Life cycle assessment: a bridge between environmental sciences and bio(chemical) engineering

LABORATORY of CHEMICAL ENGINEERING

Processes and Sustainable development

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PROCÉDÉS ET DÉVELOPPEMENT DURABLE

GÉNIE CHIMIQUE

Université de Liège

Introduction to the Laboratory of Chemical Engineering

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LGC CHEMICAL ENGINEERING

University of Liège, Belgium

- 9 faculties, 1 institute, 1 school

Philosophy & Letters

Applied Sciences

Law and Criminology school

Veterinary Medecine

Sciences

Psychology and Education

Medecine

gembloux agro bio tech

HEC ULg Management School - University of Liege

Human and Social Sciences

Architecture

✓ 38 bachelors
✓ 194 masters
✓ 68 complementary masters

Department of Applied Chemistry

- 3 groups

✓ Analysis and Synthesis of Chemical Systems – Cryotechnology laboratory

(Pr G. Heyen, Pr J.-L. Bozet, Dr M.-N. Dumont)

✓ Catalytic and electrochemical engineering - Nanomaterials

(Pr J.-P. Pirard, Pr B. Heinrichs, Dr N. Job, Dr S. Lambert, Dr C. Gommes)

✓ Chemical Engineering

(Pr M. Crine, Pr D. Toye, Pr A. Léonard)

http://www.chimapp.ulg.ac.be/

Research: 3 main topics

- Drying of deformable materials
  - Both experimental and modeling approaches
  - Long expertise in sludge drying
  - Relation between drying process and product quality
- Characterization of porous materials by X-ray microtomography
  - Initially developed to follow sludge texture during drying
    - Cracks, shrinkage, moisture profiles
  - Extension to different types of cellular materials
  - Now used for product-oriented-engineering approach
- Environmental management: Life Cycle Assessment studies, environmental reporting

The team

- Drying
  - Prof. Michel Crine
  - Thierry Salmon (industrial engineer)
  - Dr Lyes Bennamoun (FRS-FNRS postdoc)
  - Laurent Fraikin (PhD student)
  - Yvon bert PAMBOU (PhD student)
- X-ray microtomography
  - Prof. Dominique Toye
  - Dr Erwan Plougonven (FRS-FNRS postdoc)
  - Charlotte De Bien (FRIA PhD student)

The team

- LCA
  - Sandra Belboom (PhD student)
  - Saïcha Gerbinet (PhD student)
  - Raphaëlle Melon (Industrial engineer)
  - Robert Renzoni (Senior researcher)

Expertise in environmental management

- LCA: more than 10 years of expertise
  - Evaluation of the environmental impact of processes
  - Redaction of environmental declarations
  - Development of databases
  - Academic research + external studies
  - Participation to several regional and European projects
  - …

Expertise in environmental management

- LCA: some covered topics
  - Comparison of vehicles
  - Comparison of waste management scenarios
  - Comparison of packaging options
  - Comparison of several ways of renewable heat heat production
  - Comparison of several ways of renewable electricity production
  - Study of biofuels production
  - Study of agro-food by-products valorization ways
  - Impact of water management (whole anthropic water cycle)
  - CO_2 Life cycle inventory of a cement producer
  - Study of several fuel cells configurations
  - LCA training

Expertise in environmental management

- LCA: current projects
  - WALAID - Walloon Region
    - Valorization of the agrofood industry by-products
  - SOMABAT – FP7
    - Development of novel SOlid MAterials for high power Li polymer BATteries
      - LCA of the developped batteries + recyclability
  - Pierres et mabres de Wallonie
    - Realisation of environmental product declarations (FDES)
      - Blue stone, sand stone, …

Expertise in environmental management

- Environmental management: Life Cycle Assessment studies, environmental reporting
  - LCA: formation
    - Greenwin
    - Master degree course (starting in 2011)
    - Carbon Management certificate (ULg – UCL)
  - LCA: publications
    - International journals
    - Conferences, …
    - http://orbi.ulg.ac.be/browse?type=authorulg&rpp=20&value=Belboom%2C+Sandra+p005285

About (bio)chemical engineering

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(Bio)chemical engineering

- Branch of engineering concerned with the design, operation, maintenance, and manufacture of the plant and machinery used in industrial (bio)chemical processes

- All the knowledge, the technologies and the practices necessary for the design the implementation, the operation and the optimization of the transformation processes of materials by chemical, physical or biological ways

(Bio)chemical engineering

- Application fields
  - Chemical industry
  - Pharmaceutical and biotechnological industries
  - Cosmetics
  - Agrofood and agrochemical industry
  - Pulp and paper
  - Cement industry
  - Energy production
  - …

(Bio)chemical engineering

- « Core curriculum »
  - Fundamentals of science and natural sciences
  - Thermodynamics
  - Heat and mass transfer
  - Biological engineering
  - Unit operations
  - Process design and modeling
  - Safety
  - Chemical reaction engineering
  - Catalysis
  - …

About LCA

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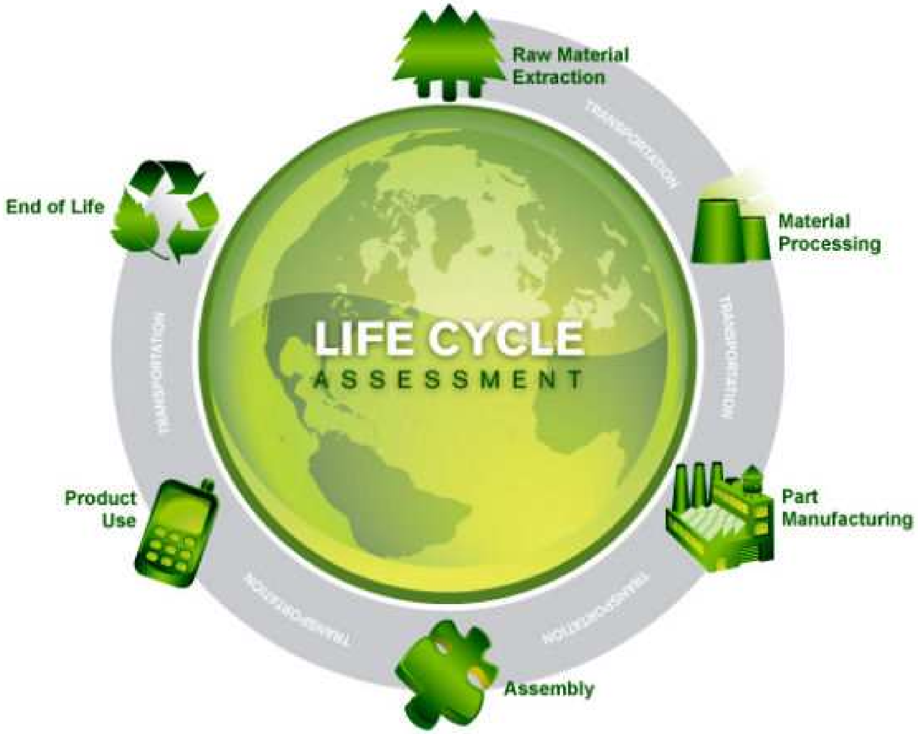
CHEMICAL ENGINEERING

LCA: a standardized methodology

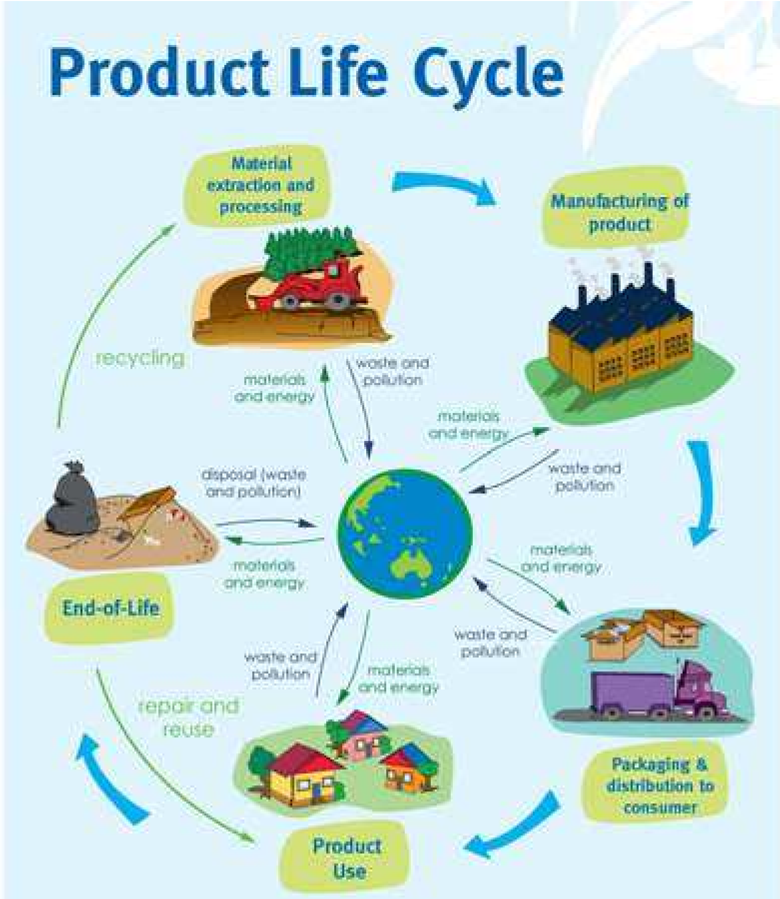
- General framework defined by international standards ISO 14040 - 14044

- « studies all the environmental aspects and potential impacts associated with all the stages of a product's life from cradle to grave, i.e. from raw material extraction to end of life»
- Product = product, activity, system or process



LCA: a standardized methodology

- Life cycle includes
  - Raw material extraction
  - Production
  - Transport
  - Packaging
  - Distribution
  - Use
  - Maintenance - Repair
  - Reuse or recycling
  - Disposal
- « Cradle to grave » approach



http://sydney.edu.au/facilities/sustainable_campus/procurement/index.shtml

LCA: typical results

- Life cycle steps ‘ranking’ following their environnemental impacts
- Identification of susbtances responsible for major environmental impacts

CO_2 footprint = 1 inventory among many others

- Determination of categories with highest environmental impacts
  - Human health, climate change, ecotoxicity …

LCA: why ?

