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Life Cycle Assessment (LCA)

MUSE, Energy track, Methods course

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Contents

- LCA methodology
  - Goal and scope
  - Inventory analysis
  - Impact assessment
  - Interpretation
- Some case studies
- Conclusions

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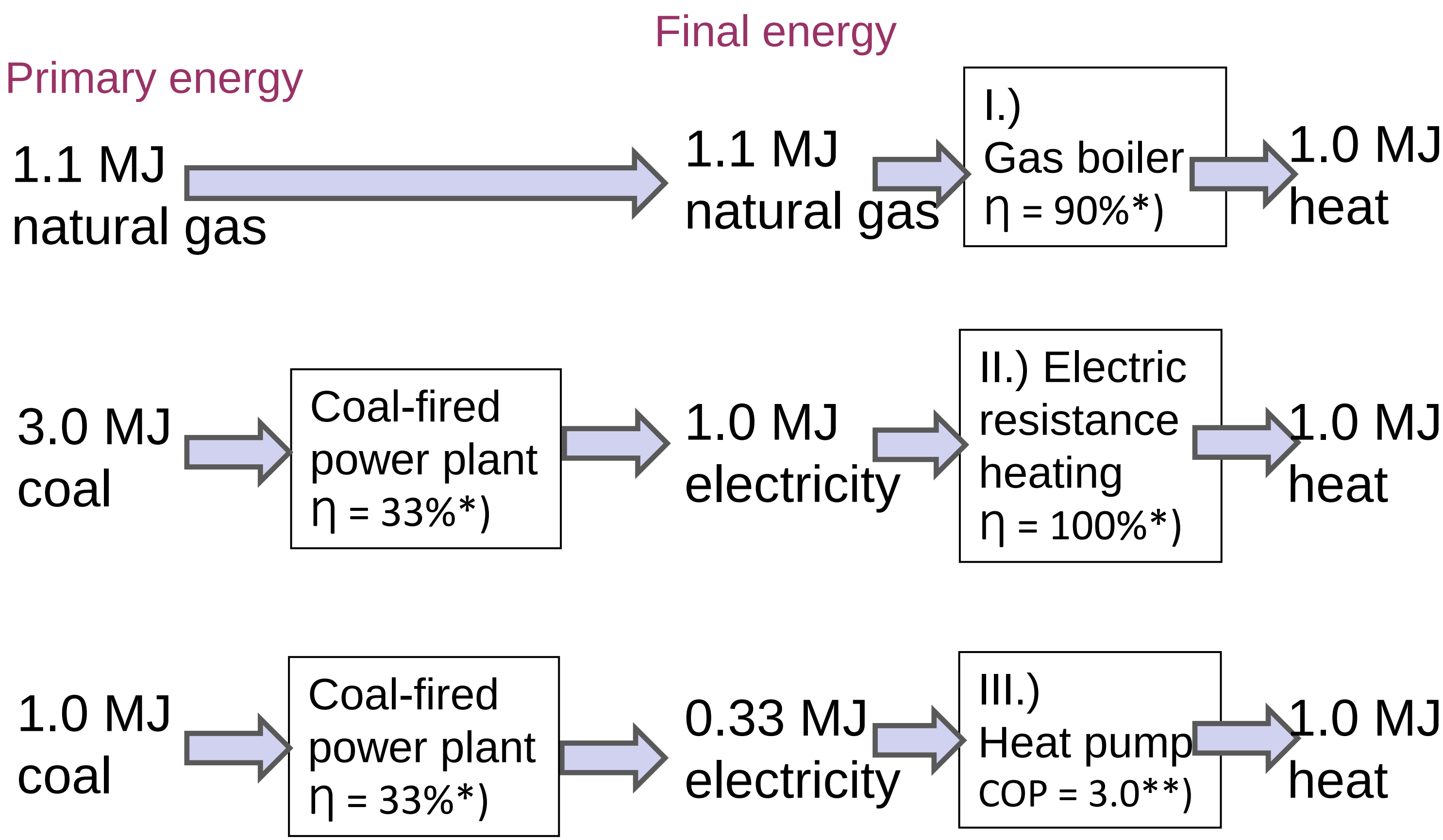
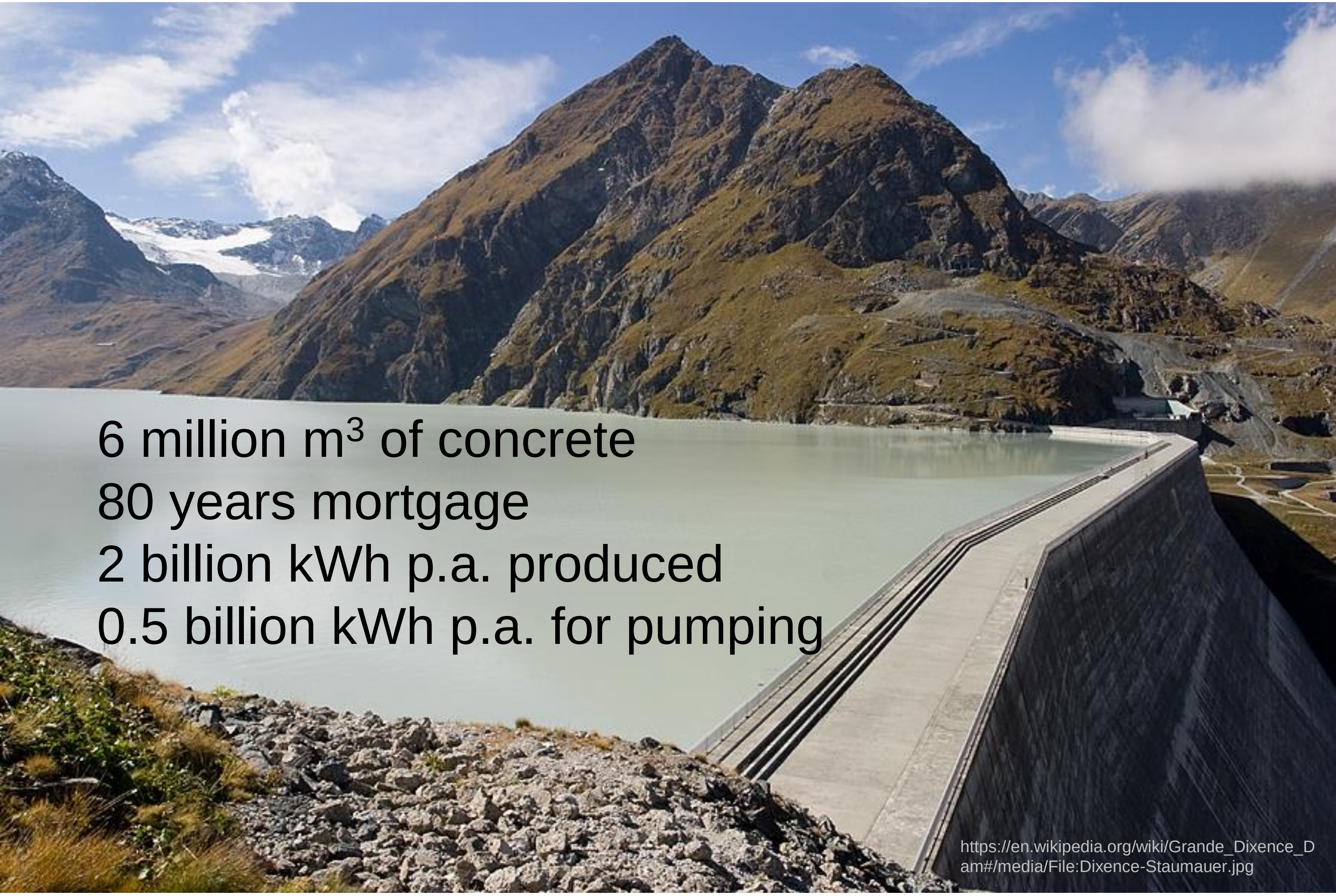
LCA for fair analysis

In primary energy terms Option II) is clearly worst while Option I) and III) are similar.



*) Efficiency = $Energy_{out}/Energy_{in}$ **) COP = $Heat_{output}/Electricity_{input}$

Reminder



https://en.wikipedia.org/wiki/Grande_Dixence_Dam#/media/File:Dixence-Staumauer.jpg

Rethinking demand

77 grammes almond bread

= 355 kcal

≈ **1.5 MJ** (without processing)

14 grammes PET

Total NREU
(material + processing)

≈ **1.4 MJ** (with processing)

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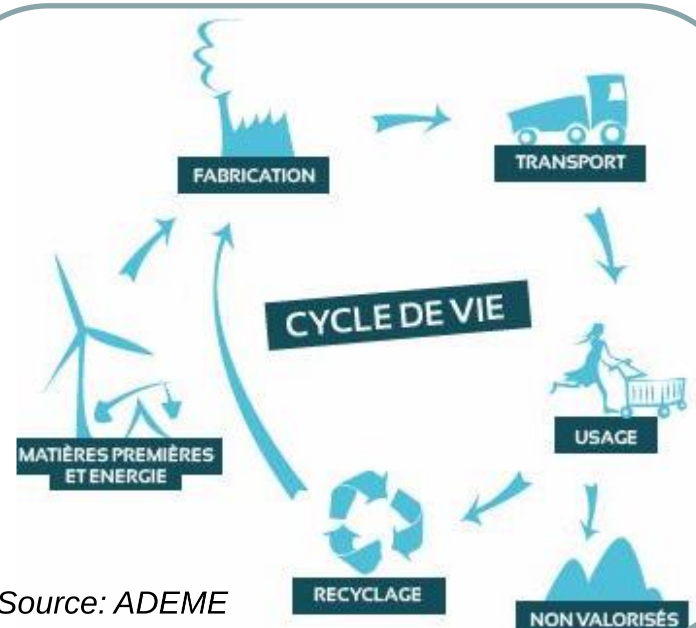
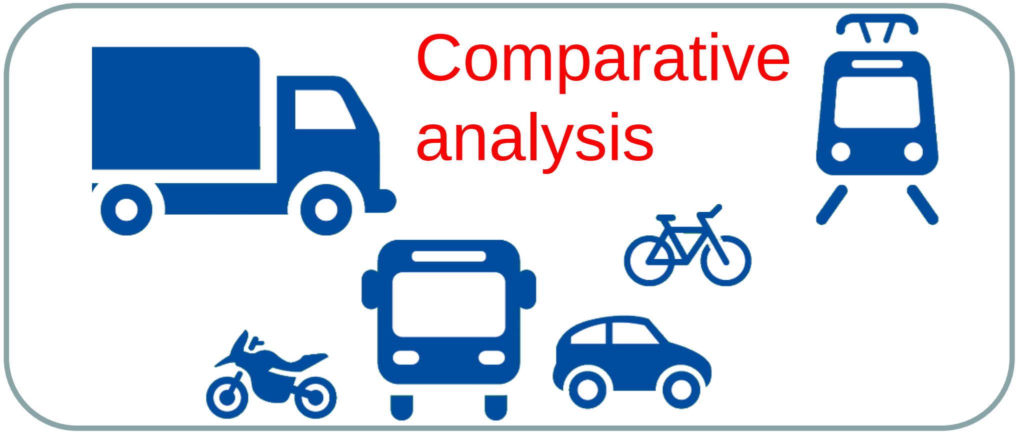
- **Some case studies**
- Conclusions

