Introduction to Sustainability evaluations

Toolbox

Prof. J. Dewulf
Ghent University
Belgium

1. Introduction

Where do we come from?

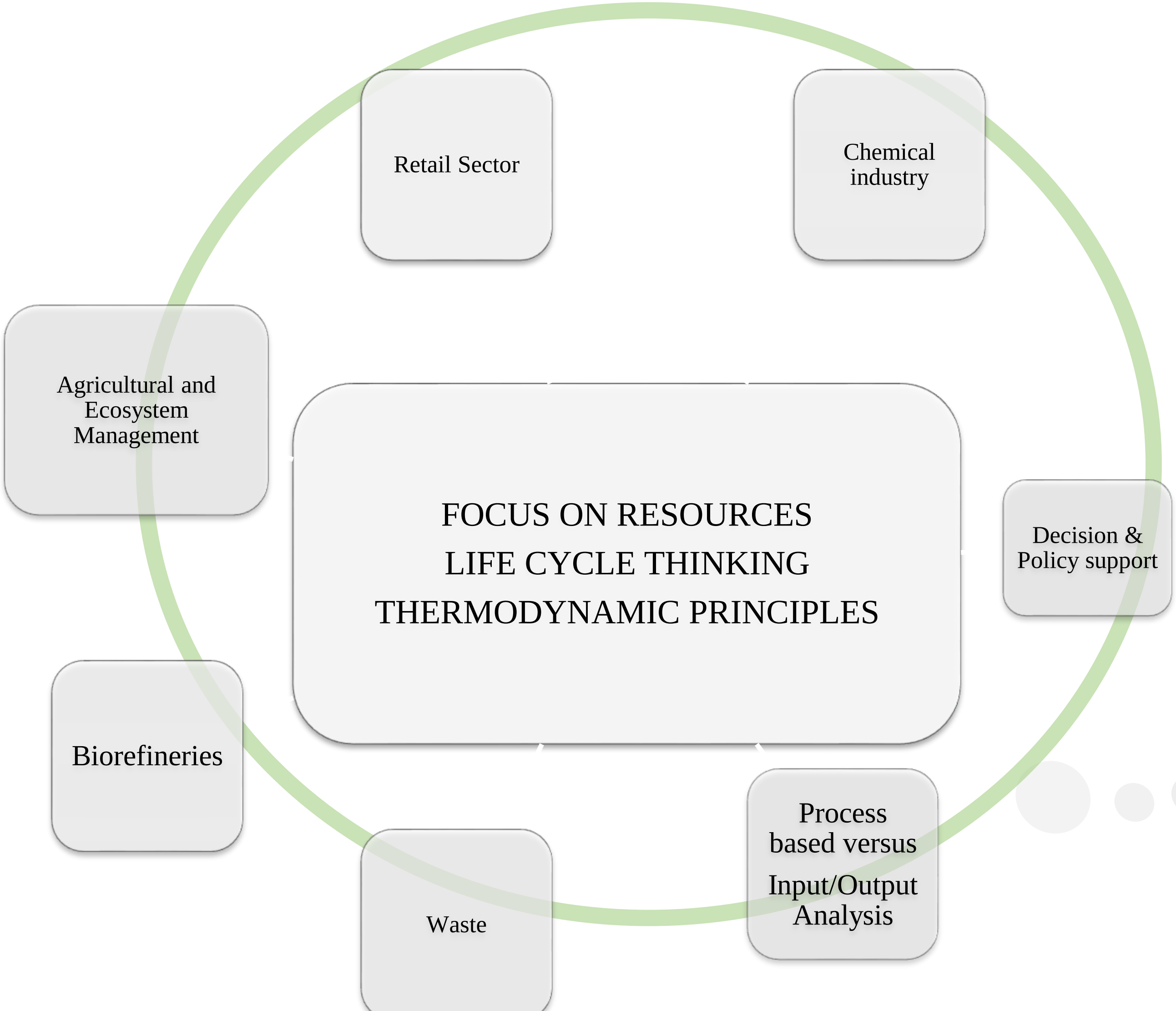
Ghent University

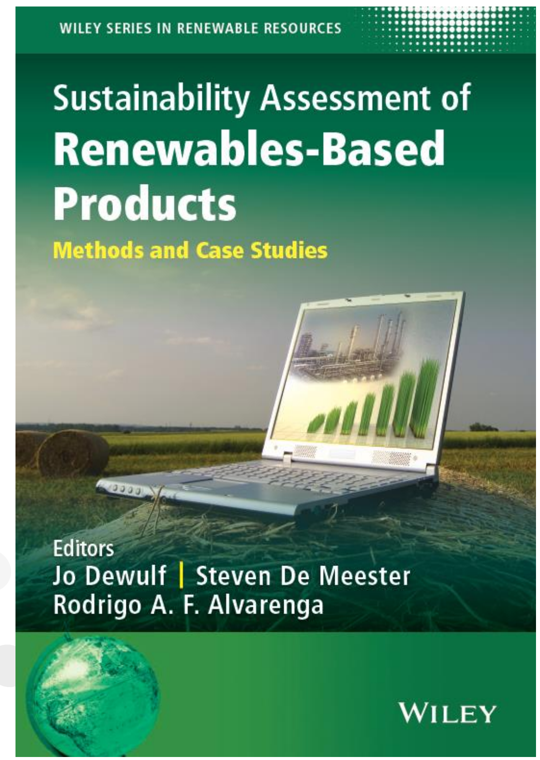
Faculty of Bioscience Engineering

Department of Green Chemistry and Technology

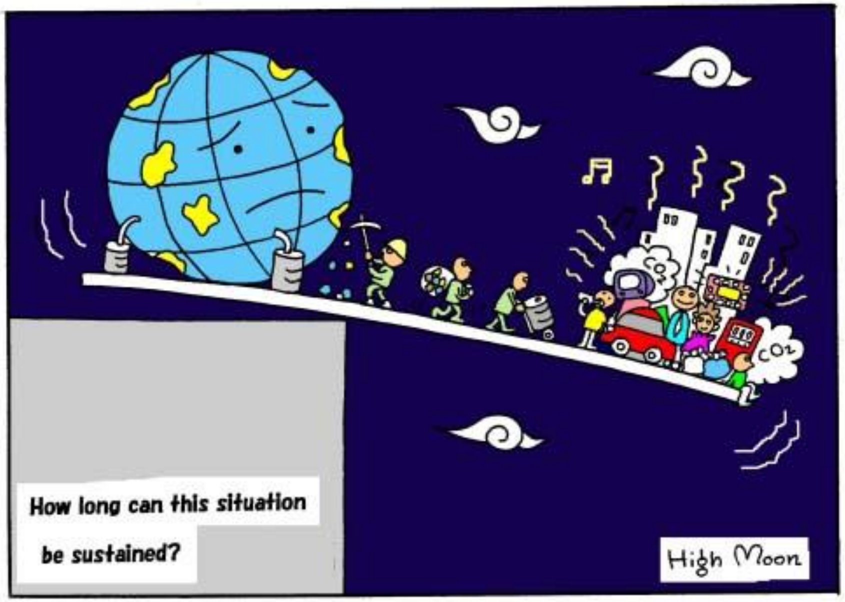
Sustainable Systems Engineering Group

Sustainability Systems Engineering group:





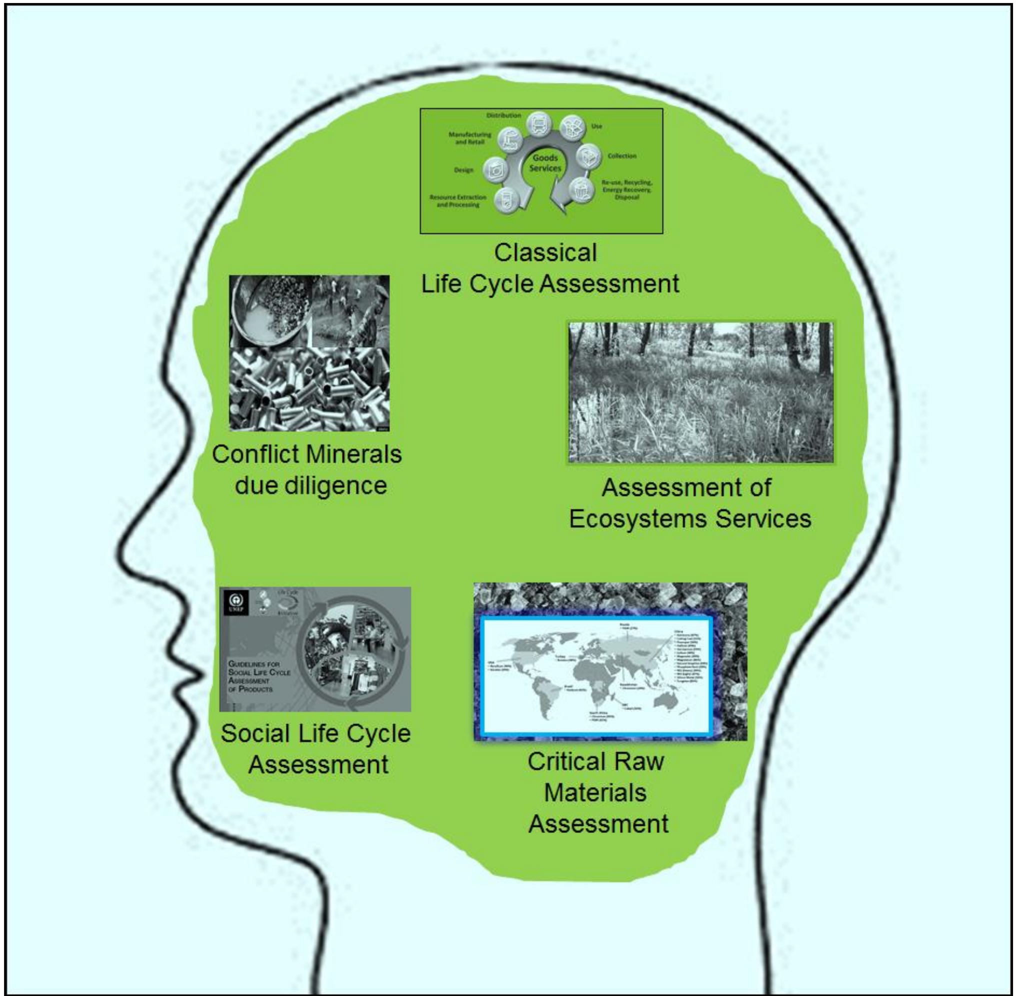
2. Sustainability Assessment toolbox



(Environmental) sustainability: increasingly a hot topic

The Sustainability Assessment Toolbox today:

Different concepts as a base for sustainable management:



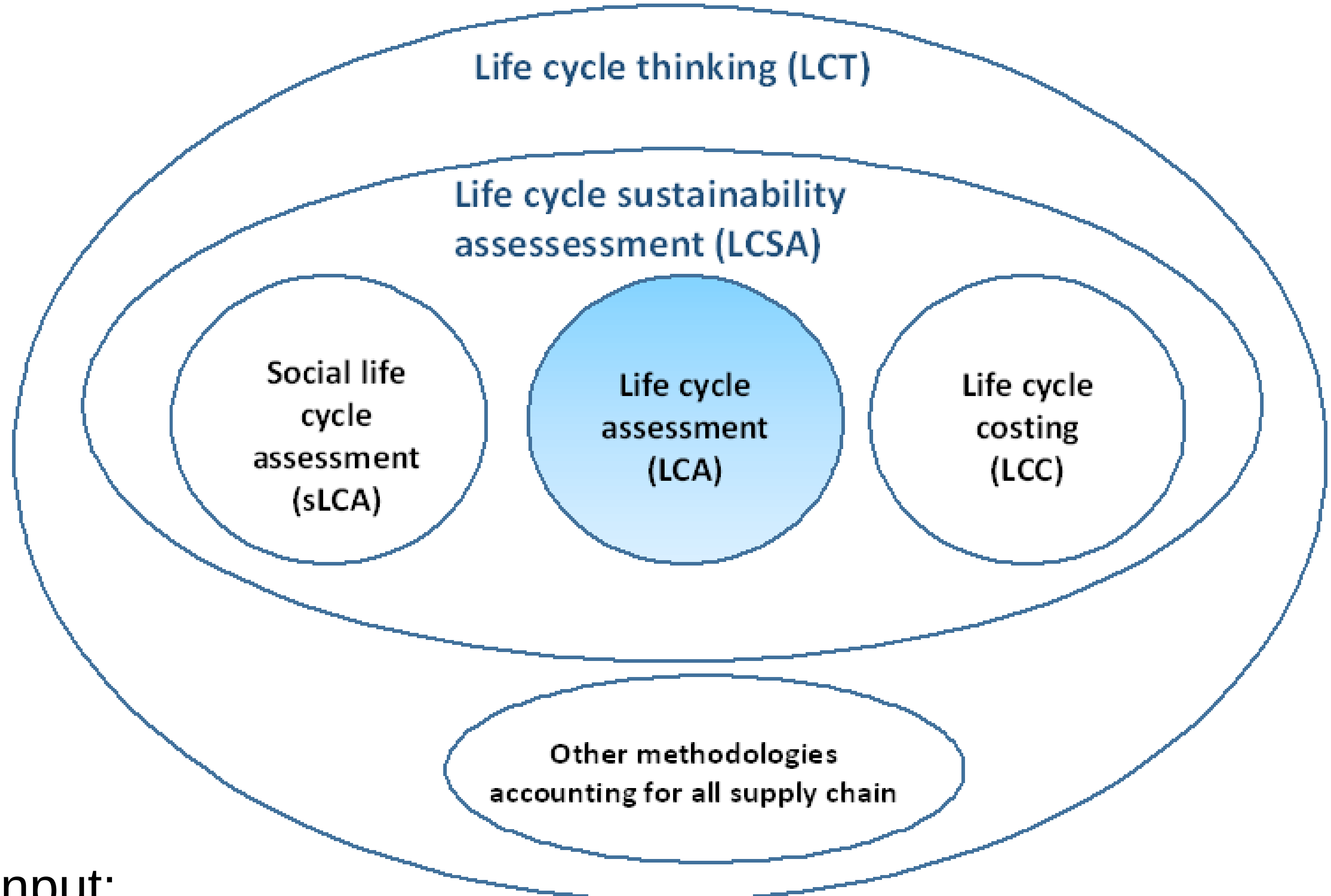
Different concepts/frameworks:

-They cover different aspects

-They partially overlap

-Need for a consistent base

-Anthropogenic focus



- Key input:
    data
- Key advantage:
    avoiding burden shifting (type of impact, place, time …)

Source: Dewulf et al., 2016

Life cycle thinking:

Life cycle assessment (LCA):

EC Communication on Integrated Product Policy (COM (2003) 302):

"*Life Cycle Assessments provide the best framework for assessing the potential environmental impacts of products currently available*"

Policy level:

European Platform for LCA (EPLCA)

JRC

EUROPEAN COMMISSION

What are Critical Raw Materials?

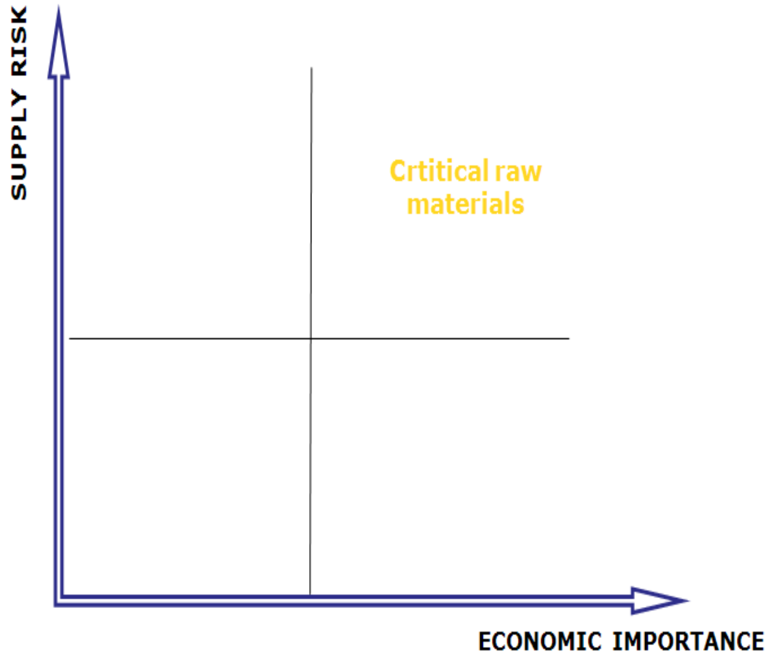
Economic importance

- Importance of a raw material per economic sector & importance of the sector in the EU economy

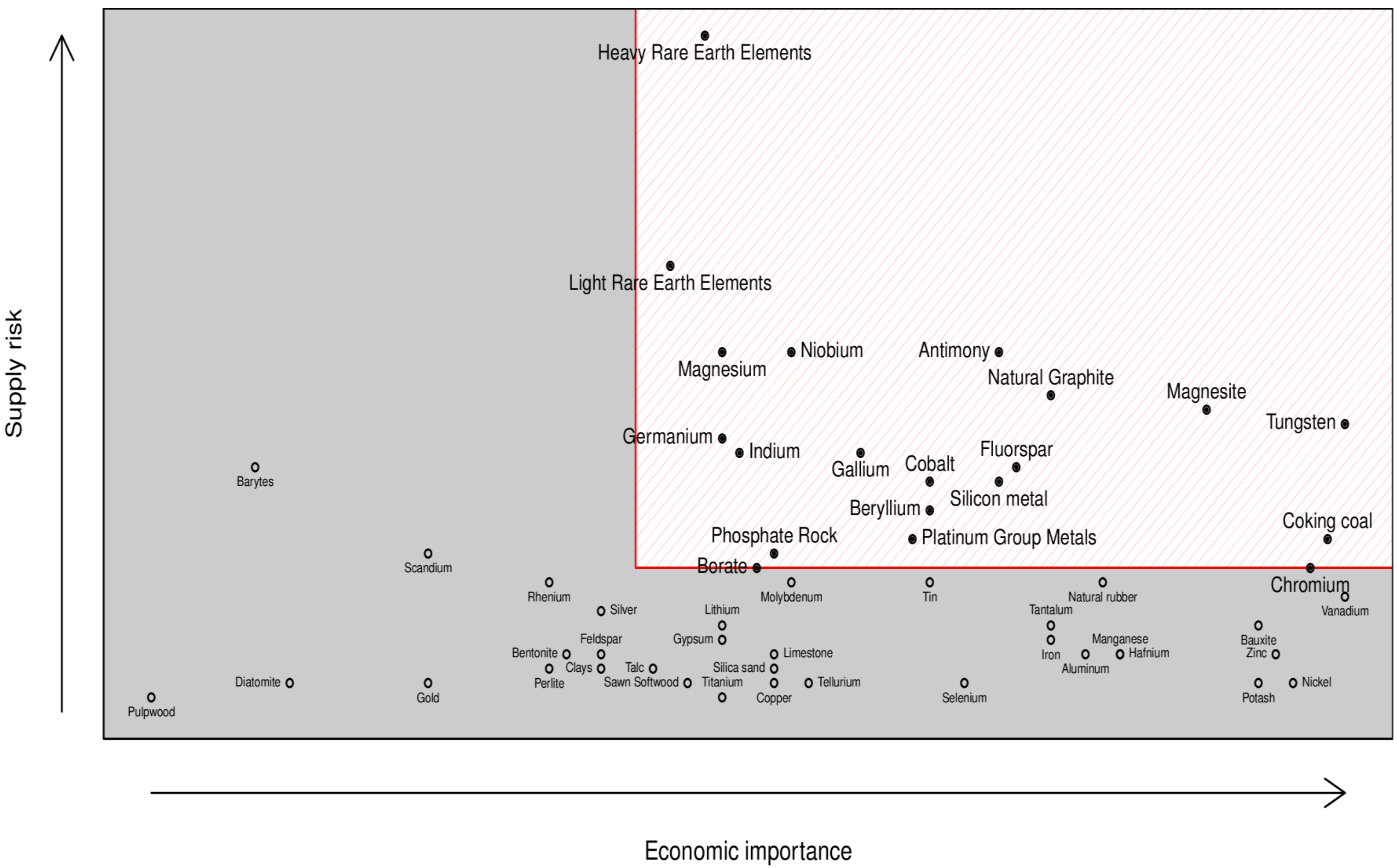
Supply risk

- Political and economic stability
- Level of production concentration
- Potential for substitution
- Recycling rate

EU 2014



EU 2014 :



Supply risk
Heavy Rare Earth Elements
Light Rare Earth Elements
Magnesium
Niobium
Antimony
Natural Graphite
Magnesite
Tungsten
Germanium
Indium
Gallium
Cobalt
Fluorspar
Silicon metal
Beryllium
Coking coal
Phosphate Rock
Platinum Group Metals
Borate
Chromium
Barytes
Scandium
Rhenium
Molybdenum
Tin
Natural rubber
Vanadium
Silver
Lithium
Tantalum
Feldspar
Gypsum
Manganese
Bauxite
Bentonite
Limestone
Iron
Hafnium
Zinc
Clays
Talc
Silica sand
Aluminum
Perlite
Diatomite
Gold
Sawn Softwood
Titanium
Tellurium
Selenium
Nickel
Pulpwood
Copper
Potash
Economic importance

Social Life Cycle Analysis

Social Impact: Quantifiable?