Internal

Strategy

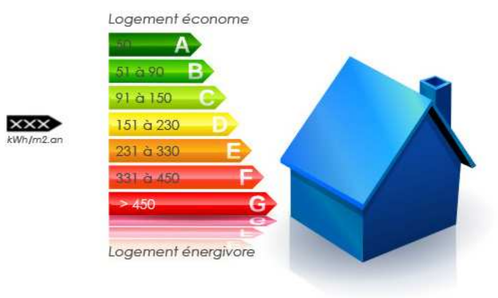
- Potential impacts of products on environment
- Investments decision support

R & D products/process

- Early identification of problems/opportunities
- Assistance in projects selection
- Assistance in defining objectives

Externa

Marketing



Policy

- Best information of authorities, consumers, etc. (legislation/regulation, eco-labels …)
- Comparative analyses

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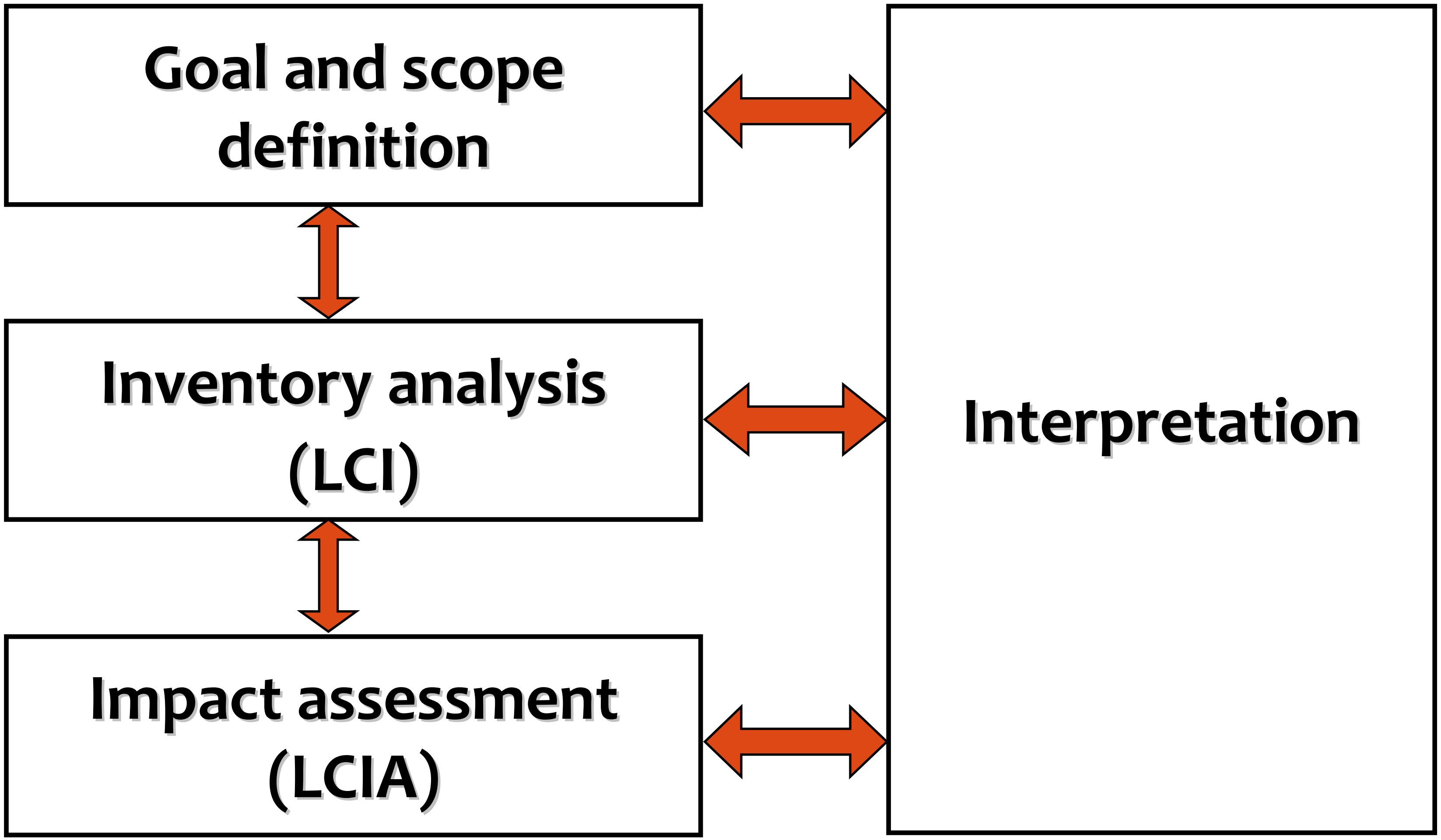
LCA associated steps

- Four steps defined by ISO 14040 – 14044



LCA associated steps

- Four steps defined by ISO 14040 – 14044

Goal and scope definition

Inventory analysis (LCI)

Impact assessment (LCIA)

Interpretation

LCA: goal and scope definition

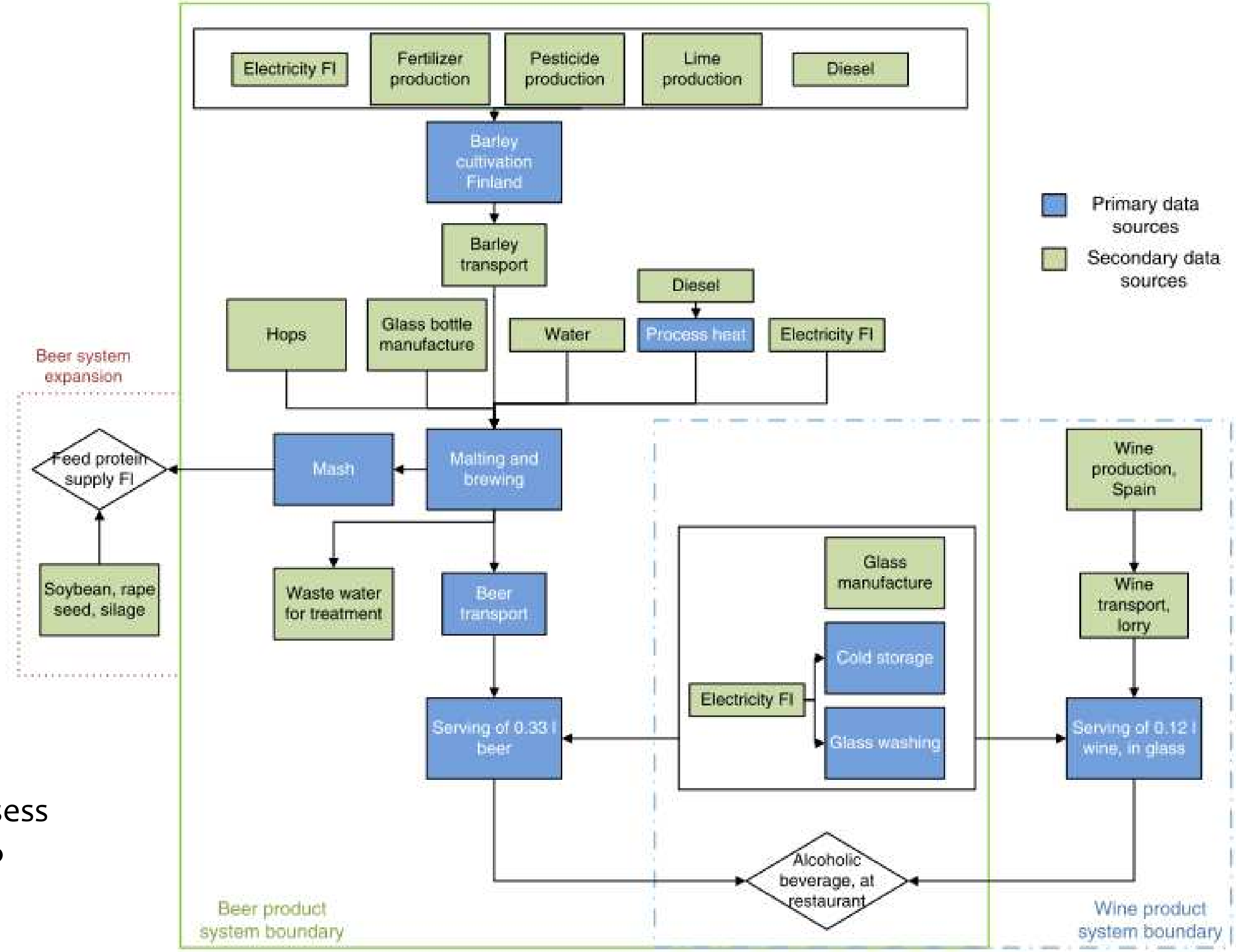
- Goal of the study
  - Why ?
  - For whom ?
  - …
- Scope
  - Choice of the functional unit
    - Production of 1 kg of yeast
    - Treatment of 1 ton of waste
    - Valorization of 1 ton of biomass
    - …

LCA: goal and scope definition

- Scope
  - Delimitation of the system boundaries
    - Determination of all the elementary processes to be included in the analysis
  - Process tree
  - Data quality requirements
  - Cut-off rules