(Environmental) Life Cycle Assessment - LCA
Analyse du cycle de vie - ACV
Analisi/Valutazione del ciclo di vita
Ökobilanz

- Assessment of Environmental impacts
- of Products/Processes or Services
- throughout the Life Cycle: resource extraction, manufacturing, product use, waste management



Source: ADEME



LCA – General framework

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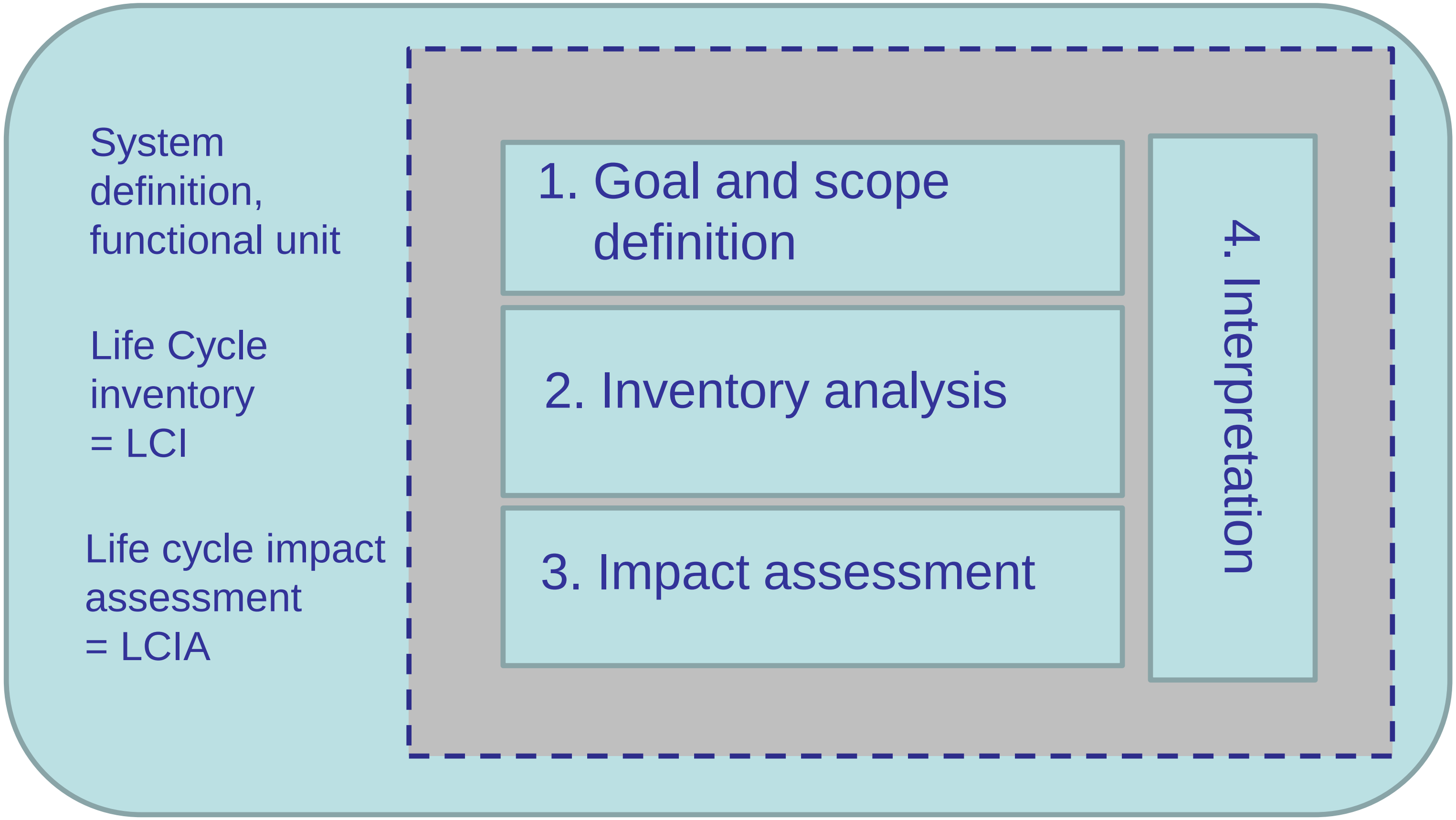

Applications:

- Product development & improvement ➔ eco-design
- Strategic planning
- Public policy making
- Marketing etc.

Source:
ISO 14040 & 14044

LCA – General framework

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Définition du système, unite fonctionnelle

Inventaire du cycle de vie
= LCI
= “inventaire”

Caractérisation et analyse des impacts = LCIA

1. Définition des objectifs et du champ de l’étude
   Goal and scope definition

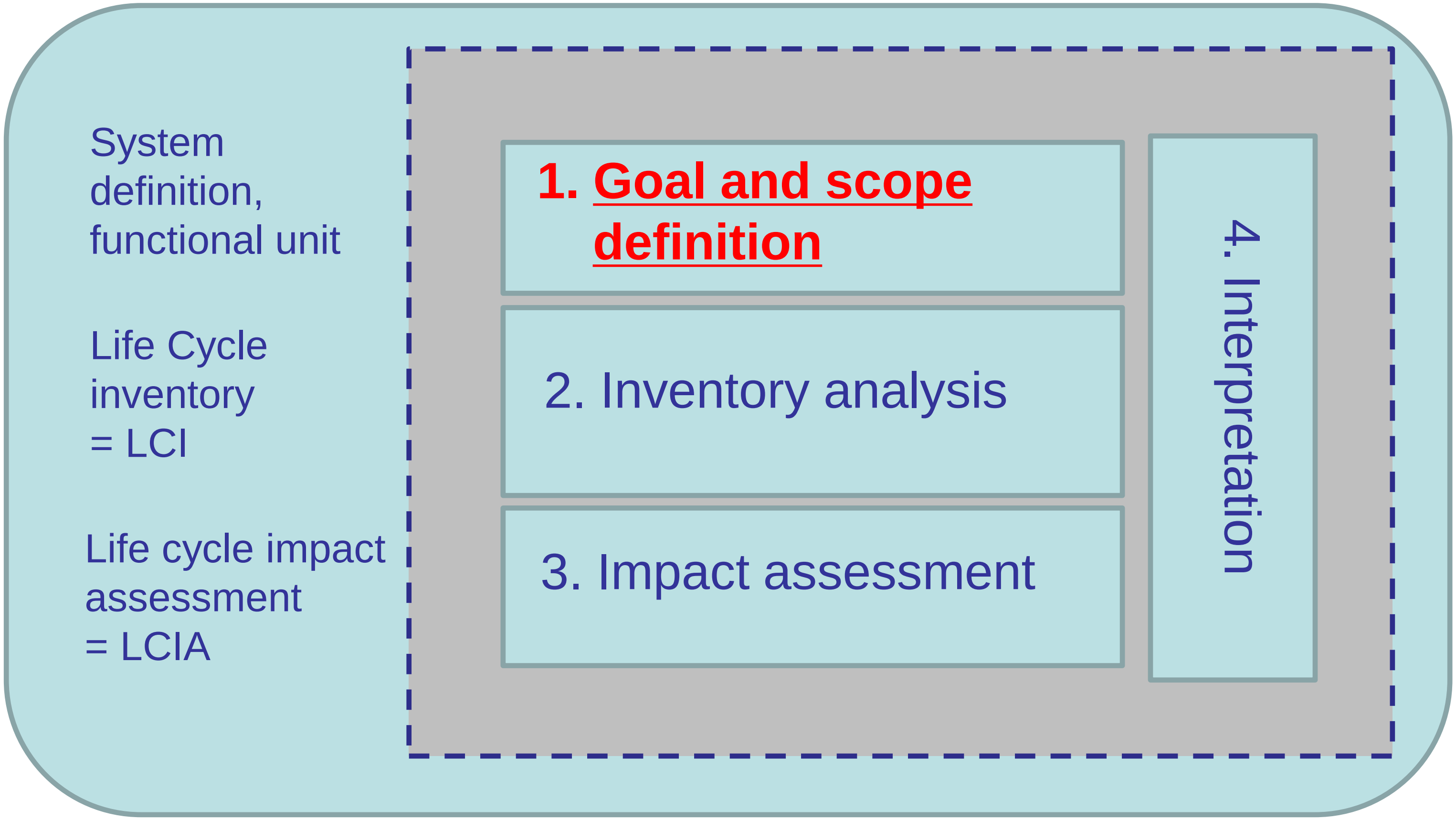
2. Collecte des données d’inventaire
   Inventory analysis

3. Evaluation de l’impact via indicateurs d’impacts
   Impact assessment

4. Interprétation

Source:
ISO 14040 & 14044

LCA – General framework



Applications:

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Step 1: Goal and scope – Functional unit and System boundaries

Goal definition

What, why and for whom and by whom? (qualitative)

Scope definition
(basis for comparison)

To which extent? How? (quantitative)

Formulation of research question / Def. of system / **Def. of Functional unit**

Step 1: Goal and scope – Functional unit and System boundaries

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Functional unit (1/2)

- **describes the *primary* function(s) fulfilled by a product system**
- **and indicates how much of this function is to be considered in the LCA study**
- **Quantity may be chosen arbitrarily**
  - does not contain the technical solution
  - contains no process data and no environmental impacts