Social Assessment: UNEP SETAC framework based on 'who affected':

Stakeholder categories	Impact categories	
	midpoint	endpoint
Workers/employees	Freedom of association and collective bargaining, child labour, fair salary, working hours, forced labour, equal opportunities/discrimination, health and safety, social benefits/social security	Human rights Working conditions Health and safety Cultural heritage Governance Socio-economic repercussions
Consumer	Health and safety, feedback mechanism, consumer privacy, transparency, end of life responsibility	
Society (national and global)	Public commitments to sustainability issues, contribution to economic development, prevention and mitigation of armed conflicts, technology development, corruption	
Local Community	Access to material and immaterial resources, delocalization and migration, cultural heritage, safe & healthy living conditions, respect of indigenous rights, community engagement, local employment, secure living conditions	
Value chain actors	Fair competition, promoting social responsibility, supplier relationships, respects of IP rights	

Social Assessment: How to quantify impacts?

Two possibilities:

- How many children are working in the production chain?

  Difficulties:

  - How to get the data
  - How to compare with other indicators (e.g. risk)

- Semi-quantification:

  The Likert scale – on a scale from 1 to 5 how many children work in the production chain?

  Very few, few, average, rather many, a lot

Social Assessment: Alternative approach: flagging

A life cycle concerns a lot of processes:

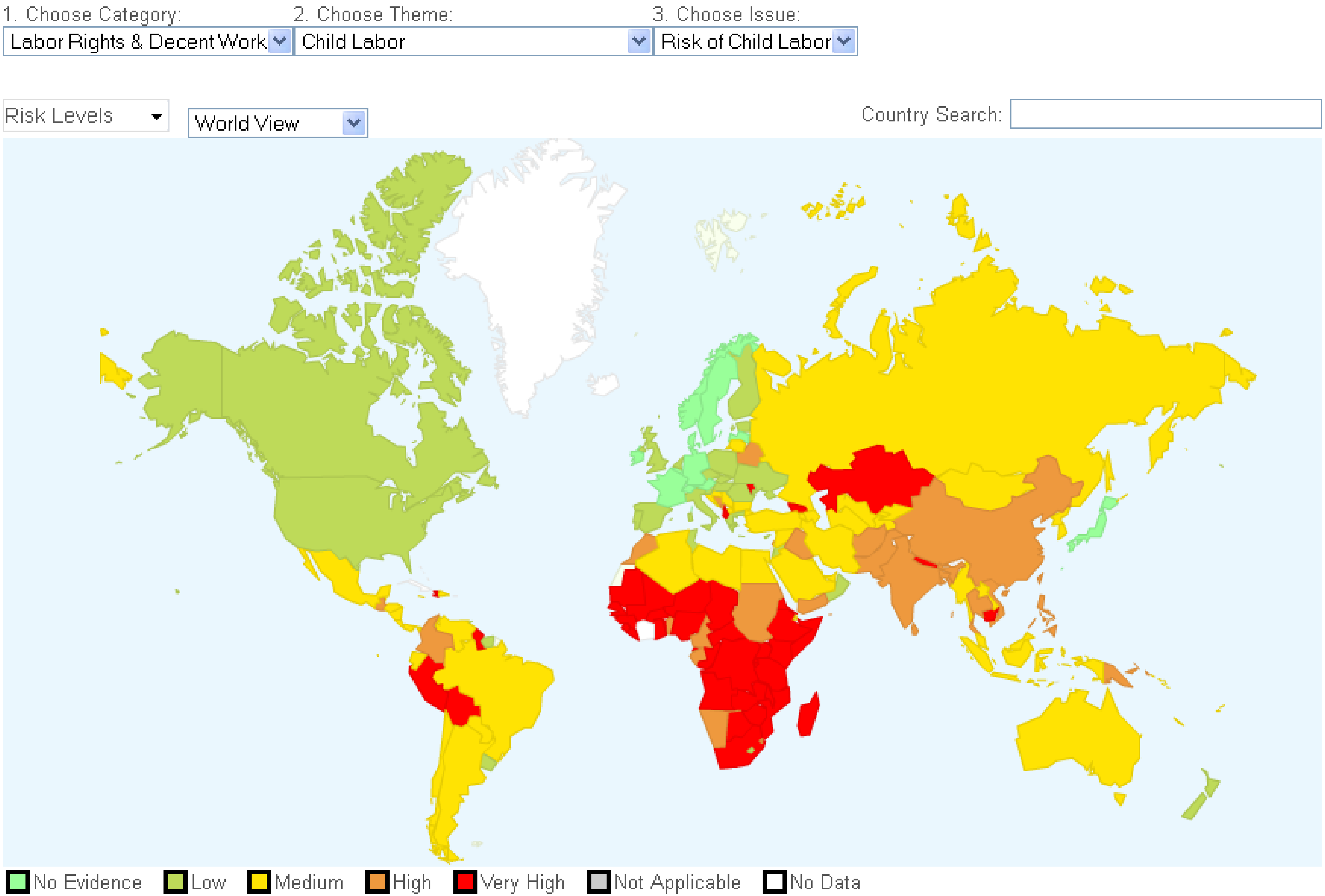
Solution = flagging

Per phase of the life cycle (resource extraction, production, use and end-of-life) identify 3 hotspots per indicator

Data from:

- Surveys
- Literature
- Databases: e.g. social hotspots database
- Expert judgement

First SLCA software: Social Hotspots DataBase (SHDB)



Second SLCA software: PSILCA (Open LCA)

Social indicators

Stakeholder	Subcategory	Indicator
WORKERS	Child labour	Children in employment, male
		Children in employm
		Children in employm
	Forced Labour	Goods produced by
		Frequency of forced
		Trafficking in persor
	Fair Salary	Living wage, per mo
		Minimum wage, per
		Sector average wag
	Working time	Weekly hours of wo
	Discrimination	Gender wage gap
	Health and Safety	Rate of non-fatal ac
		Rate of fatal accider
		DALYs due to indoo
		Presence of sufficie
		Workers affected by
	Social benefits, legal issues	Social security expe
		Evidence of violatio
	Freedom of association and collective bargaining	Trade union density
		Right of Association
		Right of Collective b
		Right to Strike
VALUE CHAIN ACTORS	Fair competition	Presence of anti-co … legislation
	Corruption	Public sector corrup
		Active involvement
	Promoting social responsibilty	Membership in an initiative that promotes social responsibility along the supply chain

Social LCA development

- Far less mature than environmental LCA
- First databases available
- Constructed:
  - Sector specific
  - Country specific
- Based on semi-quantitative indicators

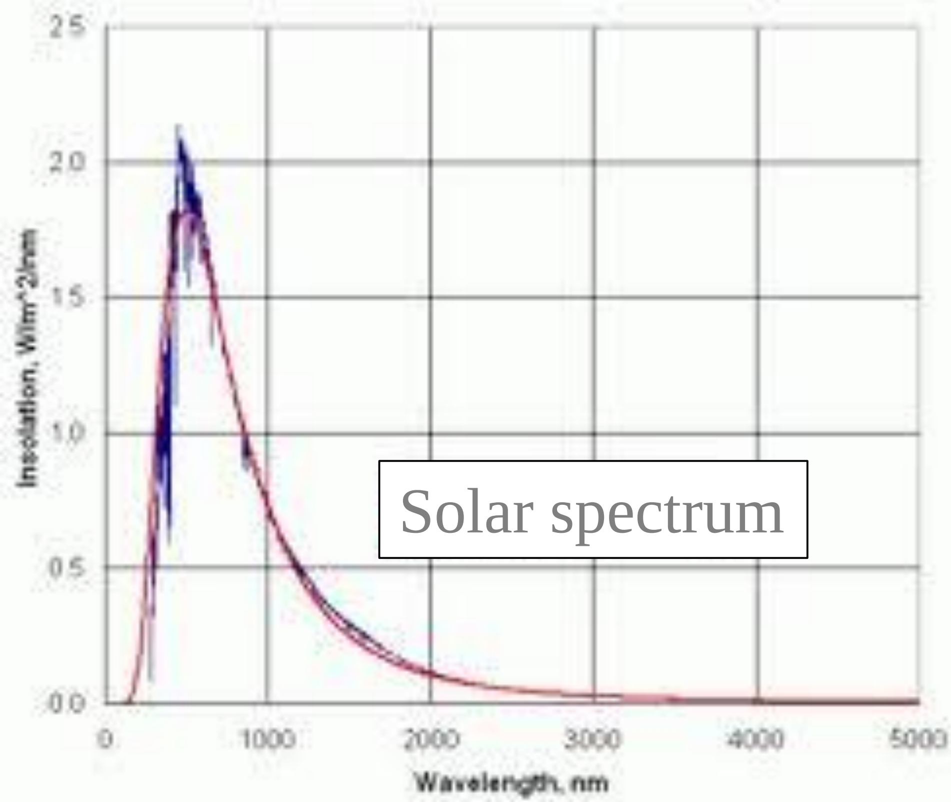
Basis: World Economic Input/Output models:

	PSILCA	SHDB
Input/output model	Eora Multi-regional input/output database (2012)	Model of the Global trade analysis project (GTAP)
Number of countries covered	189	113
Number of industry sectors	14,838 (commodities + sectors)	57

3. New challenges beyond Brundtland

Biomass

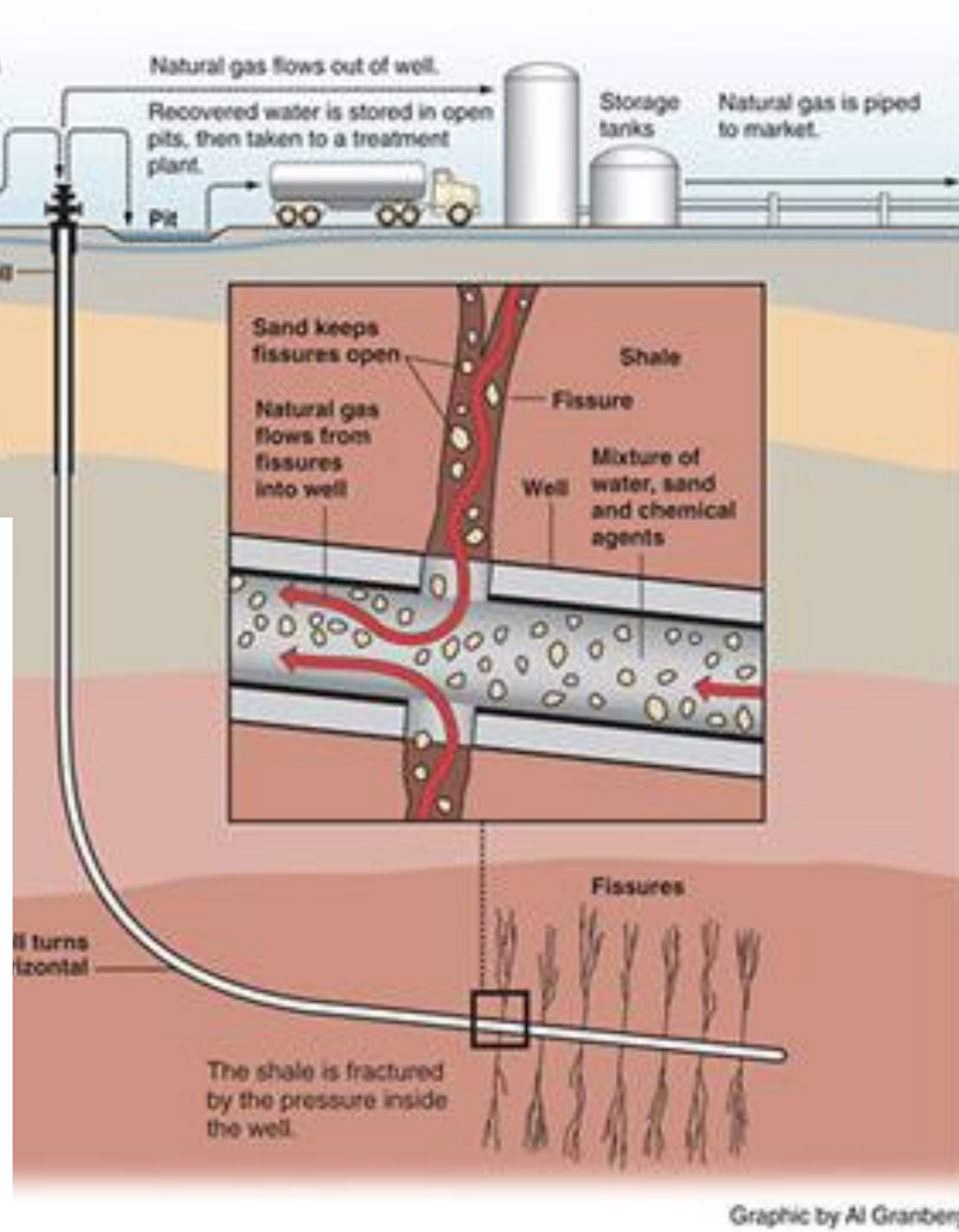
-Solar energy → photosynthesis → plants = biomass

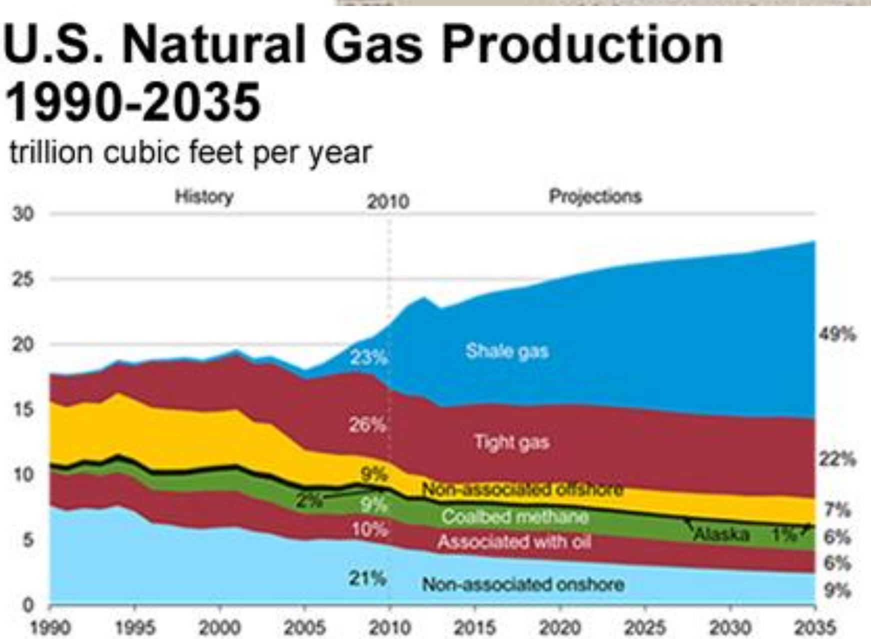


-Photosynthetically active radiation = PAR =

spectral range 400 to 700 nanometer that can be used by plants

Unconventional fossils: shale gas





Source: U.S. Energy Information Administration, *Annual Energy Outlook 2012* (June 2012).

(In)efficiencies

“Major opportunities to provide more services to the community with lower carbon footprint is not to be situated in alternative resources but rather in improved resource utilization efficiency”

Jos Delbeke, EU DG ENVIRONMENT
Keynote lecture at “Innovation for Sustainable Production”
Bruges 18–21 April (2010).