LCA: goal and scope definition

- Example: process tree + boundaries



Int J Life Cycle Assess (2012) 17:277 – 286

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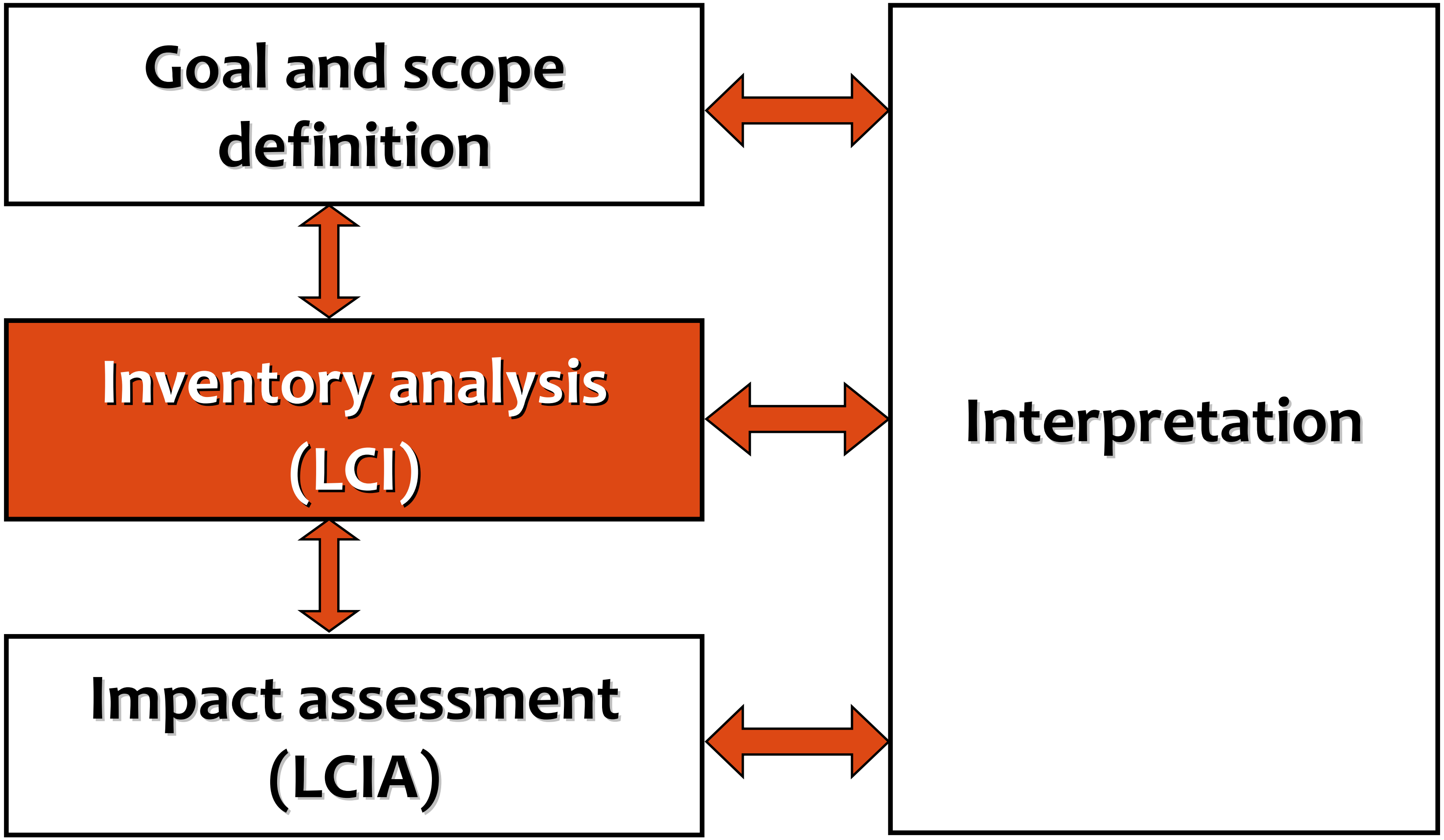
LCA associated steps

- Four steps defined by ISO 14040 – 14044



LCA: Inventory

Inputs

- Raw materials
- Energy
- Water, etc.

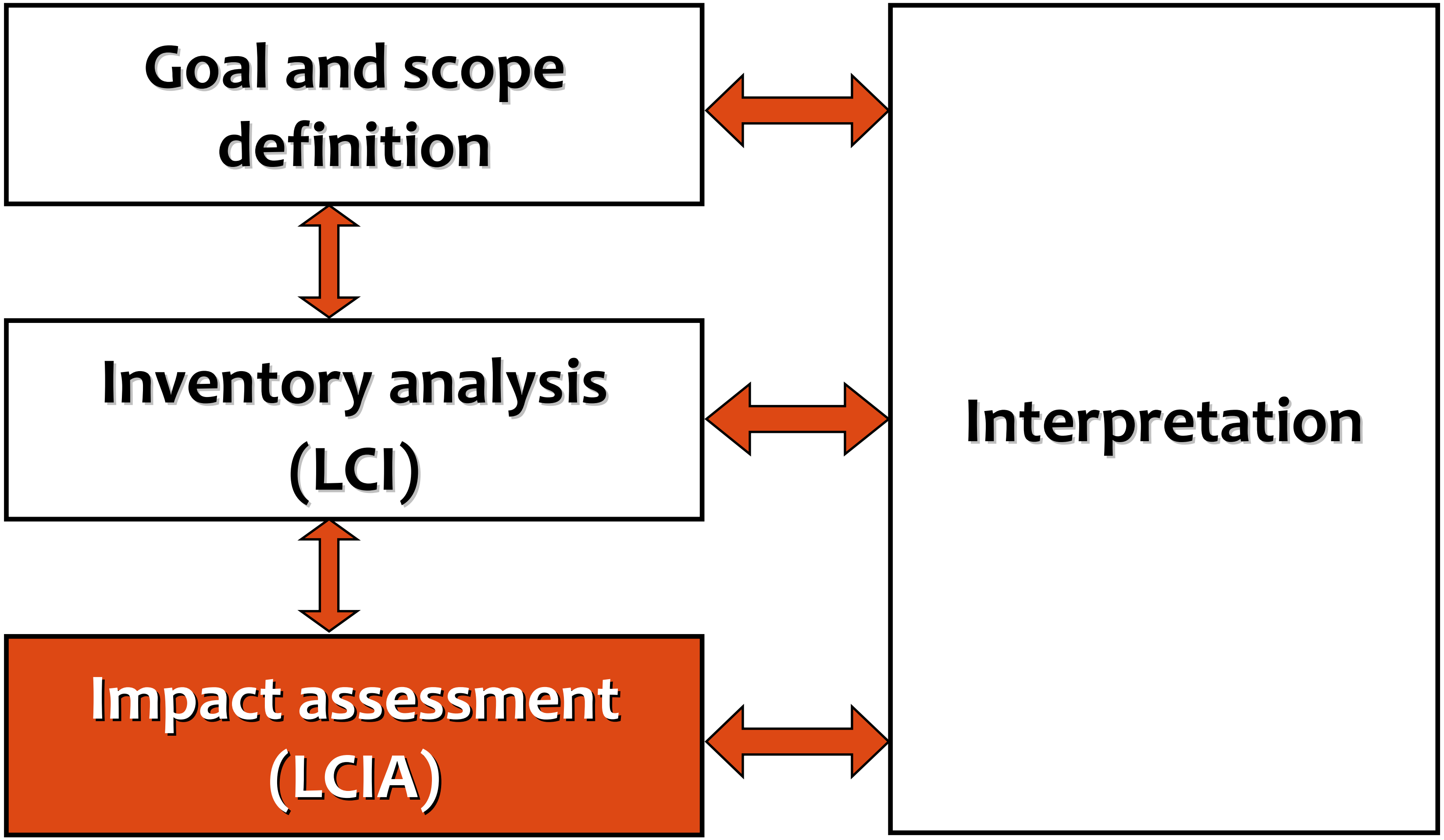
Raw materials
Processing
Assembly
Transport & distribution
Use
Final disposal

Outputs

- Air emissions
- Water emissions
- Soil emissions
- Solid waste
- Products
- Others emissions

LCA associated steps

- Four steps defined by ISO 14040 – 14044

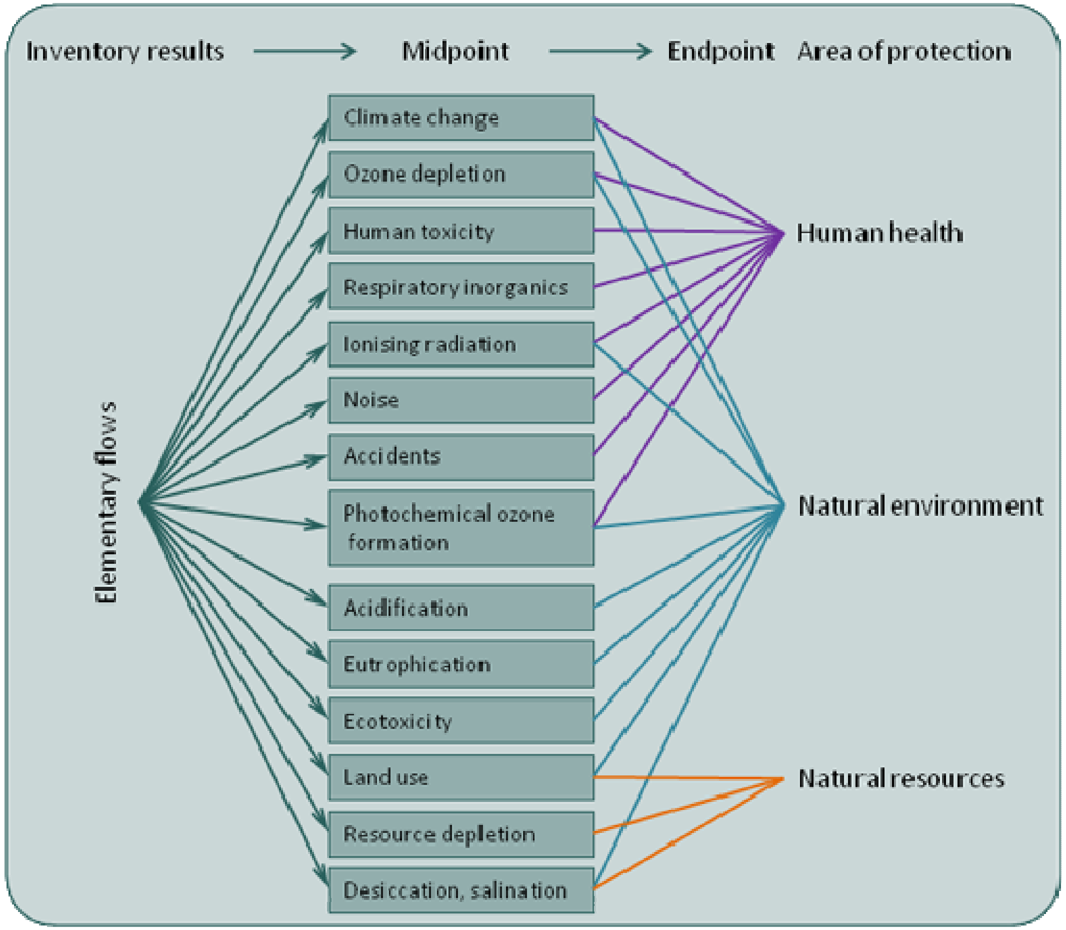


LCA: impact assessment

- Estimation of environmental impacts based on the inventory
- Mandatory elements
  - Selection of impact categories, indicators, methods
  - Classification
  - Characterization
- Optional elements
  - Normalisation
  - Grouping
  - Weighting

