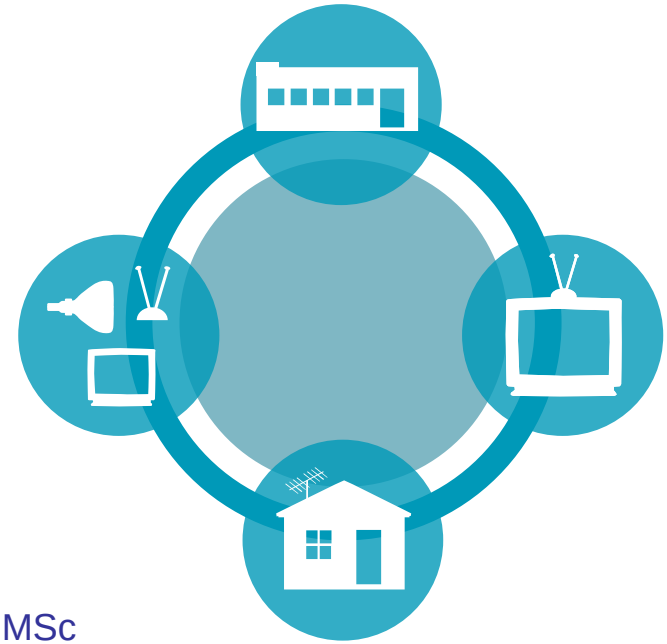
Postgraduate Education, Training and Capacity Building in Water, Environment and Infrastructure


Amsterdam
Den Haag
Rotterdam
Stadshavens
Antwerpen

A Life Cycle Perspective to Cleaner Production

Life Cycle Analysis (LCA) – Methodology and Steps



Lecturer: Léon Dijk MSc
Email: l.dijk@unesco-ihe.org; lf.dijk@rotterdam.nl; info@ecod.nl

Date: October 2012

eco-education services

UNESCO-IHE
Institute for Water Education

LCA steps

Goal and Scope: Why you make the LCA, how much effort do you want to invest; who are interested parties, what methodology will you use.

Inventory: collect data, determine total emissions and resource use.

Impact assessment: Transform (long) list of LCI results in environmental impacts, like climate change, acidification, eco-toxic impacts etc.

Interpretation: what conclusions can we draw, how (un)certain are we about these.

Goal describes…

- Intended application
- Reasons for the study
- Intended audience

Scope describes…

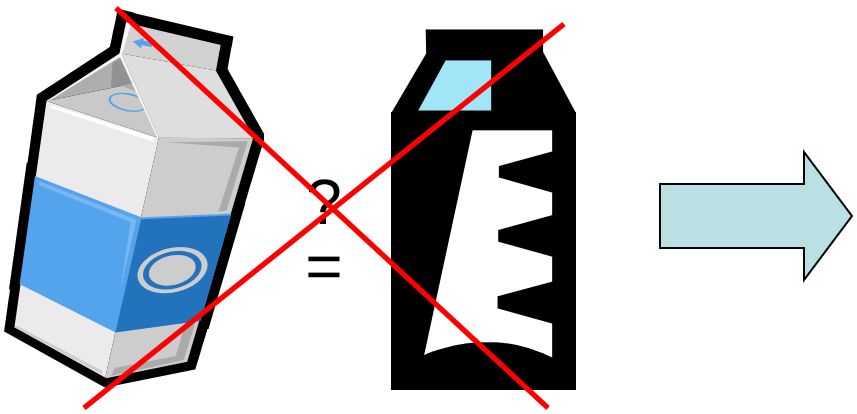
What is a functional unit?

Avoid comparing ‘apples and oranges’

FU is a basis of comparison of *similar* products…

FU	• Description of the function of the product
FU	• Number for duration of use or amount
FU	• Desired quality
FU	• Desired circumstances

- **Functional unit**: comparison of products on the basis of *equivalent function*, for example: comparison of 2 packaging systems for 1000 litres of milk by (a) 1000 disposable cartons or (b) 100 reusable bottles; instead of comparison of 1 carton and 1 bottle.
- Functional unit is basis for comparison



"Compare environmental impacts of packaging of 1000 litres milk in carton packages or glass bottles"

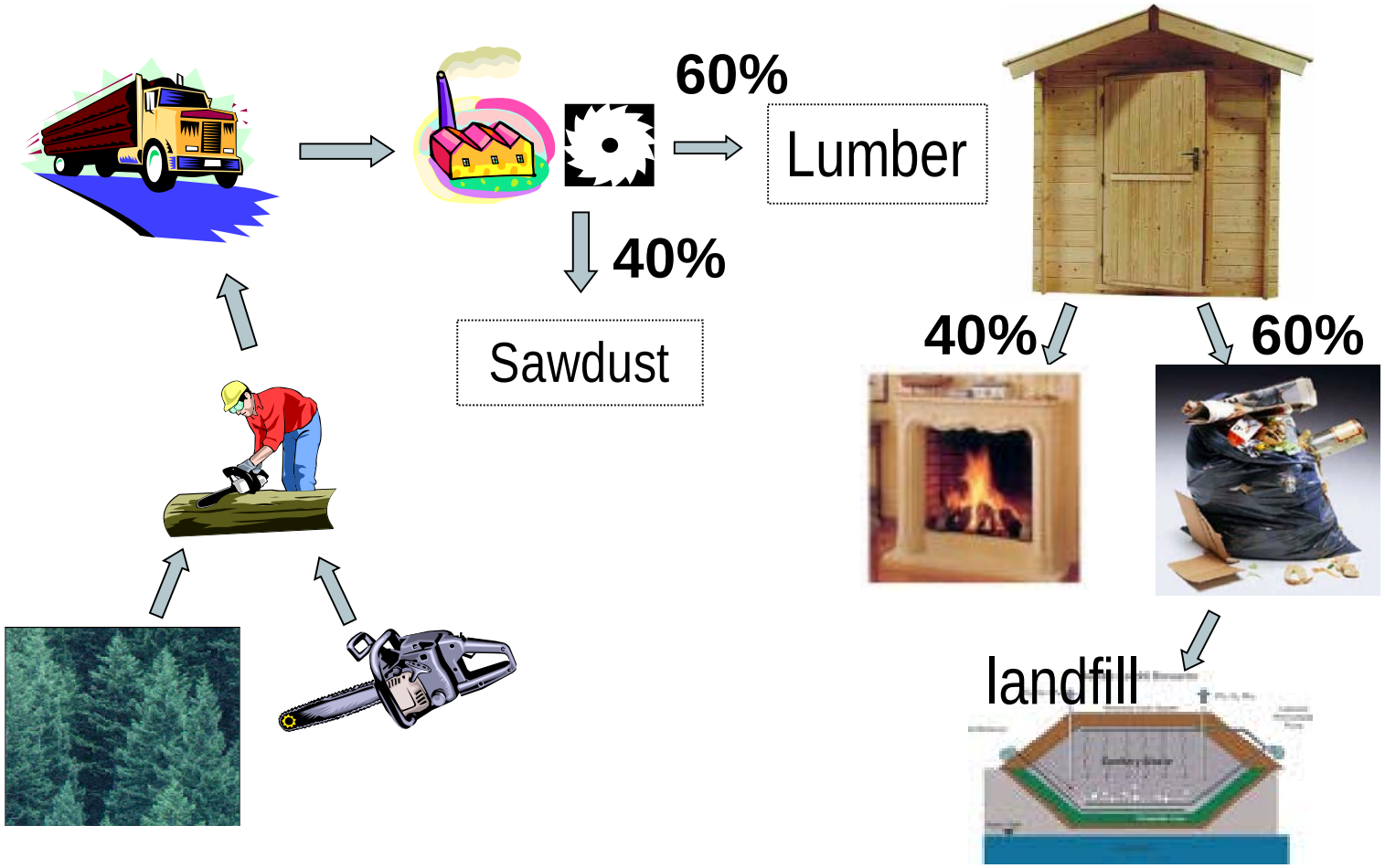
From the FU we calculate the reference flows…

"…*a reference flow is a quantified amount of materials, energy, product(s), including product parts, necessary of a specific product system to deliver the performance described by the functional unit*."

after *Weidema, B.P., Wenzel, H., Petersen, C., Hansen, K., LCA guideline No.2, The product, functional unit and reference flows in LCA, final draft, Danish EPA, Kopenhagen DK, 2001*

The reference flow is the basis for further calculations on environmental impact of the product system

Draw the product system



Define boundary of product system

60%

Lumber

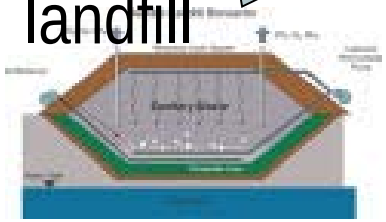
40%

Sawdust

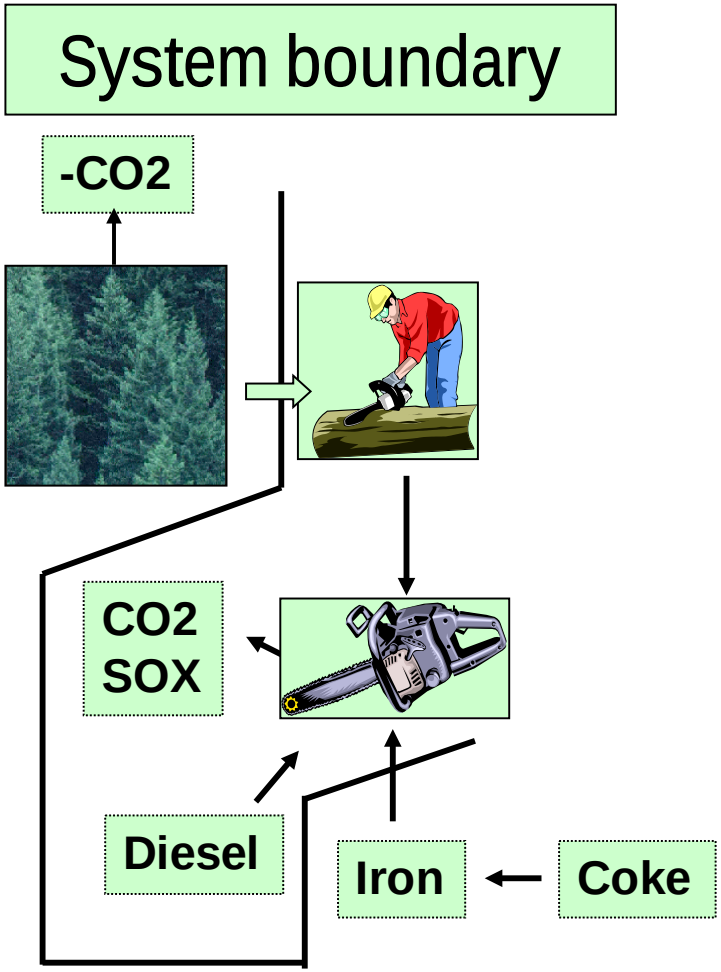
40%

60%

landfill



What's boundary with nature?