Mineral resources

Fight for natural resources:

Mobile phone

Laptop

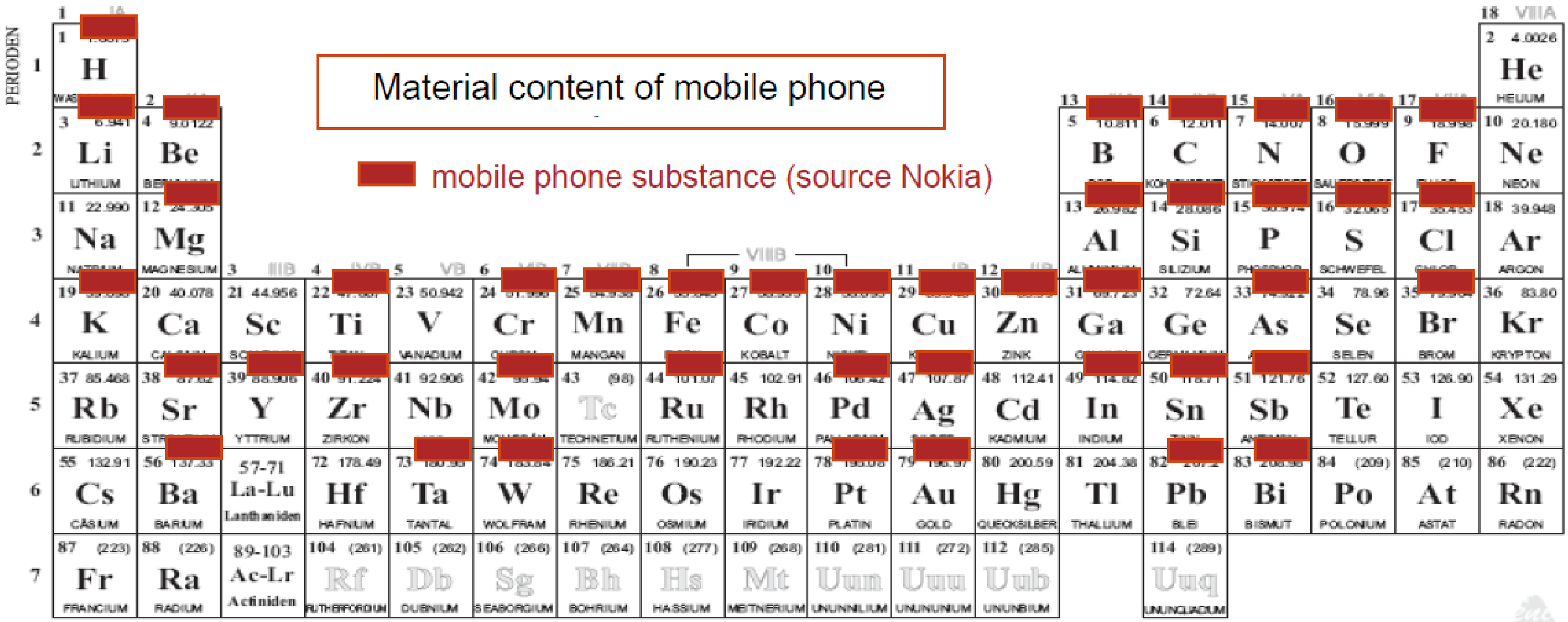
Electrical cars

Storage of (solar) energy/electricity

…

Cobalt example:

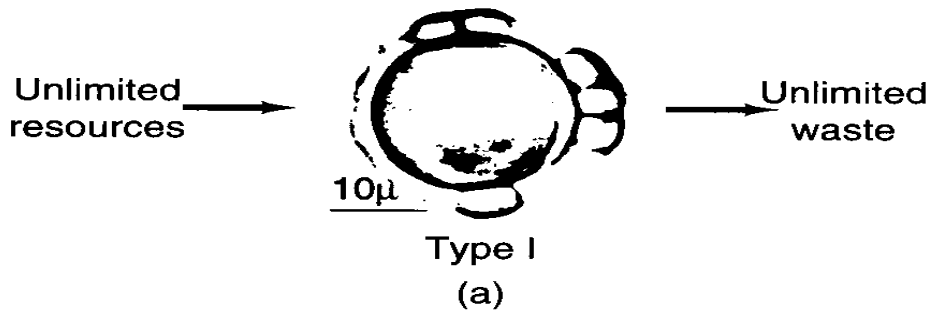
- Co for batteries: 700 t in 1995 to 12000 t in 2005
- 2007: 25% of global Cobalt market to batteries


Material content of mobile phone
mobile phone substance (source Nokia)

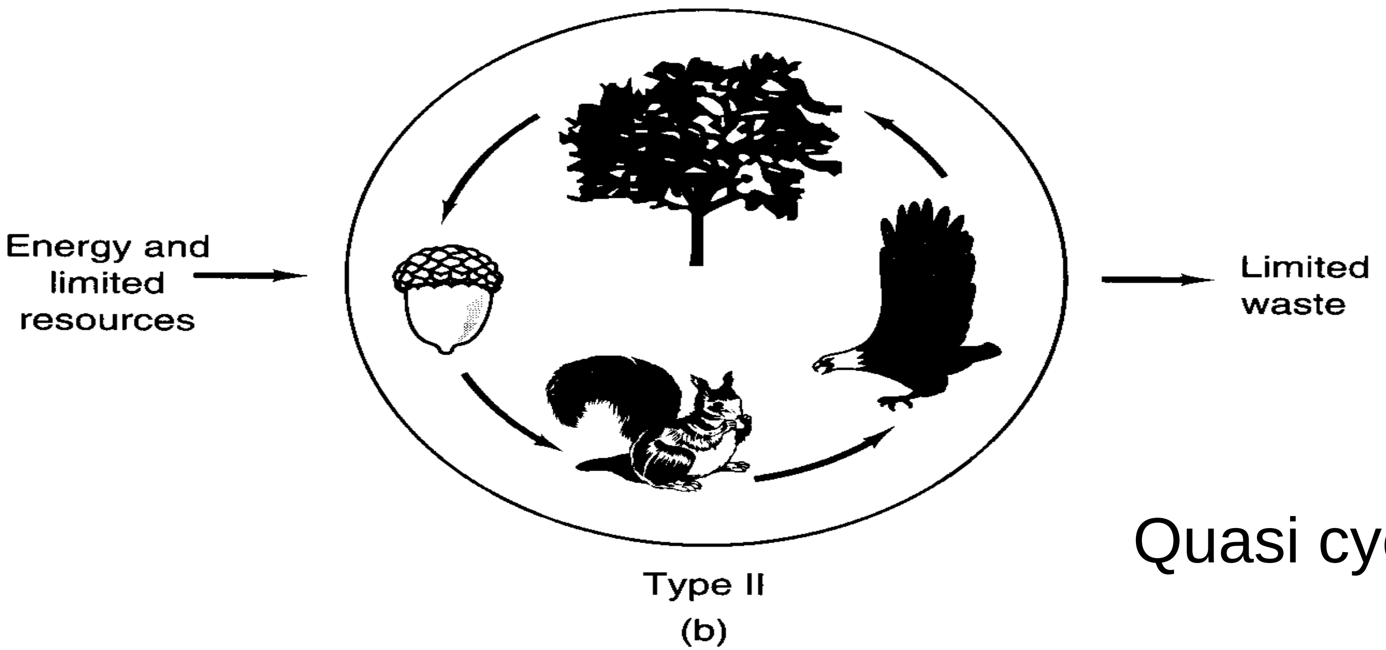
> 40 elements …

From waste to Circular Economy

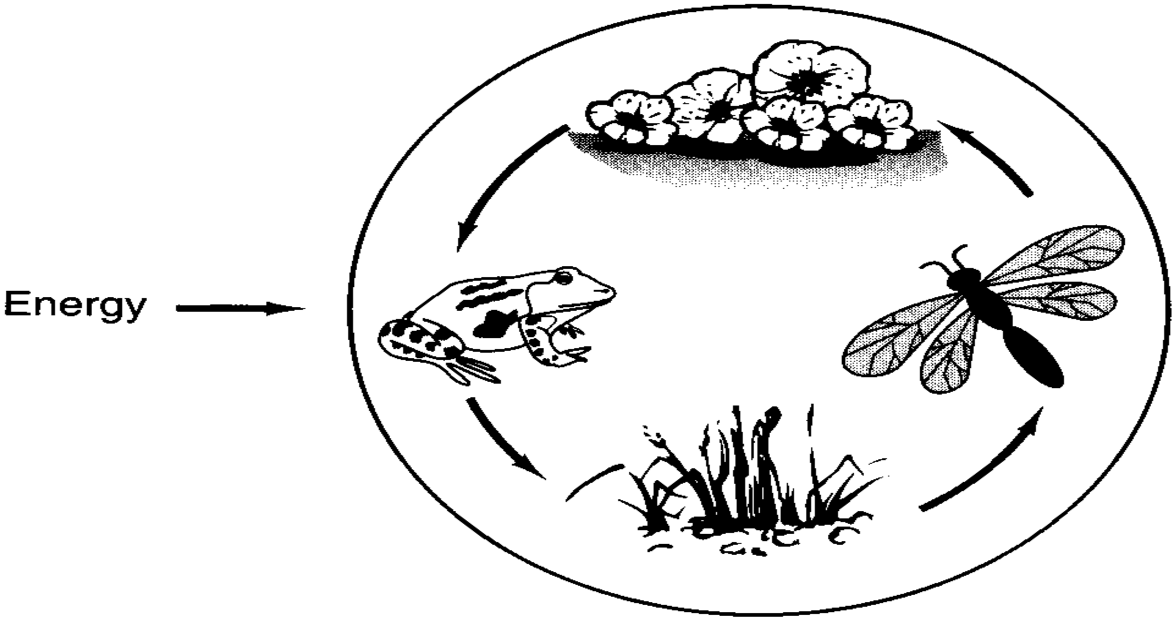
1990s: INDUSTRIAL ECOLOGY



Linear flow-through



Quasi cyclic



Type III

(c)

Cyclic

DS, 16/2/2005

2016-2020: EU project: RePair

Ivago maakt stoom van afval

Spectaculaire werkzaamheden gisterochtend bij de verbrandingsoven van de intercommunale Ivago in de Proeftuinstraat in Gent. Er worden volop stoomketels geïnstalleerd. Daardoor gaat de warmte van de verbrandingsoven niet meer verloren, maar wordt ze omgezet in stoom en elektriciteit. De gigantische onderdelen van de oven wegen elk ruim 50 ton. Ze worden als een meccano in elkaar gezet met een reuzenkraan. Via een twee kilometer lange pijplijn gaat de stoom naar het Universitair Ziekenhuis, dat er zijn gebouwen mee zal verwarmen. Normaal gezien moet de vernieuwde oven af zijn tegen het najaar. © Gianni Barbieux

From concepts in the 1990s to implementation into policy:

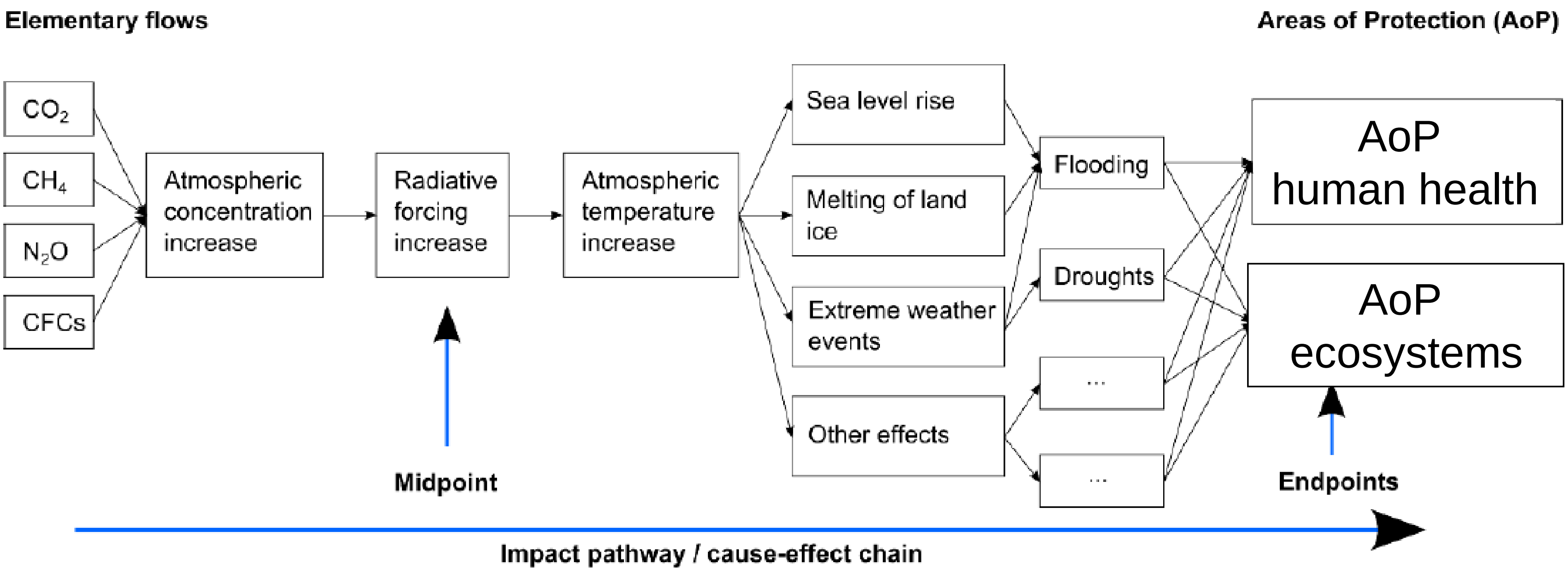
EU “Circular Economy Package” Dec 2015

4. Life Cycle Assessment

Basis:

Impact assessment modeling based on cause and effect chain

At endpoint level: example for Climate Change:



Life Cycle Assessment

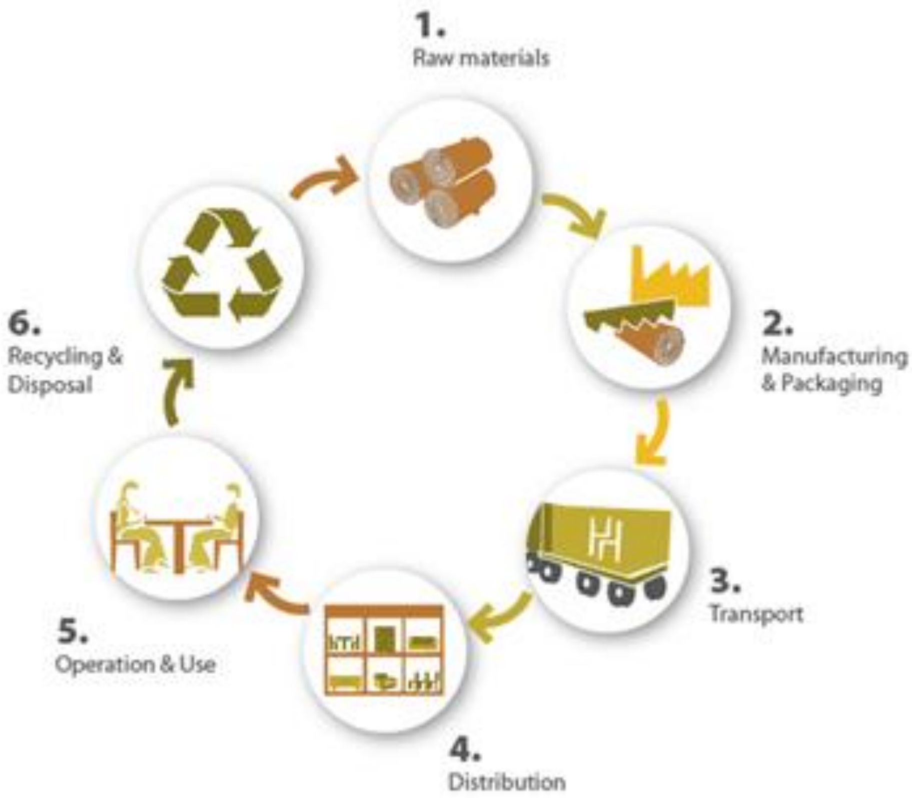
assessing impacts on 3 endpoints:

- Ecosystem health
- Human health
- Natural Resources (↔ resource depletion)

- Highly debated subject: science/policy makers/industry

- Problems with implementation in LCA (PEF pilots, 2013-2018):

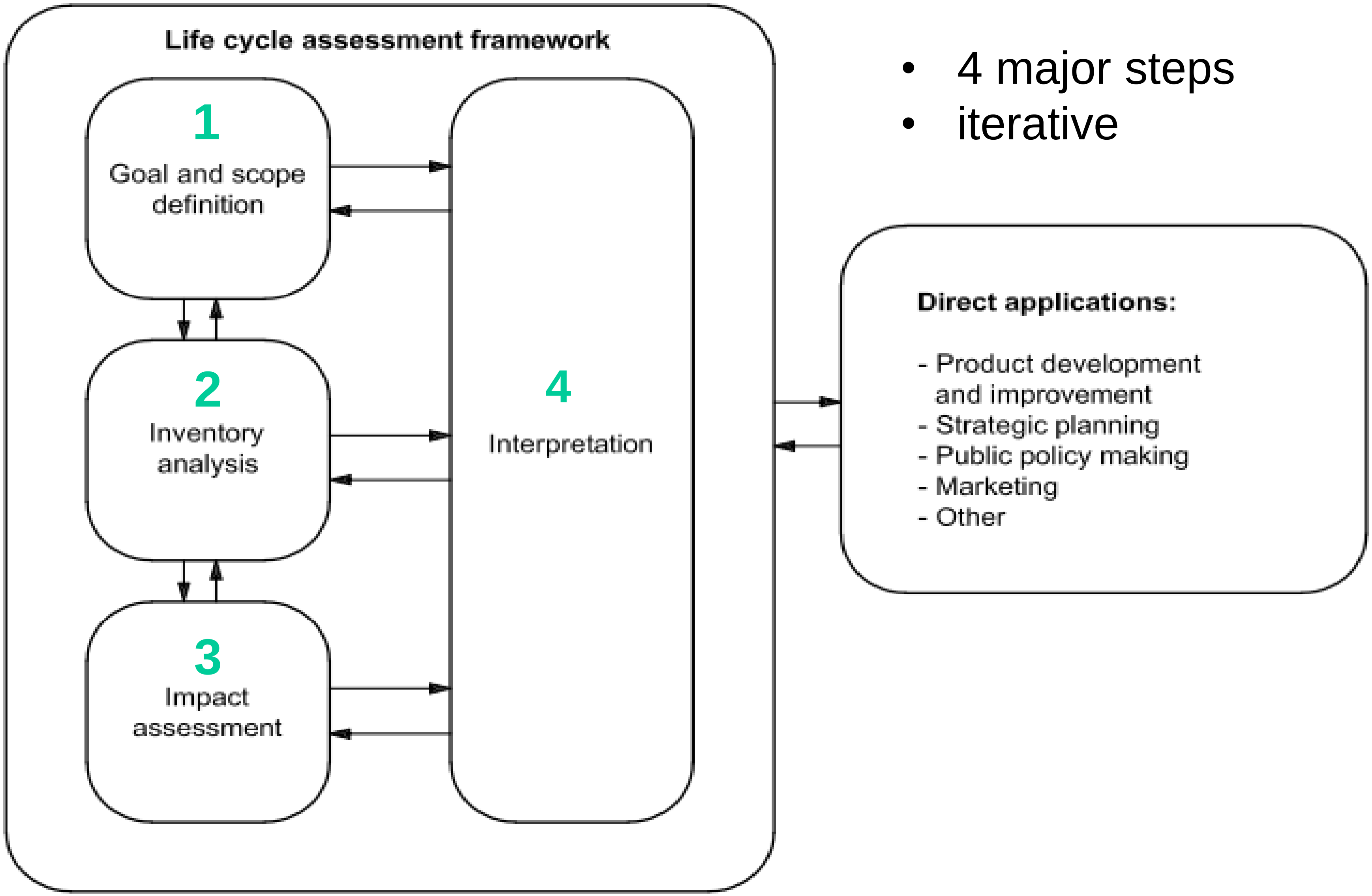
LCA: “the compilation and evaluation of the inputs, outputs and the potential environmenal impacts of a product system (good or service) throughout its life cycle, from the extraction of raw material to product disposal”



ISO

International Organization for Standardization:

guidelines for LCA



- 4 major steps
- iterative

Step 1: Goal and scope definition

Goal:

1. Intended application / reason for the study

2. Audience of the study

Example of timber

Life cycle of timber

Goal:

1. What is the impact of timber compared to concrete as a construction material?
   Which step of its life cycle has the highest impact?