Step 1: Goal and scope – Functional unit and System boundaries

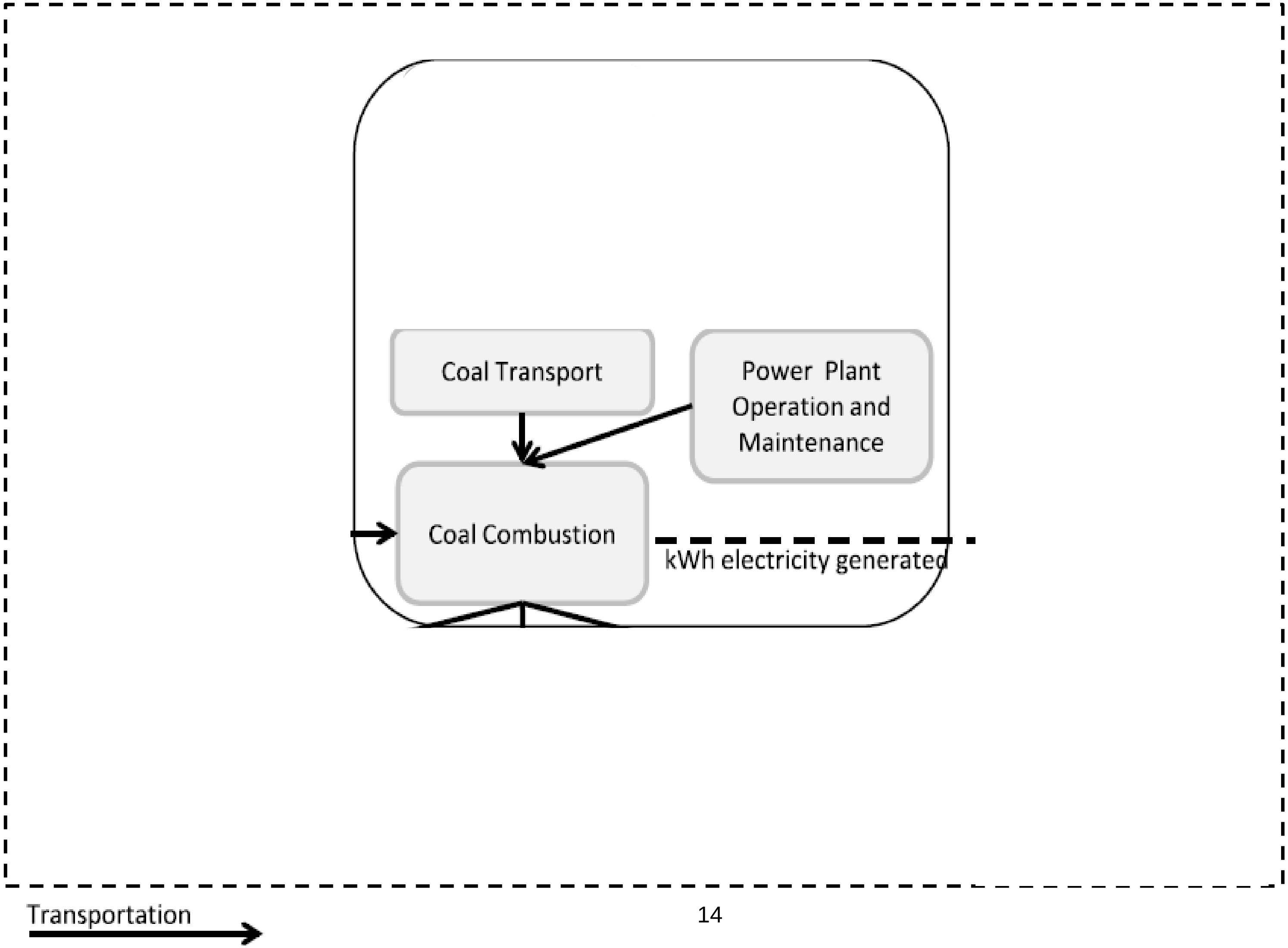
Functional unit (2/2)

- "…names and quantifies
- the qualitative and quantitative aspects
- of the function(s)
- along the questions "what", "how much", "how well", and "for how long". "

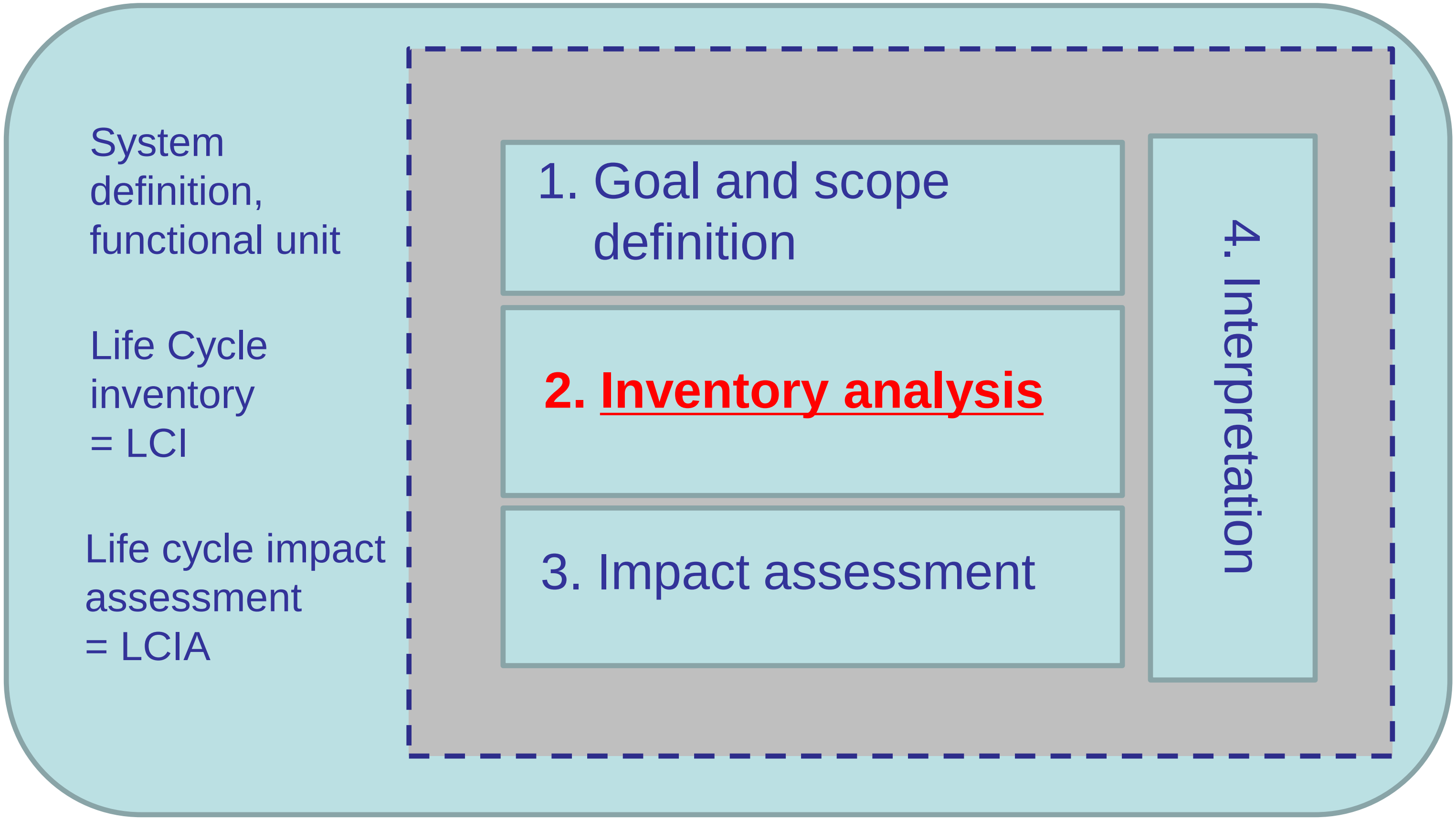
Source: ILCD Handbook

Step 1: Goal and scope – Functional unit and System boundaries

- Functional unit: unit which the impacts refer to: 1 kWh at power plant? Or 1 kWh at end user



LCA – General framework



Applications:
- Product development & improvement ➔ eco-design
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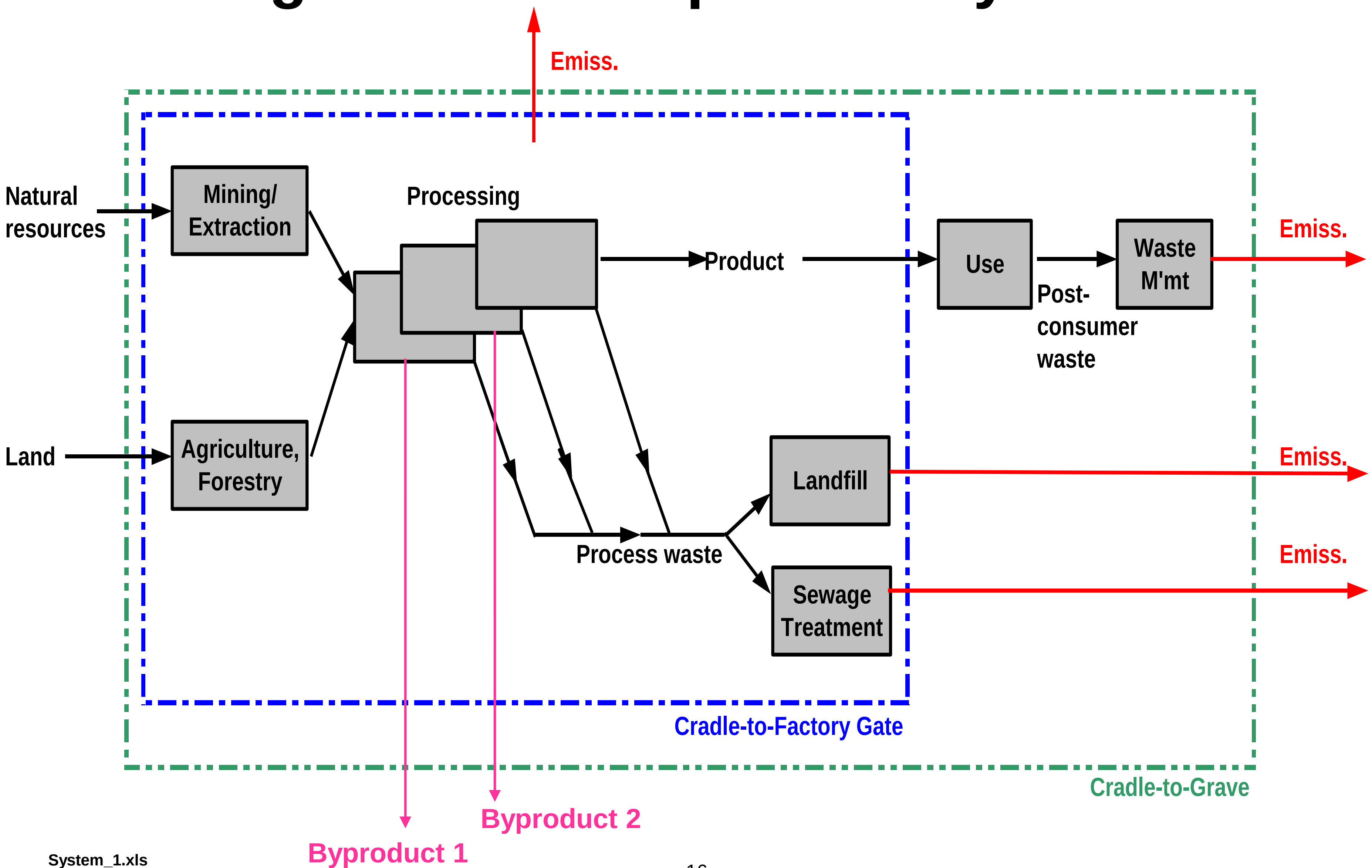
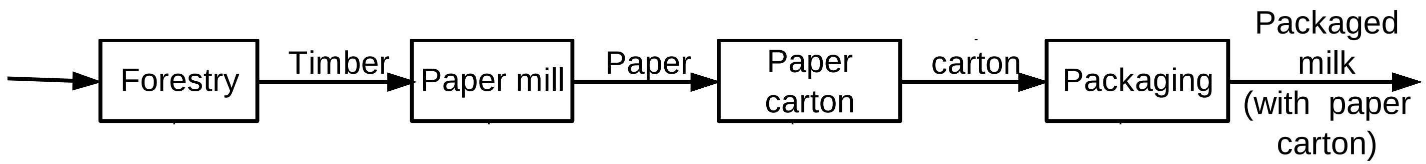
Source:
ISO 14040 & 14044

