Introduction to Life Cycle Assessment, LCA

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IRCADA – USYS TdLab – IfU-ESD workshop
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Amman, Jordan
Outline

- Introduction
  - Environmental assessment
  - Overview Life Cycle Assessment (LCA)

- LCA
  - Goal and scope definition
    - Functional unit
    - System boundaries
  - Inventory (LCI)
    - Accounting principles
    - Inventory analysis
  - Impact assessment (LCIA)
  - Interpretation of results
Learning goals

To get a first overview of…

- What (the purpose of) LCA is
- How a LCA is performed
- How to identify critical aspects in the supply chain
- How to interpret and critically assess a LCA study
Environmental assessment tools / approaches

- Material flow analysis (MFA)
- Risk assessment (RA)
- Life cycle assessment (LCA)

Approaches are complementary

Inventory

Exposure pathways

Environmental effects
LCA is a systematic method for analyzing environmental impacts of products, processes, and services over their entire life cycles.
Example LCA of detergent (for washing machine)

System boundary: life cycle of heavy-duty laundry detergents
Results – detergent example

Typical question in LCA study:
- Which alternative has the lowest overall environmental impacts?

Which product is the better choice?
Global value chains

- International value chains increase in complexity and have global environmental impacts
- LCA aims to track these impacts and assess them from a systems perspective
- The goal is to identify decisions or strategies for improvement without burden shifting
Purposes for LCA

a) To find improvement potential within life cycle of a product (not just production) → Product design / process analysis

b) Comparison of different options with the same functionality (same service) → Support decisions (ecolabels, ‘green marketing’)

c) Comparison of scenarios (in combination with Input output-analysis) → Political policies and decisions
Applications of LCA *(Hellweg & Milà i Canals 2014)*

A. Product level LCA

B. Organizational LCA

C. Consumer/lifestyle LCA

D. Country LCA

Picture source: *Science 344, p. 1109-1112*
No or limited use of LCA for...

a) Assessment of disasters / accidents

b) Evaluation of best location for facilities
   -> environmental impact assessment (*in German: UVP*)

c) Environmental management practices of companies
   -> ISO 14001 norms
International standard on LCA – ISO 14044:2006

- Guidance on **procedure**:
  - Goal and scope definition
  - Inventory analysis
  - Impact assessment
  - Interpretation

- No specific method, tool or data basis prescribed
1. Definition of goal and scope
   • What is the purpose of the LCA?
   • Who is the intended audience?
   • What are the systems under study and what are their functions?
   • What are the underlying assumptions / limitations?

2. Inventory analysis
   • What are the relevant emissions and resources the system(s) produce or consume?
   • How are these inputs and outputs allocated to the functions of the systems?

3. Impact assessment
   • Which impact categories are considered and which models are used?
   • What environmental impacts are caused by the emissions and the use of resources from the system(s)?
   • How is aggregation performed?

4. Interpretation
   • What are the conclusions?
   • How reliable and sensitive are the results?
   • What are the recommendations?
Goal & scope: main points (I)

• Purpose of study
  – For comparison, ecodesign, internal or external communication, marketing claims, ecolabelling, etc.

• Define «functional unit» of study:
  – What is the function of the system / service to the consumer?
  – Example: packing 1 liter of milk
Example: Functional unit of air transport, e.g. 1‘000 person-km transport

Source: Frischknecht, Handouts in Umweltverträgliche Technologien
Goal & scope: main points (II)

• Draw system boundaries
  – What environmental aspects are included
  – Which processes are excluded -> why?

• Define time, geographical and technological coverage
  – For what situation is the study valid?

• Critical review and other procedural aspects
  – Critical review by independent expert or panel of interested parties
    required for LCA studies «where the results are intended to be
    used to support a comparative assertion intended to be disclosed
    to the public» (ISO 14044:2006)
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Life cycle inventory (LCI) analysis

Data collection of environmentally-relevant flows for unit processes (parts of the life cycle);

→ Unit processes within flowchart
Inventory analysis – required data

- Unit processes
- Materials
- Energy use
- Consumables
- Transports
- Information on product use
- Waste disposal

Exchanges within technosphere
(products / services of other processes)
-> technosphere flows

Exchanges with the environment
(environmental flows)
Handling data gaps

- Specific data should be collected for primary processes (foreground system) and high quality representative data for others (background system, e.g. electricity generation)

- If no data can be found, conservative estimates should be used!
  - If relevant in assessment: improve data (iterative process)
Inventory database developments

Inventory databases contain inventory data on a large number of basic processes, e.g. electricity generation or production of steel, cement, chemicals, etc. etc., thereby greatly facilitating LCA studies.