2. Audience of the study: general public or building company

Scope:

1. Choice of functional unit (FU):

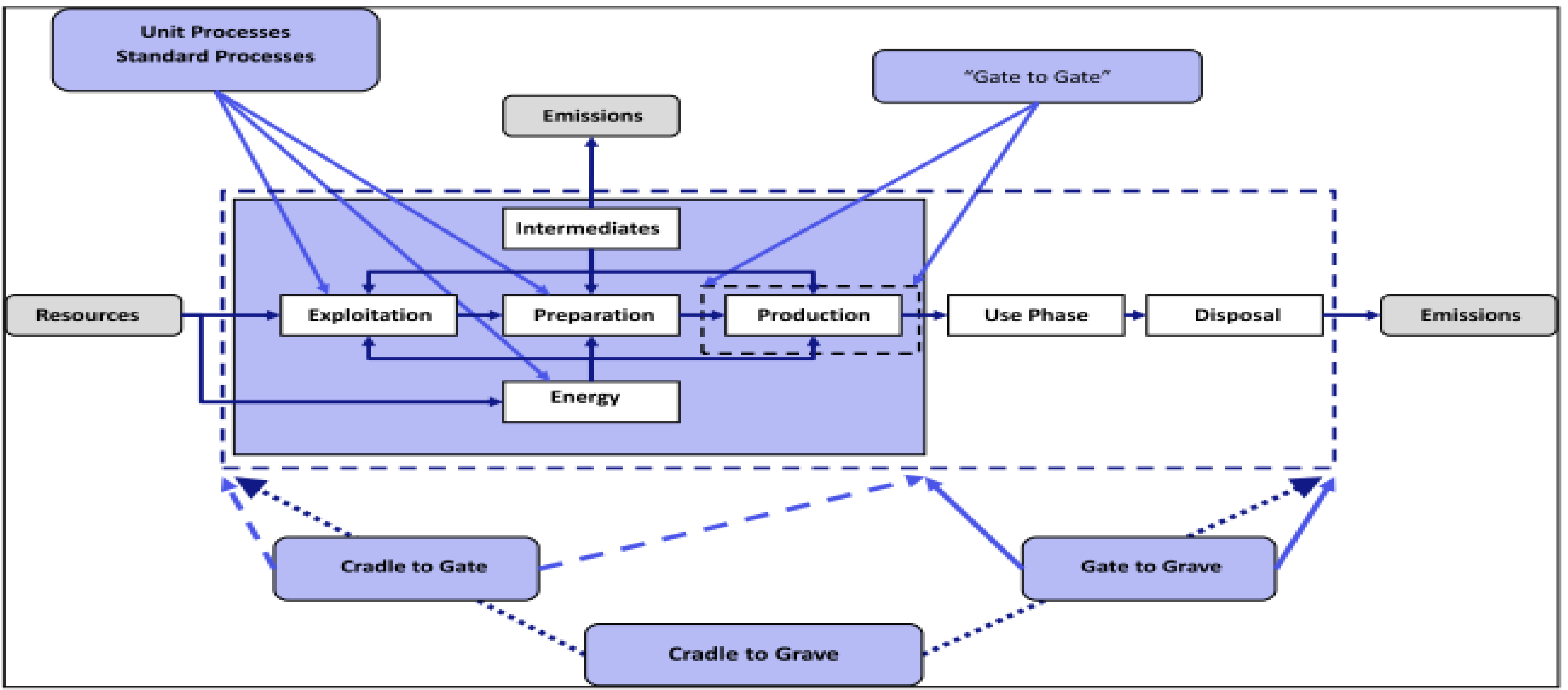
   Amount of the studied good(s) and/or service(s)
   + *How long? Which quality?*

Example: plastic vs. paper bag for shopping:
volume? carrying capacity? lifetime, re-usable?

→ fair comparison needed
→ service: carrying 10 kg of identical goods

Scope:

2. Choice of system boundaries



Scope:

2. Choice of system boundaries:

Time and money needed for data collection

Cut-off criteria

e.g. >1% of mass input

2. Choice of system boundaries

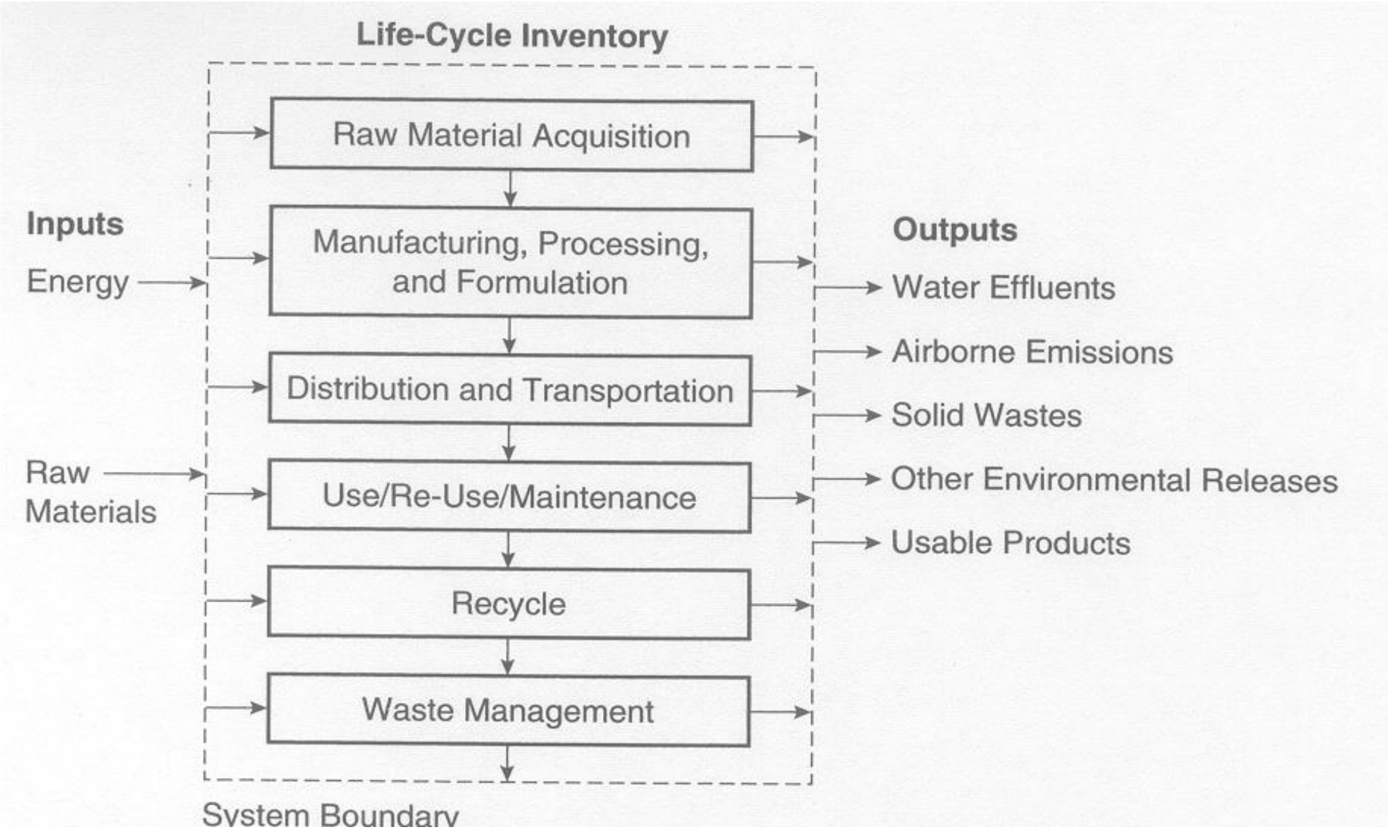
Subdivide system into:

1. **Foreground system**:
   - core processes under direct control or decisive influence
   - specific/primary data

2. **Background system**:
   - auxiliary processes
   - generic/secondary data

Step 2: Life cycle inventory analysis

Data collection about input and output flows of the system



Most time consuming step

Elementary flows to and from the natural environment:

Natural resources
Extracted from natural environment

Emissions
to natural environment

Environmental impact assessment

Cause-effect chain

Besides emissions (elementary flows), other output flows:

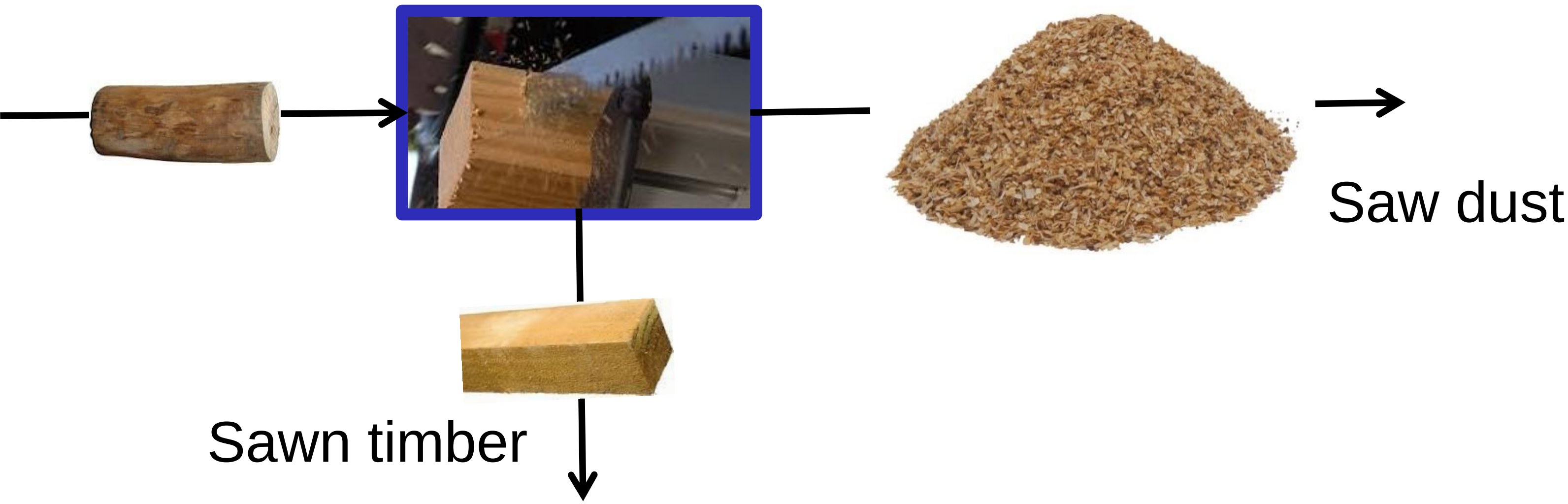
(co)products OR wastes

“substances or objects which the holder intends or is required to dispose of” (ISO, 2006)

environmental impact attributed to (co)products ⟷ no environmental impact attributed to wastes

Difficult distinction, time-dependent

Example of sawn timber:



Sawn timber: main product / Saw dust: waste or coproduct?

Saw dust as waste: no environmental impact
Saw dust as coproduct: how to divide environmental impact between sawn timber and saw dust?

Multifunctionality issue:

A system or process produces more than one product

↓

How to assign the inventory flows
and the associated environmental impacts
to two or more products?

↓

ISO guidelines (2006)

Step 3: Life cycle impact assessment

Data inventory: elementary flows (natural resource use and emissions)

Environmental impact assessment

1. Classification
2. Characterization
3. Valuation (optional)

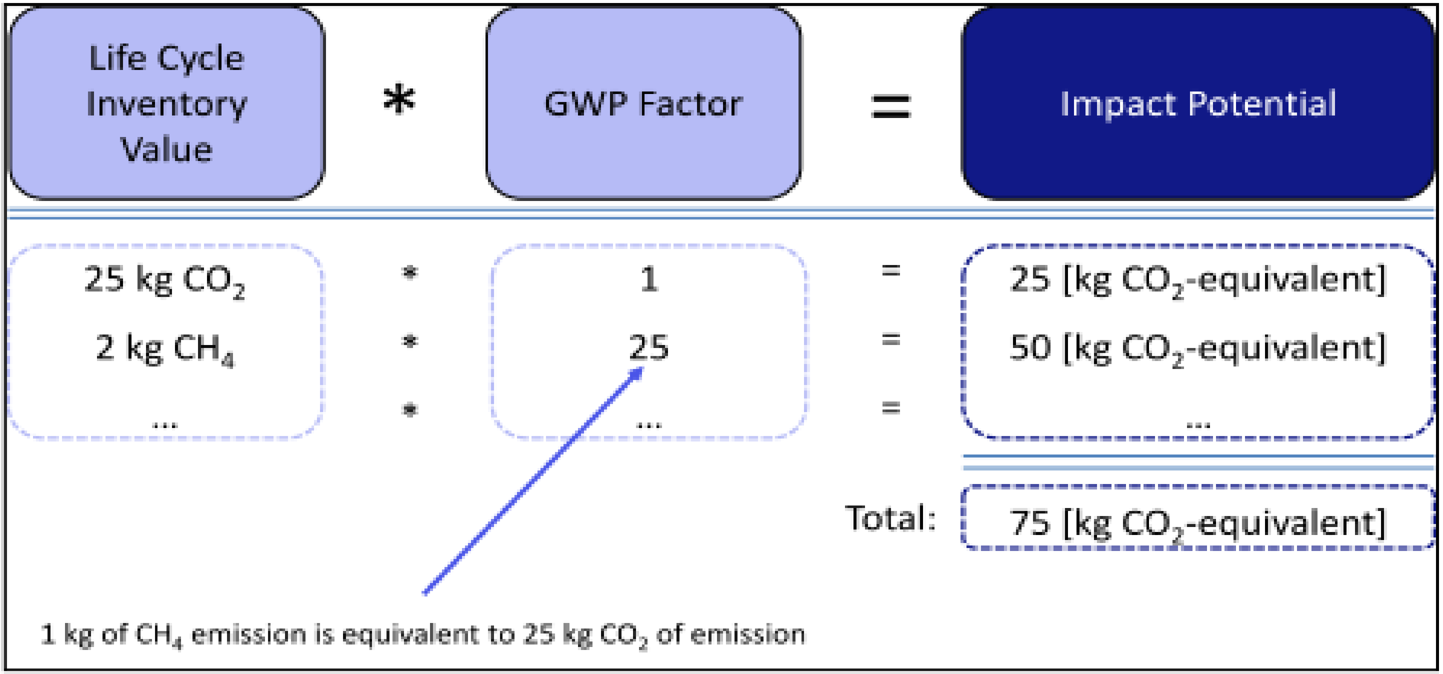
Classification of elementary flows into impact categories

Examples:

Impact categories
Global warming
Stratospheric ozone depletion
Photochemical smog formation
Human carcinogenicity
Atmospheric acidification
Aquatic toxicity
Terrestrial toxicity
Habitat destruction
Depletion of nonrenewable resources
Eutrophication

Characterization: quantification of the potency of the env. effect

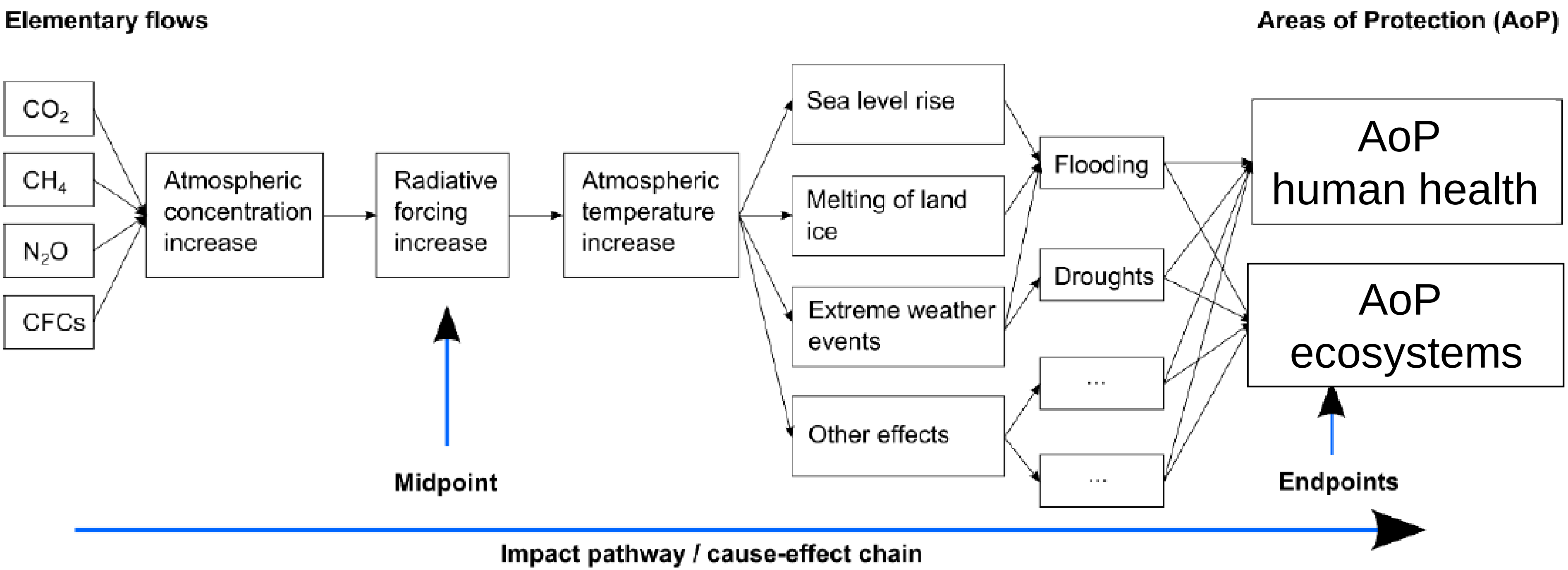
Example Climate Change impact:



GWP: global warming potential

Characterization at midpoint or endpoint level

At endpoint level: example for Climate Change

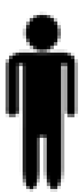


Characterization at midpoint or endpoint level

At endpoint level:

- At the end of the cause-effect chain
- Better comprehensible to broad audience
- Higher uncertainty (compared to midpoint)

Damage to the Areas of Protection (AoPs):

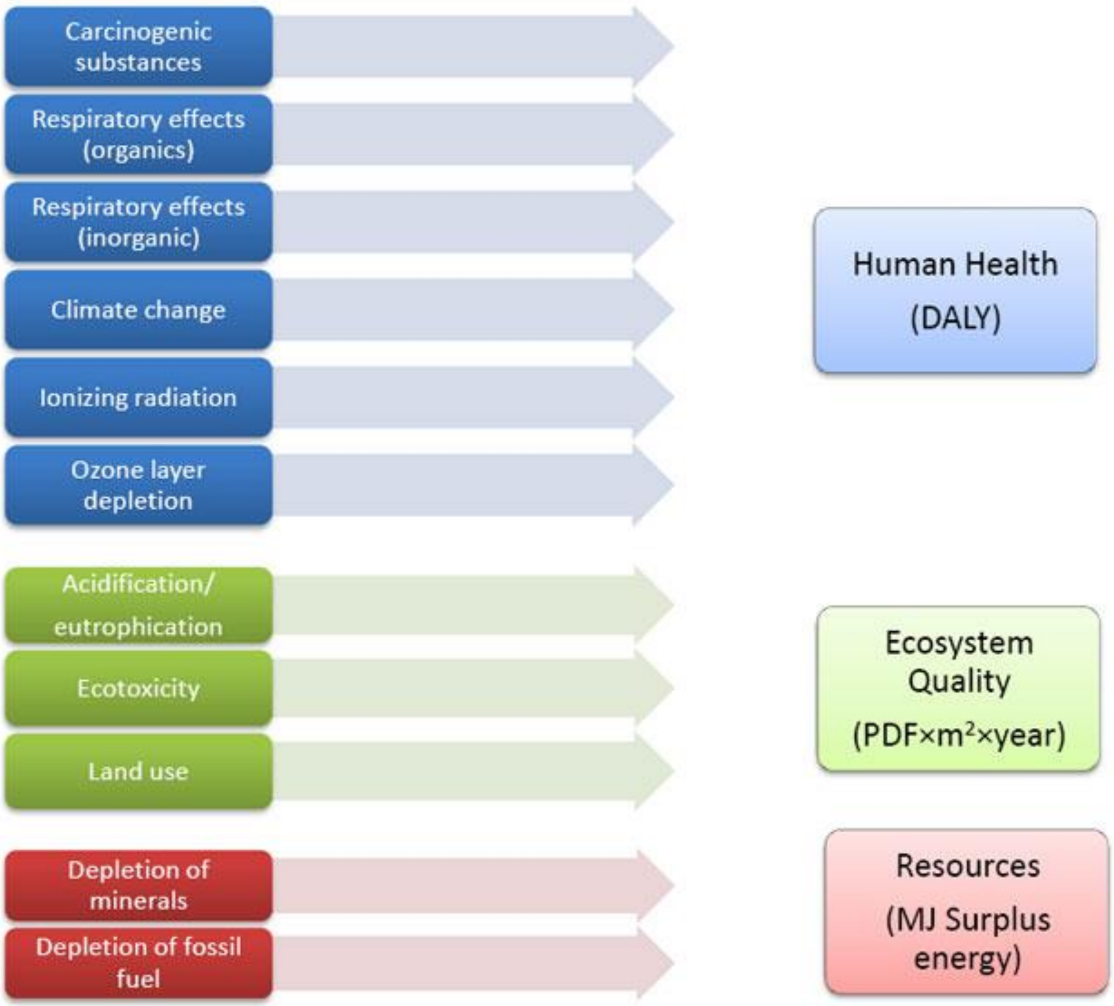


HUMAN HEALTH

NATURAL RESOURCES

ECOSYSTEMS

Midpoint indicators linked to endpoint indicators



Commonly used indicator: Disability Adjusted Life Years (DALY)

Commonly used indicator: Potentially Affected/Disappeared Fraction of species (PAF/PDF)

E.g. Extra energy necessary for extraction (no consensus yet!)

IMPACT CATEGORIES — DAMAGE TO AoPs

Step 4: Interpretation

- Interpret results of the impact assessment
- Answer research questions defined in the goal

- **One product**: identify hot spots in the life cycle
- **Two or more products**: recommend about product with lowest environmental impact

! Take into account limitations, choices and assumptions

Uses of life cycle studies

1) Product comparison

 vs. 

 vs. 

Plastic vs. fuel: Which use of the Brazilian ethanol can bring more environmental gains?

Rodrigo A.F. Alvarenga, Jo Dewulf*

Is it better to remove pharmaceuticals in decentralized or conventional wastewater treatment plants? A life cycle assessment comparison

Elorri Igos, Enrico Benetto *, Silvia Venditti, Christian Kohler, Alex Cornelissen, Ruth Moeller, Arno Biwer

Uses of life cycle studies

2) Product design and improvement

- identify processes, ingredients, and systems that are **major contributors** to environmental impacts
- compare **different options** within a particular process with the objective of minimizing environmental impacts

Eco-design

ISO: “a process **integrated within product design and development** that aims to reduce environmental impacts and continually to improve the environmental performance of the products, throughout their life cycle”

5. Key challenge in LCA: Resources

Insights from a thermodynamic approach

What basis to be chosen for integrated resource mgt?

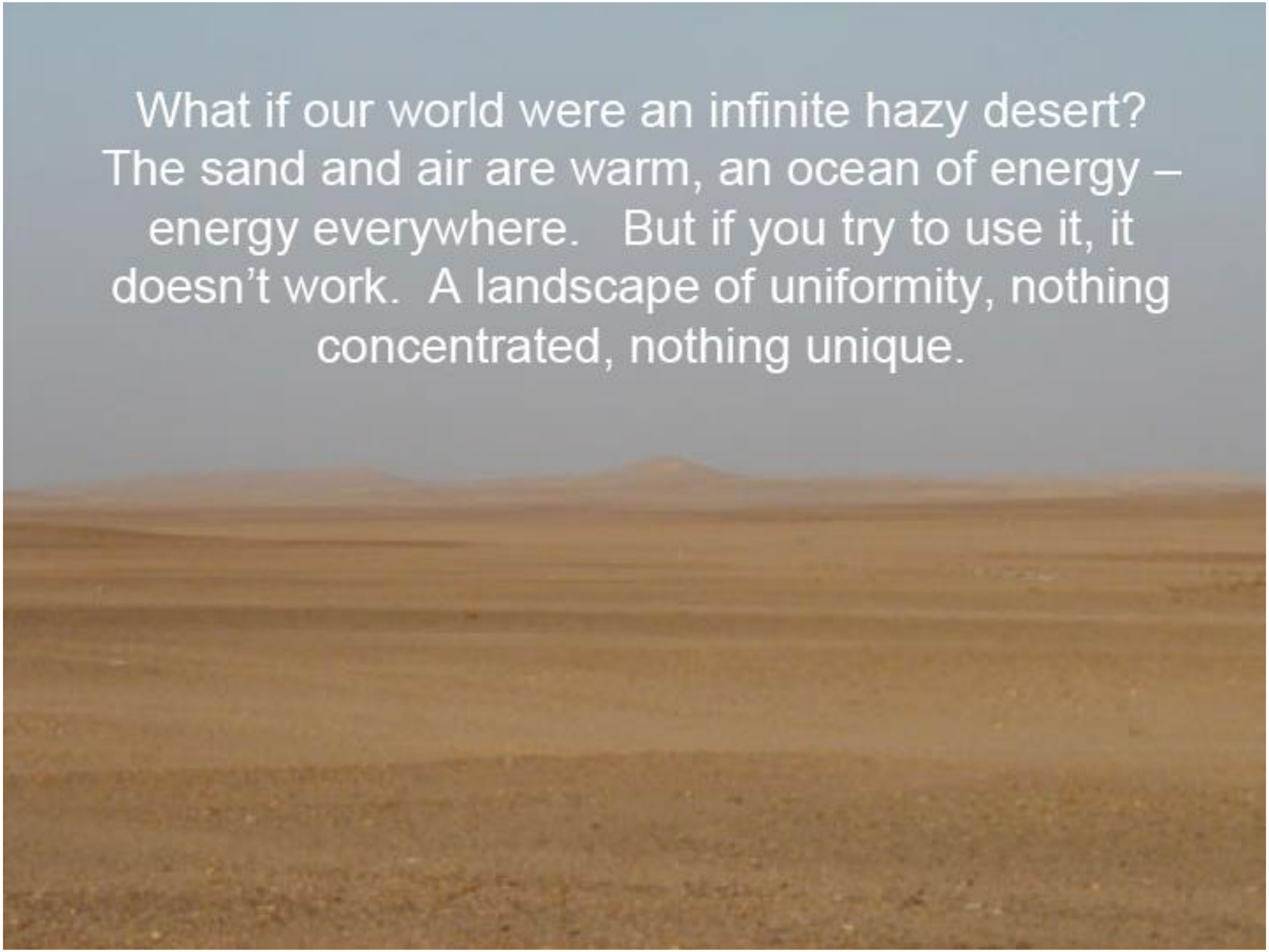
Prof. Whitesides (Harvard)
at Green Chem. Conf. (Washington, 2005):

Sustainable technology development:
If emissions are a bit under control:
- *Economically sound*
- *Thermodynamically sound*

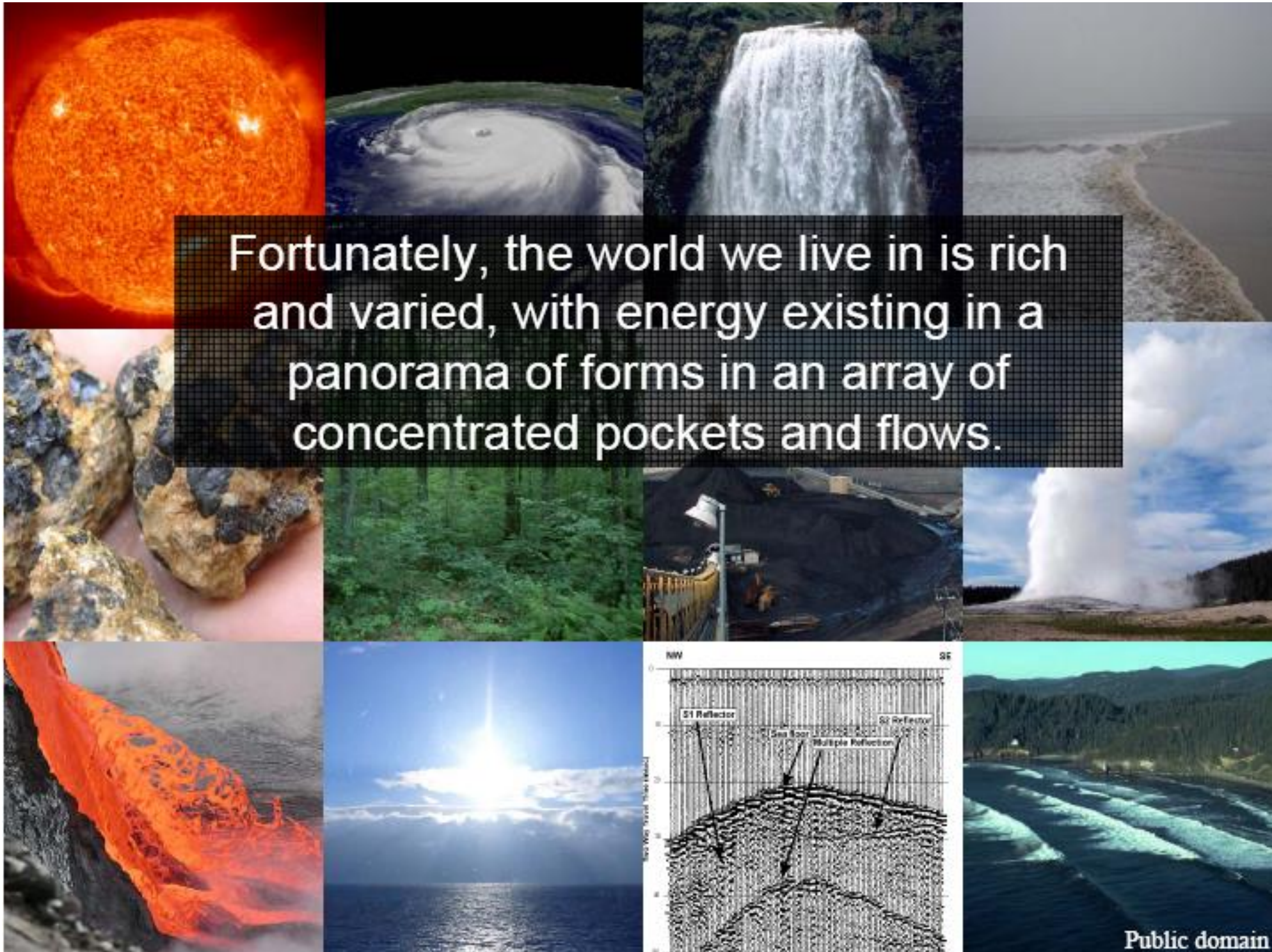
Idea: take thermodynamics as a base for resource management that enables:
- Overall resource input assessment
- Overall resource efficiency assessment

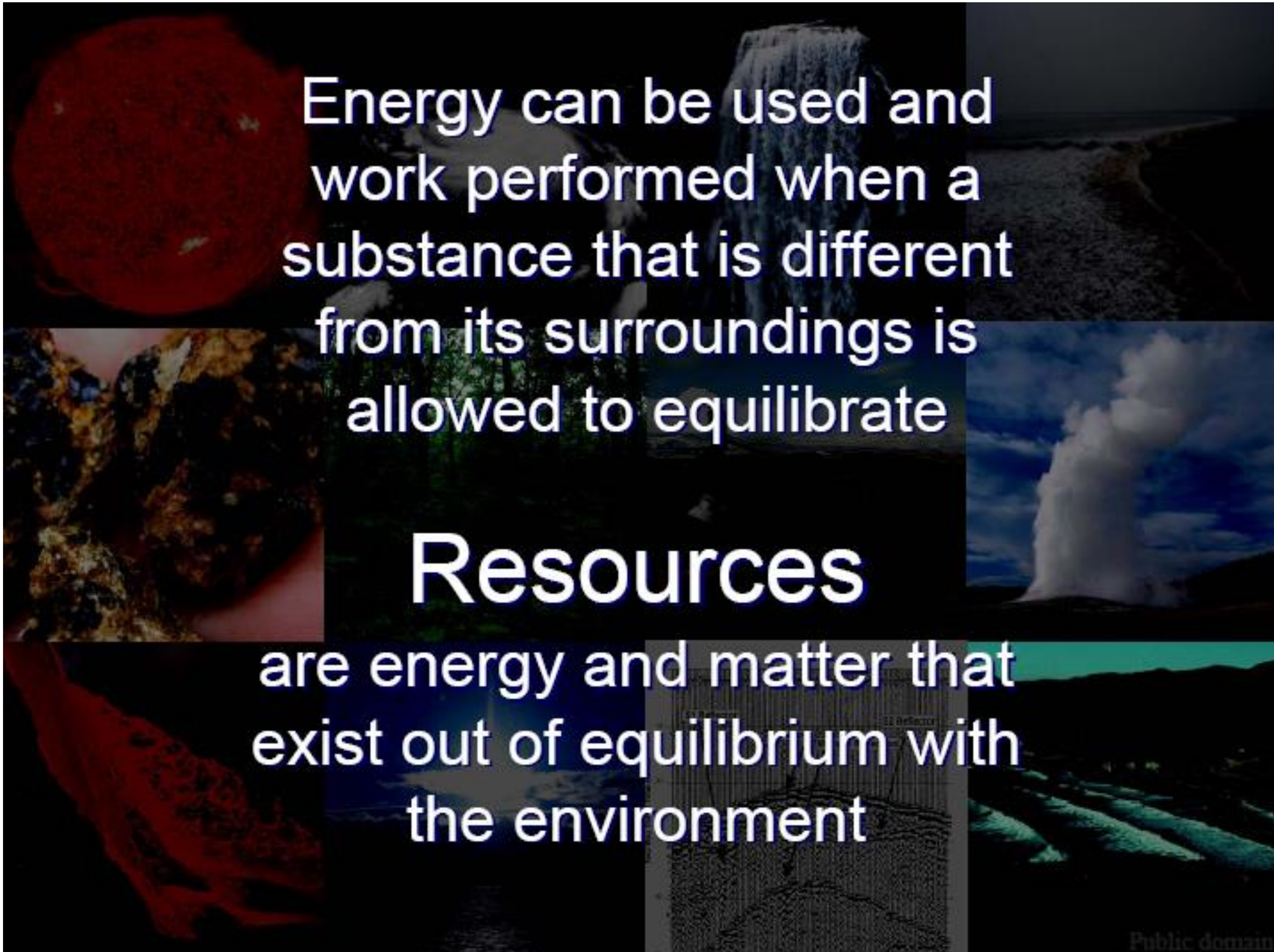
First law and Second law ...