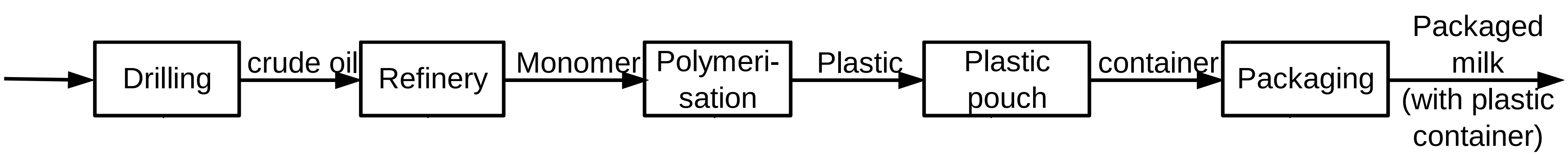
Step 2: Inventory analysis
Flow diagramme for a product system



System_1.xls

Flow diagramme for a product system: Milk packaging (1/2)

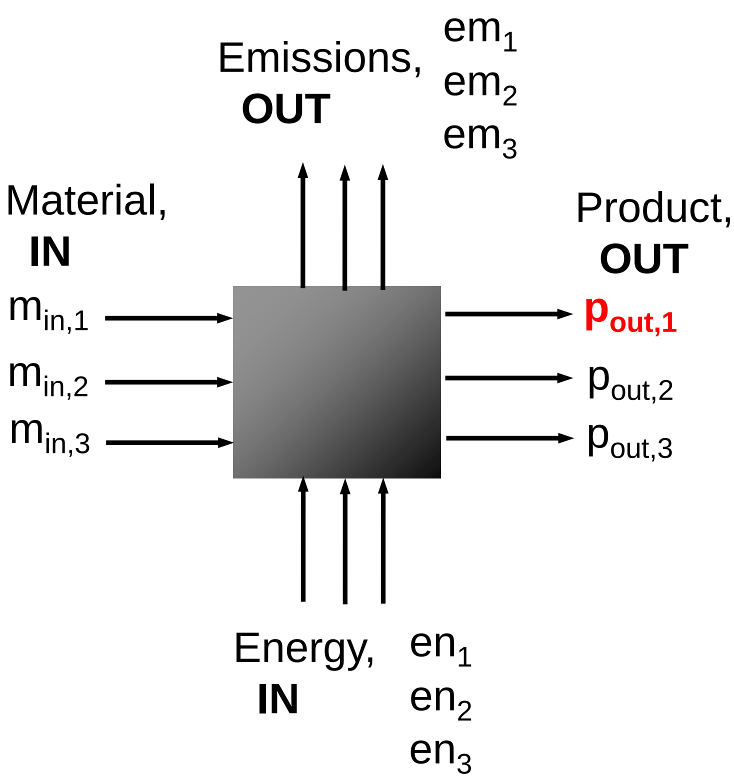




Flow diagrammes for LCAs: Focus on *main* flows

Milk_example_1_fromKirk-Othmer_adapted_1.xls

Modelling a unit process
(products and energy commodities)



m = Material (or resource or product)

p = Product (processed material, semi-finished product, final product, secondary energy)

en = Energy

em = Emission

Transfer coefficients, e.g.,
$m_{in,1}/p_{out,1}$, $m_{in,2}/p_{out,1}$, $en_1/p_{out,1}$ etc.

General practice in LCA and other simple resource, material and emission models

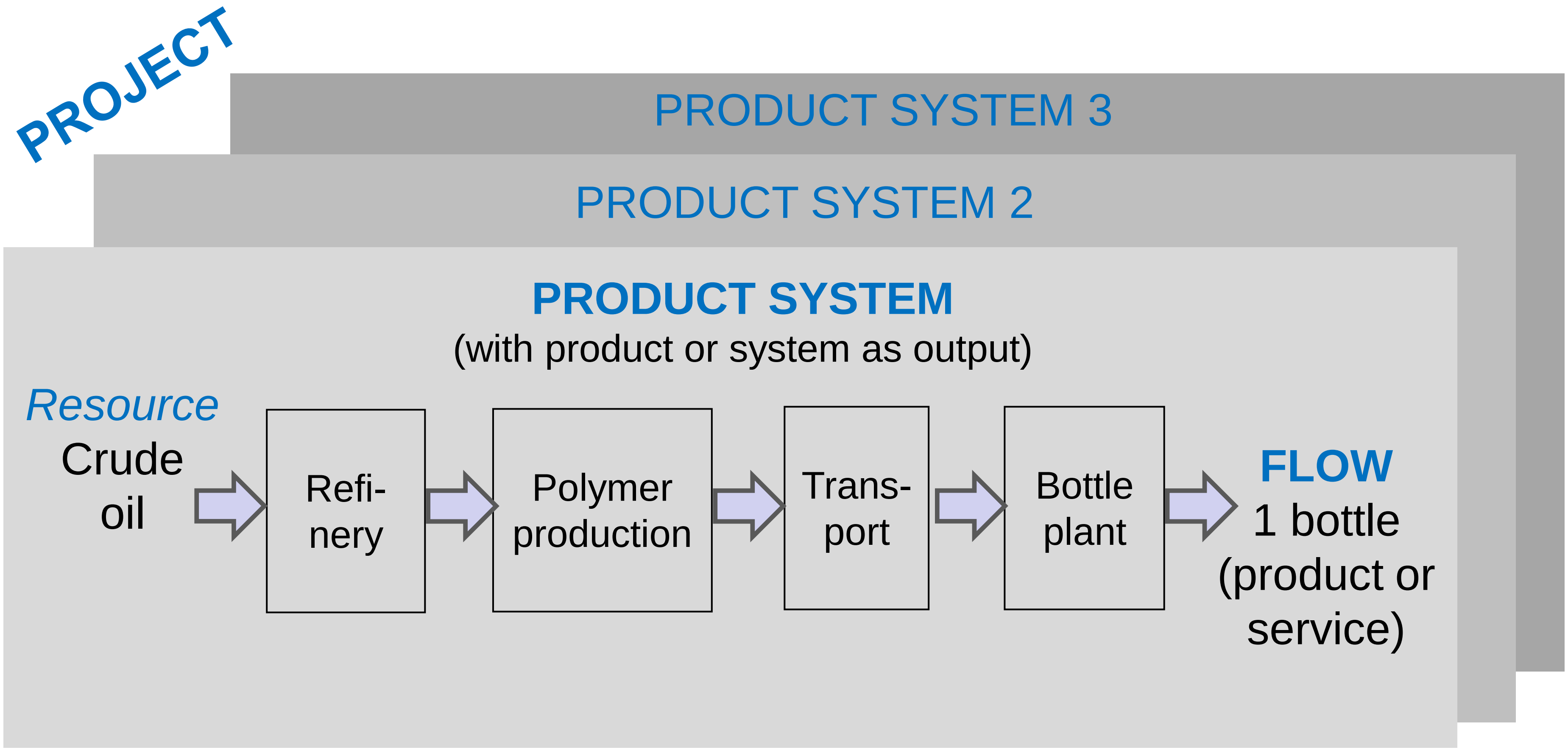
Mathematic representation of the conversion step

- Usually linear; for practical reasons all other values are then usually expressed **as function of $\mathbf{p_{out,1}}$**
- For continuous processes: Steady state (“static”)
  For batch: one entire cycle

Usual way of data processing:

- Given: all flows in **physical** units, e.g. tonnes material, GJ energy, million moles of element i
- → Flow in specific units
  Usually: Per unit of main product $p_{out,1}$ (→ transfer coefficient)

Some terms



PROJECT
PRODUCT SYSTEM 3
PRODUCT SYSTEM 2
PRODUCT SYSTEM
(with product or system as output)
Resource
Crude oil
Refi-nery
Polymer production
Trans-port
Bottle plant
FLOW
1 bottle (product or service)

Step 2: Inventory analysis
Flow diagramme for a product system

Various sources of information :

- LCI database
  - Ecoinvent – Swiss database (http://www.ecoinvent.ch/)
  - CCaLC – Carbon calculations (http://www.ccalc.org.uk/)
  - ELCD – EU database (http://eplca.jrc.ec.europa.eu/ELCD3/)
  - etc.
- Data from project partners
  - Producers of PV modules, Wind Turbine , aluminium, concrete, …

