Life Cycle Management

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Questions

- What is an "Environmentally Friendly" product?
- What is a "Green process"?
- What is "Sustainable Development"?

Possible Answers

- Recycled paper?
- Energy-saving appliances?
- A landfill for solid waste?
- Plastic packaging vs paper packaging?

Further Questions

- How far do we look?
- Raw material extraction
- Manufacturing
- Use
- Disposal (end of life)
- Energy consumption?
- Material consumption?
- Emission?

Life Cycle Management (LCM)
Life Cycle Assessment (LCA)

- Life Cycle Management is an integrated concept for managing the total life cycle of goods and services towards more sustainable production and consumption.
- Life Cycle Assessment is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle.
Brief History of LCA

- 1969: Coca-Cola performed a study to compare beverage containers.
- Early 70's: standard protocols being developed Resource and Environmental Profile Analysis (REPA).
- 1975-early 80's: slow development because of fading threat of oil crisis, Liquid Food Container Directive in 1985 by EC.
- 1988: solid waste became global issue, re-surge of LCA.
- 1991: concern over inappropriate use of LCA for marketing, lead to development of ISO14040 as a standard approach.
- 2002: United Nations Environment Programme (UNEP) and Society of Environmental Toxicology and Chemistry (SETAC) launched the Life Cycle Initiative.

The Phases of Life Cycle Assessment

- Goal and Scope Definition
  - Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.
  - Functional unit
  - Defining system boundary

- Inventory Analysis
  - Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).
Sources of data

- Meter readings from equipment
- Equipment operating logs/journals
- Industry data reports, databases, or consultants
- Laboratory test results
- Government documents, reports, databases,
- Other publicly available databases or clearinghouses
- Journals, papers, books, and patents
- Reference books
- Trade associations
- Related/previous life cycle inventory studies
- Equipment and process specifications
- Best engineering judgment.

Impact Assessment

- Assess the potential human and ecological
effects of energy, water, and material usage
and the environmental releases identified in the
inventory analysis.
- Impact categories
- Characterisation
- Weighting

Characterization of Global Warming Impacts

The following calculations demonstrate how characterization
factors can be used to estimate the global warming potential
(GWP) of defined quantities of greenhouse gases:

Chloroform GWP Factor Value* = 9, Quantity = 20 kg
Chloroform GWP Impact = 20 kg x 9 = 180 kg CO2 equivalents

Methane GWP Factor Value* = 21, Quantity = 10 kg
Methane GWP Impact = 10 kg x 21 = 210 kg CO2 equivalents

*Intergovernmental Panel on Climate Change (IPCC) Model

Examples of LCI and LCA Software

- Ecoinvent by Swiss Centre for Life Cycle Inventories
- GaBi by PE Europe GmbH and IKP University of Stuttgart
- SimaPro by PRé Consultants
- US LCI Data National Renewable Energy Lab

Interpretation

- Evaluate the results of the inventory analysis
and impact assessment to select the preferred
product, process or service with a clear
understanding of the uncertainty and the
assumptions used to generate the results.
An example
LCA of Cardboard Box

Environmental impact categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming</td>
<td>kg CO₂-equivalents</td>
</tr>
<tr>
<td>Acidification</td>
<td>kg SO₂-equivalents</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>kg PO₄-equivalents</td>
</tr>
<tr>
<td>Smog formation</td>
<td>kg C₂H₄-equivalents</td>
</tr>
<tr>
<td>Solid waste generation</td>
<td>kg</td>
</tr>
<tr>
<td>Oxygen depletion</td>
<td>kg COD</td>
</tr>
</tbody>
</table>

An example of a Life Cycle Assessment (LCA) for a cardboard box includes:

- Production of raw materials
- Manufacturing of cardboard
- Distribution and transportation
- Use and disposal
- Recovery and recycling

<table>
<thead>
<tr>
<th>Phase</th>
<th>Impact</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction of raw materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing of cardboard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution and transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery and recycling</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The environmental impact categories for LCA are:

- Global warming
- Acidification
- Eutrophication
- Smog formation
- Solid waste generation
- Oxygen depletion
### Environmental Impact Categories