Explaining second law through the exergy concept



(W. Hermann, Stanford, 2007)


Fortunately, the world we live in is rich and varied, with energy existing in a panorama of forms in an array of concentrated pockets and flows.
Public domain


Energy can be used and work performed when a substance that is different from its surroundings is allowed to equilibrate
Resources
are energy and matter that exist out of equilibrium with the environment
Public domain

exergy

is a measure of work potential or disequilibrium from the environment

While

exergy can be destroyed, energy cannot

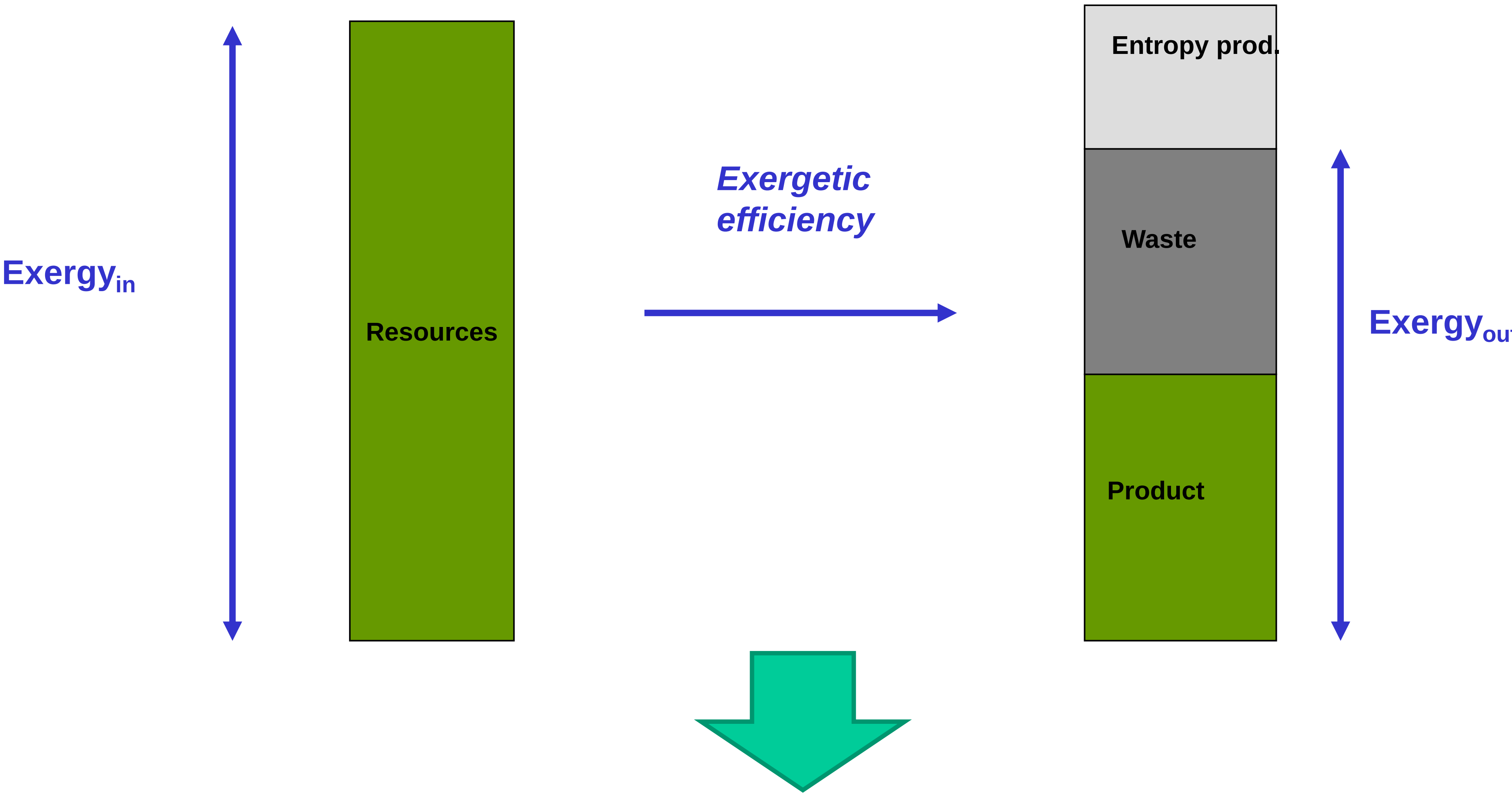
exergy is the useful portion of energy

exergy

is what most mean when they say

energy

Assess the thermodynamic efficiency: exergy analysis



Economic sustainability and Environmental sustainability

Source: Dewulf et al., 2008

Calculation of exergy: matter flow - chemical exergy

Final state in physical exergy calculation
= initial state in chemical exergy calculation

Chemical exergy is equal to the ***maximum*** *amount of work obtainable when the substance under consideration is brought* ***from the environmental state to the dead state*** through chemical reactions and exchange of compounds.

Calculation of exergy: matter flow - chemical exergy

Final state in physical exergy calculation
= initial state in chemical exergy calculation

Chemical exergy is equal to the ***maximum*** *amount of work obtainable when the substance under consideration is brought* ***from the environmental state to the dead state*** through chemical reactions and exchange of compounds.

Chemical exergy is equal to the ***minimum*** *amount of work necessary to* ***synthesise****, and to deliver in the environmental state, the substance under consideration* ***from reference substances (in dead state)*** *by means of processes involving heat transfer and exchange of substances only with the environment.*

Calculation of exergy: chemical exergy

Homogenous reference environment

- Atmosphere
- Sea (dissolved ions)
- Earth's crust

Composition → Reference substances

- Abundant and most probable in the environment
- Low chemical potential
- Chemically stable
- In equilibrium with the rest of the environment
- Present in aggregation state (solid, liquid or gas) at which they would normally occur at T_0 and P_0
- Present at average natural world concentration

Calculation of exergy: chemical exergy

By definition: a reference substance at reference concentration (or partial pressure for a gas) and reference aggregation state → Ex = 0

e.g. CO_2 (g) at P_{00} (0.03 kPa)

Following aspects should be taken into account when quantifying chemical exergy:

- Chemical formula
- Aggregation phase (solid, liquid or gas)
- Concentration (solid, liquid) or partial pressure (gas)
- Crystal structure (solid)

Calculation of exergy: chemical exergy

Non-reference substances

Transformed into reference substances (<u>at standard conditions</u>)

Example: methane $CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$

Maximum amount of work obtainable out of a reversible reaction:

$$\Delta G_r^0 = \sum G^0_{products} - \sum G^0_{reactants}$$

$$= \sum H^0_{products} - \sum H^0_{reactants} - T_0\left(\sum S^0_{products} - \sum S^0_{reactants}\right)$$

$$= \sum Ex^0_{ch,products} - \sum Ex^0_{ch,reactants}$$

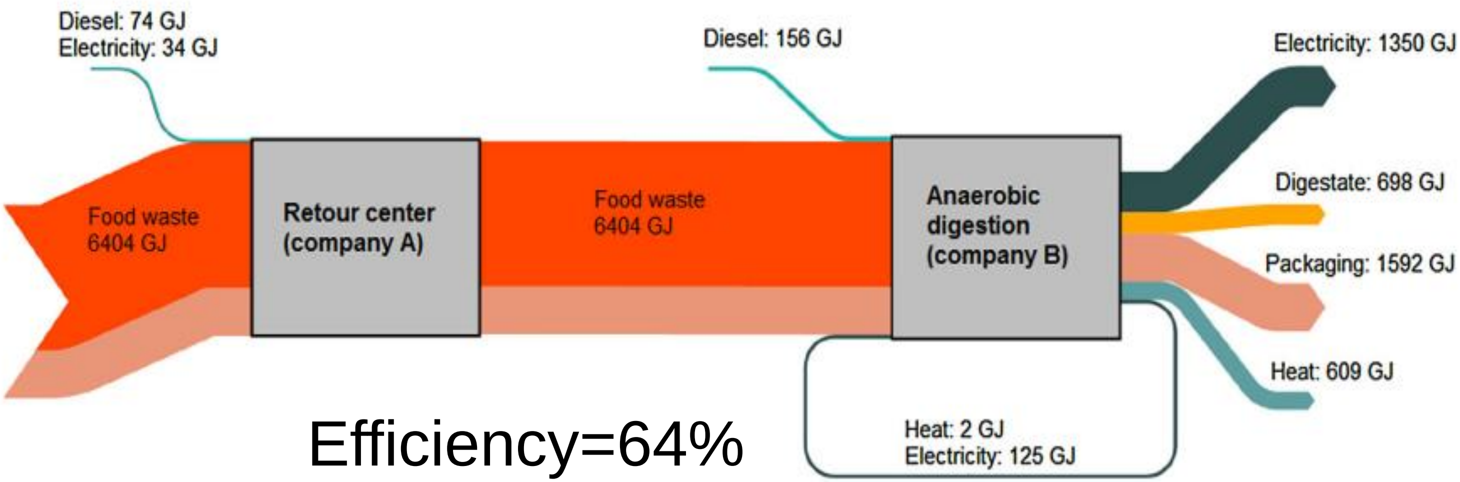
Exergy of non-reference substance is found if exergy values of other compounds are known

Calculation of exergy: chemical exergy

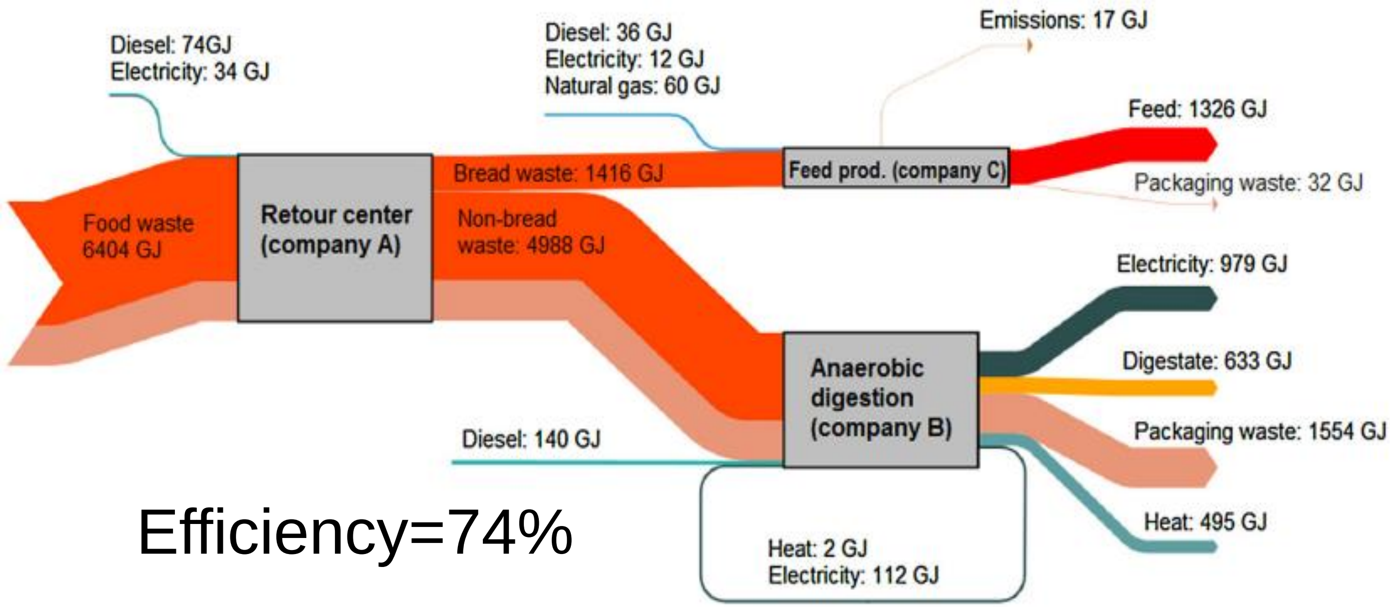
Solid fuels	Liquid fuels
Solid hydrocarbon	**Liquid hydrocarbon**
$\beta = 1.0435 + 0.0159\frac{H}{C}$	$\beta = 1.0406 + 0.0144\frac{H}{C}$
Solid C, H, O compounds	**Liquid C, H, O compounds**
$\beta = 1.0438 + 0.0158\frac{H}{C} + 0.0813\frac{O}{C} \quad \left[\frac{O}{C} \leq 0.5\right]$	$\beta = 1.0374 + 0.0159\frac{H}{C} + 0.0567\frac{O}{C} \quad \left[\frac{O}{C} \leq 1\right]$
$\beta = \frac{1.0414 + 0.0177\frac{H}{C} - 0.3328\frac{O}{C}\left[1 + 0.0537\frac{H}{C} \leq 0.5\right]}{1 - 0.4021\frac{O}{C}} \quad \left[\frac{O}{C} \leq 2\right]$	
Solid C, H, O, N compounds	**Liquid C, H, O, S compounds**
$\beta = 1.0437 + 0.014\frac{H}{C} + 0.0968\frac{O}{C} + 0.0467\frac{N}{C} \quad \left[\frac{O}{C} \leq 0.5\right]$	$\beta = 1.0407 + 0.0154\frac{H}{C} + 0.0562\frac{O}{C} + 0.5904\frac{S}{C}\left(10.175\frac{H}{C}\right) \quad \left[\frac{O}{C} \leq 1\right]$
$\beta = \frac{1.044 + 0.016\frac{H}{C} - 0.3493\frac{O}{C}\left[1 + 0.0531\frac{H}{C}\right] + 0.0493\frac{N}{C}}{1 - 0.4124\frac{O}{C}} \quad \left[\frac{O}{C} \leq 2\right]$	
Bituminous coal, lignite, coke, peat	**Liquid technical fuels**
$\beta = 1.0437 + 0.1896\frac{Z_{H2}}{Z_c} + 0.0617\frac{Z_{O2}}{Z_c} + 0.0428\frac{Z_{N2}}{Z_c} \quad \left[\frac{Z_{O2}}{Z_c} \leq 0.667\right]$	$\beta = 1.0401 + 0.01728\frac{Z_{H2}}{Z_c} + 0.0432\frac{Z_{O2}}{Z_c} + 0.5904\frac{Z_s}{Z_c}\left(1 - 2.0628\frac{Z_{H2}}{Z_c}\right)$
Wood	
$\beta = \frac{1.0412 + 0.216\frac{Z_{H2}}{Z_c} - 0.2499\frac{Z_{O2}}{Z_c}\left[1 + 0.7884\frac{Z_{H2}}{Z_c}\right] + 0.045\frac{Z_{N2}}{Z_c}}{1 - 0.3035\frac{Z_{H2}}{Z_c}} \quad \left[\frac{Z_{O2}}{Z_c} \leq 2.67\right]$	

Environmental sustainability assessment of food waste valorization options

T. Vandermeersch[a,b], R.A.F. Alvarenga[a], P. Ragaert[b], J. Dewulf[a,*]

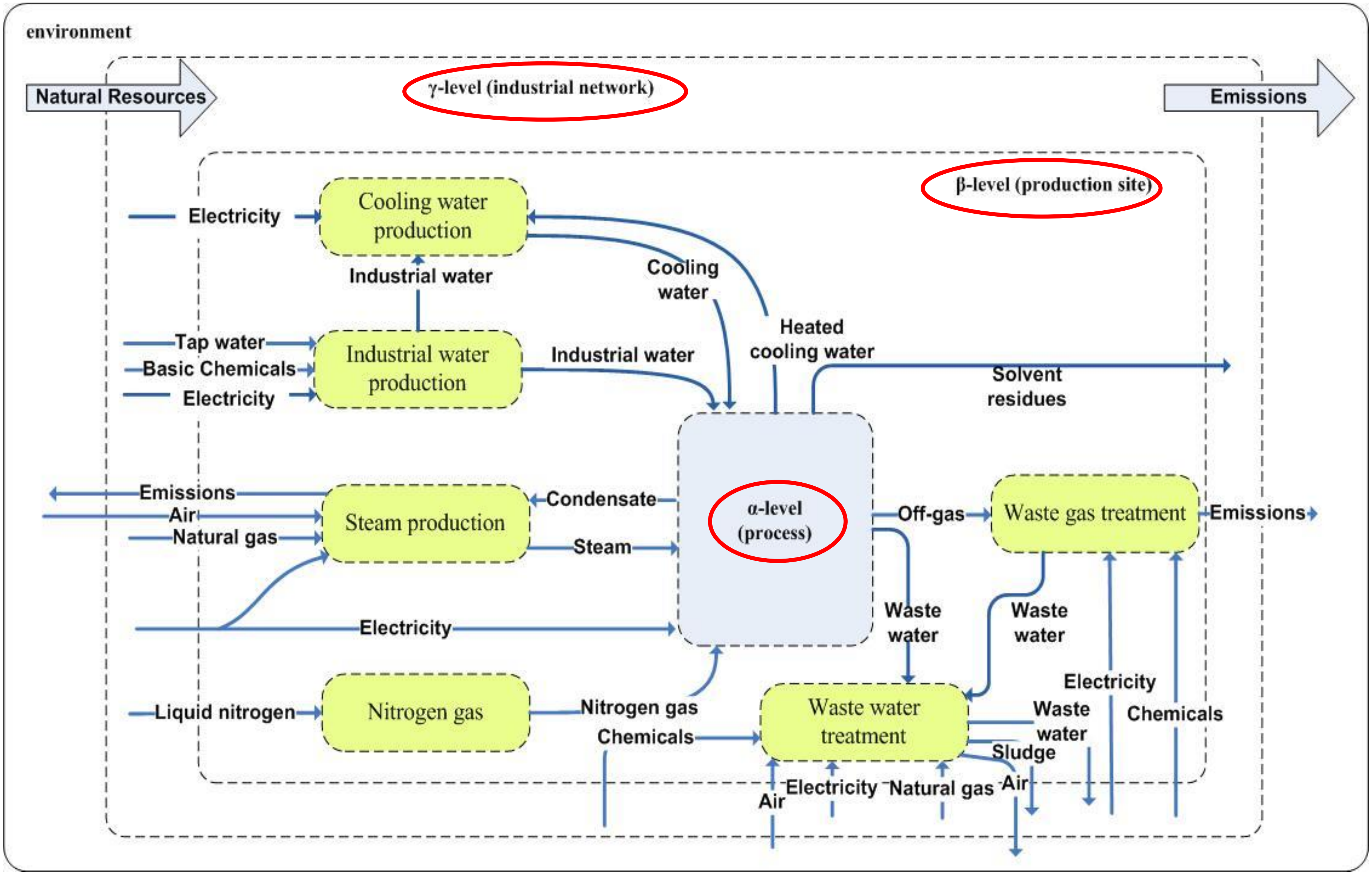


Efficiency=64%



Efficiency=74%

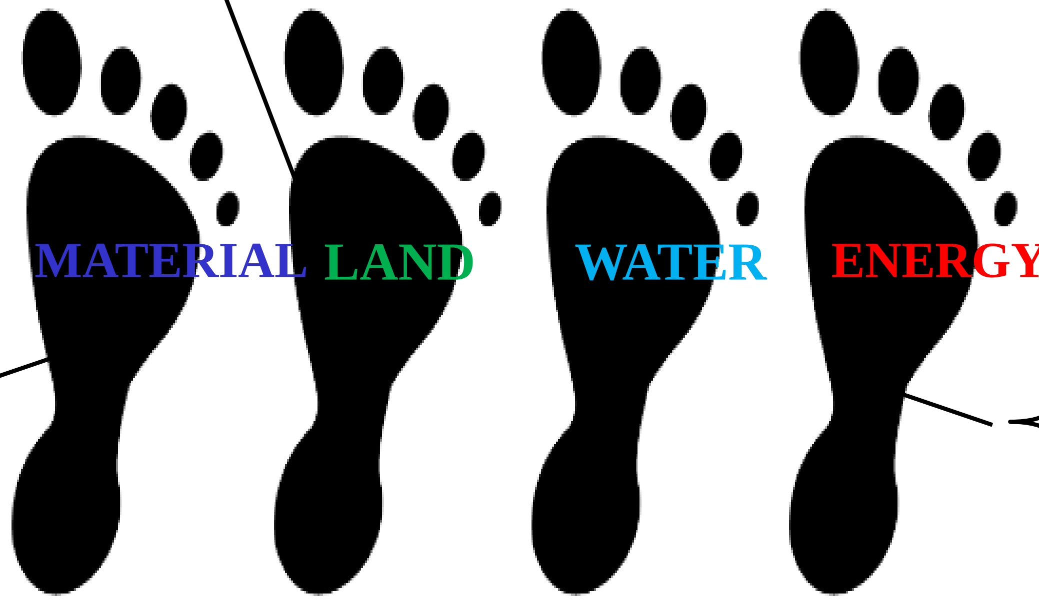
Resource management: from process to life cycle level