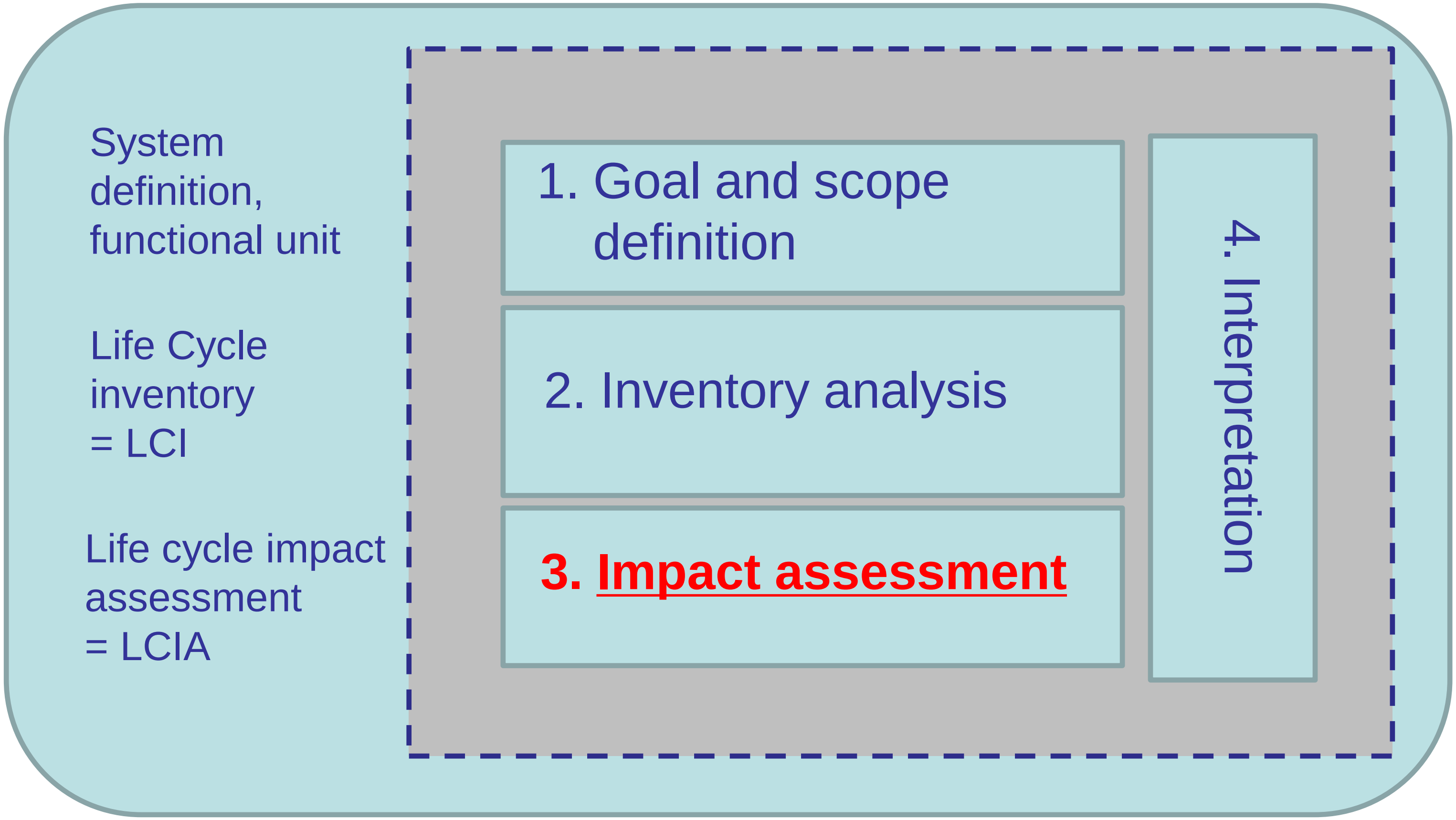
If some information is not available or not representative, the scope of the study should be redefined (iterative work)

- Ex: End-of-life of nuclear power plant


MATRA


MATIERE PREMIERE
PRODUCTION
TRANSPORT
DISTRIBUTION
PRODUIT
FIN DE VIE
ANALYSE
DE CYCLE
DE VIE

LCA – General framework



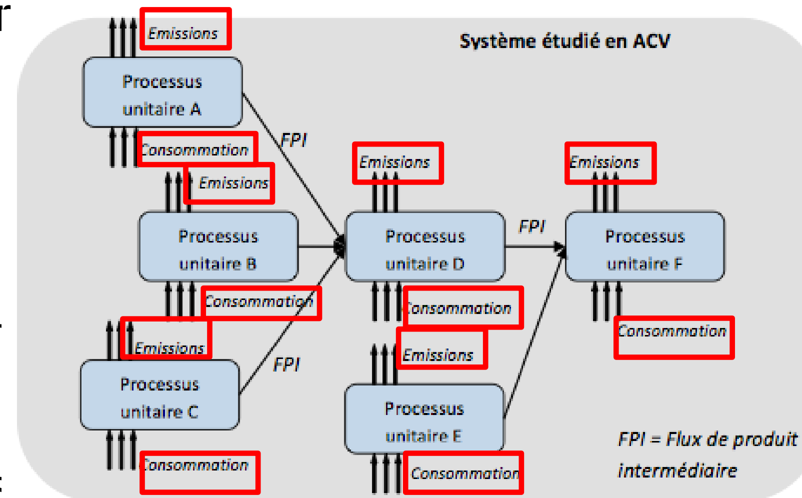
Applications:

- Product development & improvement ➔ eco-design
- Strategic planning
- Public policy making
- Marketing etc.

Source:
ISO 14040 & 14044

Step 3: From flow diagramme to environmental impacts

1. Make a flowsheet (e.g. PV)
2. Determine mass flows of all compounds (mass balance)
3. Investigate grey energy and emissions per tonne product, e.g. CO_2/t, PCB/t, etc.
   - For commodity products (e.g., PE): from databases
   - For unknown/new products or process steps (e.g. nanoparticle production): Investigate data.
4. Multiply each mass flow (from 2) with emissions per tons of product (from 4)
5. Determine energy requirements for processes and multiply (by analogy with 3 & 4)
6. Add everything up in an inventory table
   - Ecoinvent database currently contains around 1600 compounds (e.g., CO_2, NOx, CH_4)



Inventory database

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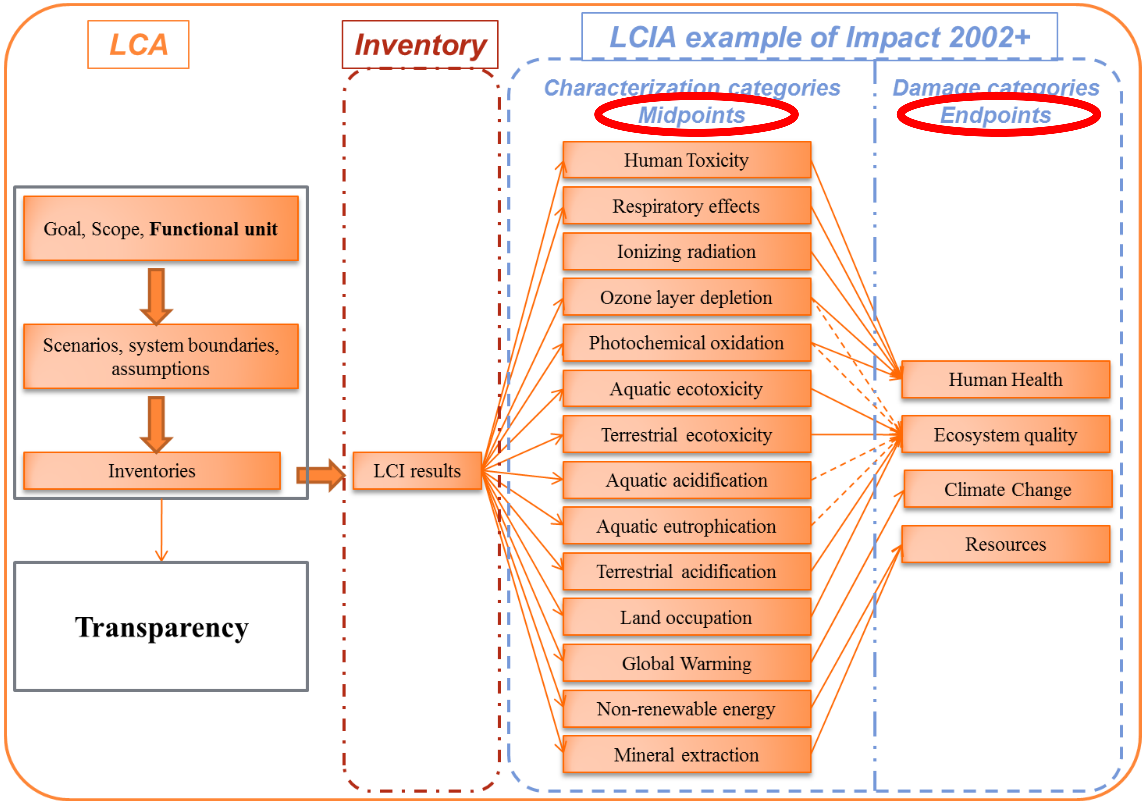
Example: Characterization factors for climate change

Compounds contributing to Climate Change (100 year time period):

- CO_2 : 1.0 kg CO_2 equivalents/kg CO_2
- N_2O : 296 kg CO_2 equivalents/kg N_2O
- CH_4 : 25 kg CO_2 equivalents/kg CH_4 (4th IPPC Ass. Rep.)
  34 kg CO_2 equivalents/kg CH_4 (5th IPPC Ass. Rep.)
  30 kg CO_2 equivalents/kg CH_4 (6th IPPC Ass. Rep.)
- etc.

Step 3: From flow diagramme to environmental impacts

- LCIA: Life Cycle Impact Assessment
- Convert all the emissions with a same impact on the environment into a single unit
  - kg of CO_2 equivalent
  - kg of Sb equivalent, etc.



In more detail:
Characterization factor CF
$= f$ (location, t, Δt, interaction, …)

Environmental Impact Categories (ReCiPe method)

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Midpoint level

1. Climate change (CC)
2. Ozone depletion (OD)
3. Terrestrial acidification (TA)
4. Freshwater eutrophication (FE)
5. Marine eutrophication (ME)
6. Human toxicity (HT)
7. Photochem. oxidant formation (POF)
8. Particulate matter formation (PMF)
9. Terrestrial ecotoxicity (TET)
10. Freshwater ecotoxicity (FET)
11. Marine ecotoxicity (MET)
12. Ionising radiation (IR)
13. Agricultural land occupation (ALO)
14. Urban land occupation (ULO)
15. Natural land transformation (NLT)
16. Water depletion (WD)
17. Mineral resource depletion (MRD)
18. Fossil fuel depletion (FD)

Endpoint level

Damage to

1. Human health (HH)
2. Ecosystem diversity (ED)
3. Resource availability (RD)

New method:

Environmental Footprint (EF),

https://eplca.jrc.ec.europa.eu/LCDN/developerEF.html

Goedkoop, Heijungs, Huijbregts, De Schryver, Struijs, van Zelm: ReCiPe method, 2009

So, what is Grey Energy…?