LCA: impact assessment

- Impact categories



http://lct.jrc.ec.europa.eu/assessment

LCA: impact assessment

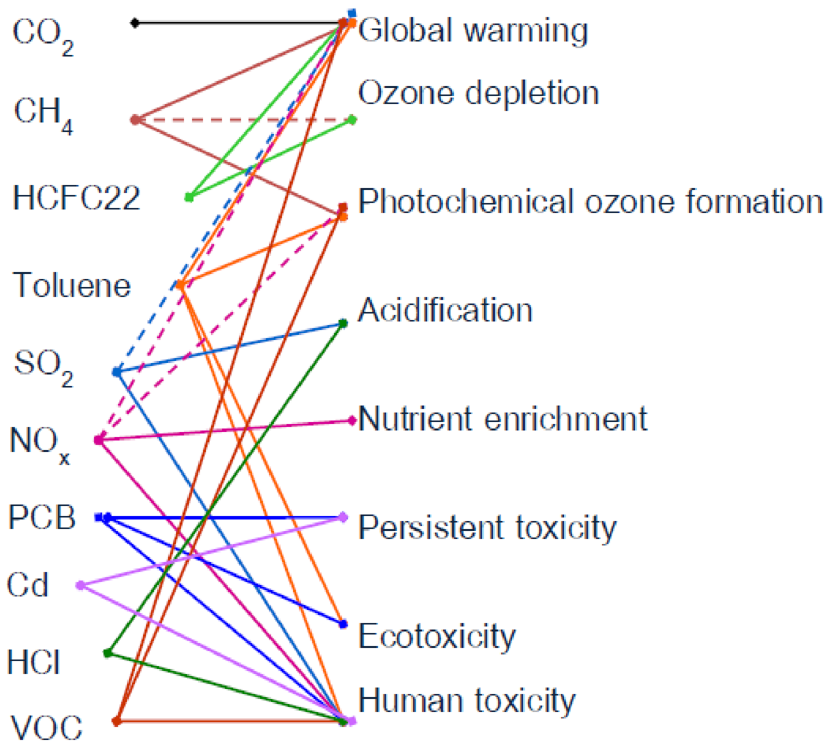
- Impact assessment methods

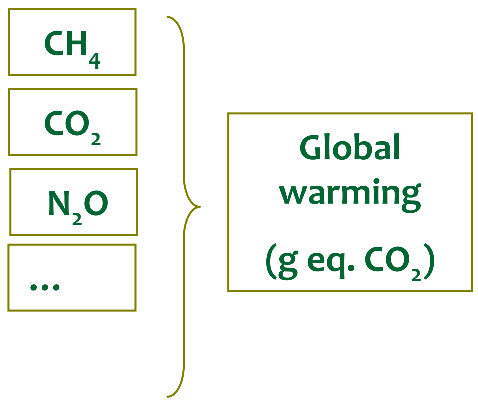
Method name	Temporal validity	Regional validity	Type of impact category (IC) indicators	Weighting principle
CML 2002	Present state (year 2002)	Global, except for acidification (Europe) and photo-oxidant formation (European trajectory)	Midpoint	No baseline method is proposed
ECO-indicator 99	Present state (year 1999)	Global for the impact categories (IC) climate, ozone depletion and resources. European model for the other IC. Acidification and eutrophication based on Dutch model, land use based on Swiss model.	Midpoint and Endpoint	Three options: Panel method is used for default weights. Monetization and a specific weighting triangle can also be used.
Eco-scarcity	Actual flows reflect 2004 state and critical flows correspond to 2005 political objectives.	Originally developed for Switzerland, but versions for Netherlands, Sweden, Norway, and Japan are also available.	Midpoint- distance to target principle. Endpoints indirectly considered by political targets.	Relative reduction of distance to target by multiplying by the square of the ratio of actual flow and critical flow.
EDIP	Present state (year 2003)	Global	Midpoint	Distance to political targets.
EPS 2000	Present state (year 1999)	Majority global, the largest exception is for Biodiversity where Swedish models are used.	Endpoint effects	Willingness To Pay to avoid changes on safeguard subjects.
ReCiPé	Present state (year 2010)	Europe, but global for climate change, ozone layer and resources.	Combination of midpoint and endpoint methodologies in a consistent way.	Three options: For midpoints a monetization method on the basis of the prevention costs is provided. For endpoints panel weighting is used and monetization on the basis of damage costs can be used.

http://www.tosca-life.info/wordpress/wp-content/uploads/2011/06/LCIAmethods.jpg

LCA: impact assessment

- Classification
  - Assignment of inventory results to the selected impact categories





LCA: impact assessment

- Characterization
  - Conversion of LCI results into representative indicators of impact using charaterization factor
  - Substances belonging to the same impact category are expressed in 'equivalent' units

Inventory Data × Characterization Factor = Impact Indicators

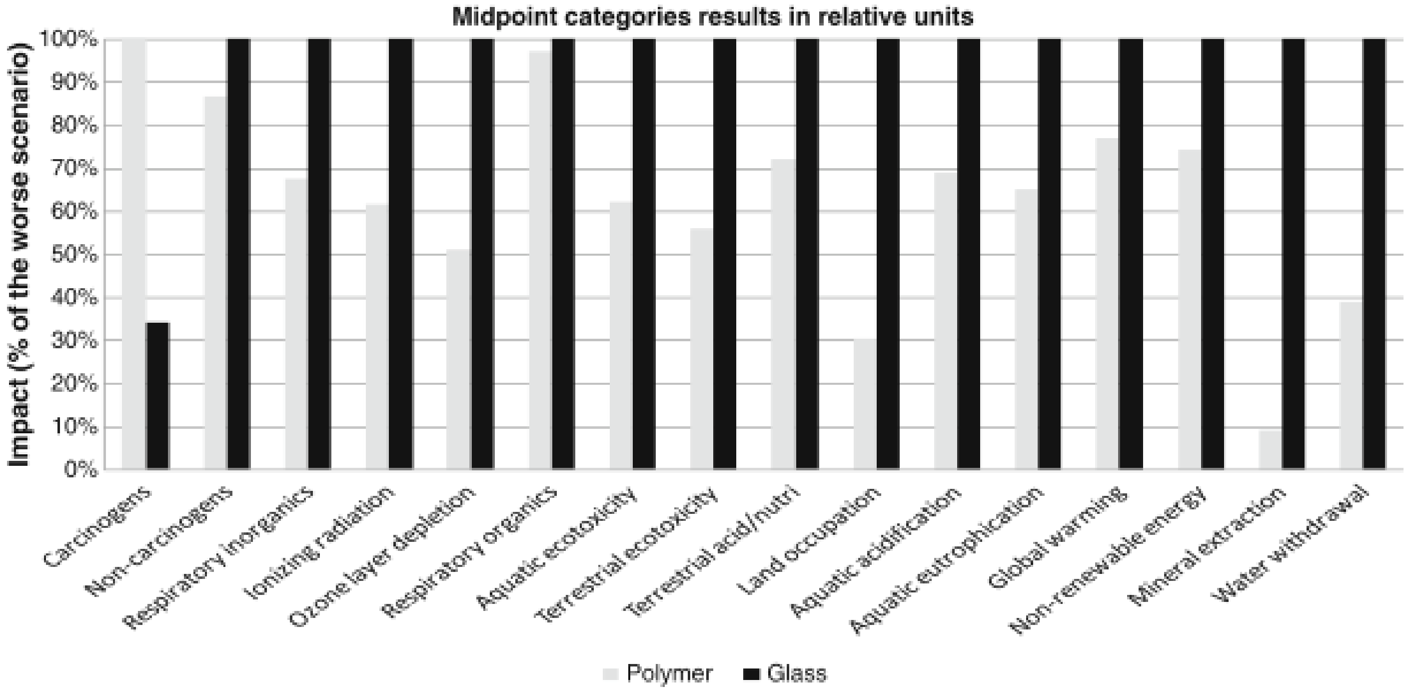
kg CO_2/FU
kg CH_4/FU
kg N_2O/FU

$\Rightarrow$ **eq-kg CO_2/FU**

Global warming:	eq-kg CO_2/FU
Acidification:	eq-kg SO_2/FU
Ozone depletion:	eq-kg CFC-11/FU
Fossil fuels:	MJ/FU
…	

LCA: impact assessment

- Characterization: example - Vials comparison



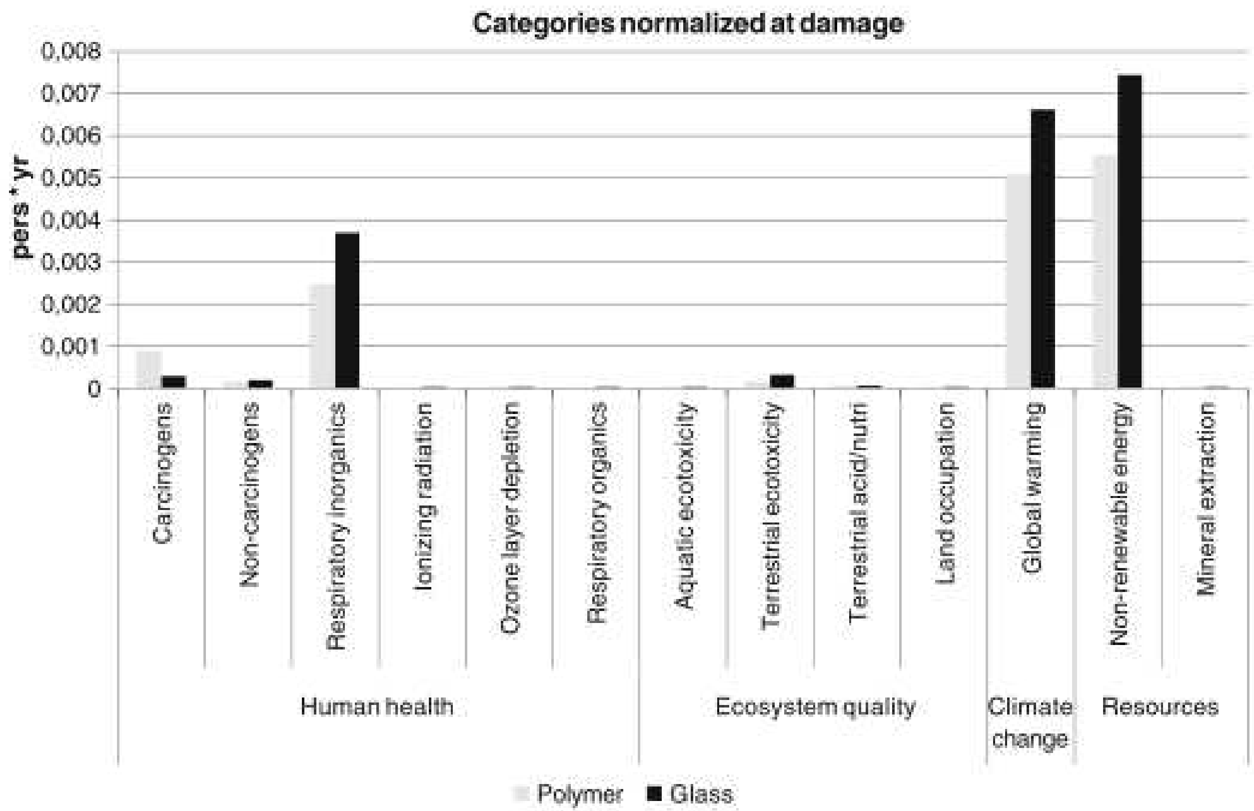
S. Belboom et al. Int J Life Cycle Assess (2011) 16:159-167