Methods were developed to calculate natural resource “footprints”

Biomass

Fossil fuels
Minerals
Metals
Biomass

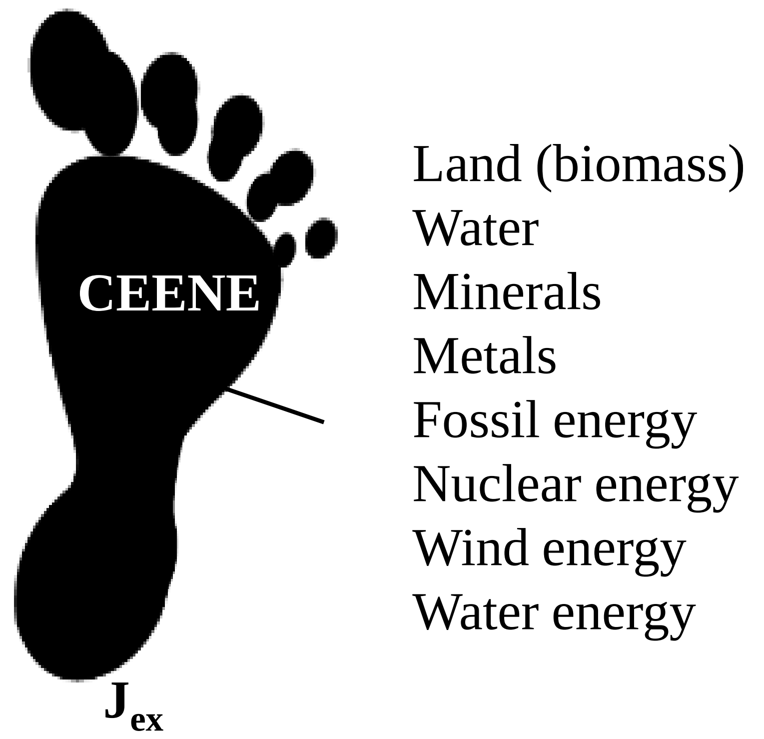


Fossil energy
Nuclear energy
Wind energy
Water energy

Per person:	**ton** +	**ha** +	**m³** +	**J_{en}** =	**overall resource footprint?**
World average	4.9	1.0	209		
Belgium	17.8	2.8	492		

Source: Ivanova et al., 2016

Methods were developed to calculate natural resource "footprints"



<u>C</u>umulative **<u>E</u>**xergy **<u>E</u>**xtraction of the **<u>N</u>**atural **<u>E</u>**nvironment

(Dewulf et al., 2007)

6. Illustrative cases

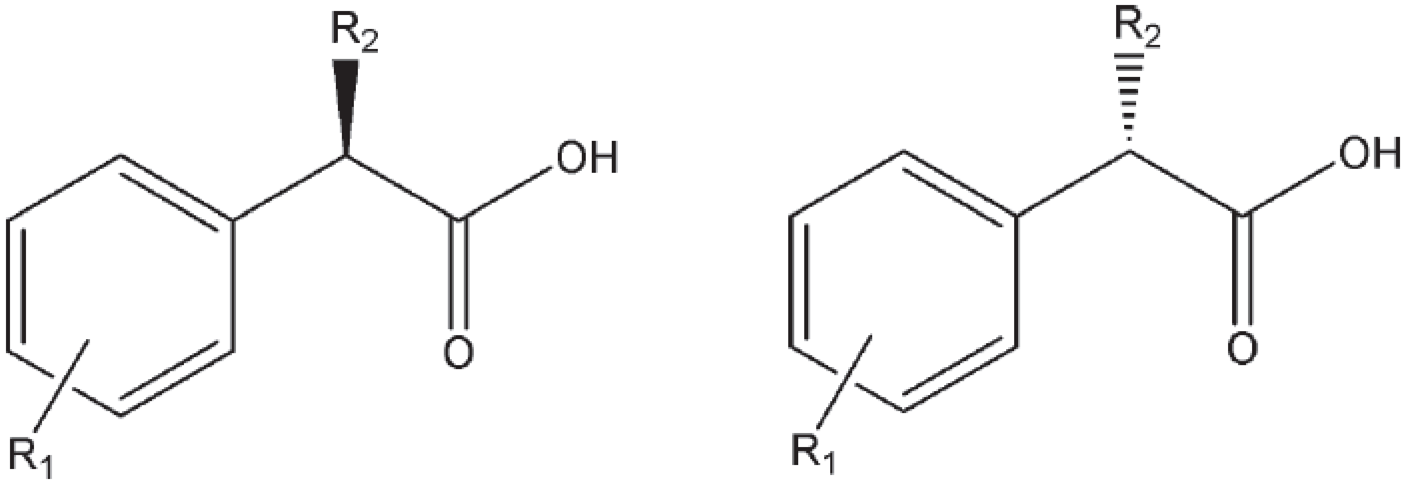
SUBSTANTIATING ENVIRONMENTAL SUSTAINABILITY CLAIMS

Case :
Are supercritical solvents green?

Green Chemistry Principle 5:
The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used. *(Anastas & Warner)*

Supercritical CO_2 as a Solve

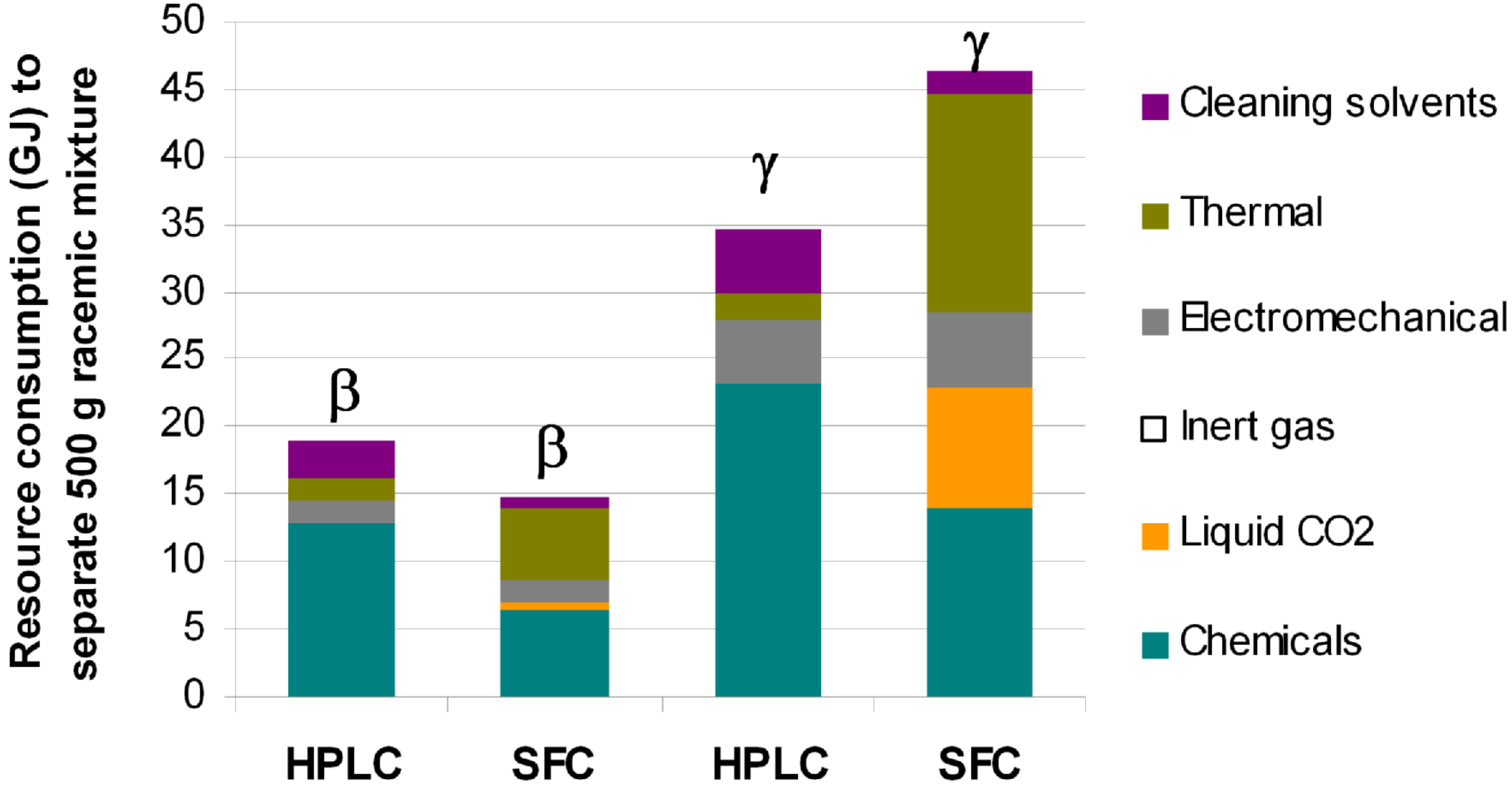
Case at Janssen Pharmaceutica (J&J):



Substitute classical solvent separation
by using supercritical CO_2:

Is this more environmental sustainable from a resource point of view?

- at process level : α
- at plant level: β
- at overall supply chain: γ



(Van der Vorst et al., Green Chem., 2010)

Environmental Sustainability Assessment of Algae Production Systems

Methodological development and case studies

Ir. Sue Ellen Taelman

Public PhD defense - 12/05/2016

Promotors
Prof. Dr. Ir. Jo Dewulf
Prof. Dr. Ir. Steven De Meester

- Potential applications of algae

Pollution treatment

Feed

Energy

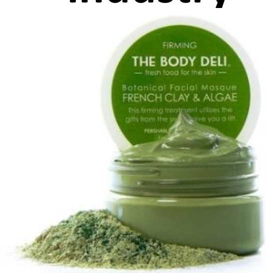
Food

Chemical industry

Fertilizer

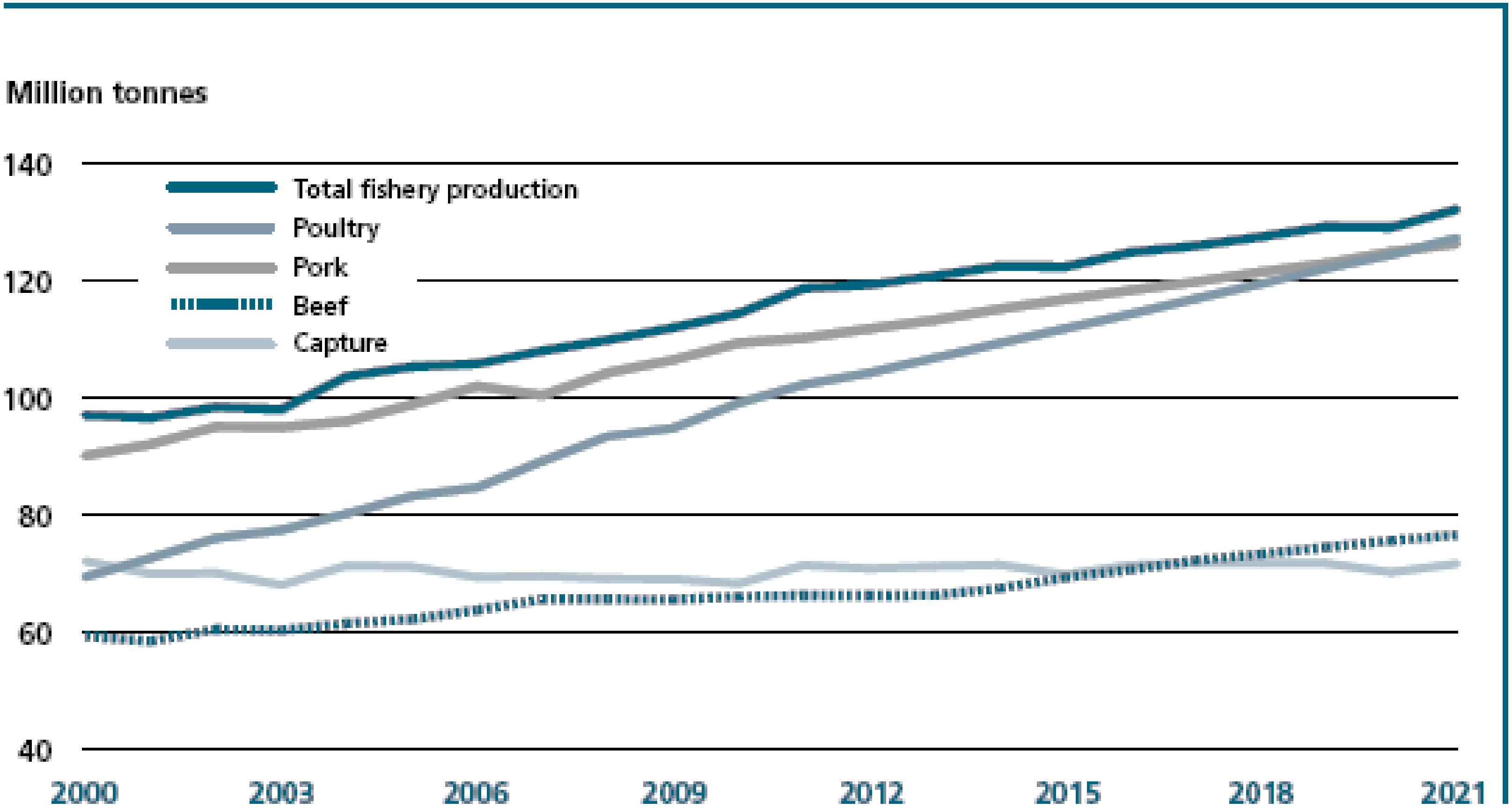
Pharmaceutical industry

Cosmetic industry



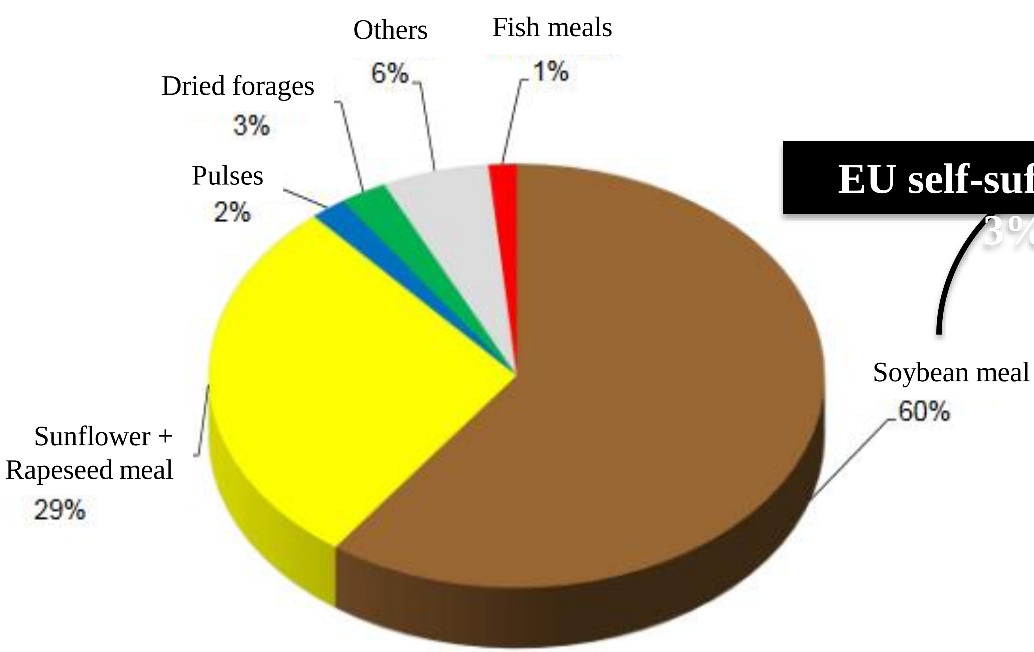
- Feed sector is extremely interested

Meat and fishery production, dressed weight or eviscerated basis



Notes: Total fishery production = capture + aquaculture. Beef and pork on a dressed-weight basis; poultry and fish on an eviscerated basis.
Sources: OECD and FAO Secretariats.