System boundaries determine the type of LCA

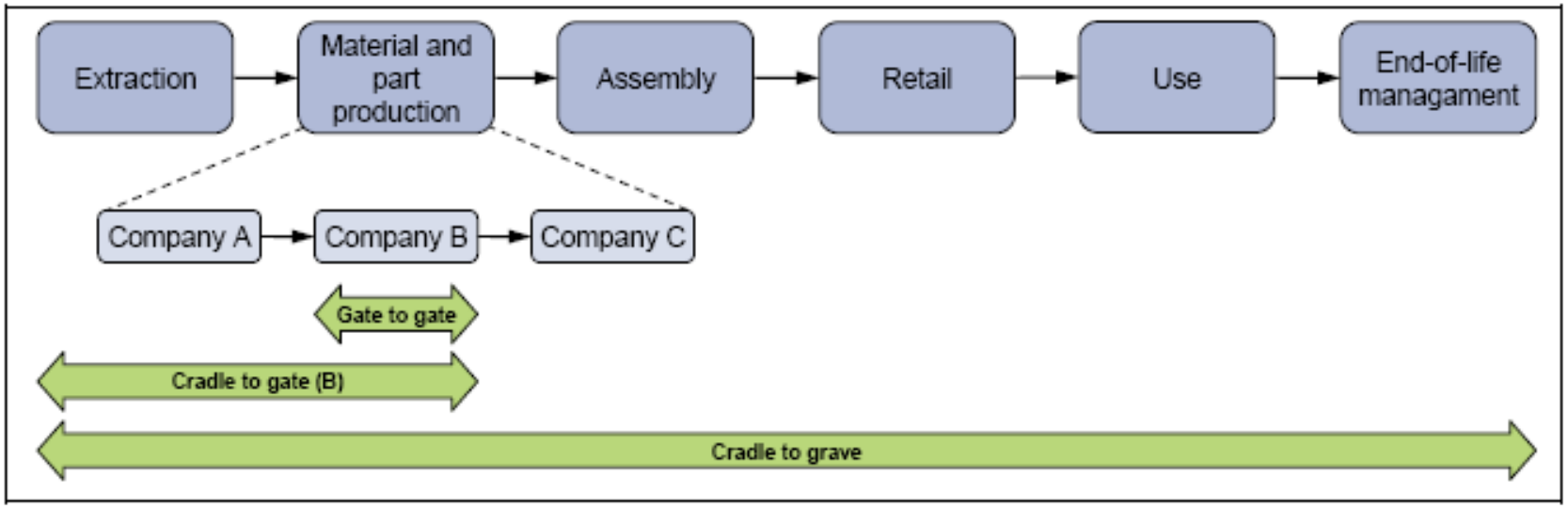


Figure 12 Cradle to grave, cradle to gate and gate to gate data sets as parts of the complete life cycle; schematic. Each type fulfils a specific function as module for use in other LCA studies.

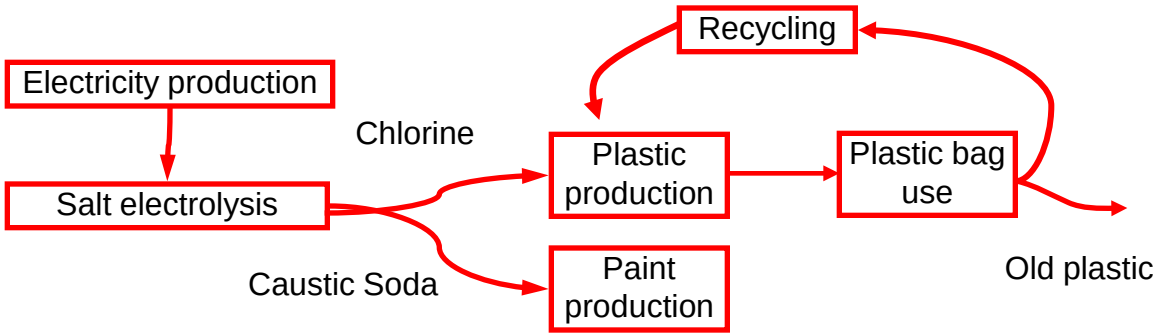
Source: JRC, 2010. ILCD Handbook General Guide for Life Cycle Assessment-Detailed guidance, 1ste edition. European Commission, International Reference Life Cycle Data System ILCD

Other criteria for inclusion of processes

% mass	• if the mass of the flow is lower than certain %
% value	• If economic value is lower than certain %
% impact	• If environmental relevance is below a certain %

Set allocation rules

- **Allocation** of environmental interventions in case of **multiple output processes**;
  - Many processes are ‘multifunctional’ (e.g. co-production, combined waste treatment.) and interventions can be allocated to more outputs:



- **Recycling and reuse**
  - Allocation determined by number of reuse times and fraction of materials that can be recycled at a certain quality

For example: allocation of environmental impacts to multifunctional processes

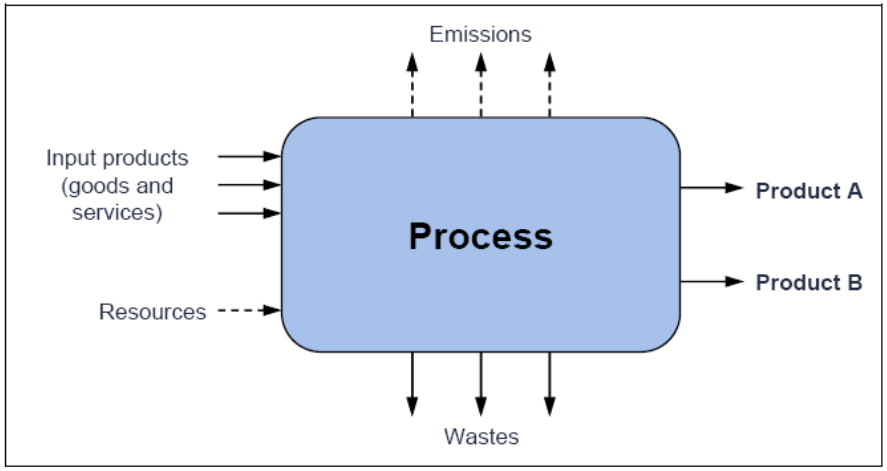


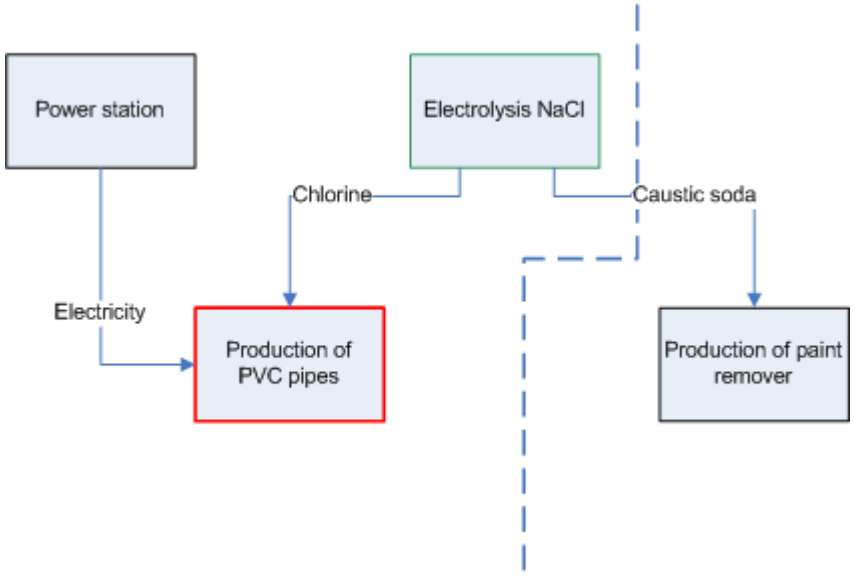
Figure 6 Multifunctional process with several input products and resources consumed and various wastes and emissions generated as well as providing the two co-products 1 and 2.

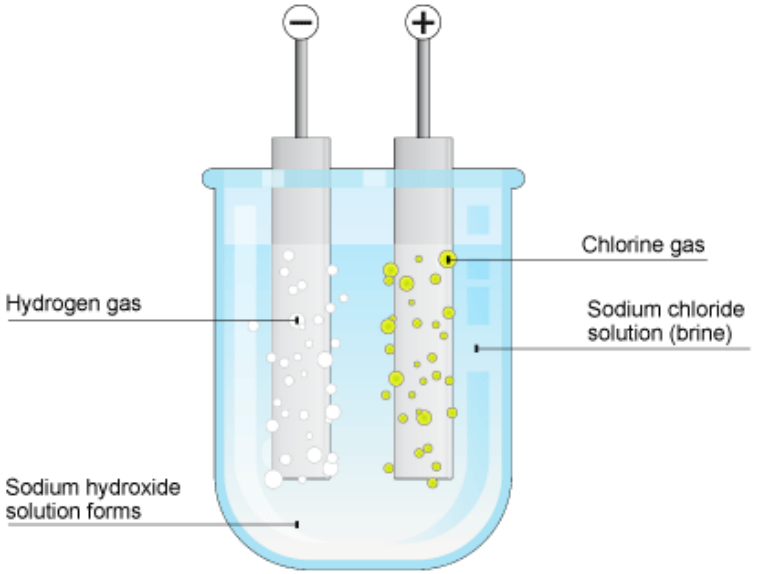
Source: JRC, 2010. ILCD Handbook General Guide for Life Cycle Assessment-Detailed guidance, 1ste edition. European Commission

- Multiple output processes (electrolysis; production of carbon black)
- Waste treatment processes (recycling and energy reclamation, end-of-life allocation)

Example of multiple output process

Example from chemical industry: PVC production from Cl_2





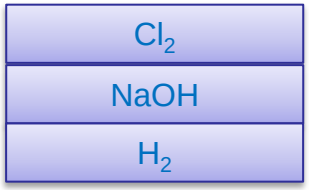
2 strategies to deal with allocation in your LCA model

1. Expand system boundary

- Make inventory of alternative process
- Subtract environmental impact of this process from main output

2. Divide impact over output products

- Use physical causality
- Use economic causality

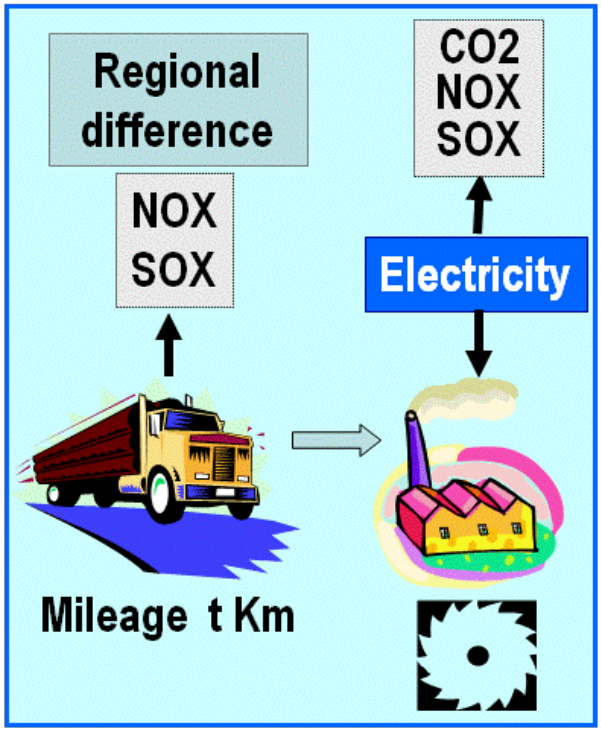


fictional allocation %

Mass	Value
46%	63%
52%	35%
2%	2%

Other important issues

Describe time and geographical location



Important effects on:

- Transport model
- Electricity fuel mix.
- Level of technology
- Waste treatment.

Also important for impact assessment, especially for damage modelling.

Describe selection of impact calculation methods (Eco-indicator, IMPACT 2000, ReCiPe etc.)

Wrap up: Why is Goal and Scope important?