LCA: impact assessment

- Normalisation
  - Tool to express impact indicator data in a way allowing to compare among impact categories
  - Indicator normalisation by dividing results by a selected reference value such as global or regional averages
- Grouping
  - Impact categories are sorted and grouped, depending on the chosen impact assessment method

LCA: impact assessment

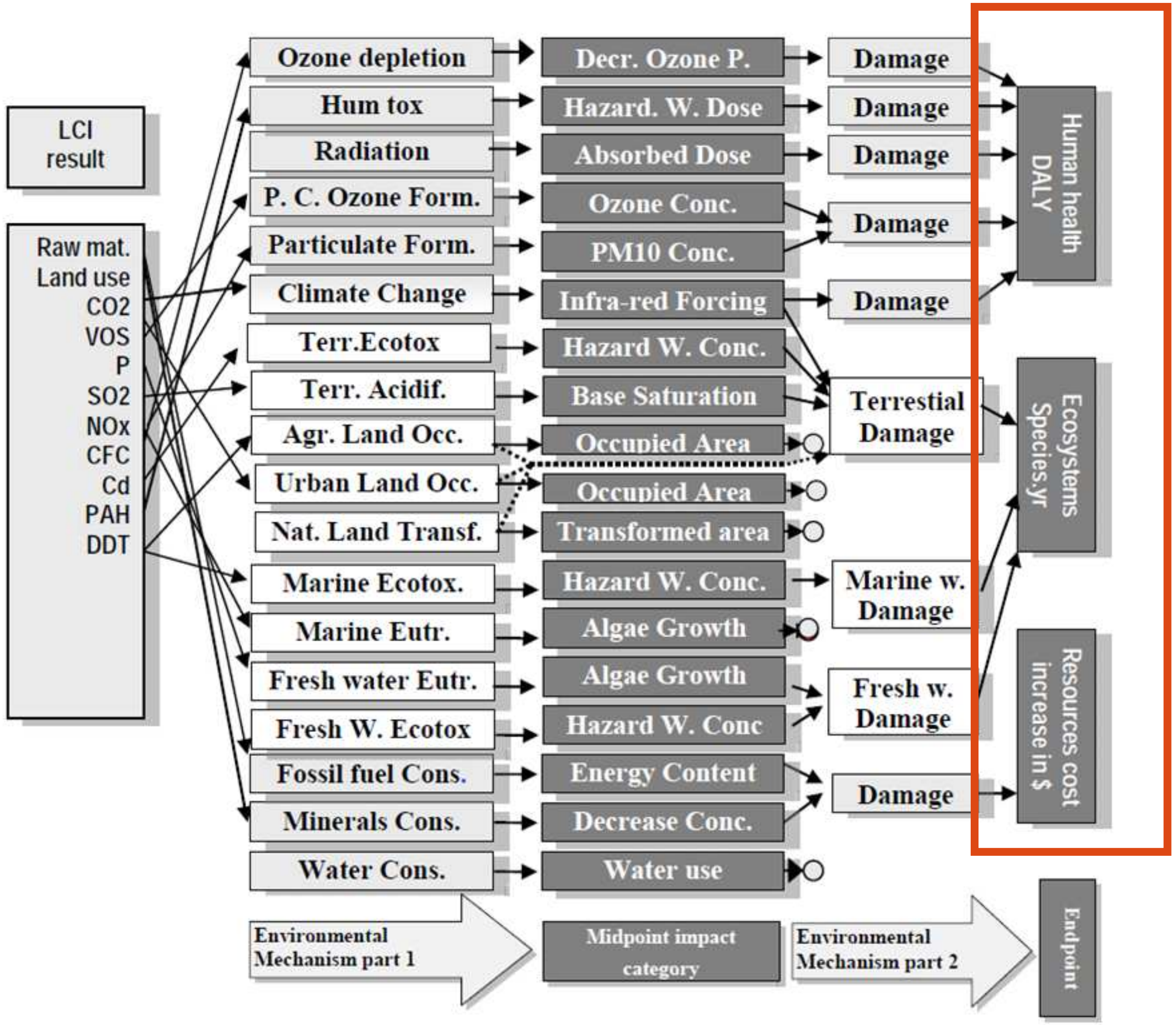
- Normalization/Grouping: vials comparison



S. Belboom et al. Int J Life Cycle Assess (2011) 16:159-167

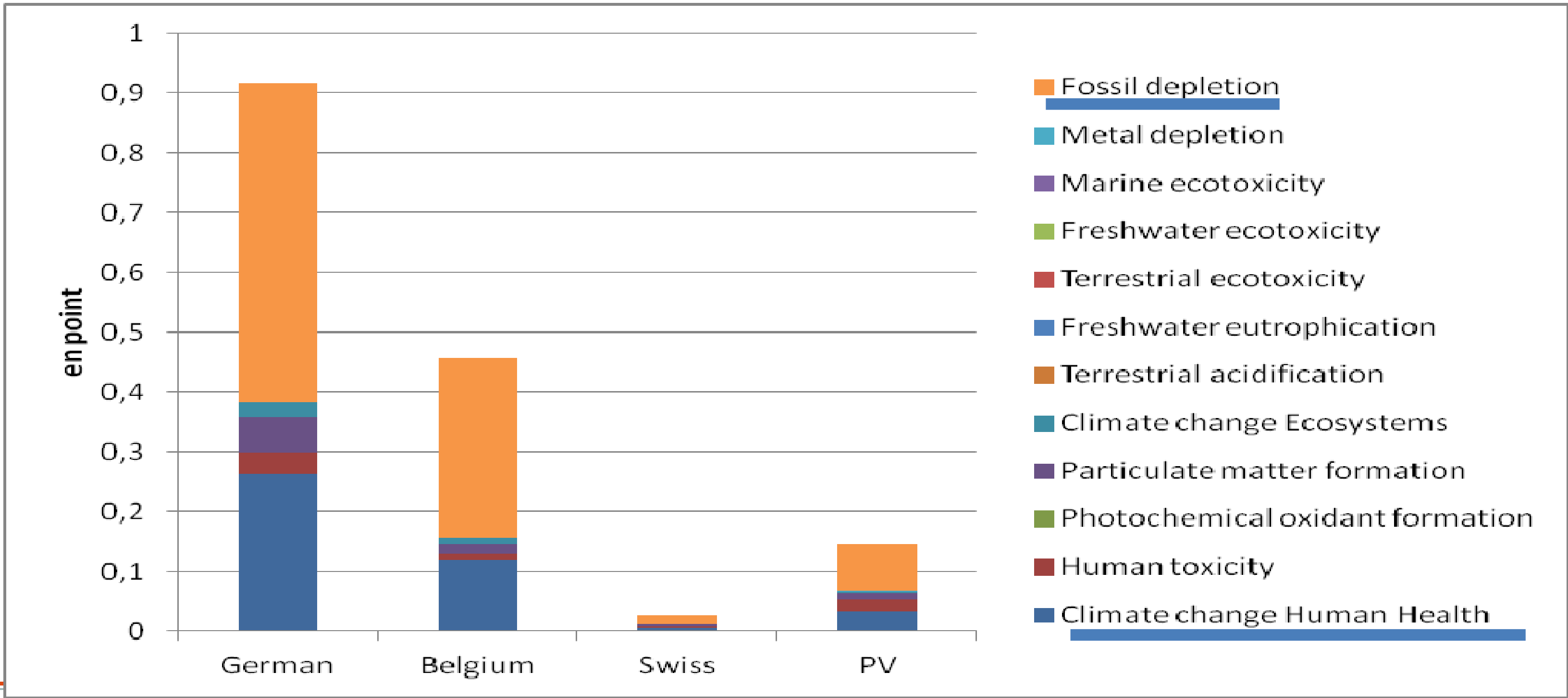
LCA: impact assessment

- Grouping



LCA: impact assessment

- Weighting
  - Indicator results for different impact categories are converted to a common unit by using factors based on value-choices → “Single score” result



Environmental impact of photovoltaic power by LCA, S. Gerbinet et al.
Congrès ACV, Lilles, 3-4 novembre 2011

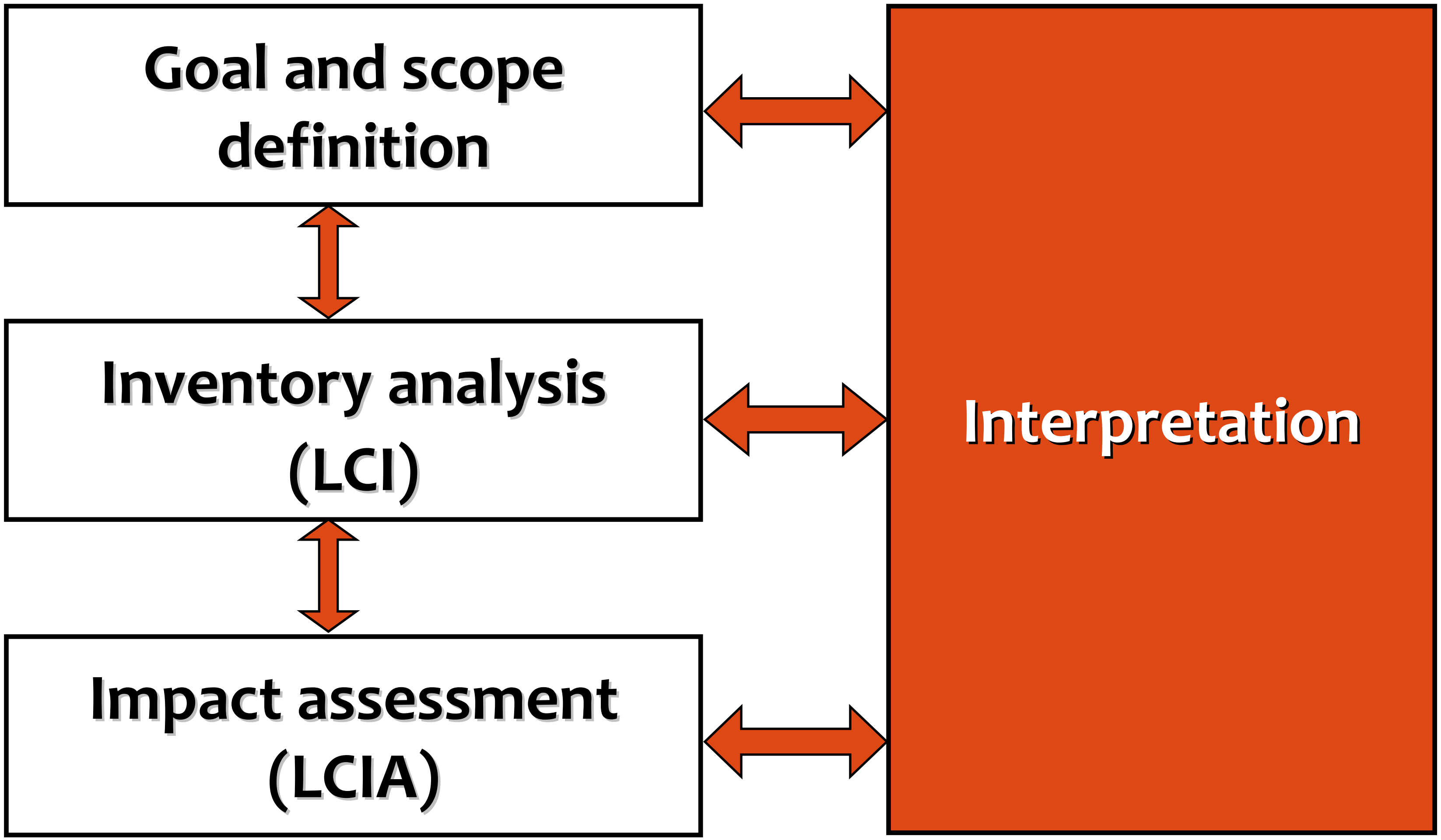
Important role during impact assessment

- Determination of characterization factors !
  - Land use, water use, still in development

Land Use	Global Regional Local	Quantity disposed of in a landfill or other land modifications	Land Availability	Converts mass of solid waste into volume using an estimated density.
Water Use	Regional Local	Water used or consumed	Water Shortage Potential	Converts LCI data to a ratio of quantity of water used versus quantity of resource left in reserve.

