>CH₃CCl₃</td>
<td>5</td>
<td>0.06</td>
<td>506</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>CHCIF₂</td>
<td>12</td>
<td>0.2</td>
<td>1,500</td>
</tr>
<tr>
<td>HCFC-123</td>
<td>CHCl₃CF₃</td>
<td>1.3</td>
<td>0.14</td>
<td>90</td>
</tr>
<tr>
<td>HCFC-124</td>
<td>CHClF₃CCl₃F₃</td>
<td>5.8</td>
<td>0.22</td>
<td>470</td>
</tr>
<tr>
<td>HCFC-141b</td>
<td>CH₃CCl₂F</td>
<td>9.3</td>
<td>0.14</td>
<td>2,250</td>
</tr>
<tr>
<td>HCFC-142b</td>
<td>CH₃CClF₂</td>
<td>17.9</td>
<td>0.2</td>
<td>1,800</td>
</tr>
<tr>
<td>HCFC-225ca</td>
<td>CHCl₂CF₂CF₃</td>
<td>1.9</td>
<td>0.2</td>
<td>429</td>
</tr>
<tr>
<td>HCFC-225cb</td>
<td>CHClF₂CClF₂</td>
<td>5.8</td>
<td>0.32</td>
<td>2,030</td>
</tr>
</tbody>
</table>

Source: IPCC, 2007. WG1 TS.
Midpoints indicators and endpoints indicators

![Diagram showing midpoints and endpoints indicators in the context of environmental mechanisms and protection areas.](image)

**Midpoints**
- Human toxicity
- Radiation
- Carcinogens
- Respiratory inorganics
- Climate change
- Ozone layer
- Acidification
- Eutrophication
- Ecotoxicity (freshwater, marine, terrestrial)
- Summer smog
- Land-use
- Resource depletion

**Endpoints**
- Resource scarcity

**Inventory**
- NOx, Cd, CO₂, CH₄, dioxins, hard coal, silver from ore, land use, … and other emissions and resource flows

**Area of Protection**
- Human Health
- Natural environment
- Natural resources

**Environmental mechanism (impact pathway)**

This diagram illustrates the relationship between different environmental impacts and their corresponding midpoints and endpoints, emphasizing the role of inventory and protection areas in industrial ecology.
Midpoints indicators and endpoints indicators

Simplified environmental mechanisms for climate change impacts (cause-response pathway)

<table>
<thead>
<tr>
<th>Term</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact category</td>
<td>Climate change</td>
</tr>
<tr>
<td>LCI results</td>
<td>Amount of a greenhouse gas per functional unit</td>
</tr>
<tr>
<td>Characterization model</td>
<td>Baseline model of 100 years of the Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>Category indicator</td>
<td>Infrared radiative forcing (W/m²)</td>
</tr>
<tr>
<td>Characterization factor</td>
<td>Global warming potential (GWP&lt;sub&gt;100&lt;/sub&gt;) for each greenhouse gas (kg CO₂-equivalents/kg gas)</td>
</tr>
<tr>
<td>Category indicator result</td>
<td>Kilograms of CO₂-equivalents per functional unit</td>
</tr>
<tr>
<td>Category endpoints</td>
<td>Coral reefs, forests, crops</td>
</tr>
<tr>
<td>Environmental relevance</td>
<td>Infrared radiative forcing is a proxy for potential effects on the climate, depending on the integrated atmospheric heat adsorption caused by emissions and the distribution over time of the heat absorption</td>
</tr>
</tbody>
</table>

In the problem-oriented approaches, flows are classified into environmental themes to which they contribute.

Themes covered in most Life Cycle Assessment (LCA) studies are:
- Greenhouse effect (or climate change), Natural resource depletion, Stratospheric ozone depletion, Acidification, Photochemical ozone creation, Eutrophication, Human toxicity, Aquatic toxicity.

These methods aim at simplifying the complexity of hundreds of flows into a few environmental areas of interest.

The EDIP or CML 2000 methods are examples of problem-oriented methods.
The damage-oriented methods also start by classifying a system's flows into various environmental themes, but model each environmental theme's damage to human health, ecosystem health or damage to resources.