Grey energy = embodied energy = indirect energy (next to direct energy related to operation of a device)

SIA (cahier technique 2032) *): „cumulative non-renewable energy use“ (NREU)

Cumulative energy demand (CED) acc. to VDI
= cumul. non-renewable + cumul. renewable energy demand

And: Gross Energy Requirements (GER), “energy“, “primary energy“ etc.

*) http://www.sia.ch/fileadmin/content/download/sia-norm/korrigenda_sn/2032-C1_2010_d.pdf:
SIA Merkblatt 2032: Gesamte Menge nicht erneuerbarer Primärenergie, die für alle vorgelagerten Prozesse, vom Rohstoffabbau über Herstellungs- und Verarbeitungsprozesse und für die Entsorgung, inkl. der dazu notwendigen Transporte und Hilfsmittel, erforderlich ist. Sie wird auch als kumulierter, nicht erneuerbarer Energieaufwand bezeichnet.

**) http://www.vdi.eu/guidelines/vdi_4600-kumulierter_energieaufwand_kea_begriffe_berechnungsmethoden/

Critical issues in LCAs

Phase	Problem
Goal and Scope Definition	Functional unit definition Boundary selection Consideration of alternative product systems
Life Cycle Inventory analysis	Allocation Negligible contribution ('cutoff criteria')
Life Cycle Impact Assessment	Impact category and methodology selection Spatial variation Local environmental uniqueness Time horizons
All phases	Data availability and quality

Simplified summary based on: Reap J., Roman, F., Duncan, S., Bras, B., 2008a, “A Survey of Unresolved Problems in Life Cycle Assessment”, International Journal of Life Cycle Assessment 13(4): 290-300

Functional unit

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- For standard products (textbook examples)
  - 1 tonne steel, 100 m^2 of residential space, 1 person-kilometer travelled
- Commercialized products, e.g.
  - Different types of milk packaging or different cars, as sold
  - Different manufacturing processes, e.g. primary steel vs. recycled steel
- Theoretical, e.g.
  - Based on material science (e.g. physically defined strength of a material)

Critical issues in LCAs

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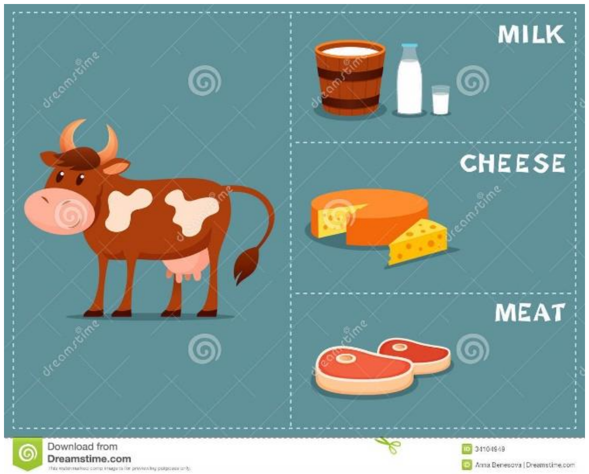
Allocation - Intro

Needs to be dealt with in the case of “multi-product processes”



http://opening.download/first-downloading.html
https://fineartamerica.com/featured/piles-of-logs-and-sawdust-at-a-sawmill-david-nunukscience-photo-library.html
https://economictimes.indiatimes.com/industry/indl-goods/svs/steel/sail-bsp-blown-in-plants-blast-furnace-no-8-mahamaya/articleshow/62769611.cms
https://www.shapecut.com.au/blog/can-steel-slag-help-to-save-the-world/
https://www.bbcgoodfood.com/howto/guide/top-10-ways-leftover-egg-whites-and-yolks

Allocation – Approaches (general)

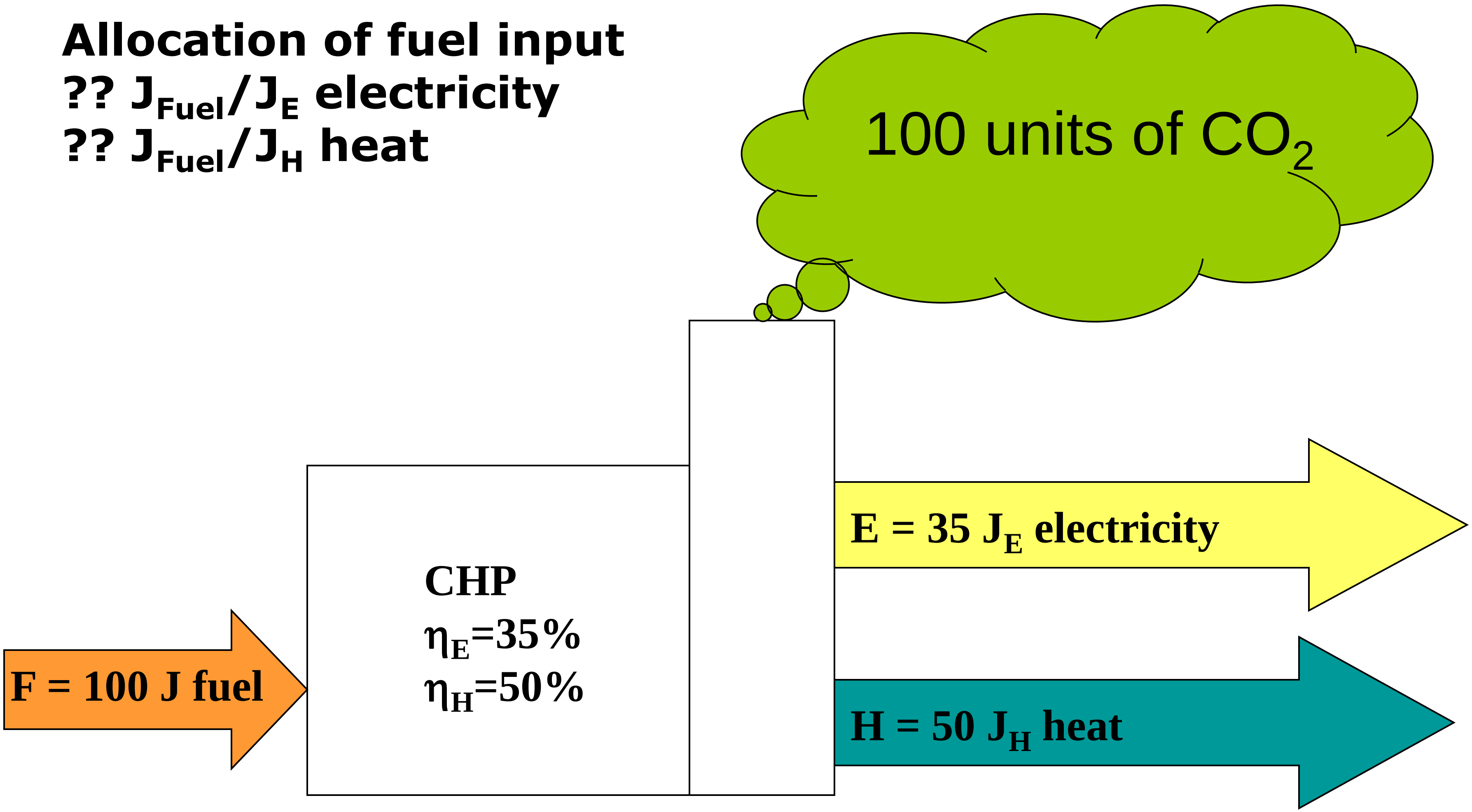
How to deal with multi product processes (co-products) ?

When flows cannot be related only to functional unit (e.g., ethylene production)

- Allocation (=Partitioning)
  - Flows and emissions are divided among the co-products of the process (e.g. according to physical or economic criteria)
- System expansion
  - System boundaries are expanded to include all co-products of the process

Allocation options for Combined Heat and Power (CHP)