LCA associated steps

- Four steps defined by ISO 14040 – 14044



Links between LCA and bio(chemical) engineering

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Important role during LCA inventory

Inputs

- Raw materials
- Energy
- Water, etc.

Raw materials

Processing

Assembly

Transport & distribution

Use

Final disposal

Outputs

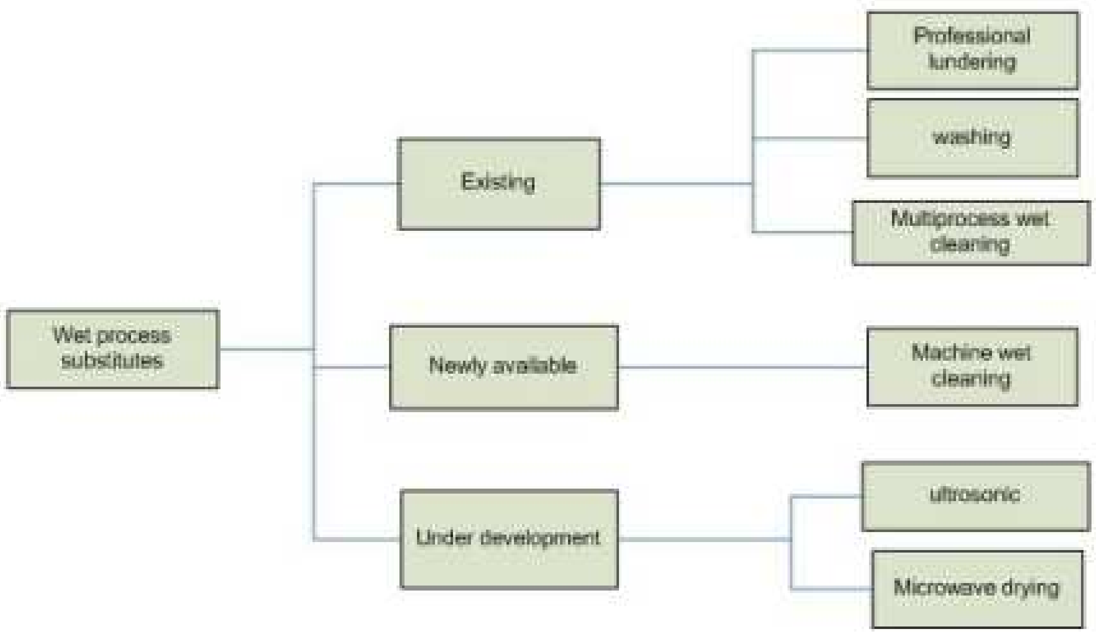
- Air emissions
- Water emissions
- Solid waste
- Products
- Others emissions

Important role during LCA inventory

- Practically …
  - Commercial databases
  - Data provided by industrials
  - (Inter)national databases
  - Scienfitic and technical literature
- But … data are ofter missing or quality is questioning
  - Process modeling
  - Data reconciliation
  - Knowledge of unit operations, …

LCA = tool to improve existing processes

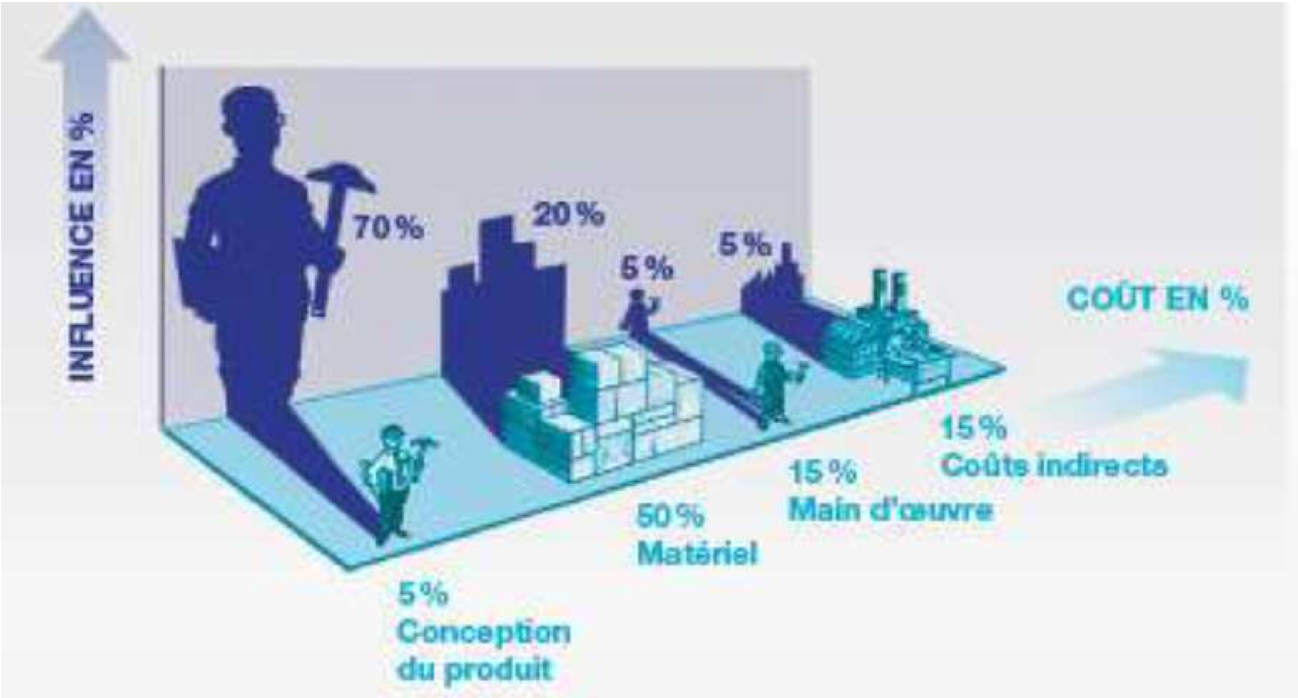
- Identification of more ‘penalizing’ steps
- Identification of harmful substances
  - → ways of improvement



LIFE CYCLE ASSESSMENT IN DESIGNING GREENER SEMICONDUCTOR, Tao Zhu, 2004, Ms Thesis in Chem. Eng., UNIVERSITY OF ARIZONA

LCA = way to « ecodesign » new processes

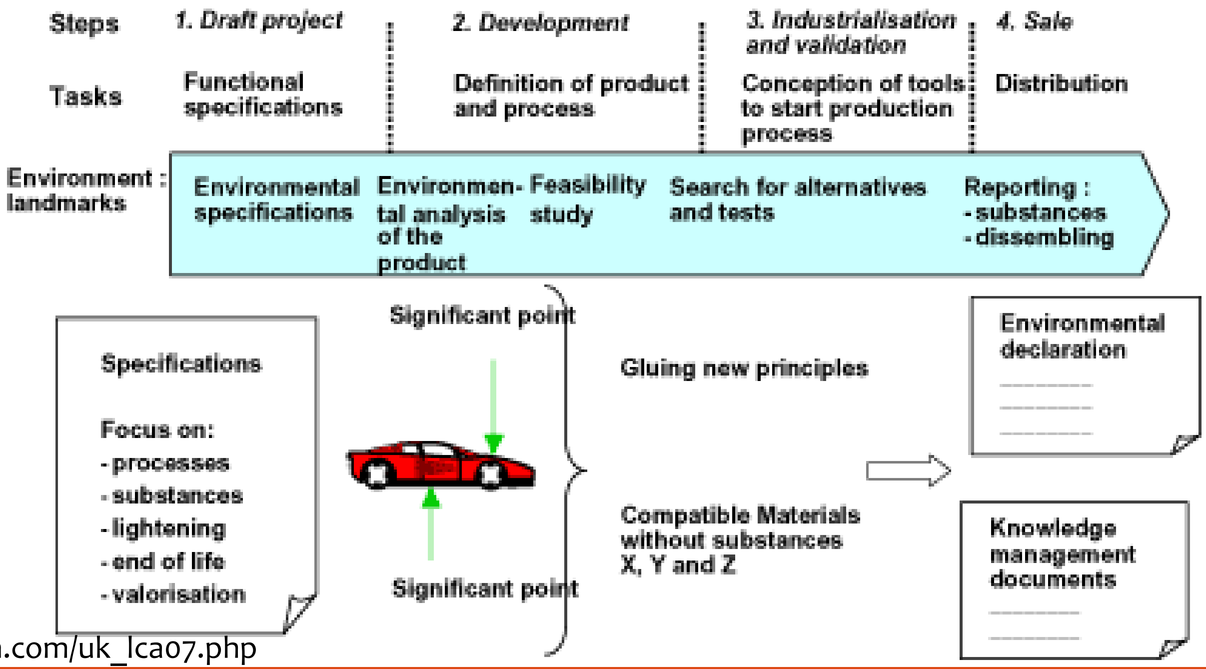
- 70% of « the environmental impact » already fixed during the design step



L'écoconception, source d'innovation dans l'approche cycle de vie;
l'expérience du Québec, Guy Belletête, Congrès ACV, Lilles, 4/11/2011

LCA = way to « ecodesign » new processes

- Ecodesign = integration of environmental aspects into product or process design with the aim of improving the environmental performance throughout the whole life-cycle



https://www.ecobilan.com/uk_lca07.php

Links between LCA and environmental sciences

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Important role during impact assessment

- Determination of characterization factors !
  - Consensus for some impact categories

Impact Category	Scale	Examples of LCI Data (i.e. classification)	Common Possible Characterization Factor	Description of Characterization Factor
Global Warming	Global	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Bromide (CH_3Br)	Global Warming Potential	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials can be 50, 100, or 500 year potentials.
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons Methyl Bromide (CH_3Br)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Acidification	Regional Local	Sulfur Oxides (SOx) Nitrogen Oxides (NOx) Hydrochloric Acid (HCL) Hydroflouric Acid (HF) Ammonia (NH_4)	Acidification Potential	Converts LCI data to hydrogen (H+) ion equivalents.