For example, acidification - often related to acid rain - may cause damage to ecosystems, but also to buildings or monuments.

In essence, this method aims to answer the question: Why should we worry about climate change or ozone depletion?

EcoIndicator 99 is an example of a damage-oriented method.
Normalization

- Normalization is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem.

- This is done by dividing the impact category indicators by a “Normal” value.

- There are different ways to determine the “Normal” value. The most common procedure is to determine the impact category indicators for a region during a year and, if desired, divide this result by the number of inhabitants in that area.
Normalization serves two purposes

- Impact categories that contribute only a very small amount compared to other impact categories can be left out of consideration, thus reducing the number of issues that need to be evaluated.

- The normalized results show the order of magnitude of the environmental problems generated by the products life cycle, compared to the total environmental loads in Europe.
Results for beverages containers – comparing different materials

Environmental Impact for 1000 L / year

- Greenhouse gases (Greenh.)
- Ozone (Ozone)
- Acidification (Acidification)
- Eutrophication (Eutrophic.)
- Heavy metals (H. metals)
- Carcinogenic substances (Carcinog.)
- W. smog (W. smog)
- S. smog (S. smog)
- Pesticides
- Energy
- Solid waste

Environmental Impact of an average European citizen per year

- Glass non-Returnable
- Glass Returnable
- PET
- Al can
- Steel can
- Liquid packaging board
- Stainless steel barrel

Damage assessment

- In these methods, the category indicators are defined close to an endpoint to achieve an optimum environmental relevance.
- The impact category indicators that refer to the same endpoint are all defined in such a way that the unit of the indicator result is the same. Thus, allows addition of the indicator results per group.
- This means that the indicator results can be presented as a set of indicators at endpoint level without any subjective weighting.
- Interpreting less indicators (3 in Eco-indicator 99) instead of a multiple set of indicators is much easier.
• Weighting
  - Weighting is the most controversial and most difficult step in life cycle impact assessment, especially for midpoint methods. Several solutions have been proposed to solve or simplify the weighting problem:
    • Use a panel that assesses the impact category and proposes default weights
    • Distance to target. If it is possible to set a reduction target for an impact category, this target can be used as a weighting factor. If the difference is high, the weight is high
    • Monetarization. In EPS2000 all damages are expressed in the same monetary unit: Environmental Load Units comparable to Euros
### Example of Normalization and Weighting Factors

**Categories**

<table>
<thead>
<tr>
<th>Category</th>
<th>Normalization</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming 100a</td>
<td>0,000115</td>
<td>1,1</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>9,71</td>
<td>63</td>
</tr>
<tr>
<td>Ozone formation (Vegetation)</td>
<td>7,14E-06</td>
<td>1,2</td>
</tr>
<tr>
<td>Ozone formation (Human)</td>
<td>0,1</td>
<td>1,2</td>
</tr>
<tr>
<td>Acidification</td>
<td>0,000455</td>
<td>1,3</td>
</tr>
<tr>
<td>Terrestrial eutrophication</td>
<td>0,000476</td>
<td>1,2</td>
</tr>
<tr>
<td>Aquatic eutrophication EP(N)</td>
<td>0,0833</td>
<td>1,4</td>
</tr>
<tr>
<td>Aquatic eutrophication EP(P)</td>
<td>2,44</td>
<td>1</td>
</tr>
<tr>
<td>Human toxicity air</td>
<td>5,88E-09</td>
<td>1,1</td>
</tr>
<tr>
<td>Human toxicity water</td>
<td>1,69E-05</td>
<td>1,3</td>
</tr>
<tr>
<td>Human toxicity soil</td>
<td>0,00323</td>
<td>1,2</td>
</tr>
<tr>
<td>Ecotoxicity water chronic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ecotoxicity water acute</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ecotoxicity soil chronic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>0,0483</td>
<td>1,1</td>
</tr>
<tr>
<td>Slags/ashes</td>
<td>0,00286</td>
<td>1,1</td>
</tr>
<tr>
<td>Bulk waste</td>
<td>0,000741</td>
<td>1,1</td>
</tr>
<tr>
<td>Radioactive waste</td>
<td>28,6</td>
<td>1,1</td>
</tr>
<tr>
<td>Resources (all)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Normalization and weighting factors**

Persons equivalents, 1990

Targets emissions per person, 2000

**EDIP 2003**

Normalization and weighting factors
• The impact assessment methods themselves are described in ISO 14042.