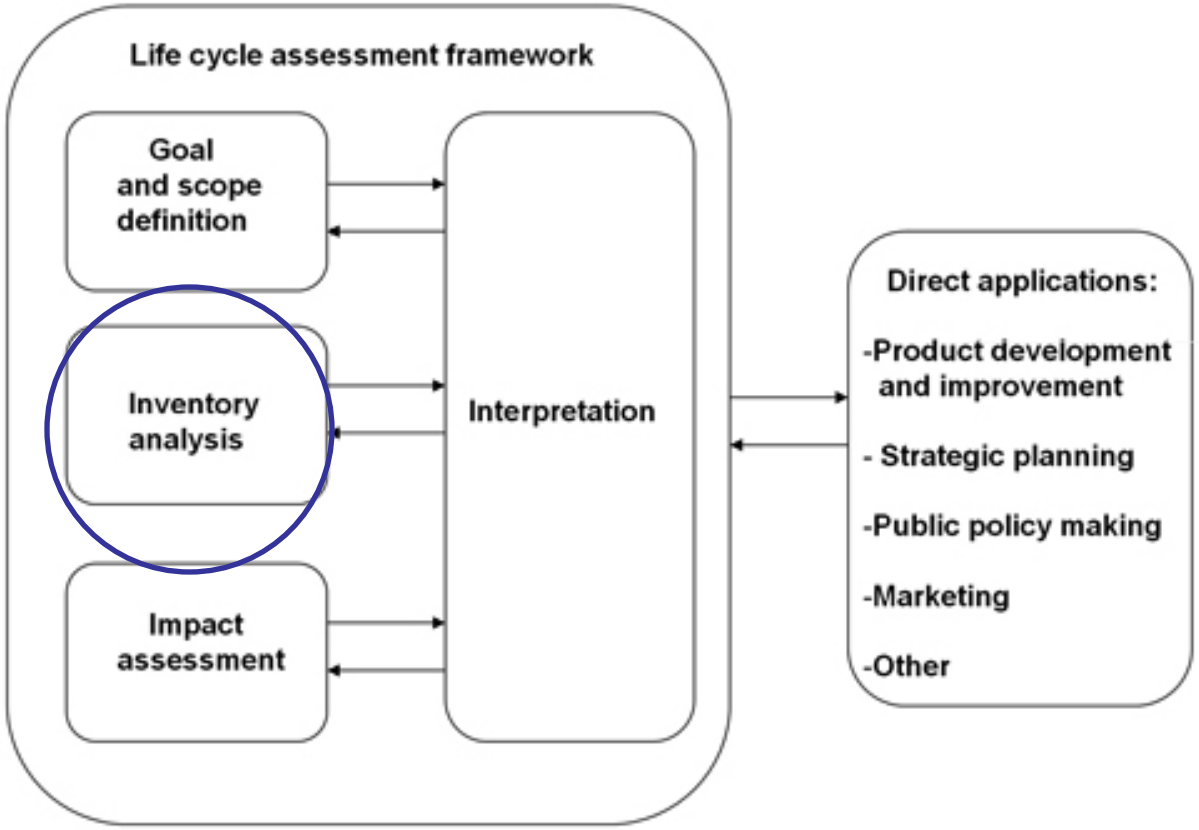
During the data collection for the model:

- *Guidance in data collection phase.*
- *Communication with data providers.*
- *Define and manage data quality.*

Afterwards:

- *Explain how choices are made*

LCA framework



Data Inventory

Data inventory is also called Life Cycle Inventory (LCI)

Data collection is determined by your goal and scope

What is the uncertainty of data?

What is your time and budget to collect data?

Maybe you need to review your initial Goal and Scope…

Initial decisions are not practicable

Too ambitious for the budget

What do you do during the Inventory step?

- Compiling and quantifying of inputs and outputs
- Collecting of data, determination of total emissions and resource use
- Detailed defining of product system and economy-environment boundary. Only data collection for processes that are controlled by human beings (economic processes). Examples: coal mining, electricity production, controlled dumping of solid waste etc.
- Visualizing connected processes in product system
- Scaling of available technical data (e.g. from data libraries) to functional unit
- Aggregating the inputs and outputs in an Inventory Table

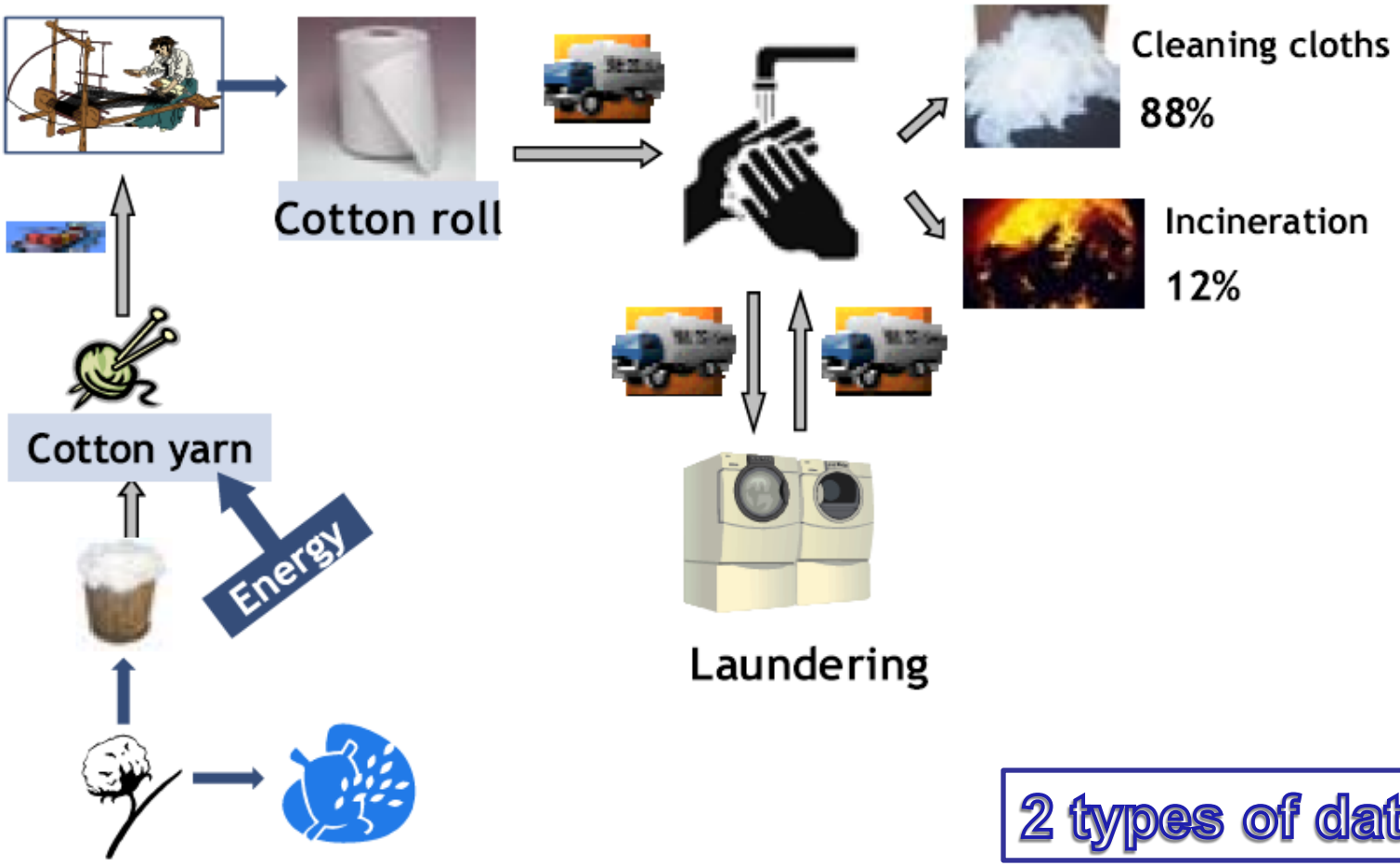
Difficulties in finding the right data…

- **Data availability and quality**
  - Data rarely available, usually special data gathering studies needed
  - Measurement procedures rarely standardized

- **Geographic variations**
  - quality of raw materials/energy sources
  - production methods
  - relevant environmental impacts

- **Technology**
  - Which type of electricity production?
  - Salt Electrolysis with Mercury or Membrane process?
  - Oldest, average or modern Waste Incineration Plant?

Data collection…



2 types of data…

Collecting background data

Data on generic processes, materials, energy, transport, waste management systems

Databases with frequently used data are available (most OECD regions)

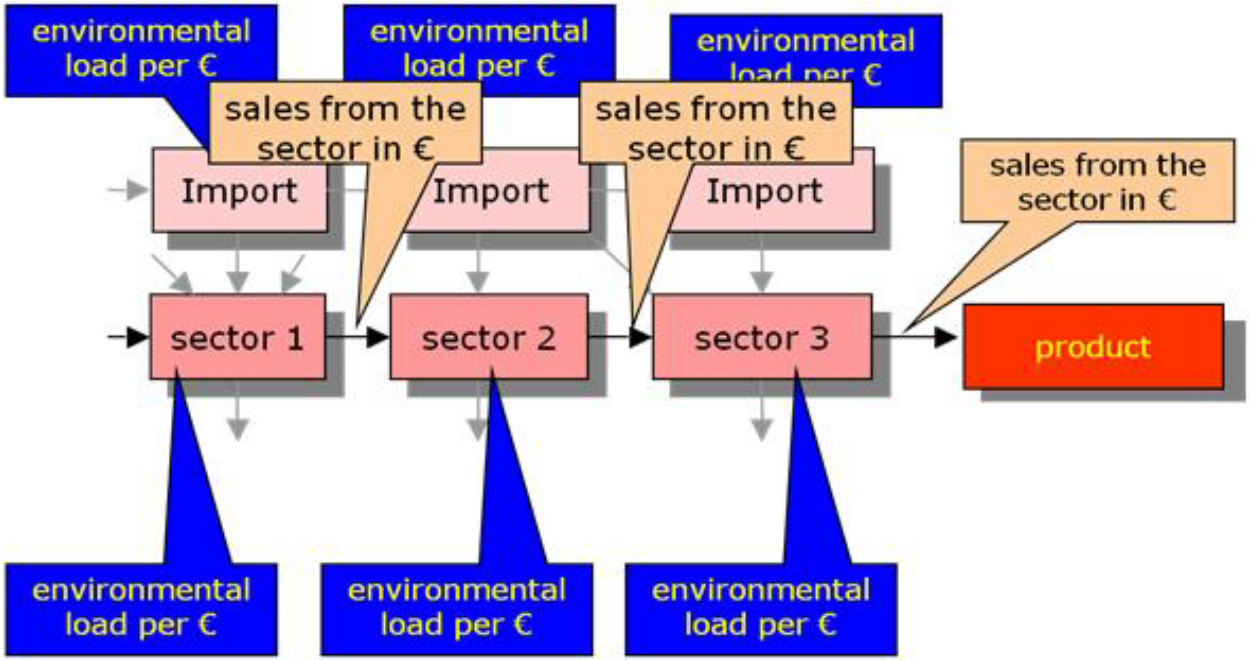
Available in data libraries: e.g.:

- Eco-invent v2. database: >4000 processes (including capital goods, well documented, background reports etc., for some processes even regional differences) www.ecoinvent.org
- Idemat 2008 (TU Delft)
- Many others from Japan, Australia, USA…

Collection foreground data

- Refers to processes that are of specific interest for the current LCA, like specific production processes
- Collect data from literature (papers) or from suppliers (reports of companies)
- When using questionnaires, check the correctness of the answers