Allocation of fuel input
?? J_{Fuel}/J_E electricity
?? J_{Fuel}/J_H heat

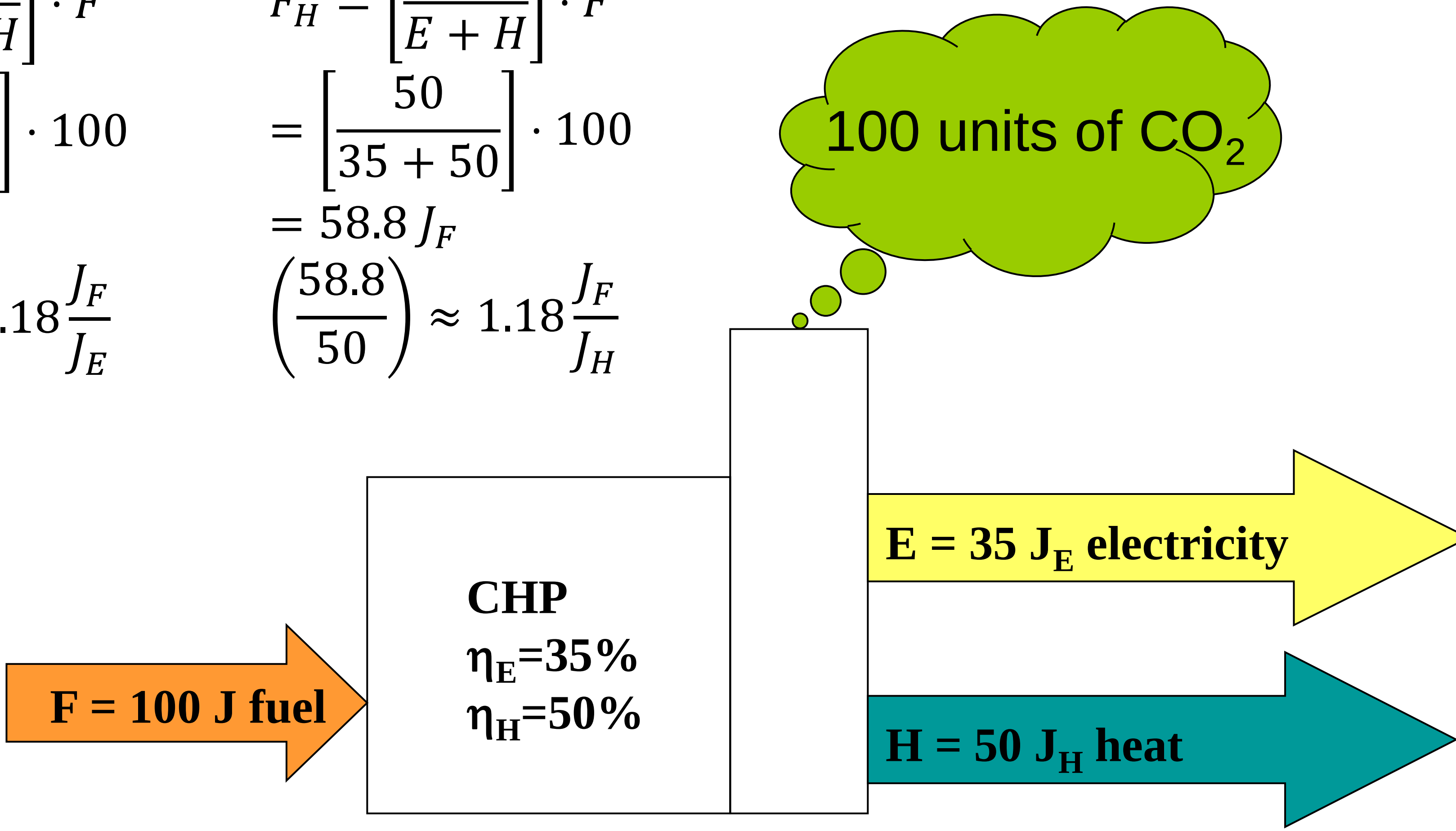


See Book [Blok and Nieuwlaar]

1. Allocation based on final energy of outputs

$$F_E = \left[\frac{E}{E+H}\right] \cdot F$$
$$= \left[\frac{35}{35+50}\right] \cdot 100$$
$$= 41.2\, J_F$$
$$\left(\frac{41.2}{35}\right) \approx 1.18 \frac{J_F}{J_E}$$

$$F_H = \left[\frac{H}{E+H}\right] \cdot F$$
$$= \left[\frac{50}{35+50}\right] \cdot 100$$
$$= 58.8\, J_F$$
$$\left(\frac{58.8}{50}\right) \approx 1.18 \frac{J_F}{J_H}$$

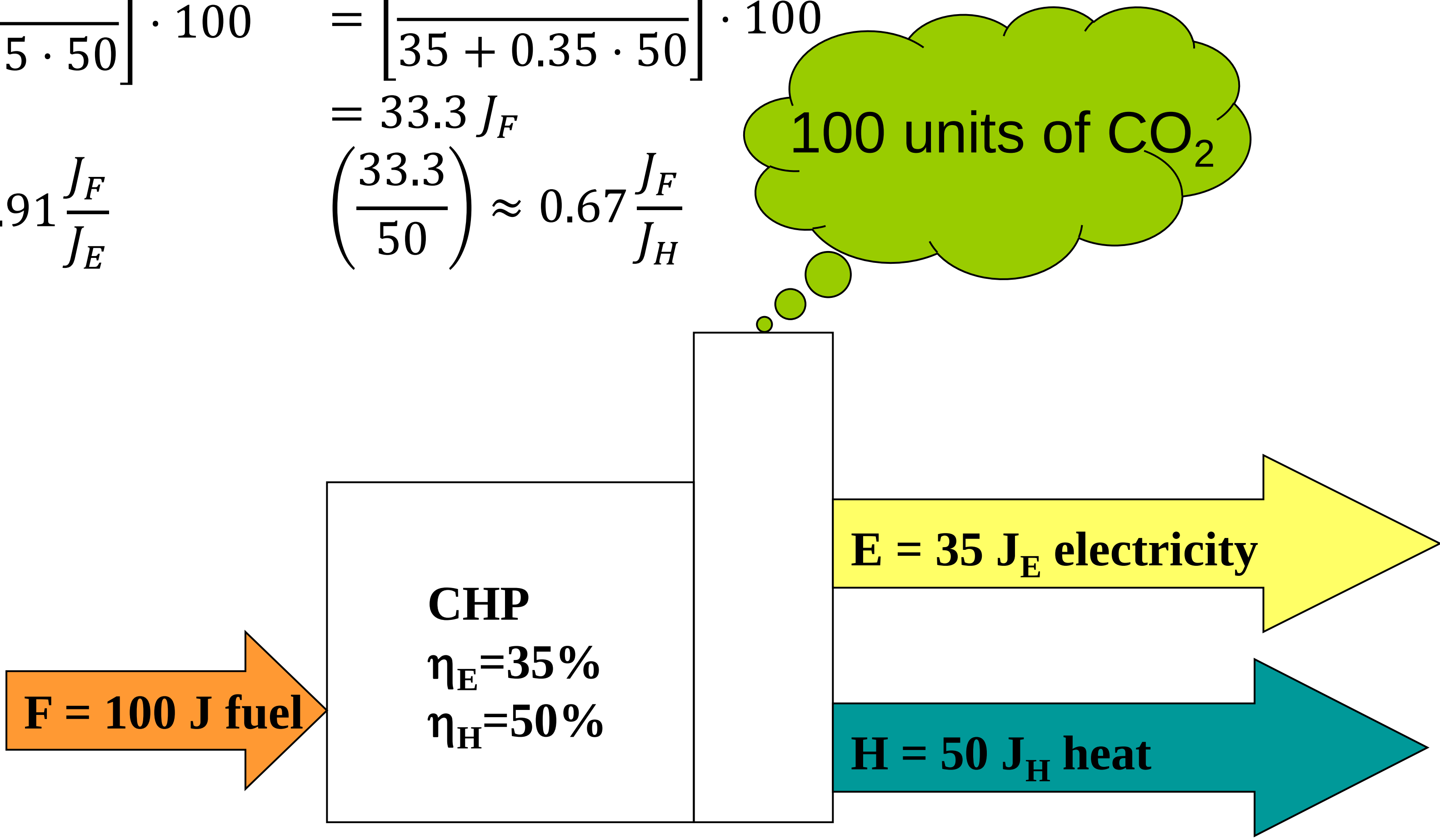


Slide copy Evert Nieuwlaar, Utrecht University

2. Allocation based on exergy*) of outputs

$$F_E = \left[\frac{E}{E + \beta H}\right] \cdot F$$
$$= \left[\frac{35}{35 + 0.35 \cdot 50}\right] \cdot 100$$
$$= 66.7\ J_F$$
$$\left(\frac{66.7}{35}\right) \approx 1.91 \frac{J_F}{J_E}$$

$$F_E = \left[\frac{\beta H}{E + \beta H}\right] \cdot F$$
$$= \left[\frac{0.35 \cdot 50}{35 + 0.35 \cdot 50}\right] \cdot 100$$
$$= 33.3\ J_F$$
$$\left(\frac{33.3}{50}\right) \approx 0.67 \frac{J_F}{J_H}$$



*) see additional slides on exergy at the end of this slideset

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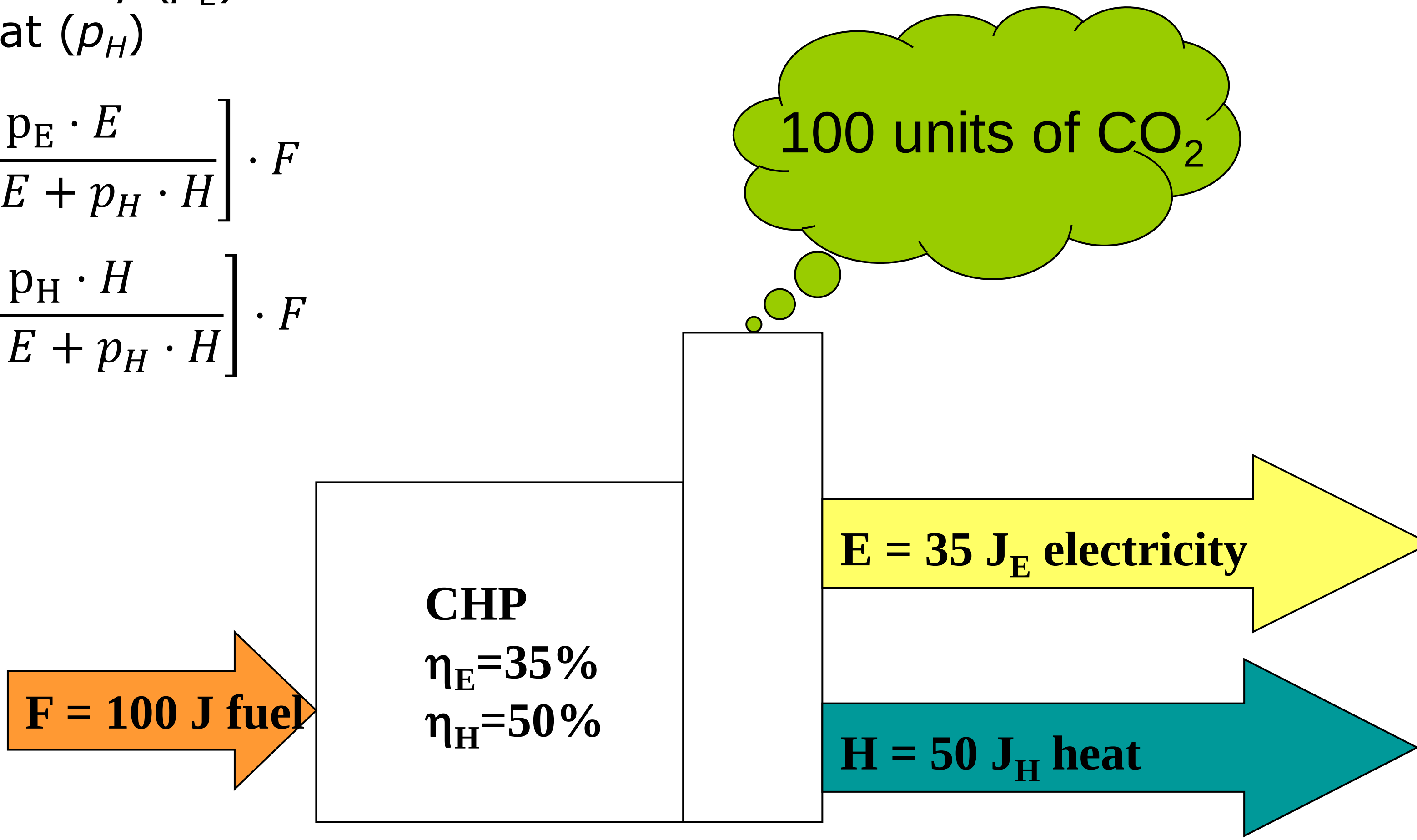
3. Economic allocation