• In this standard a distinction is made between:
  – Obligatory elements, such as classification and characterization
  – Optional elements, such as normalization or weighting

• See the ILCD Handbook, developed by the JRC

Interpretation
LCA step 4
Interpretation
• The evaluation method for calculating the Eco-Indicator 95 strongly focuses on the effects of emissions on the ecosystem.
• For the valuation, the distance to target principle is used, but the targets are based on scientific data on environmental damage and not on policy statements.
• The targets values are related to three types of environmental damage:
  – **ecosystems impairment** (a target level has been chosen at which “only” 5% ecosystem degradation will still occur over several decades)
  – **human health impairment** (this refers in particular to winter and summer smog and the acceptable level set is that smog periods should hardly ever occur again); **human deaths** (the level chosen as acceptable is 1 fatality per million inhabitants per year).
<table>
<thead>
<tr>
<th>Impact</th>
<th>Effect</th>
<th>Damage</th>
<th>Valuation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFC, Pb, Cd, PAH, Dust, VOC, DDT, CO₂, SO₂, NOₓ, P</td>
<td>Ozone layer depl., Heavy metals, Carcinogenics, Summer smog, Winter smog, Pesticides, Greenhouse effect, Acidification, Eutrophication</td>
<td>Fatalities, Health impairment, Ecosystem impairment</td>
<td>Subjective damage assessment</td>
<td>Eco-indicator value</td>
</tr>
</tbody>
</table>
### Greenhouse gas effect

<table>
<thead>
<tr>
<th>Compound</th>
<th>$\text{kg}_\text{CO}_2\text{ equivalent}$</th>
<th>Ozone layer depletion</th>
<th>$\text{Kg}_\text{CFC}_11\text{ equivalent}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFC-13</td>
<td>13000</td>
<td>HALON-1301</td>
<td>16</td>
</tr>
<tr>
<td>CFC (hard)</td>
<td>7100</td>
<td>HALON-2402</td>
<td>7</td>
</tr>
<tr>
<td>CFC-12</td>
<td>7100</td>
<td>HALON-1211</td>
<td>4</td>
</tr>
<tr>
<td>CFC-114</td>
<td>7000</td>
<td>HALON-1201</td>
<td>1.4</td>
</tr>
<tr>
<td>CFC-115</td>
<td>7000</td>
<td>HALON-1202</td>
<td>1.25</td>
</tr>
<tr>
<td>CFC-116</td>
<td>6200</td>
<td>Tetraclorometano</td>
<td>1.08</td>
</tr>
<tr>
<td>HALON-1211</td>
<td>4900</td>
<td>CFC-113</td>
<td>1.07</td>
</tr>
<tr>
<td>HALON-1301</td>
<td>4900</td>
<td>CFC (hard)</td>
<td>1</td>
</tr>
<tr>
<td>CFC-113</td>
<td>4500</td>
<td>CFC-11</td>
<td>1</td>
</tr>
<tr>
<td>CFC-14</td>
<td>4500</td>
<td>CFC-12</td>
<td>1</td>
</tr>
<tr>
<td>HFC-143a</td>
<td>3800</td>
<td>CFC-13</td>
<td>1</td>
</tr>
<tr>
<td>CFC-11</td>
<td>3400</td>
<td>CFC-114</td>
<td>0.8</td>
</tr>
<tr>
<td>HFC-125</td>
<td>3400</td>
<td>methyl bromide</td>
<td>0.6</td>
</tr>
<tr>
<td>HCFC-142b</td>
<td>1800</td>
<td>CFC-115</td>
<td>0.5</td>
</tr>
<tr>
<td>CFC (soft)</td>
<td>1600</td>
<td>HALON-2401</td>
<td>0.25</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>1600</td>
<td>HALON-2311</td>
<td>0.14</td>
</tr>
<tr>
<td>Tetraclorometano</td>
<td>1300</td>
<td>Tricloroetano</td>
<td>0.12</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>1200</td>
<td>HCFC-141b</td>
<td>0.11</td>
</tr>
<tr>
<td>HCFC-141b</td>
<td>580</td>
<td>HCFC-142b</td>
<td>0.065</td>
</tr>
<tr>
<td>HCFC-124</td>
<td>440</td>
<td>CFC (soft)</td>
<td>0.055</td>
</tr>
<tr>
<td>N2O</td>
<td>270</td>
<td>HCFC-22</td>
<td>0.055</td>
</tr>
<tr>
<td>HFC-152a</td>
<td>150</td>
<td>HCFC-225cb</td>
<td>0.033</td>
</tr>
<tr>
<td>1,1,1-trichloroethane</td>
<td>100</td>
<td>HCFC-225ca</td>
<td>0.025</td>
</tr>
<tr>
<td>HCFC-123</td>
<td>90</td>
<td>HCFC-124</td>
<td>0.022</td>
</tr>
<tr>
<td>Triclorometano</td>
<td>25</td>
<td>HCFC-123</td>
<td>0.022</td>
</tr>
<tr>
<td>Diclorometano</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metano</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Setting equivalents for these damage levels is a subjective choice. The current choice (see below) came about after consultation with various experts and a comparison with other systems.