Other data types: Regional Input-Output



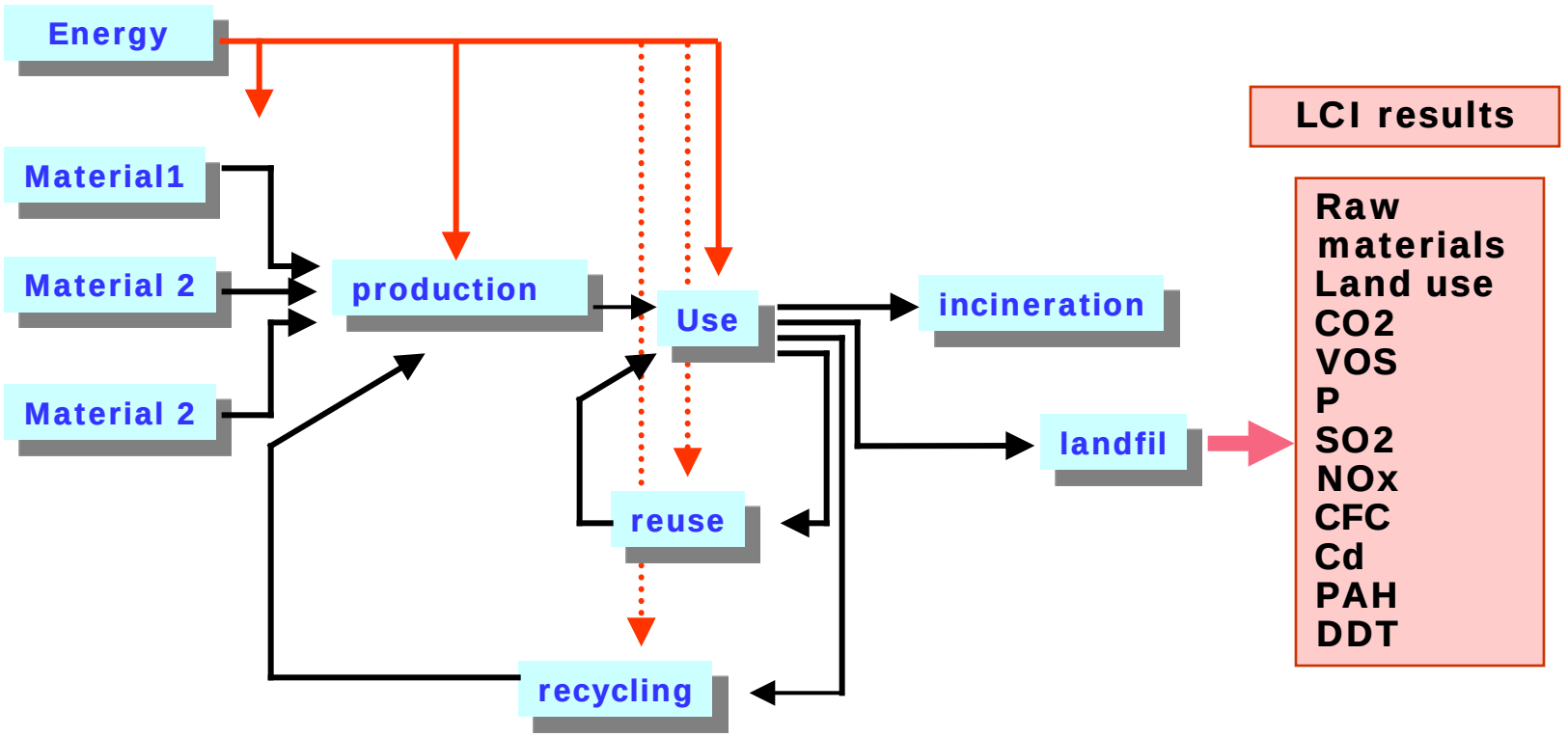
How to start with data collection?

Start with quick screening

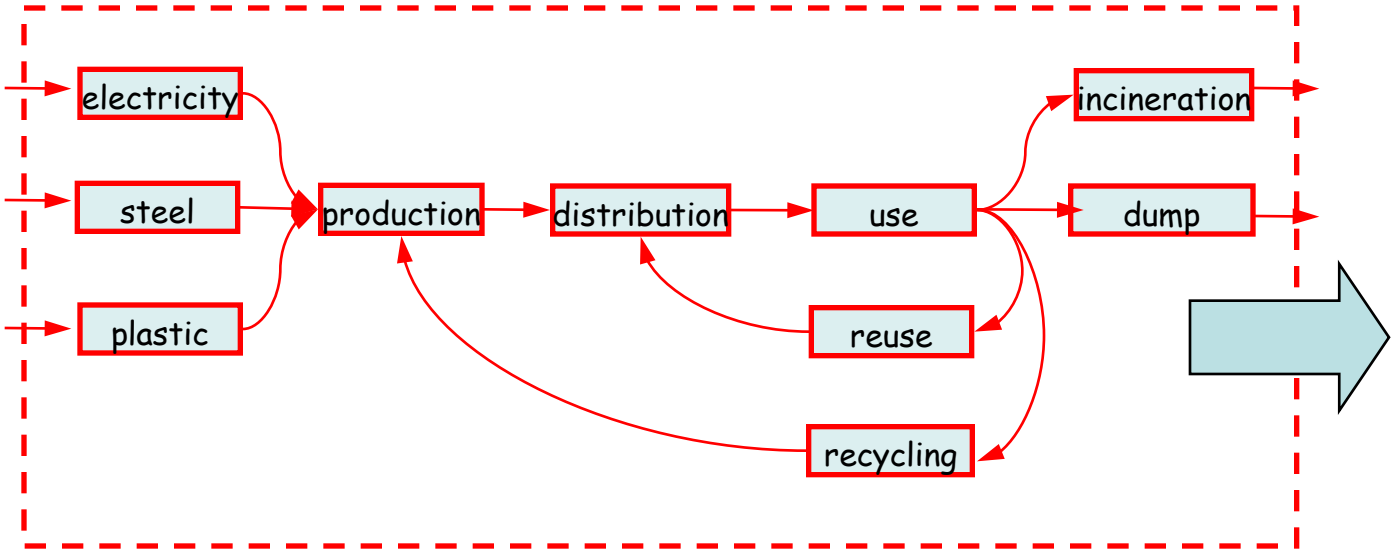
Use estimates

Use IO data if other data are not available

Organise the LCI results

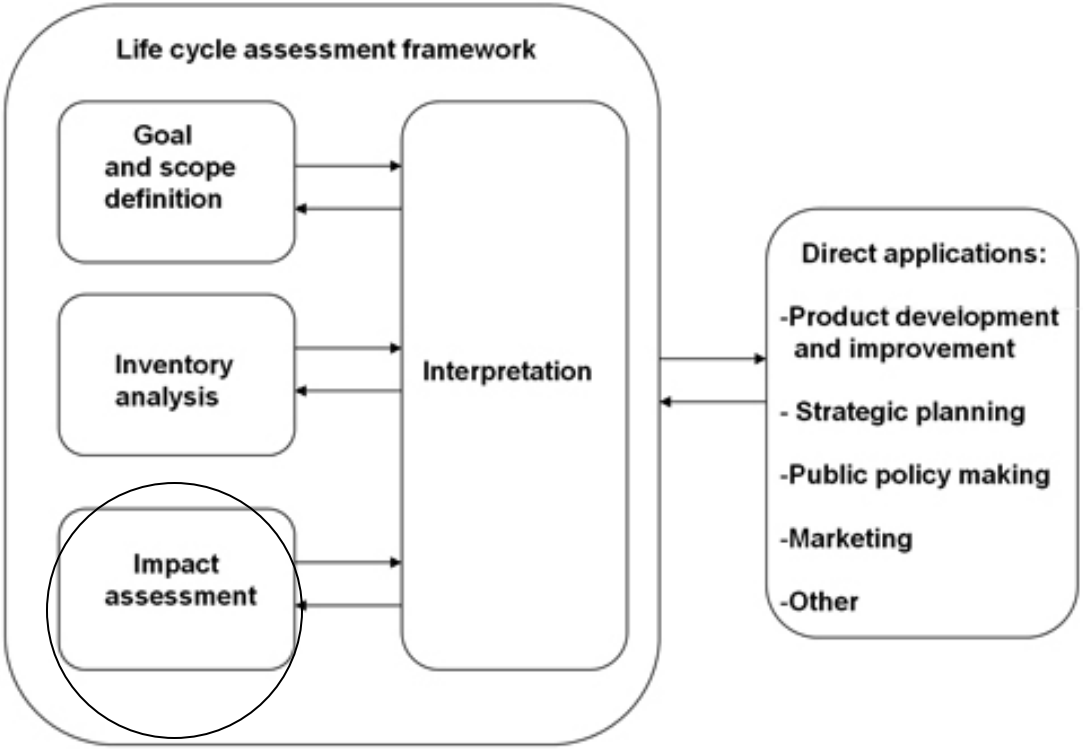


Example of Product system and Inventory Table



LCI table with environmental interventions	
Crude oil from earth	40000 kg
CO2 to air	3500
SO2 to air	20 kg
NOx to air	100 kg
Cd to water	5 g
PAH to water	8 kg
Etc.	…….

LCA framework

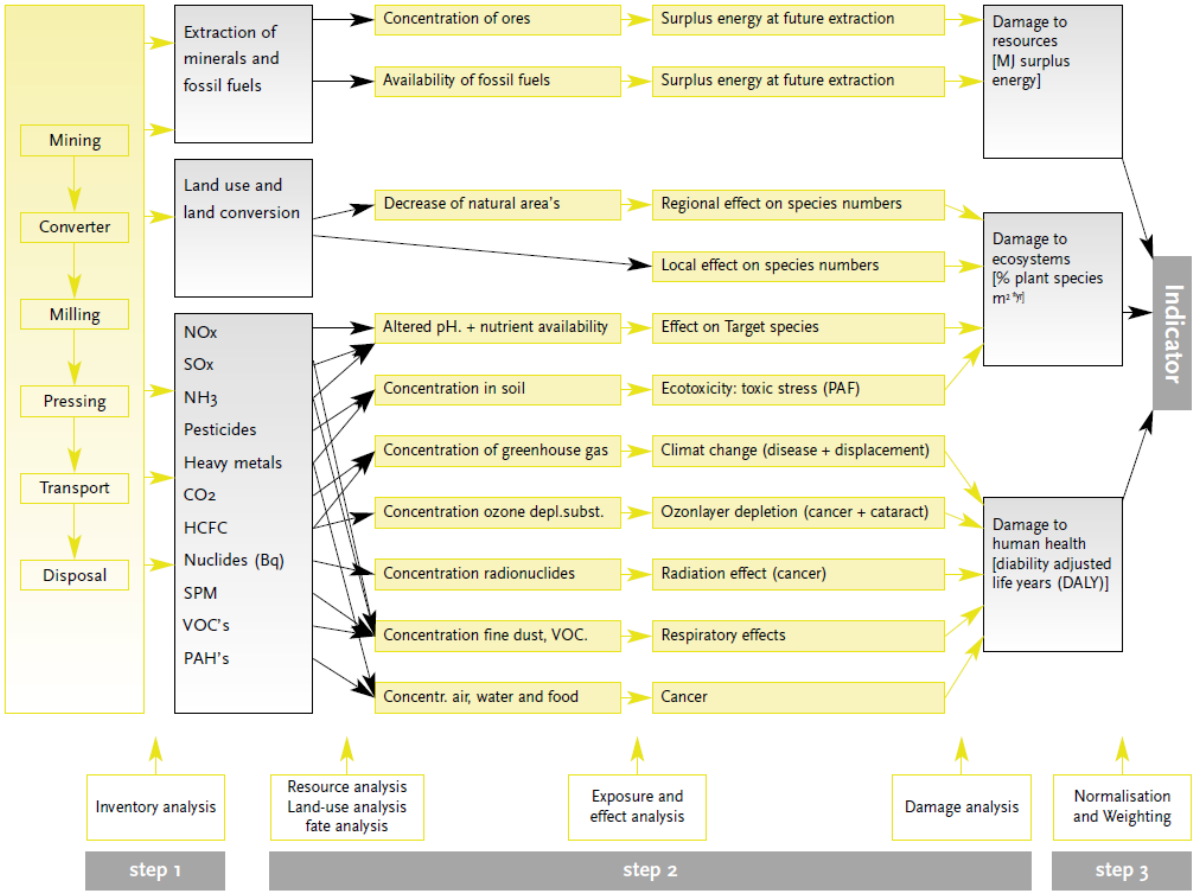


Life Cycle Impact Assessment (LCIA)