Calm down, I can do this. Why don‘t you just take a brake…
Life cycle impact assessment (LCIA)
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## From LCI to LCIA

### Inventory Analysis

<table>
<thead>
<tr>
<th>Emission/ Unit Resource</th>
<th>Compart- tement</th>
<th>Amount per funct. unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Air</td>
<td>0.5</td>
</tr>
<tr>
<td>CH₄</td>
<td>Air</td>
<td>1.5</td>
</tr>
<tr>
<td>SOₓ</td>
<td>Air</td>
<td>1.0</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Air</td>
<td>0.5</td>
</tr>
<tr>
<td>Cd²⁺</td>
<td>Water</td>
<td>0.0001</td>
</tr>
<tr>
<td>Fe</td>
<td>Soil</td>
<td>0.5</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Life Cycle Impact Assessment

#### Global Warming

<table>
<thead>
<tr>
<th>Emission</th>
<th>Characterization factor</th>
<th>Ref. unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>CH₄</td>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>42.5</td>
</tr>
</tbody>
</table>

#### Acidification

<table>
<thead>
<tr>
<th>Emission</th>
<th>Ref. unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOₓ</td>
<td>1</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.7</td>
</tr>
<tr>
<td>Sum</td>
<td>1.35</td>
</tr>
</tbody>
</table>

#### Human toxicity

<table>
<thead>
<tr>
<th>Emission</th>
<th>Ref. unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOₓ</td>
<td>1.4</td>
</tr>
<tr>
<td>Cd²⁺</td>
<td>23</td>
</tr>
<tr>
<td>Sum</td>
<td>0.7023</td>
</tr>
</tbody>
</table>
LCIA framework

Environmental interventions

- Emissions (air, water and soil)
- Resource extraction

LCI results

Impact categories

- Climate change
- Ozone depletion
- Photochemical ozone creation
- Human toxic effects
- Ecotoxic effects
- Eutrophication
- Acidification
- Land stress
- Water stress
- Resource depletion

Midpoints

Damage categories

- Human Health
- Ecosystem Quality
- Resource Depletion

Endpoints

Areas of Protection

29.02.2016
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IRCADA – USYS TdLab – IfU-ESD workshop
Impact category ‘climate change’ = carbon footprint

Characterization factors (CF) based on IPCC 2013 factors; 3 time horizons

<table>
<thead>
<tr>
<th>Greenhouse gas (GHG)</th>
<th>Global warming potential (GWP) 20 years [kg CO₂-eq]</th>
<th>Global warming potential (GWP) 100 years [kg CO₂-eq.]</th>
<th>Global warming potential (GWP) 500 years [kg CO₂-eq.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>62</td>
<td>28</td>
<td>8</td>
</tr>
<tr>
<td>Nitrous oxide (N₂O)</td>
<td>264</td>
<td>265</td>
<td>131</td>
</tr>
<tr>
<td>Sulfur hexafluoride (SF₆)</td>
<td>17’500</td>
<td>23’507</td>
<td>31’510</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>3’710</td>
<td>1’301</td>
<td>371</td>
</tr>
</tbody>
</table>

100 years is typically recommended
Standard elements of impact assessment

**Mandatory elements**

- Selection impact categories and LCIA methods (characterization models)
- Classification (grouping emissions/resource use in impact categories)
- Characterization (quantification of environmental impacts)

Results of impact categories -> interpretation or:

**Optional elements**

- Normalization, Grouping, Weighting

Source: ISO 14044:2006
Regional aspects in LCA

- Regionalization relevant in, for example, land use/water consumption and biodiversity
- Not implemented in standard LCA softwares
  - Data in google earth available from [www.esdmaps.ethz.ch/](http://www.esdmaps.ethz.ch/)
  - e.g. Midpoint indicator: Water Stress Index (WSI)

→ takes into account water availability, use, and variation in precipitation
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The LCA methodology – an iterative process

- Results should be used to refine the model concerning relevant processes and emissions

- Analyze the contribution of processes and emissions

- Understand the underlying reasons for the results
  - Is it realistic or maybe an artefact?
  - Is it robust?
Uncertainties

- LCA results are highly uncertain
  - Assumptions
  - Uncertainty of inventory data
  - Uncertainty in characterization models
  - Uncertainty in weighting schemes

- Careful consideration is required for proper conclusions
  (typically a factor 2 is not highly significant)

- Results should be considered relative to other options
Example: assessing uncertainty in carbon footprints: natural gas *versus* biogas in car

<table>
<thead>
<tr>
<th>Impacts</th>
<th>natural gas car:</th>
<th>0.16 kg CO$_2$-eq. / person-km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impacts</td>
<td>methane (biogas) car</td>
<td>0.12 kg CO$_2$-eq. / person-km</td>
</tr>
</tbody>
</table>

biogas impact < 75% of natural gas

10’000 Monte Carlo runs

19% chance that biogas performs worse!
A few illustrative examples...

- Life Cycle Inventory and Carbon and Water FoodPrint of Fruits and Vegetables (Stoessel et al. 2012)
- Carbon footprint per person and year in a Swiss municipality (PhD thesis of Dominik Saner)
- Spatially explicit impacts from phosphorus emissions in agriculture (Scherer & Pfister 2015)
Scope

- Study performed for major Swiss food retailer
- 28 vegetables and fruits
- 29 countries of origin
- Open-field and greenhouse production
- Background data for transport, energy, fertilizer, pesticide production etc. from ecoinvent v2.01 / SimaPro 7
- Functional unit: 1 kg of vegetable or fruit (as fresh matter) at the point of sale

System boundaries

Exchange with environment: emissions, extraction of resources: water, peat, land use

- **Upstream processes**
  - Peat-Transport
  - Greenhouse heating
  - Fertilizer production
  - Pesticide production (mulch films & flame treatment incl.)
  - Machinery work
  - Greenhouse heating & electricity use
  - Irrigation (Infrastructure incl.)