<table>
<thead>
<tr>
<th>Environmental effect</th>
<th>Reduction factor</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse effect</td>
<td>2.5</td>
<td>0.1°C rise every 10 years, 5% ecosystem degradation</td>
</tr>
<tr>
<td>Ozone layer depletion</td>
<td>100</td>
<td>Probability of 1 fatality per year per million inhabitants</td>
</tr>
<tr>
<td>Acidification</td>
<td>10</td>
<td>5% ecosystem degradation</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>5</td>
<td>Rivers and lakes, degradation of an unknown number of aquatic ecosystems (5% degradation)</td>
</tr>
<tr>
<td>Summer smog</td>
<td>2.5</td>
<td>Occurrence of smog periods, health complaints, particularly amongst asthma patients and the elderly, prevention of agricultural damage</td>
</tr>
<tr>
<td>Winter smog</td>
<td>5</td>
<td>Occurrence of smog periods, health complaints, particularly amongst asthma patients and the elderly</td>
</tr>
<tr>
<td>Pesticides</td>
<td>25</td>
<td>5% ecosystem degradation</td>
</tr>
<tr>
<td>Airborne heavy metals</td>
<td>5</td>
<td>Lead content in children’s blood, reduced life expectancy and learning performance in an unknown number of people</td>
</tr>
<tr>
<td>Waterborne heavy metals</td>
<td>5</td>
<td>Cadmium content in rivers, ultimately also impacts on people (see airborne)</td>
</tr>
<tr>
<td>Carcinogenic substances</td>
<td>10</td>
<td>Probability of 1 fatality per year per million people</td>
</tr>
</tbody>
</table>
Some LCA Sources of Information
Internet resources for LCA:

http://www.lcacenter.org/ (American Center for LCA)
http://www.epa.gov/nrmrl/lcaccess/index.html (EPA website on LCA)
http://www.nrel.gov/lci/ (US LCI Database)
http://www.uneptie.org/pc/sustain/lcinitiative/ (UNEP/SETAC life cycle initiative)
http://www.ecoinvent.ch (Swiss centre for LCI data)
http://www.netzwerk-lebenszyklusdaten.de (German LCA network)
http://www.pre.nl/ (Pre: SimaPro, downloads available)
Eco-indicator 95 reports
Eco-Indicator 99 reports
ReCiPe 2008 Reports

ILCD Handbook, developed by the JRC
http://eplca.jrc.ec.europa.eu/?page_id=86