Impact Assessment (ISO)

Selection	• Impactcategories • Indicators • Characterisation methods
Classification	• Assign interventions (LCI results) to impact categories
Characterisation	• Modelling of environmental mechanisms
Normalisation	• Compare impact assessment results with an indicator
Weighting	• Rank , prioritize alternatives on the basis of relative importance of the impacts

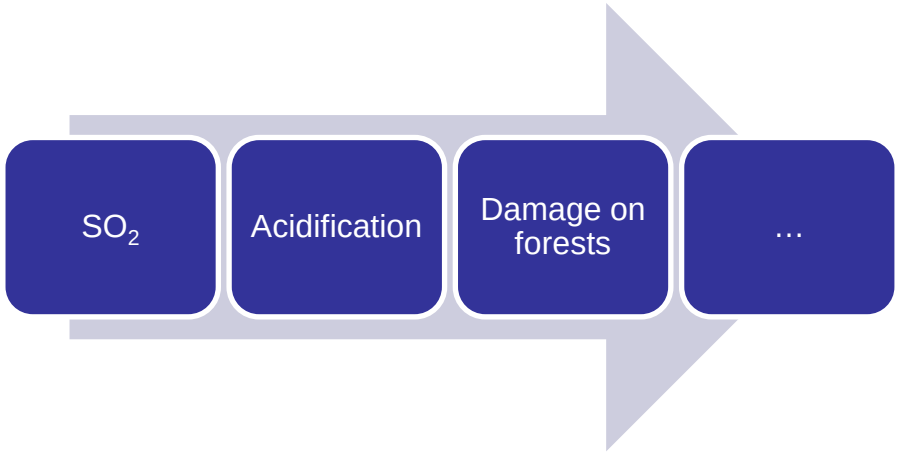
The Eco-indicator 99 damage model



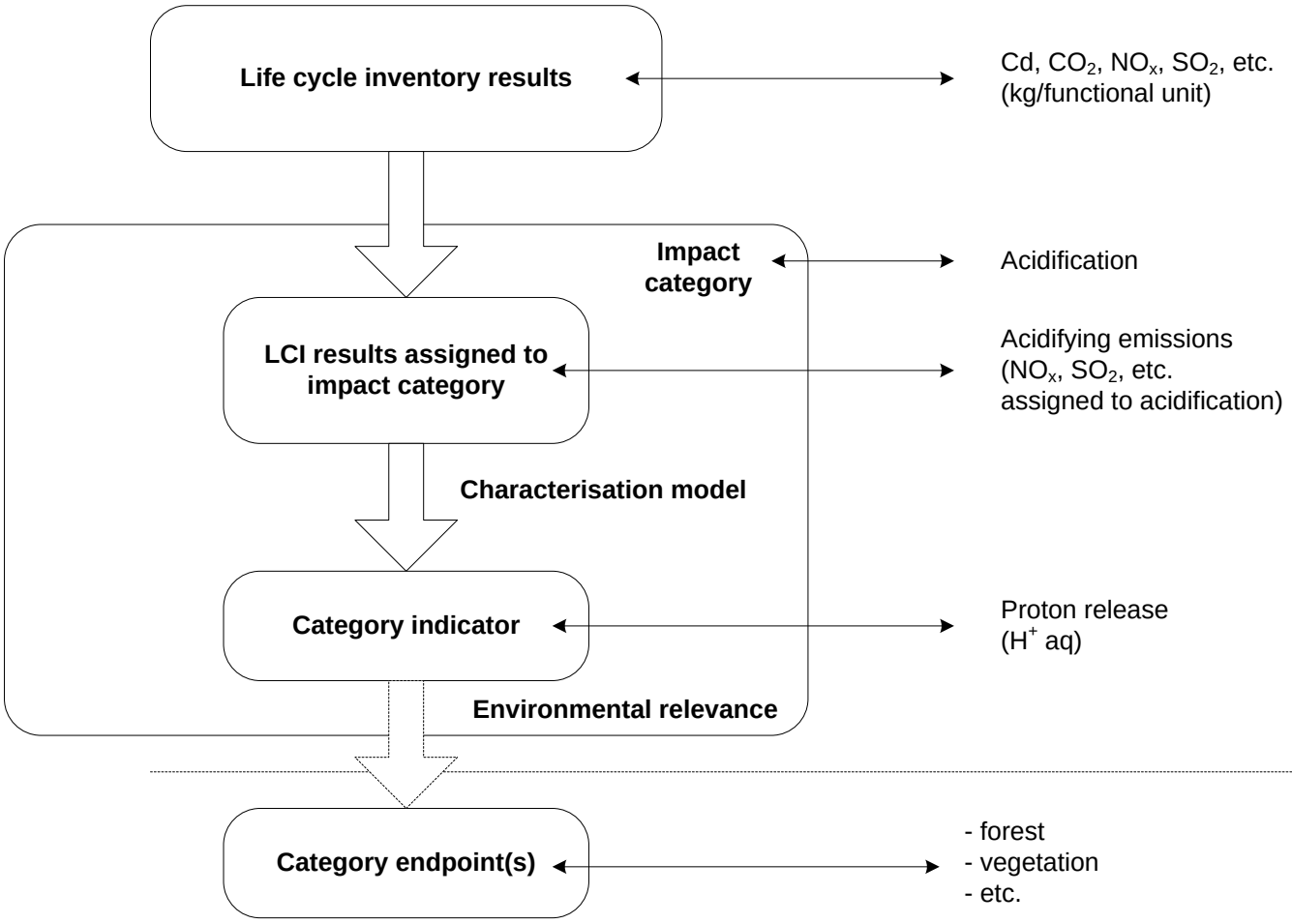
Source: VROM (2000), The Eco- Indicator 99 Manual for designers, Ministry of Housing , Spatial Planning and the Environment, The Netherlands

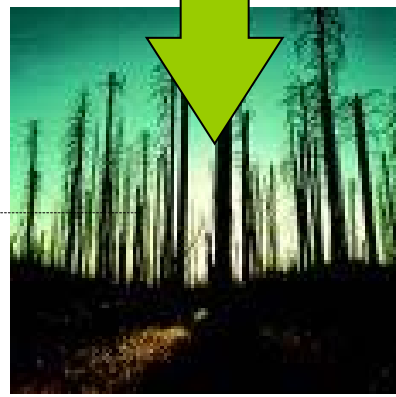
How can we define environmental *impact*?

- ✓ Quantifiable, induced, (non) temporary modification within an environmental compartment (water, air, soil)
- ✓ Originates from activities in the antroposhere/ technosphere
- ✓ Determined by measurement of an indicator

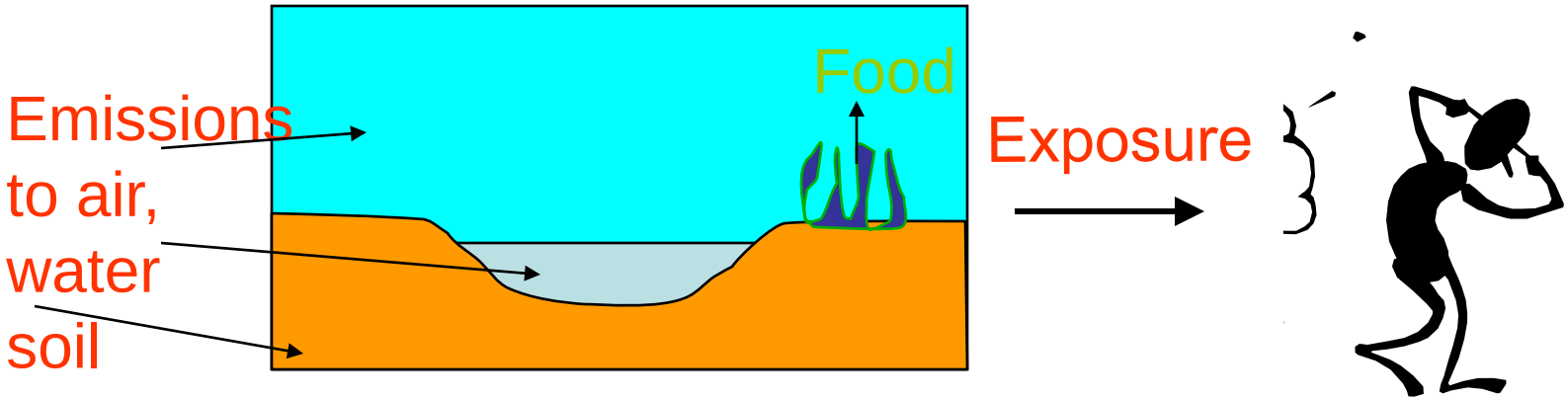


Impact assessment model for ecological damage





Example for determining characterisation factors



Fate model

Fate and exposure models are used (by experts) to determine the fraction of an emission that is actually exposed to people or ecosystems.

Selection and classification

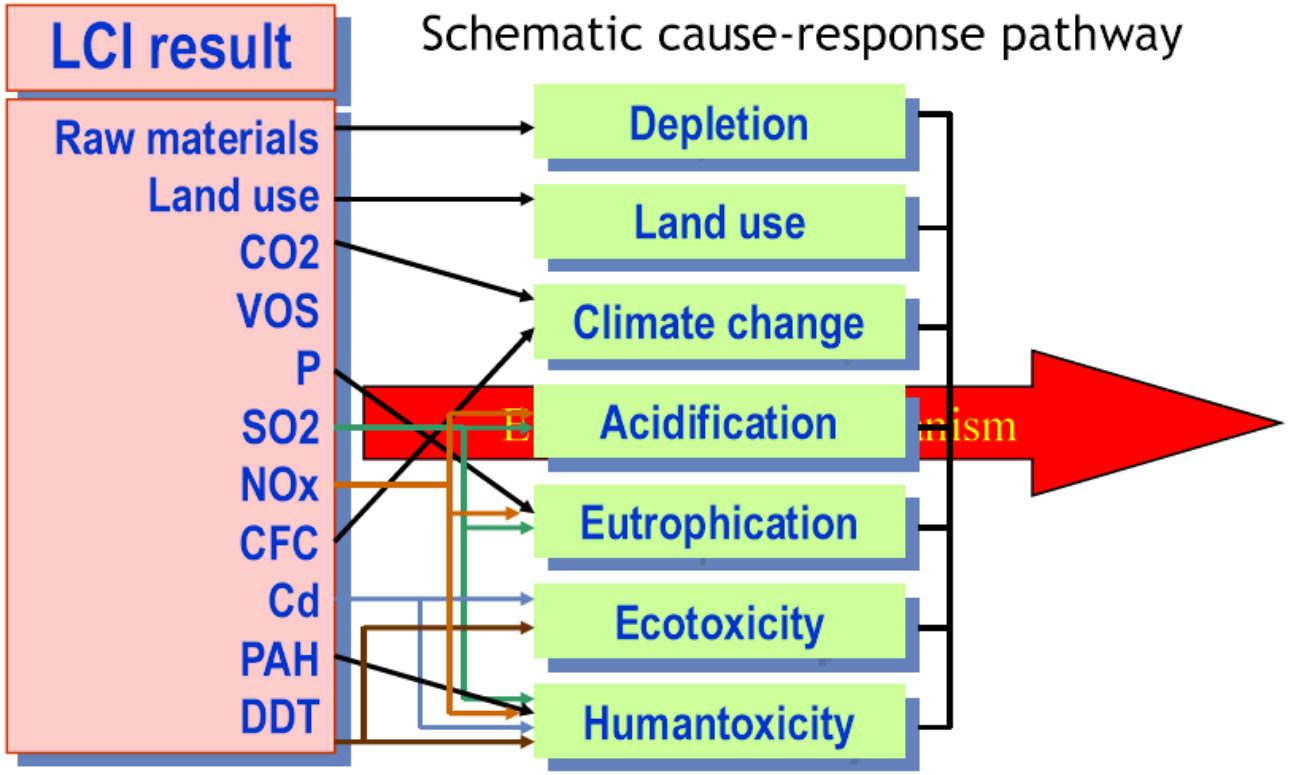
ISO definition: assignment of LCI results to impact categories