Important role during impact assessment

- Determination of characterization factors !
  - Toxicity: need for more data and modeling tools

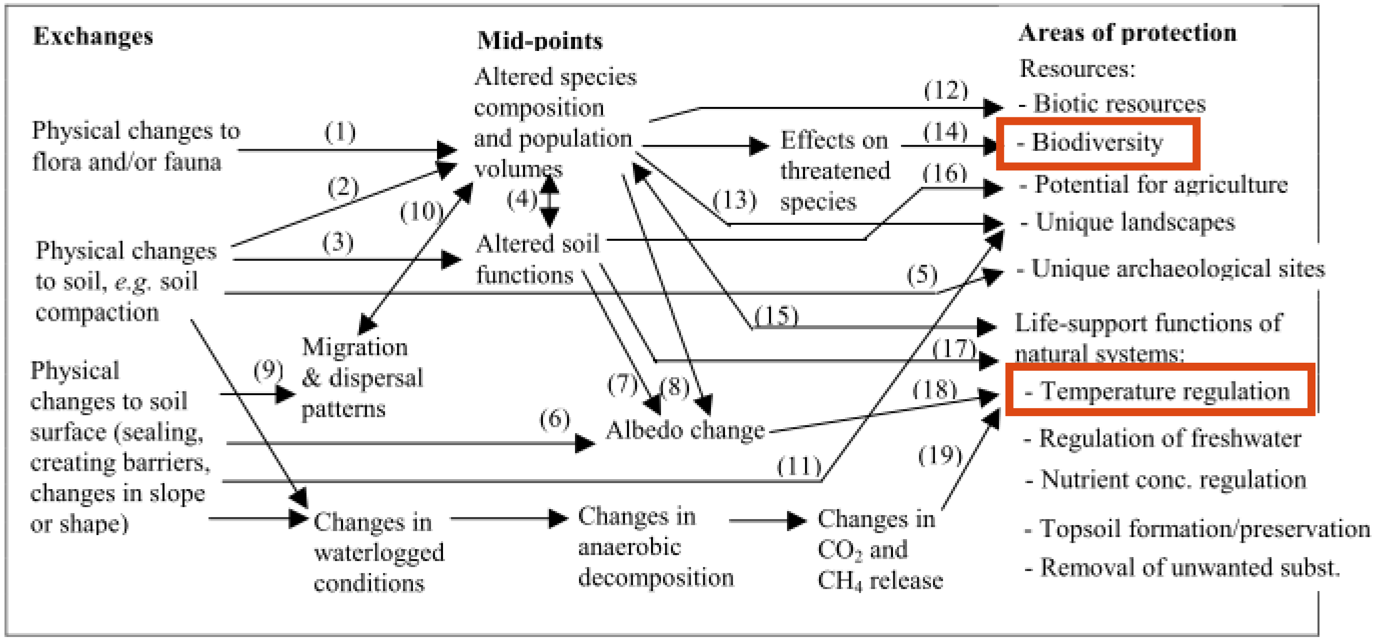
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.
Human Health	Global Regional Local	Total releases to air, water, and soil.	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.

  - Difficulty to get the same toxicity characterization score for a substance when using different methods

Important role during impact assessment

- About land use and land use change
  - No established and globally applicable practice on land use occupation and transformation available for use in LCA
  - A lot of associated impacts

Physical impacts of land use in product life cycle assessment. EURENVIRON-LCAGAPS sub-project on land use. Bo P. Weidema with contributions from Erwin Lindeijer 2001.12.31.



Important role during impact assessment

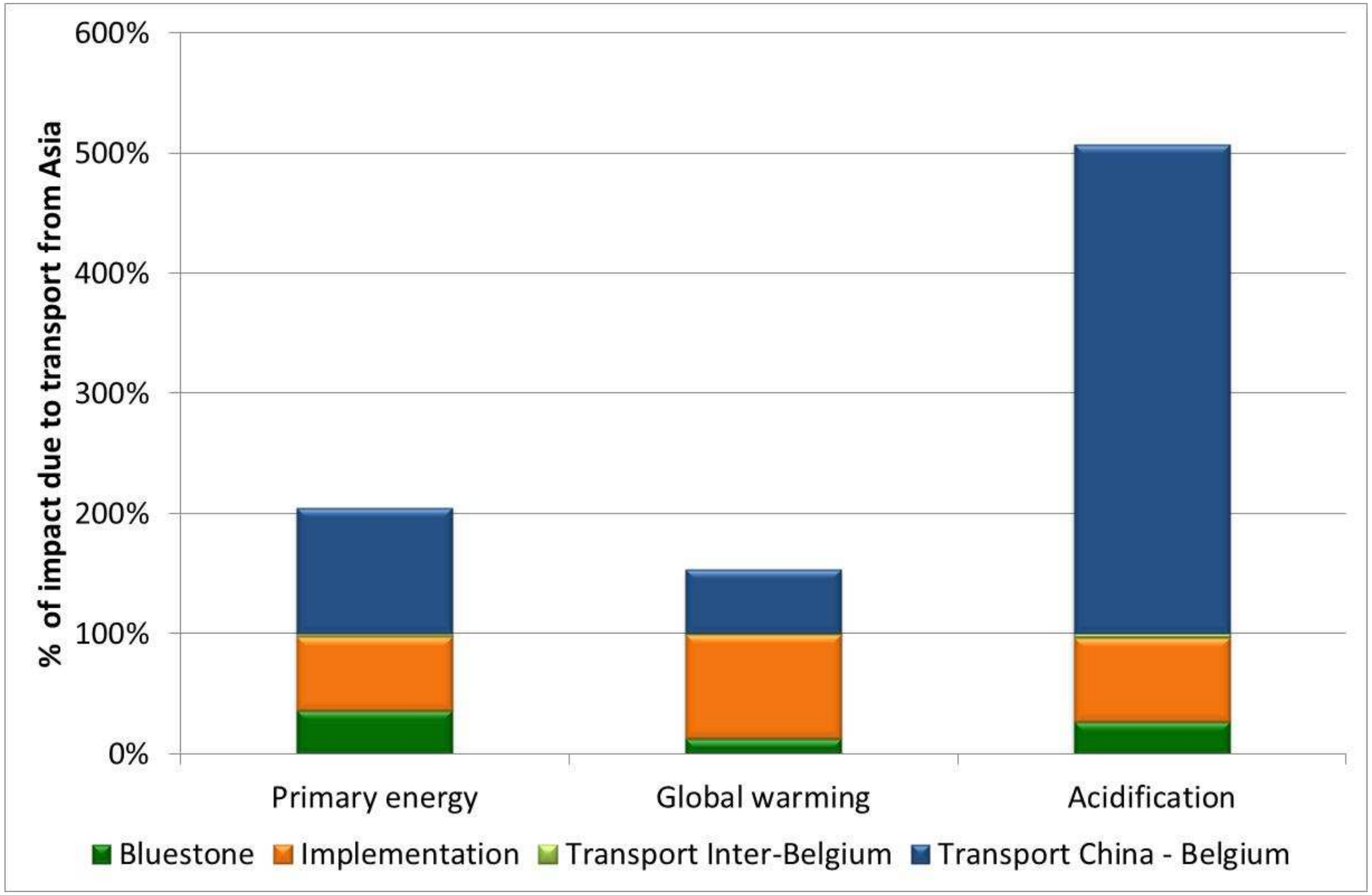
- About land use and land use change
  - A lot of different indicators
    - resource depletion
    - soil quality impacts
      - changes in soil organic carbon and soil organic matter
      - erosion resistance
      - filtration potential
      - …
    - biodiversity
    - …
  - A lot of research needs
    - regional data en soil quality
    - criteria to select effective ecological indicators, …

Int J Life Cycle Assess (2012) 17:277–286

Some examples …

Bluestone vs. Chinese stone

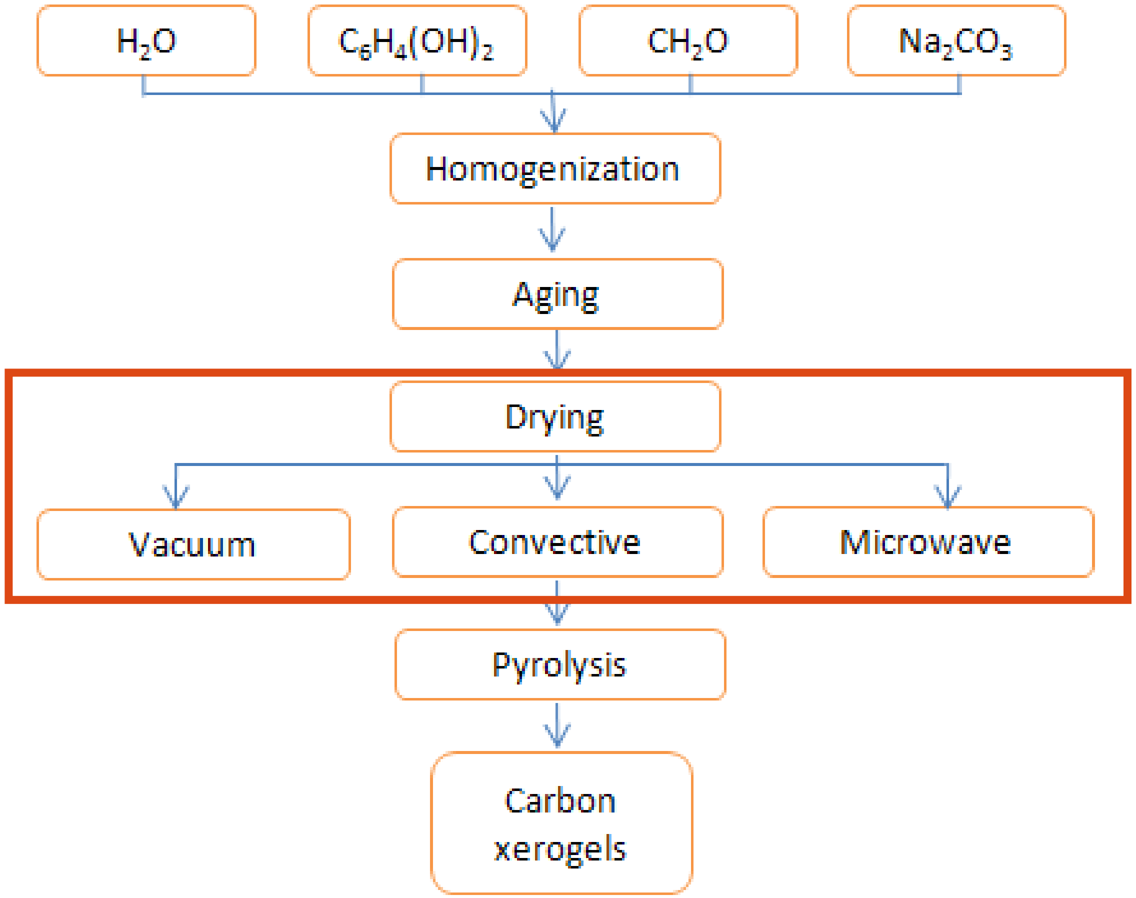
- Impact of transport on environmental impact