- **Agricultural processes**
  - Seedling production
  - Transport
  - Fruit & vegetable production

- **Downstream processes**
  - Cleaning
  - Storage
  - Packaging
  - Refrigerated transports

Supply chain of electricity, heating oil, diesel, natural gas & ancillary materials

Stössel et al (2012)
Carbon Footprint of vegetables/fruits (as total annual sales)

Asparagus
Lettuce
Banana
Tomato
Pear
Citrus
Cucumber
Apple
Vine Tomato
Grape
Bell pepper
Potato
Avocado
Melon
Kiwi
Strawberry
Leek, Onion, Carrot
Cauliflower
Pineapple
Fennel
Broccoli
Eggplant
Fennel, Cauliflower, Broccoli
Zucchini
Spinach

Top 5 crops
Top 6 to 10 crops
Remaining crops

Relative global warming potential (GWP) of the sales of a crop in % of the total GWP

Carbon Footprint of vegetables/fruits (per kg)

Carbon footprint of asparagus

Stössel et al, (2012)
Carbon footprint of cucumbers

Stössel et al, submitted
Lowering the carbon footprint of vegetables

1. Avoid air transport

2. Prefer non-heated production over heated greenhouses
   - But tradeoff with water impacts (typically water scarce areas)!

3. As little truck transport as necessary
Carbon footprint per person and year in a Swiss municipality

→ consumption of meat and dairy products decisive

Source Dominik Saner, ETH Zürich
Spatially explicit impacts from phosphorus emissions in agriculture

Motivation:
- Aquatic eutrophication threatens biodiversity
- Phosphorus emissions are the chief cause for freshwater eutrophication
- Agriculture is the major non-point source
- Emissions are likely to increase
- Previous assessments were limited to a few countries, a few crops and/or were too simplified
Coupling of models

USLE model
- Soil loss

SALCA model
- P loss from erosion
- P loss from runoff
- P loss from drainage
- P loss from groundwater leaching

Modified parameters:
- Soil erodibility (K)
- Slope length factor (LS)
- Crop factor (C₁)
- Tillage factor (C₂)
- Practice factor (P)

Fate & Effect
- Environmental exchanges
- Fate (Helmes et al. 2012)
- Effect (Azevedo et al. 2013)

Impact
- Impact of crop production on species richness

Scherer & Pfister (2015)
Results: Global average phosphorus emissions (kg P / kg crop)

Our study

Ecoinvent

Scherer & Pfister (2015)
Dominant processes of phosphorus emissions

**Scherer & Pfister (2015)**

- **Soybean**
  - Erosion: 67%
  - Runoff: 6%
  - Drainage: 4%
  - Groundwater: 3%

- **Maize**
  - Erosion: 29%
  - Runoff: 6%
  - Drainage: 3%
  - Groundwater: 6%

- **Rice**
  - Erosion: 66%
  - Runoff: 5%
  - Drainage: 3%
  - Groundwater: 26%

- **Wheat**
  - Erosion: 56%
  - Runoff: 6%
  - Drainage: 35%
  - Groundwater: 6%
Erosion loss per cropland use

Ton soil / (ha yr)
Phosphorus emissions (kg P / kg crop)

Scherer & Pfister (2015)
Impacts on biodiversity (days m$^3$ / kg crop)

Scherer & Pfister (2015)
Conclusions

- Detailed erosion model for different crops with high spatial resolution
- Improvement of modelling scheme of phosphorus emissions
- Underestimation of phosphorus emissions in ecoinvent
- Importance of regionalising both inventory results and characterisation factors
- Major limitations
  - Management factors effect on erosion (factor 16)
  - Bioavailability of phosphorus
  - Soil erodibility
  - No crop specific fertilization
  - Interactions with nitrogen

Scherer & Pfister (2015)
Introduction to LCA – wrap-up
Summary LCA

- LCA is a comprehensive assessment of very complex systems
- Tries to avoid burden shifting (e.g. from GHG emissions to radioactive waste)
- Features high uncertainties
- Is most valuable for understanding the system and not for reporting absolute numbers
- Is still a growing research field with many gaps
Thank you for your attention!

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References

Introduction to SimaPro LCA software
A really small case… PET vs. Glass bottle

PET container, full life cycle

1 PET beverage container

PET beverage container prod.

20 gr PET bottle

3 gr ABS cap

PET bottle production

plastic bottle cap production

22 gr PET

3.75 gr ABS plastic

energy/transport waste

Glass container, full life cycle

1 glass beverage container

glass beverage container prod.

200 gr glass bottle

5 gr Al cap

glass bottle production

Al bottle cap production

210 gr glass

5 gr aluminium

energy/transport waste