- LCA has essentially a flow character:
  emissions/ resource extractions in kg per functional unit
- Impacts have therefore a similar character:
  climate change/toxicity/depletion/etc. per functional unit
- Some impacts do not fit well. Extremely non-linear and path dependent impacts (like those related to biodiversity) cannot be in included in LCA in an appropriate way

Example: CO_2 and CH_4 are assigned to climate change

Source: Heijungs, R. CML/UNEP LCA training kit

Selection, classification, characterisation models

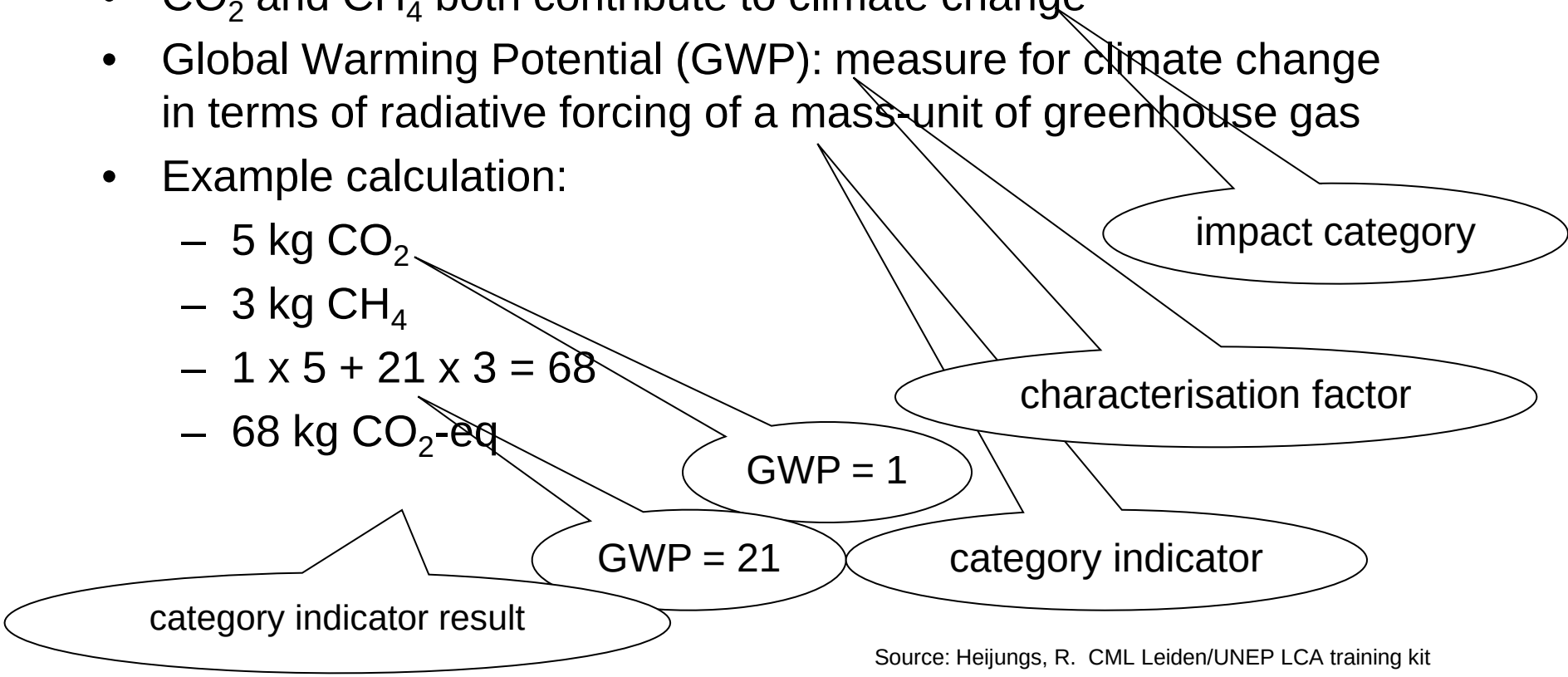


Characterisation models

- ✓ Describes the causal connection between the environmental intervention (emissions, extractions etc.) and the change of its indicator of the assigned impact category
- ✓ These connections, like environmental mechanisms are subject of scientific research other than LCA
- ✓ LCA *uses* available characterisation methods
  - ✓ Eco-indicator 99
  - ✓ CML 92
  - ✓ Impact 2002+
  - ✓ IPCC 2007
  - ✓ Etc.

The principle of characterisation (1)

- CO_2 and CH_4 both contribute to climate change
- Global Warming Potential (GWP): measure for climate change in terms of radiative forcing of a mass-unit of greenhouse gas
- Example calculation:
  - 5 kg CO_2
  - 3 kg CH_4
  - 1 x 5 + 21 x 3 = 68
  - 68 kg CO_2-eq

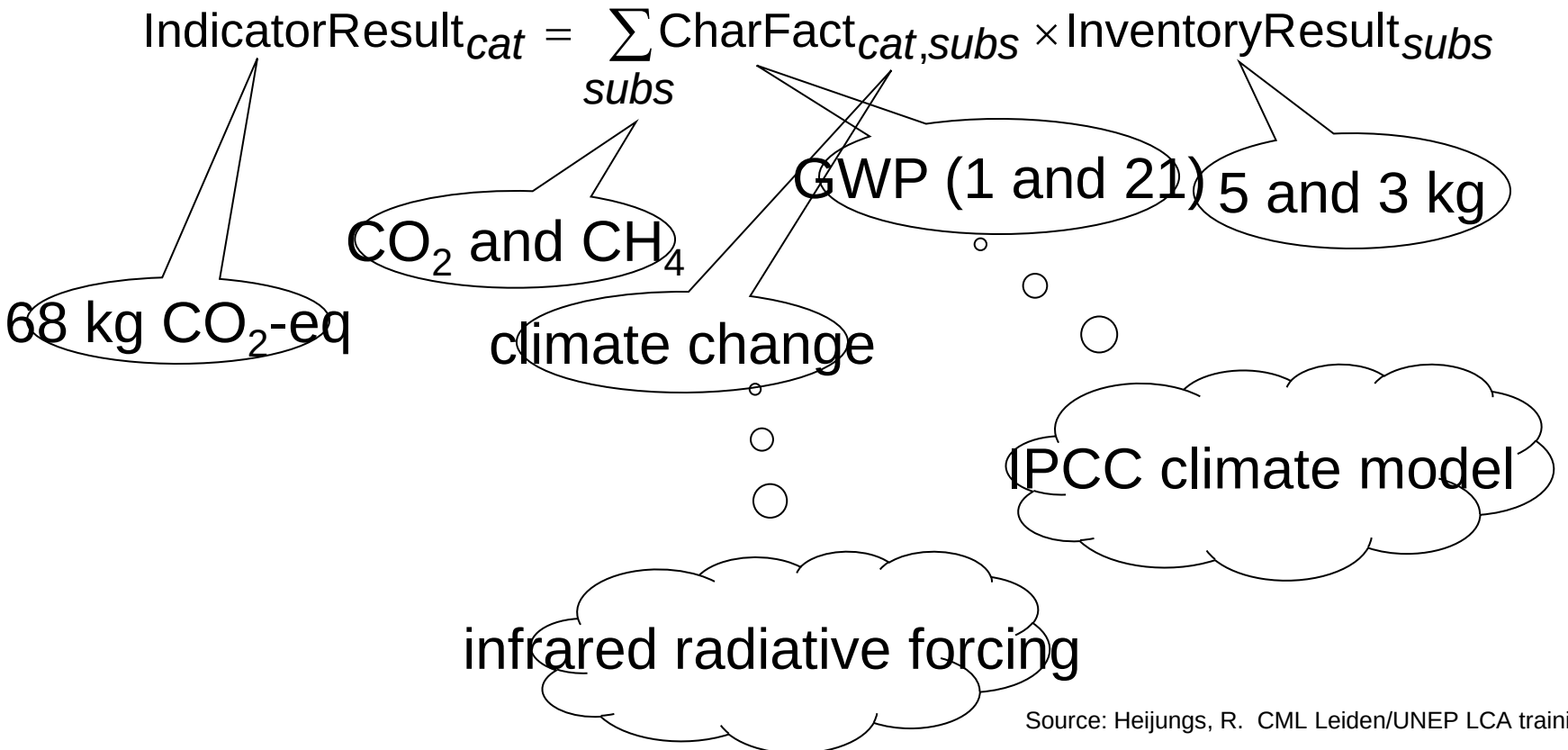


Source: Heijungs, R. CML Leiden/UNEP LCA training kit

The principle of characterisation (2)

- Generalisation by simple conversion and aggregation:

$$\text{IndicatorResult}_{cat} = \sum_{subs} \text{CharFact}_{cat,subs} \times \text{InventoryResult}_{subs}$$