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Amount per functional unit</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming</td>
<td>7.47</td>
<td>kg CO₂-eq</td>
</tr>
<tr>
<td>Acidification</td>
<td>43.1</td>
<td>g SO₂-eq</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>20.2</td>
<td>g PO₄-eq</td>
</tr>
<tr>
<td>Smog formation</td>
<td>5.64</td>
<td>g C₂H₄-eq</td>
</tr>
<tr>
<td>Solid waste generation</td>
<td>0.01</td>
<td>kg</td>
</tr>
<tr>
<td>Oxygen depletion</td>
<td>0.57</td>
<td>g COD</td>
</tr>
</tbody>
</table>

### Global Warming Potential

- Chipping, and pulp production: 33%
- Turbo-aerated cleaning of recycled pulp: 31%
- Refining of recycled pulp: 6%
- Paper forming: 6%
- Paper pre-drying: 6%
- Paper post-drying: 6%
- Paperboard production: 6%
- Box production: 6%
- Old box collection and transport: 6%
- Landfilling: 6%
- Other processes: 6%

### Smog Formation Potential

- Chipping and pulp production: 26%
- Refining of recycled pulp: 26%
- Paper forming: 13%
- Paper pre-drying: 13%
- Paper post-drying: 13%
- Paperboard production: 13%
- Box production: 13%
- Old box collection and transport: 13%
- Landfilling: 13%
- Other processes: 13%

### Energy Use

- Tree growing and logging: 30%
- Chipping, and pulp production: 17%
- Paper forming: 11%
- Paper pre-drying: 11%
- Paper post-drying: 11%
- Other processes: 20%

### Emission Table

<table>
<thead>
<tr>
<th>Substance, Category</th>
<th>Emission Q₀</th>
<th>Equivalency factor EF(pfu)</th>
<th>Emission’s potential EP(pfu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>999 g</td>
<td>1 g CO₂-eq/g substance</td>
<td>999 g CO₂-eq</td>
</tr>
<tr>
<td>CH₄</td>
<td>21 g</td>
<td>21 g CO₂-eq/g substance</td>
<td>21 g CO₂-eq</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.02 g</td>
<td>270 g CO₂-eq/g substance</td>
<td>5.4 g CO₂-eq</td>
</tr>
<tr>
<td>Other substances</td>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total per boi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EP(pfu) per functional unit</td>
<td></td>
<td></td>
<td>7472</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Substance, Category</th>
<th>Emission Q₀</th>
<th>Equivalency factor EF(pfu)</th>
<th>Emission’s potential EP(pfu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>21.1 g</td>
<td>0.007 g CO₂-eq/g substance</td>
<td>0.149 g CO₂-eq</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.09 g</td>
<td>0.418 g CO₂-eq/g substance</td>
<td>0.245 g CO₂-eq</td>
</tr>
<tr>
<td>VOSCs</td>
<td>0.0087 g</td>
<td>0.988 g CO₂-eq/g substance</td>
<td>0.0196 g CO₂-eq</td>
</tr>
<tr>
<td>Other substances</td>
<td>0.1095</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total per boi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EP(pfu) per boi</td>
<td></td>
<td></td>
<td>0.021</td>
</tr>
<tr>
<td>EP(pfu) per functional unit</td>
<td></td>
<td></td>
<td>5.84</td>
</tr>
</tbody>
</table>
"The A380 has been designed in order to optimise environmental performance at each stage of the aircraft life cycle. In particular, the high passenger capacity with a 2-deck design and the use of new light weight materials has decreased the energy consumption per passenger dramatically. The A380 is expected to use less than 3 litres of fuel per 100 passengers kilometres."

Benefits of LCA
- Quantifies and pinpoints environmental impact for improvement
- Identifies the transfer of environmental impacts from one media to another and/or from one life cycle stage to another
- Helps decide on product/activity with least overall environmental impact
- Combines with cost and social factors to evaluate sustainability
- Eco-marketing

Improvement and Management
- Modify unit process with high impacts
- Modify product design
- Mitigation measures
- Compensation e.g. carbon offset
Limitations of LCA

- Resource demanding
- Availability, accuracy and applicability of data
- Does not imply sustainability
- No easy communication to the public (e.g. a single indicator, eco-labels)

- It is better to be roughly right than to be exactly wrong

Thank You