- High amounts of proteins used in EU for animal feeding: 26 million tonnes annually



Sources of proteins used for animal feeding in the EU (2012/2013), in % of total protein use (both import and EU-production) (FEFAC)

EU self-sufficiency: 3%

WWF

Deforestation &
loss of valuable ecosystems
Water & soil pollution

- **Challenge**: increase feed production while reducing the ecological footprint worldwide (import ↘)

- **Solution?** Farming for protein self-sufficiency in Europe but avoid competition for fertile land

Algae? Main driving forces…

→ High protein content found in several algal species

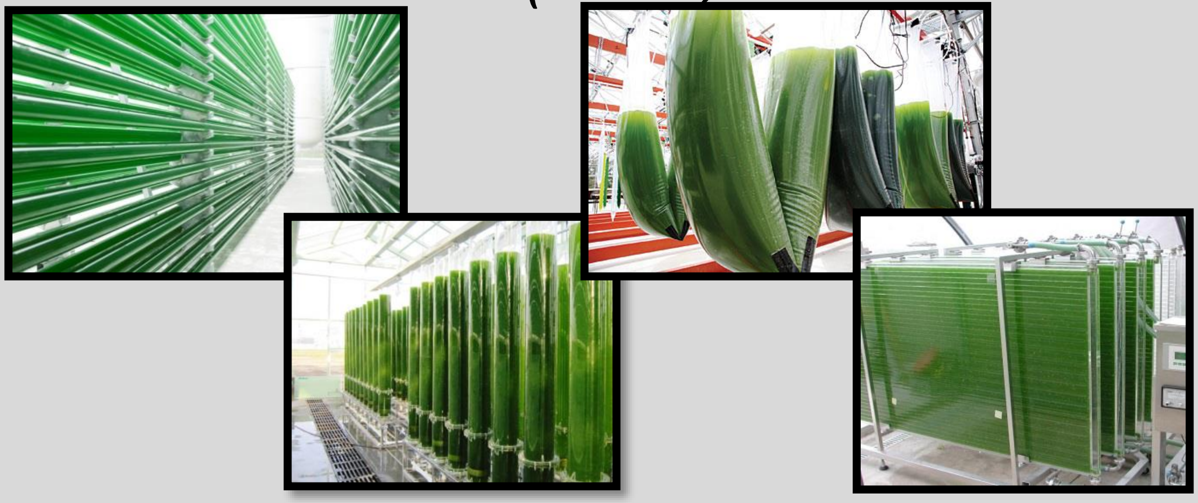
	Proteins (% DM)	Carbohydrates (% DM)	Lipids (% DM)
Scenedesmus obliquus	50-56	10-17	12-14
Chlorella vulgaris	51-58	12-17	14-22
Dunaliella salina	57	32	6
Tetraselmis maculata	52	15	3
Spirulina platensis	46-63	8-14	4-9
Spirulina maxima	60-71	13-16	6-7
Soybeans	**42**	**20**	**33**

Sources:
Encarnación et al., 2010
Keshun (1997)

→ Shift to unproductive land or oceans

- A few cultivation systems tested in Europe

Photobioreactors (PBRs)



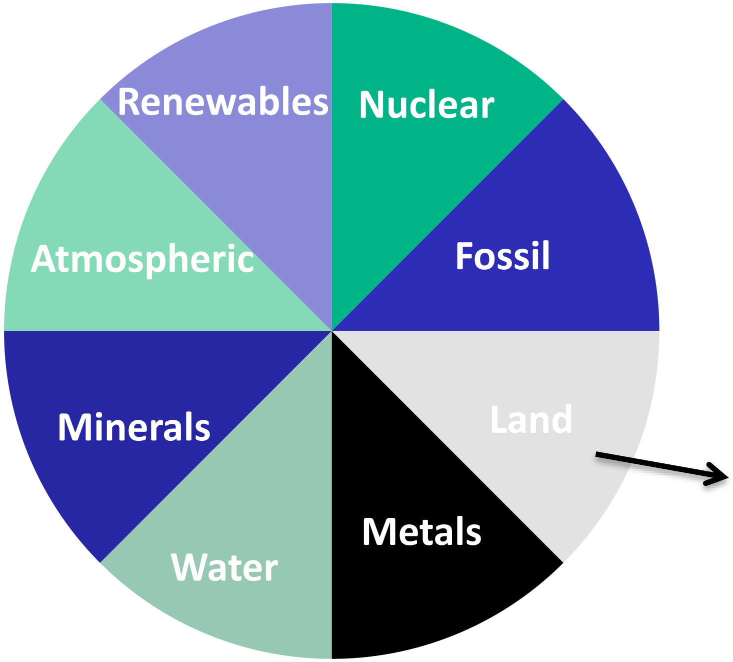
Open ponds

Coastal regions

- Several LCIA methods are developed during recent years focusing on emissions to the environment (e.g., IPCC 2007)

- However, resource efficiency is a major challenge in our everyday life, but only few LCIA methods account for resource consumption

E.g., CEENE method (*Dewulf et al. 2007*)



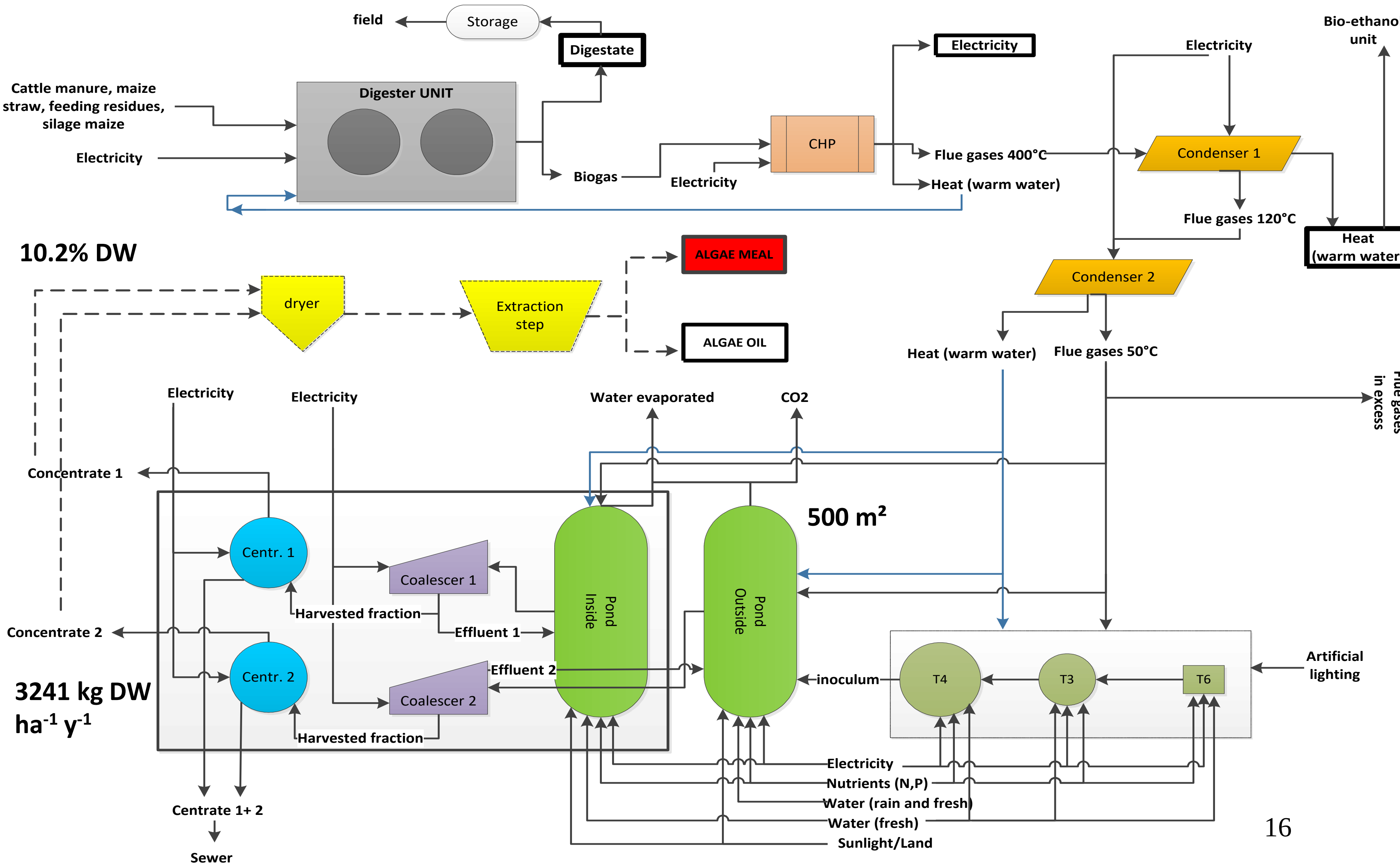
All resources expressed in exergy

→*not only the quantity but also the quality of a resource can be assessed*

Sum of all natural resources consumed= environmental resource footprint

Advantage algae cultivation: usage of waste streams

-> **Integrated algal biorefinery** in The Netherlands (Lelystad)



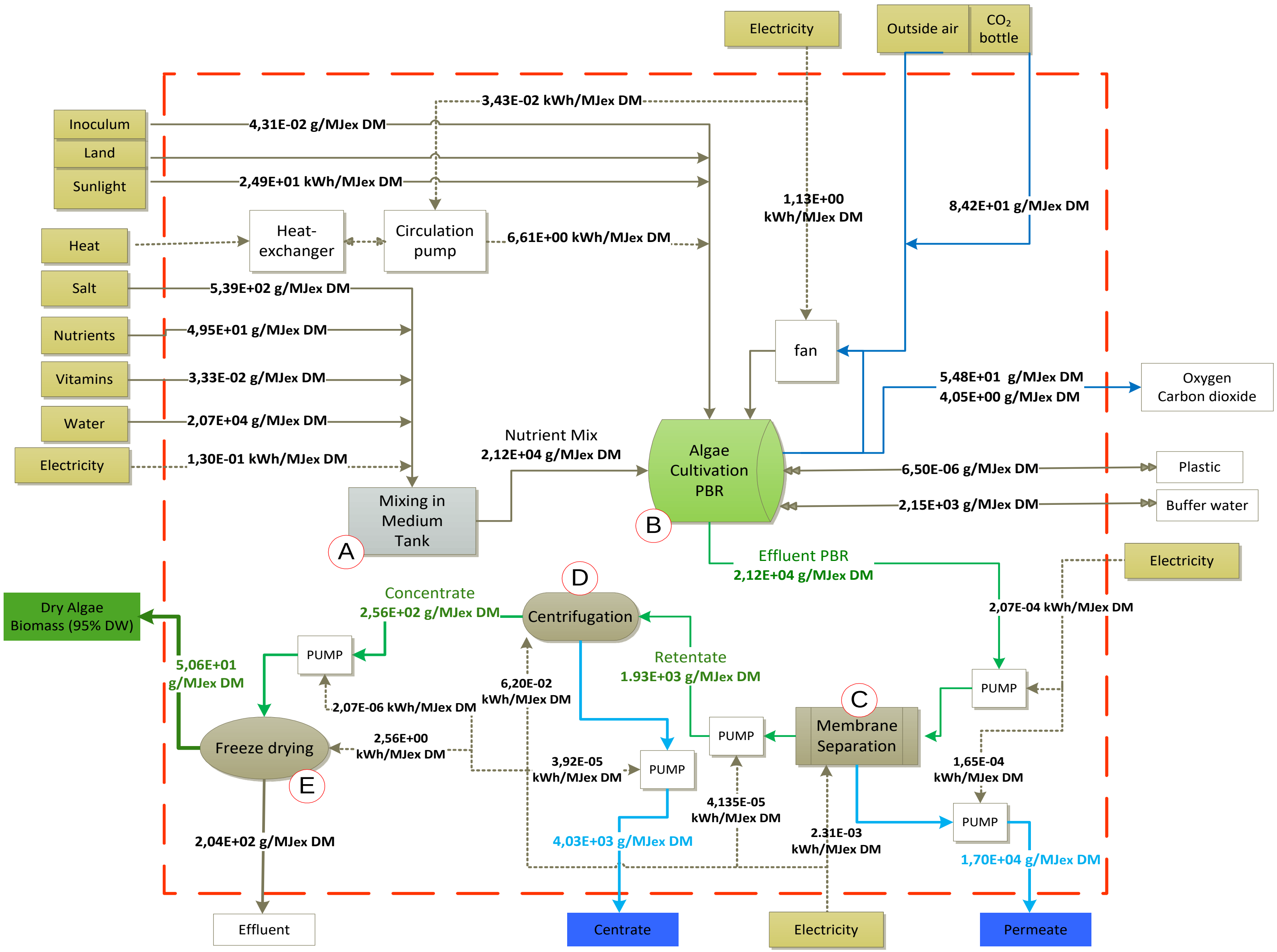
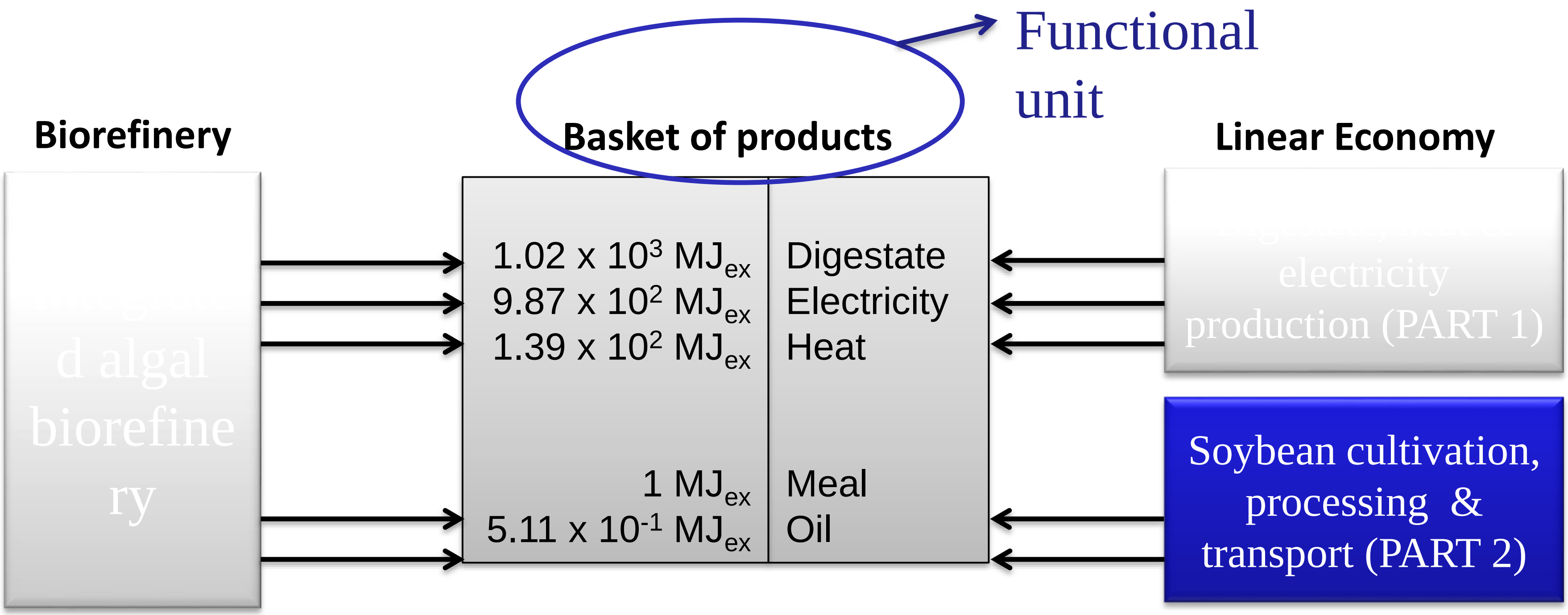


Figure 7 Process flow scheme microalgae production chain (pilot 2012, scale 240 m^2). Data inventory per MJ_{ex} dry matter algal biomass. Overall there are five distinct subprocesses within the foreground system (indicated by the red dotted line): nutrient mixing (process A), cultivation *Nannochloropsis sp.* (process B), membrane separation (process C), centrifugation (process D),

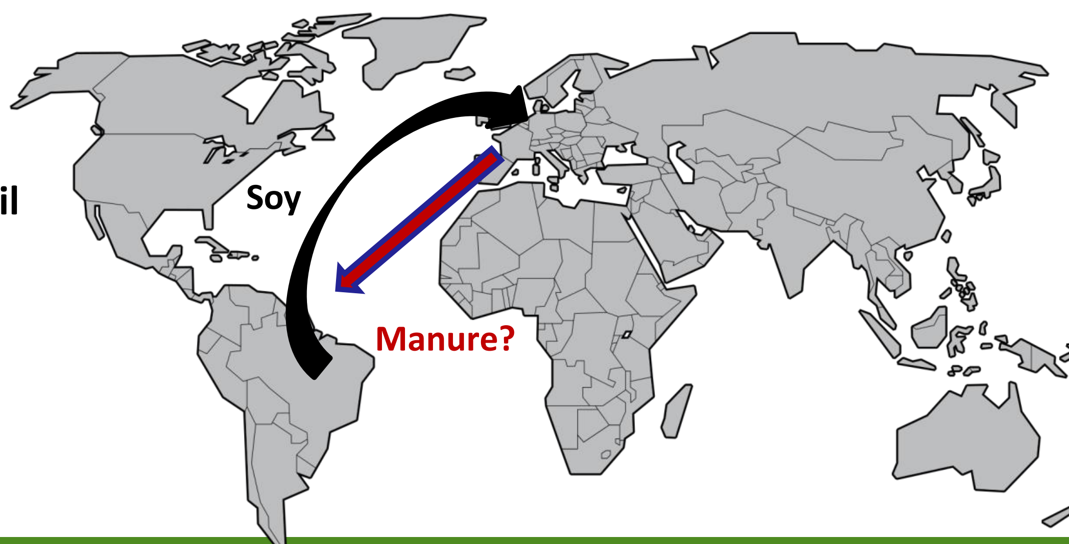


Data from Prudêncio da Silva et al.

Comparison with a relevant protein alternative :

A linear economy

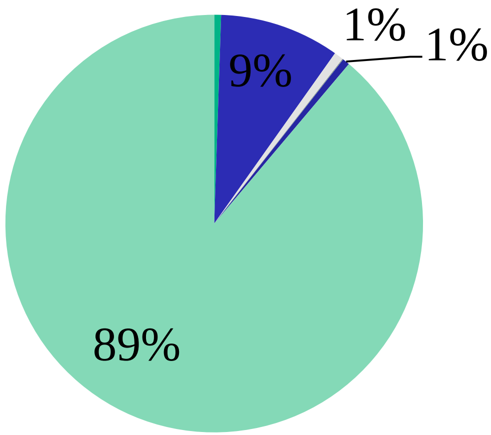
Soybean production in brazil
→ soil depletion
Livestock production in EU
→ manure treatment

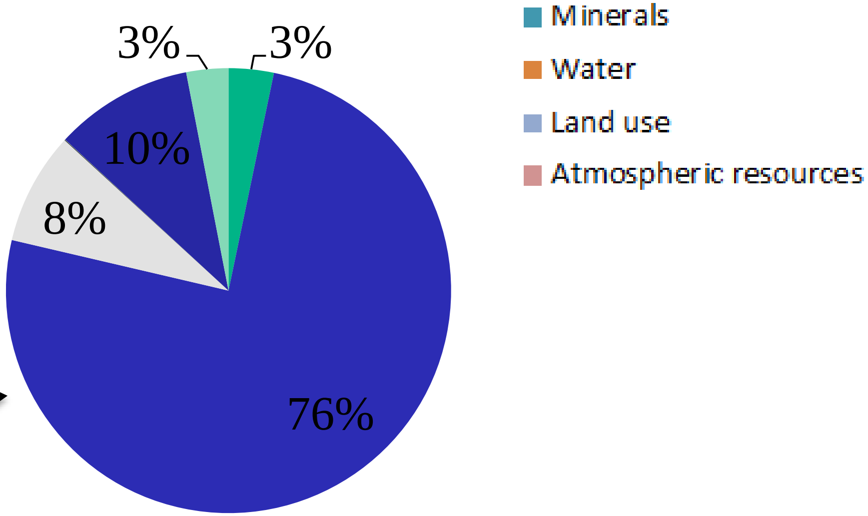


CEENE results

Focus on:
1 MJ_{ex} meal
0.5 MJ_{ex} oil

MJ_{ex}/functionalities	TOTAL	Relative contribution (%)
LINEAR ECONOMY		
Soybean cultivation	5.15	91.47
Drying	0.18	3.19
Crushing	0.10	1.75
Export to The Netherlands	0.20	3.58
TOTAL	5.63	
BIOREFINERY		
Algae cultivation	622	99.53
Drying	2.82	0.45
Crushing	0.13	0.02
TOTAL	625	





> factor 100 difference could be expected:
mature large scale technology (soybean) versus young small scale technology (algae)

Future outlook?

Possible to achieve a lower footprint? Let's have a look…

- Electricity based on renewables (wind energy)
- Reducing operating hours of blowing and mixing
- More efficient ventilators (not oversized)
- Higher yields under current climate possible
- Higher harvesting efficiency possible

Total resource footprint (CEENE) drops with factor 20!

When abiotic renewables are considered inexhaustible -> similar footprint!

Even other possibilities:
Recycling of centrate
Use of digestate