Source: Heijungs, R. CML Leiden/UNEP LCA training kit

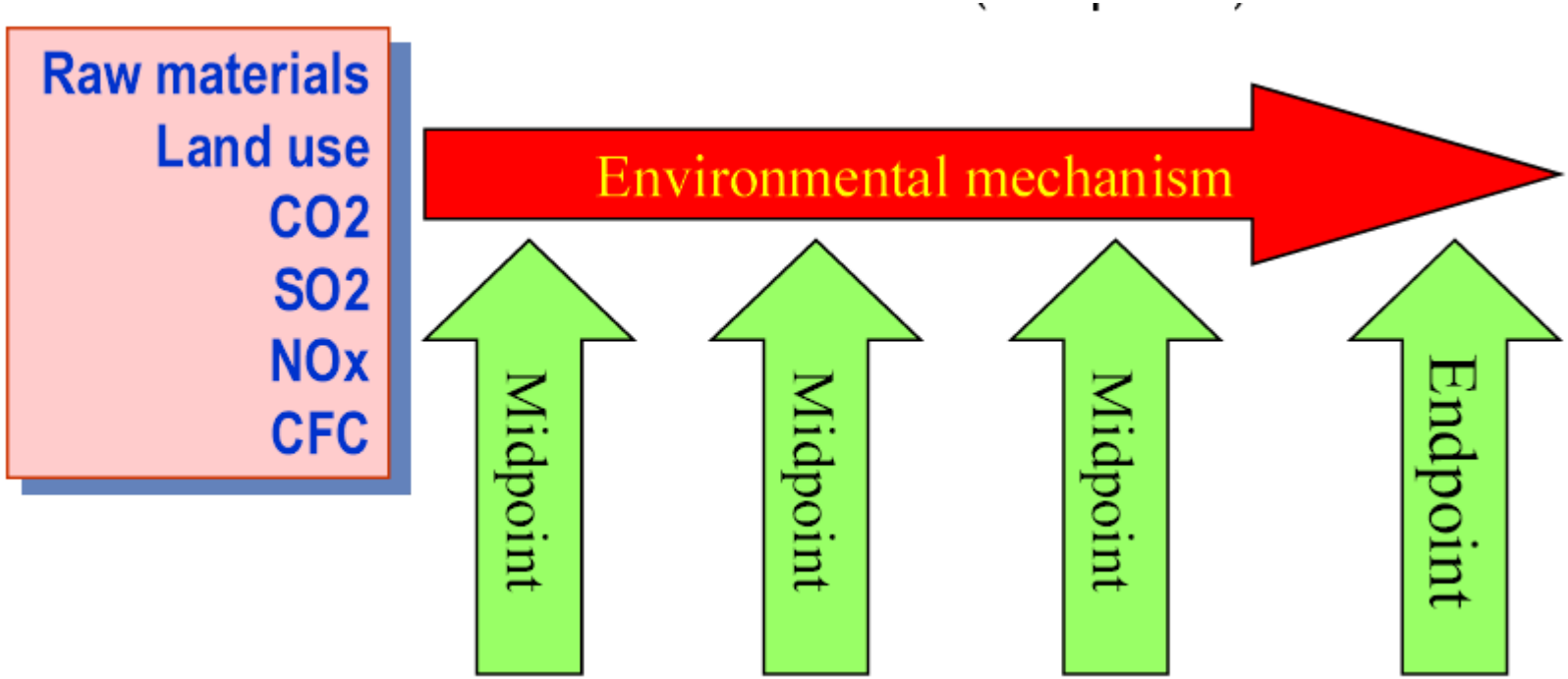
Midpoint and endpoint

Located differently along the ‘cause-effect chain’

Midpoints is an interpretation of characterized results (threats): e.g. toxic potential, ozone layer depletion, global warming effect, acidification (expressed in CO_2 or SO_2 eq. etc.)

Endpoints reflect ultimate ‘damages’ or ‘issues of concern’ (value changes), e.g. flooding, ecological quality, lost human lives (expressed in Disability Adjusted Life Years DALY, Potential Disappeared Fraction of plants PDF etc.)

Emissions, extractions etc. set off *chain* effects…



…in practice, we distinguish mid-point and end-point effects

Schematic steps from inventory to impact categories

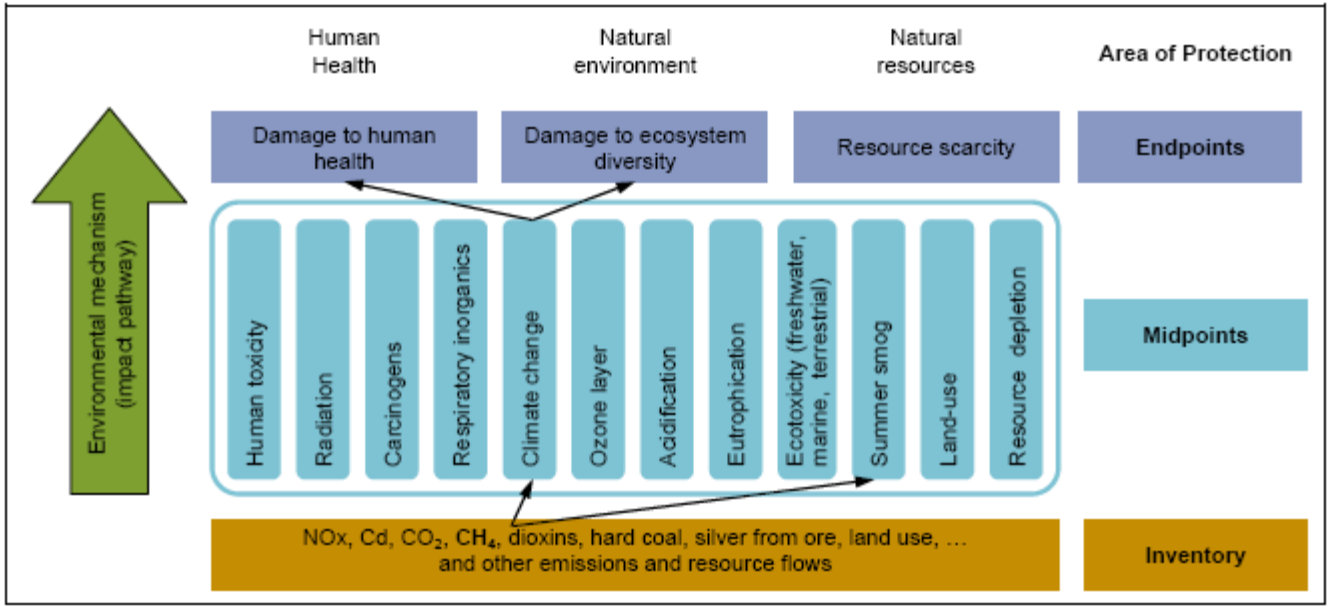
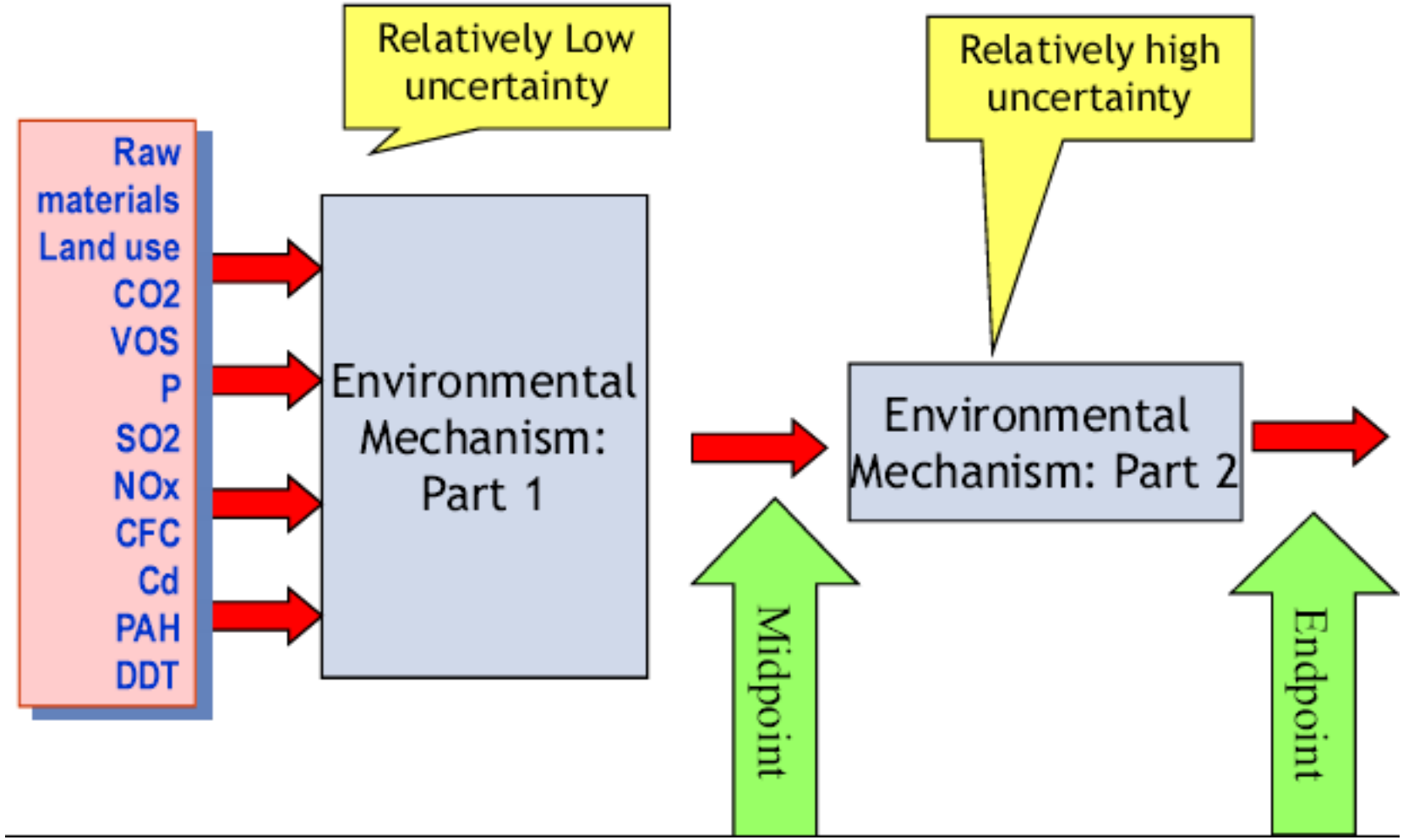
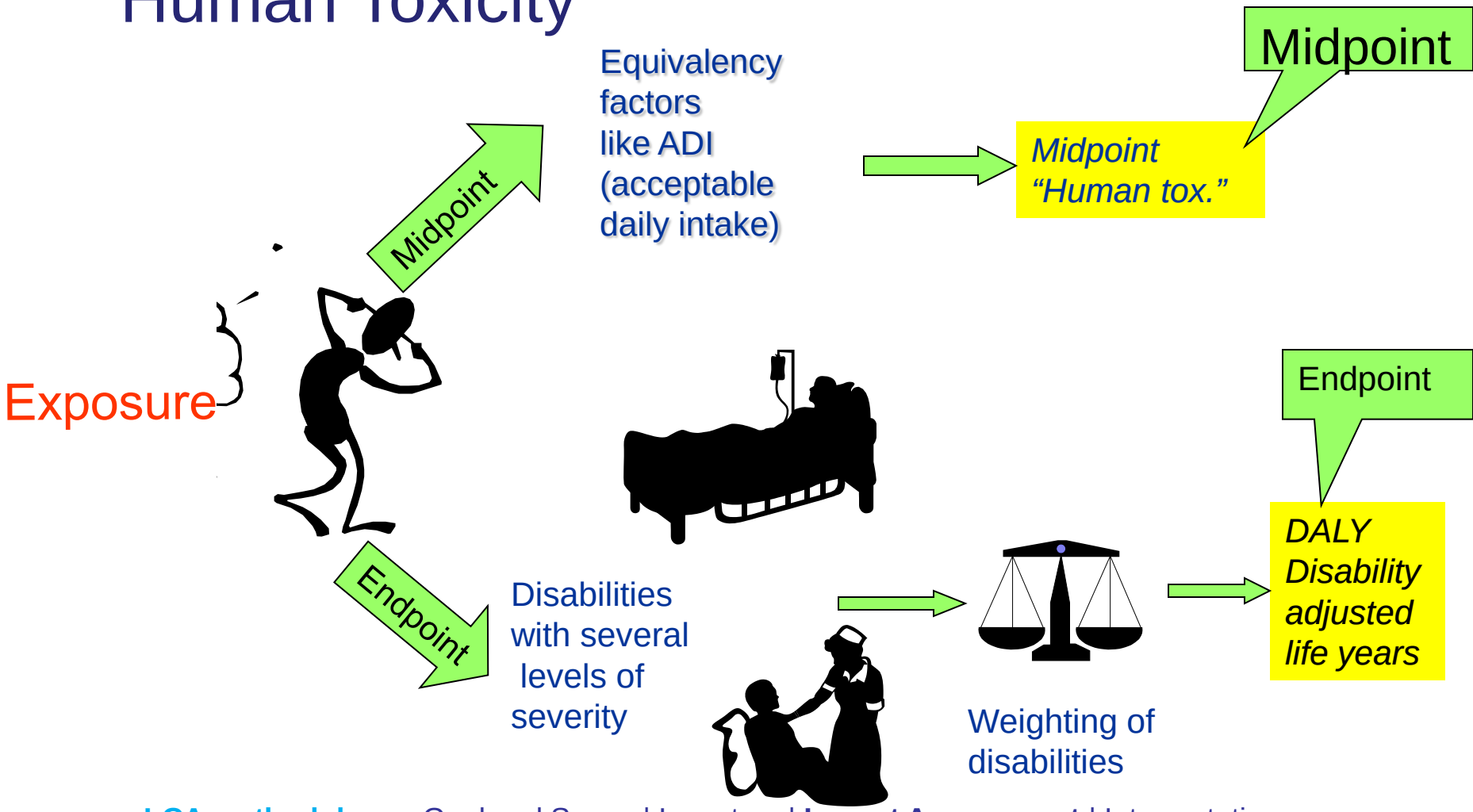


Figure 15 Life cycle impact assessment. Schematic steps from inventory to category endpoints. Note that normalisation and weighting are not shown and can start from either midpoints or endpoints.