LCA as decision tool for sustainable choices in mineral materials field: environmental declarations of Belgian products and their foreign equivalents, S. Belboom et al. Congrès ACV, Lilles, 3-4 novembre 2011

Comparison of drying technologies

- Production of carbon xerogels: ecodesign approach



Analyse du cycle de vie de xérogels de carbone, R. Melon et al.
Congrès ACV, Lilles, 3-4 novembre 2011

SOMABAT

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Some examples

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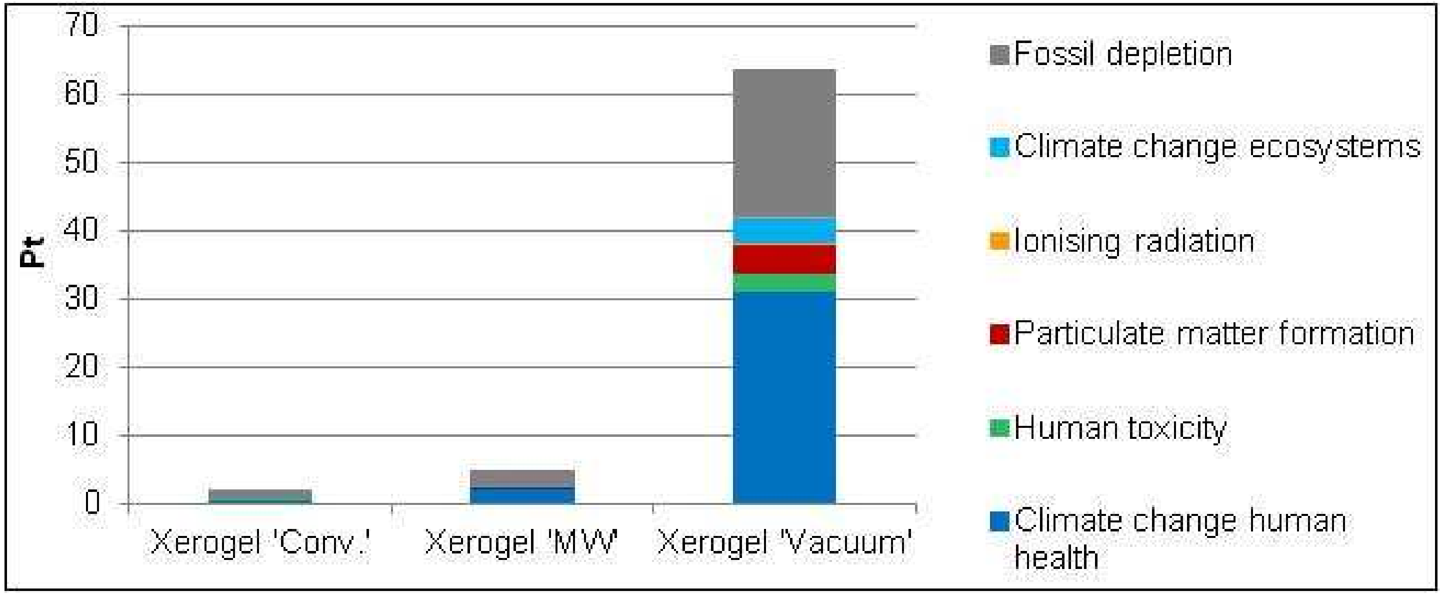
Comparison of drying technologies

- Weighted results



Best environmental choice = convective drying

Analyse du cycle de vie de xérogels de carbone, R. Melon et al.
Congrès ACV, Lilles, 3-4 novembre 2011

SOMABAT

Comparison of waste treatment technologies

- Before 1970: wild landfilling
- From 1990 until 2009: waste grinding and sorting
- From 2009 until now: incineration of the whole waste fraction
- Short term project: methanation of the biodegradable fraction after collect and sorting

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Some examples

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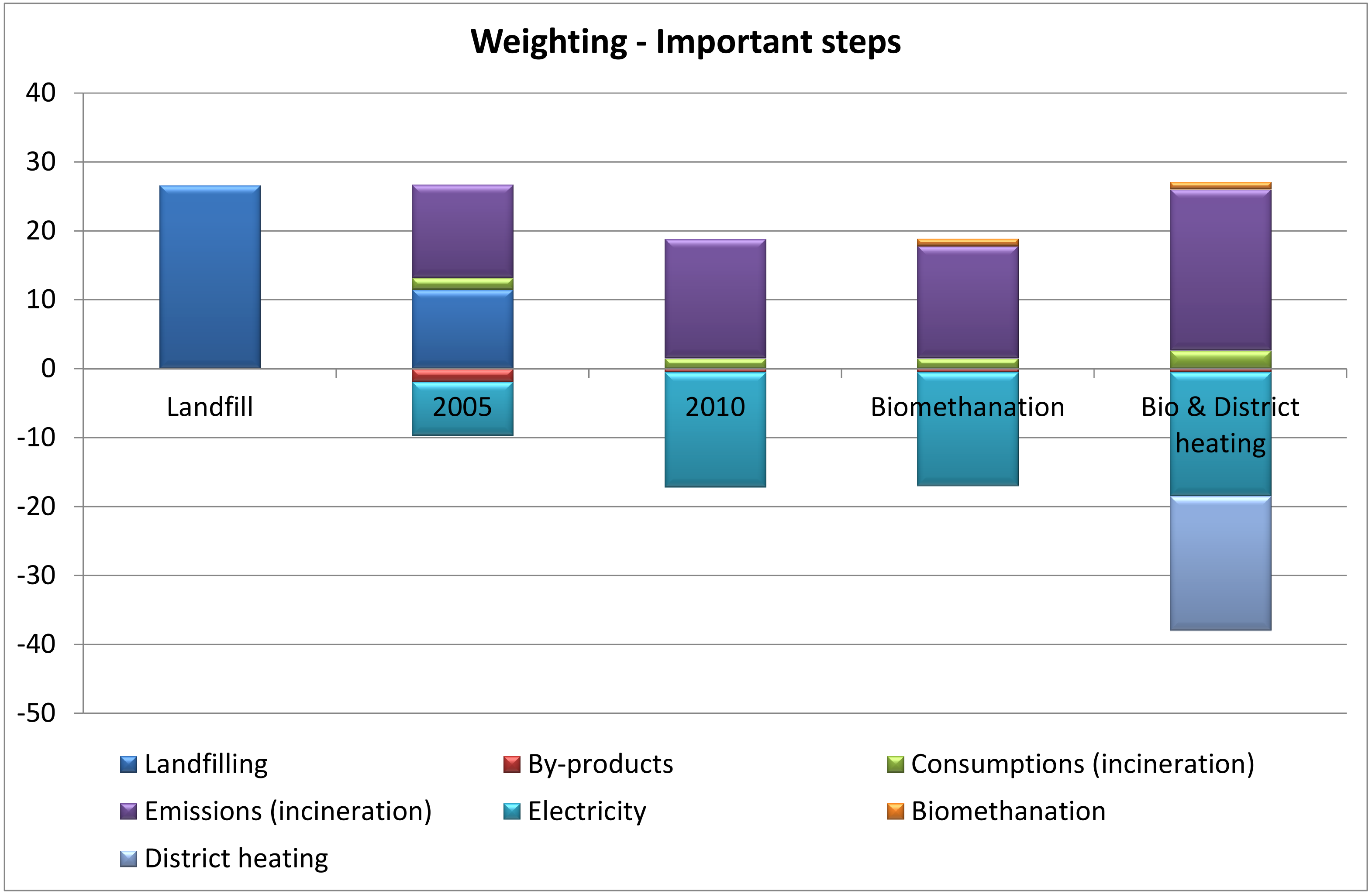
Comparison of waste treatment technologies



To conclude …

To conclude

(Bio)chemical engineering

Process modeling
Data reconciliation
...

Process improvement
Sustainable process design
...

LCA

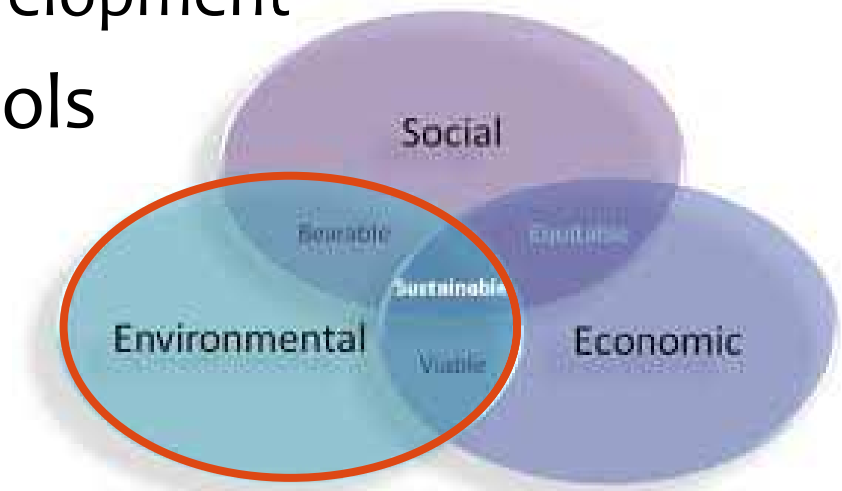
Focus on environmental concerns
Create needs for new data
...

Characterization factors
Assessment methods
...

Environmental sciences

To conclude

- LCA → environmental impact evaluation
  - 1 aspect of sustainable development
- Development of other tools
  - LCC = Life cycle cost
  - SLCA = Social LCA



LCSA = Life Cycle Sustainability Assessment

Thanks for your kind attention !

Thanks to the LCA team!

Some questions ?

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