Source: JRC, 2010. ILCD Handbook General Guide for Life Cycle Assessment-Detailed guidance, 1ste edition. European Commission, International Reference Life Cycle Data System ILCD


Relatively Low uncertainty
Relatively high uncertainty
Raw materials
Land use
CO2
VOS
P
SO2
NOx
CFC
Cd
PAH
DDT
Environmental Mechanism: Part 1
Environmental Mechanism: Part 2
Midpoint
Endpoint

From exposure to midpoint and endpoint Human Toxicity



Classification/characterisation (midpoint)

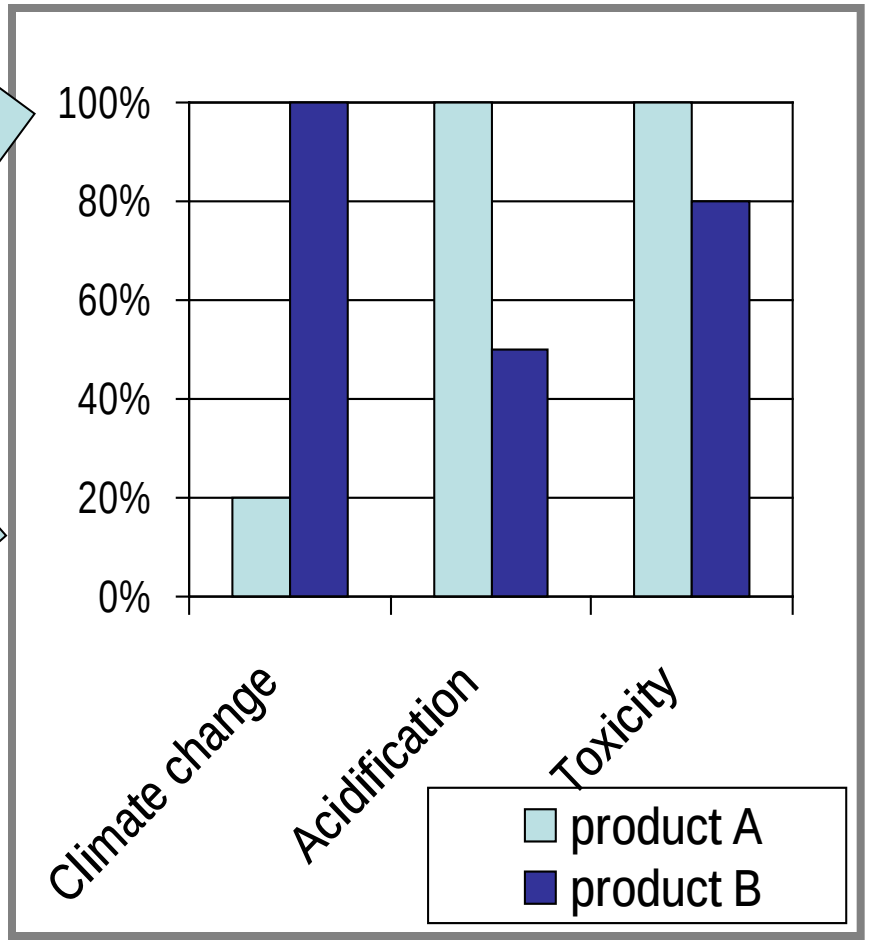
LCI result	Climate change	Acidification	Human tox.
1000 gr CO2	x 1 = 1000		
10 gr. CH4	x 21 = 210		
10 gr. SO2		x 1 = 10	x 1.2= 12
5 gr. NOx		x 0.7= 3.5	x 0.78= 3.9
10^{-6} gr dioxine			x $3.3x10^{6}$ = 3.3
Total	1210	13.5	19.4

CO_2 eq. SO_2 eq. Human Toxicity Potential

Result of classification using just three indicators

Scores are plotted as percentage; highest score is set to 100%.

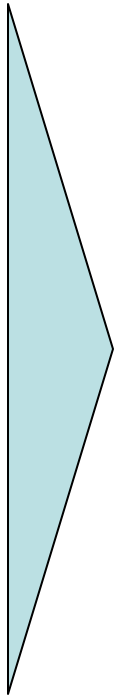
Is product A preferable over product B?



- *Does 100% refer to high or low emissions?.*
- *Is climate change more important?*

Normalisation, weighing: optional steps (ISO)

- ✓ Compares impact category results with a reference (normal value)
- ✓ Divide each indicator by a reference value:
  - ✓ To find out if 100% refers to high or low emission.
  - ✓ to get a dimensionless score (as each indicator is devided by a parameter with the same unit).
- ✓ Useful references: average yearly load of a citizen.



•Relative importance of impact categories visible
•Relative env. impact of life cycle compared to total env. loads in the region

Normalisation

Aim: better understand the relative magnitude for each indicator results of the product system under study.

- checking for inconsistencies
- providing and communicating information on the relative significance of the indicator results
- preparing for additional procedures

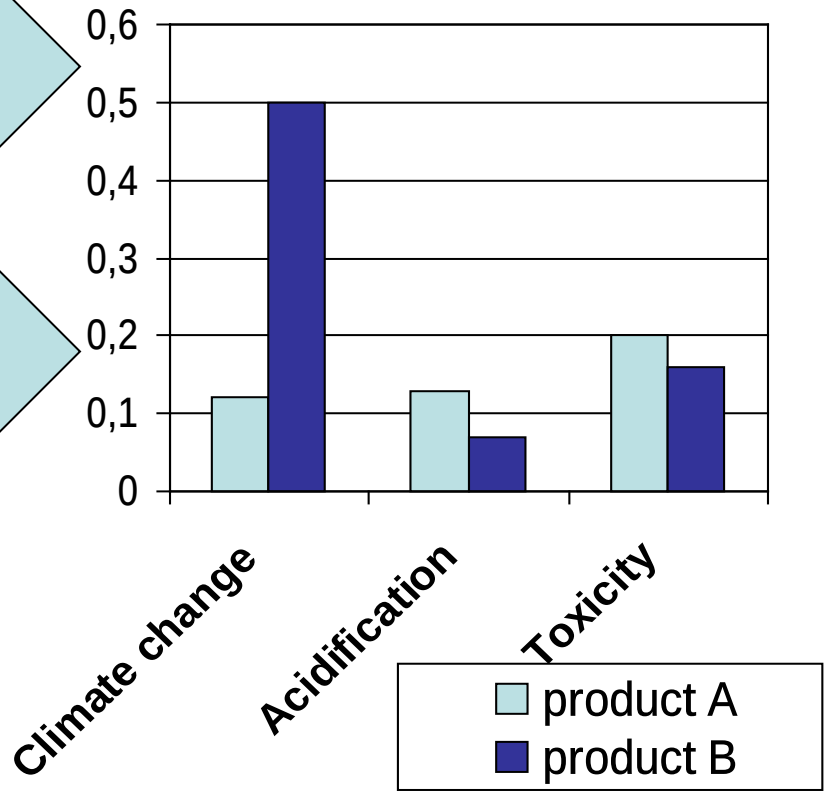
Normalisation (2)

LCI result	Climate change	Acidification	Human tox.
1000 gr CO2	x 1 = 1000		
10 gr. CH4	x 21 = 210		
10 gr. SO2		x 1 = 10	x 1.2= 12
5 gr. NOx		x 0.7= 3.5	x 0.78= 3.9
10^{-6} gr dioxine			x 3.3×10^{6} = 3.3
Total	1210	13.5	19.4
Reference (approx.)	10.000	100	100
Normalised	0.12	0.13	0.2

Result of normalisation using just three indicators

Scores are plotted dimensionless numbers

Apparently contribution to climate change is relatively high.



But: high score is not the same as 'important'… Weighting is still needed.

Weighting

ISO definition: converting and possibly aggregating indictor results across impact categories using numerical factors

- based on value-choices
- ISO: “weighting shall not be used for comparative assertions disclosed to the public”

The debate around weighting

- Controversial because of subjective choices
- Implies environmental impact categories are interchangeable
- According to ISO 14042:
  - *Classification and characterisation is an obligatory step.*
  - *Normalisation is an optional step.*
  - *Weighting is only permitted for internal decision making, and not for comparison of products to the public.*
- Recent developments on impact assessment focus on solving the weighting problem.

Interpretation

- Compare LCA results with your initial question
- To interpret an LCA, you must analyse the goal and scope:
  - Are the general assumptions reasonable?
  - Are important decisions on allocation and boundaries justified (sensitivity analysis)?
  - Is the functional unit well chosen?
  - How about the scaling factors
  - Is all according to ISO 14040 and up?
- Has a peer review been conducted?

Sensitivity analysis

- The impact of important choices or assumptions need to be analysed.
  - *What if other allocations are applied.*
  - *What if other boundaries are applied.*
  - *What if other impact assessment is used*.
  - By recalculating the LCA with other assumptions, we can verify if the conclusions depend on assumptions.
- *If they do, this needs to be reported clearly*

Is the quality sufficient?

- Is the transparency of the data and the way data has been treated clear?
- Is the data of sufficiently recent and based on reliable sources, and in line with “common sense”?.
- Does the applied impact assessment method cover all significant impact categories or have important aspects been “forgotten”?

Always keep in mind…

- Results are valid for the underlying product system and boundaries of your LCA
- Be careful when making extrapolations
- Changes of consumer behaviour as a result of changes in the product are beyond the scope of the LCA study!

Closing remarks on LCA

- LCA helps to identify processes and environmental impacts that are critical in product chains
- Goal and scope define the methodological choices needed
- Numerous applications: eco-design, process improvement, policy making, product oriented sustainability analysis
- Benefits and constraints: model projects lifecycle independently of location and time, data availability sometimes difficult, always cut-off in system boundaries
- Can be combined with other tools, like LCC, MFA
- Dedicated LCA software with predefined databases is available, e.g. Sima Pro, CMLCA (http://www.cmlca.eu/), Umberto
- Databases contain “background” data on commonly available processes, such as transport, electricity generation, basic materials etc.
- Impact assessment methods are usually included.
- See also UNEP LCA Training Kit and numerous other books on LCA