use prices
for electricity (p_E)
and heat (p_H)

$$F_E = \left[\frac{p_E \cdot E}{p_E \cdot E + p_H \cdot H}\right] \cdot F$$

$$F_H = \left[\frac{p_H \cdot H}{p_E \cdot E + p_H \cdot H}\right] \cdot F$$



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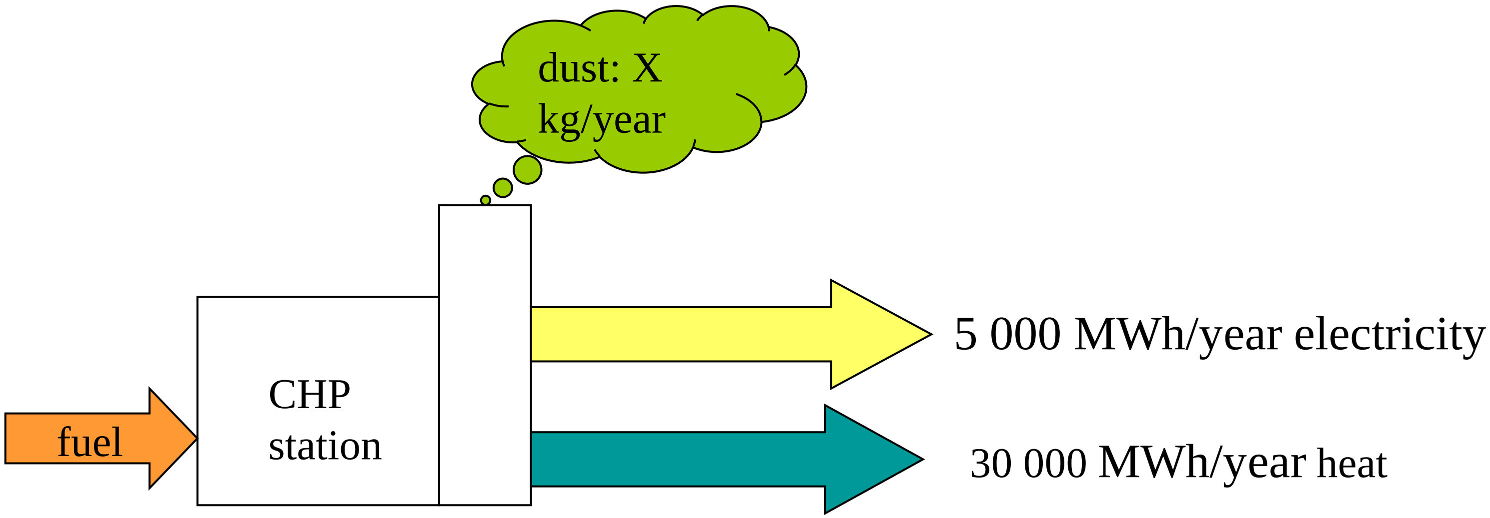
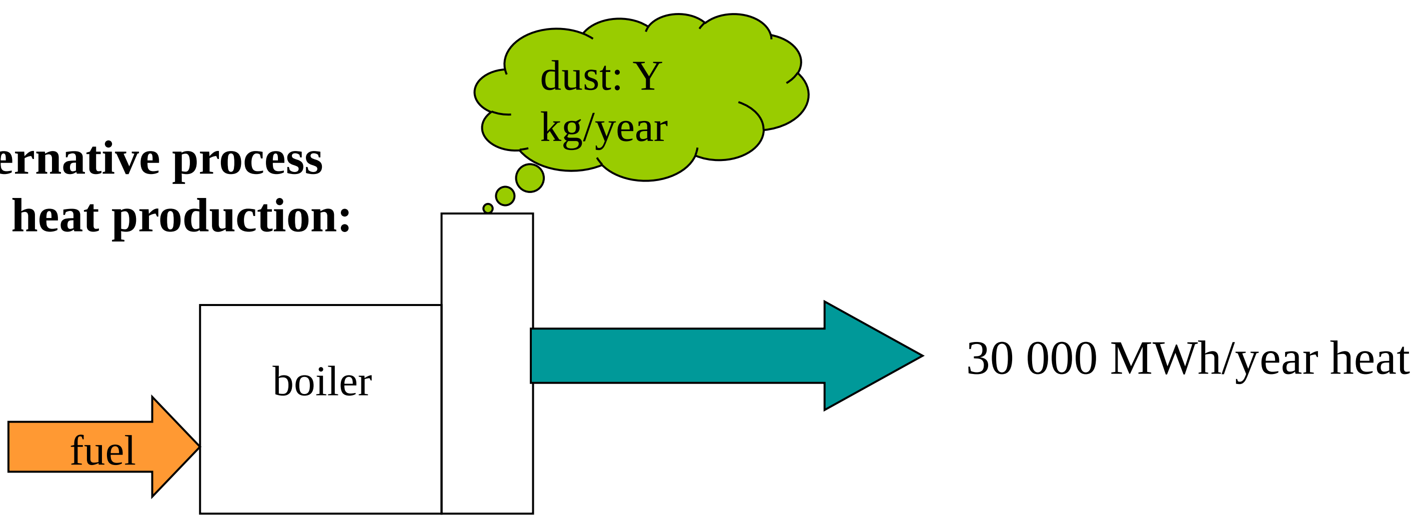
4. System expansion (1/2)



alternative process for heat production:



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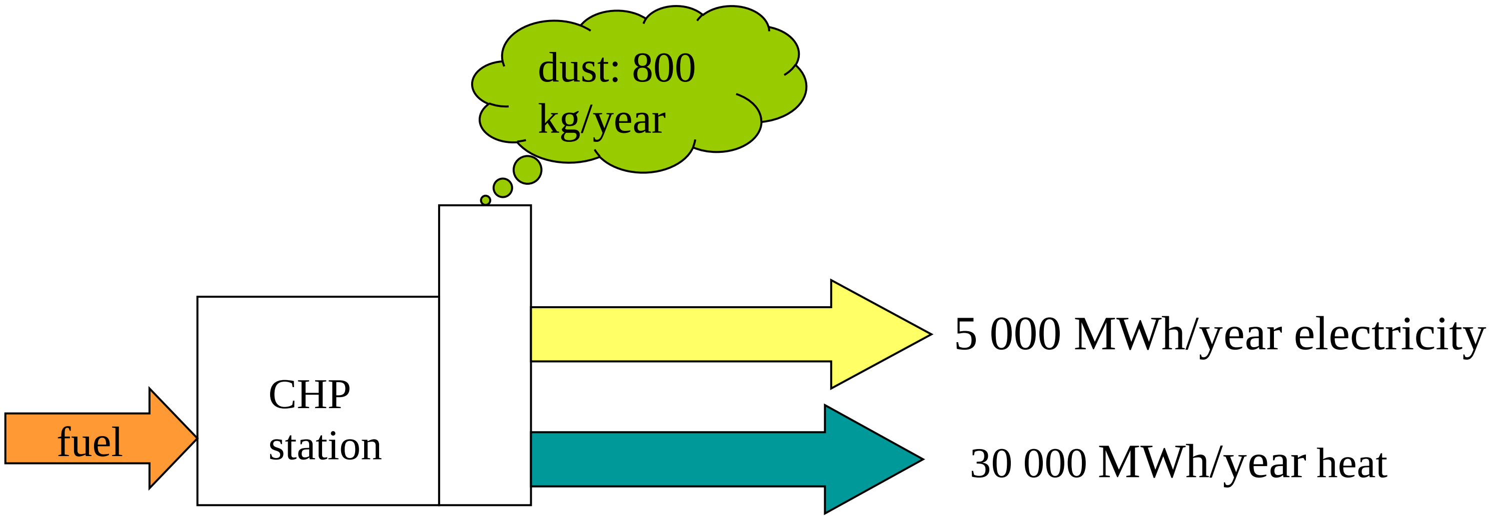
4. System expansion (1/2)



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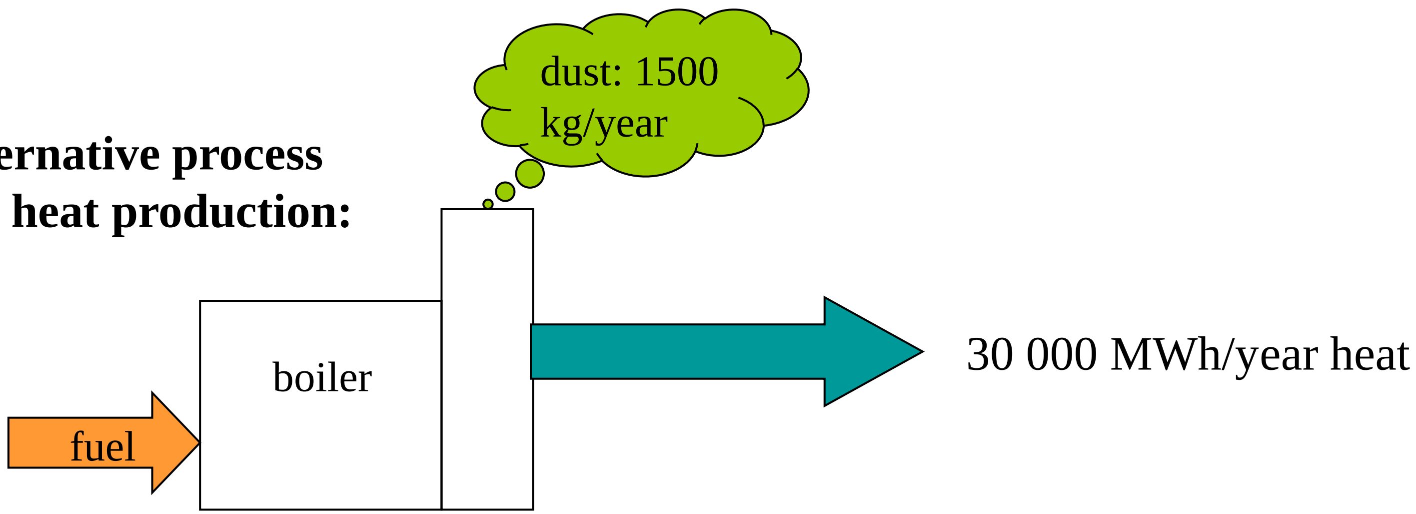

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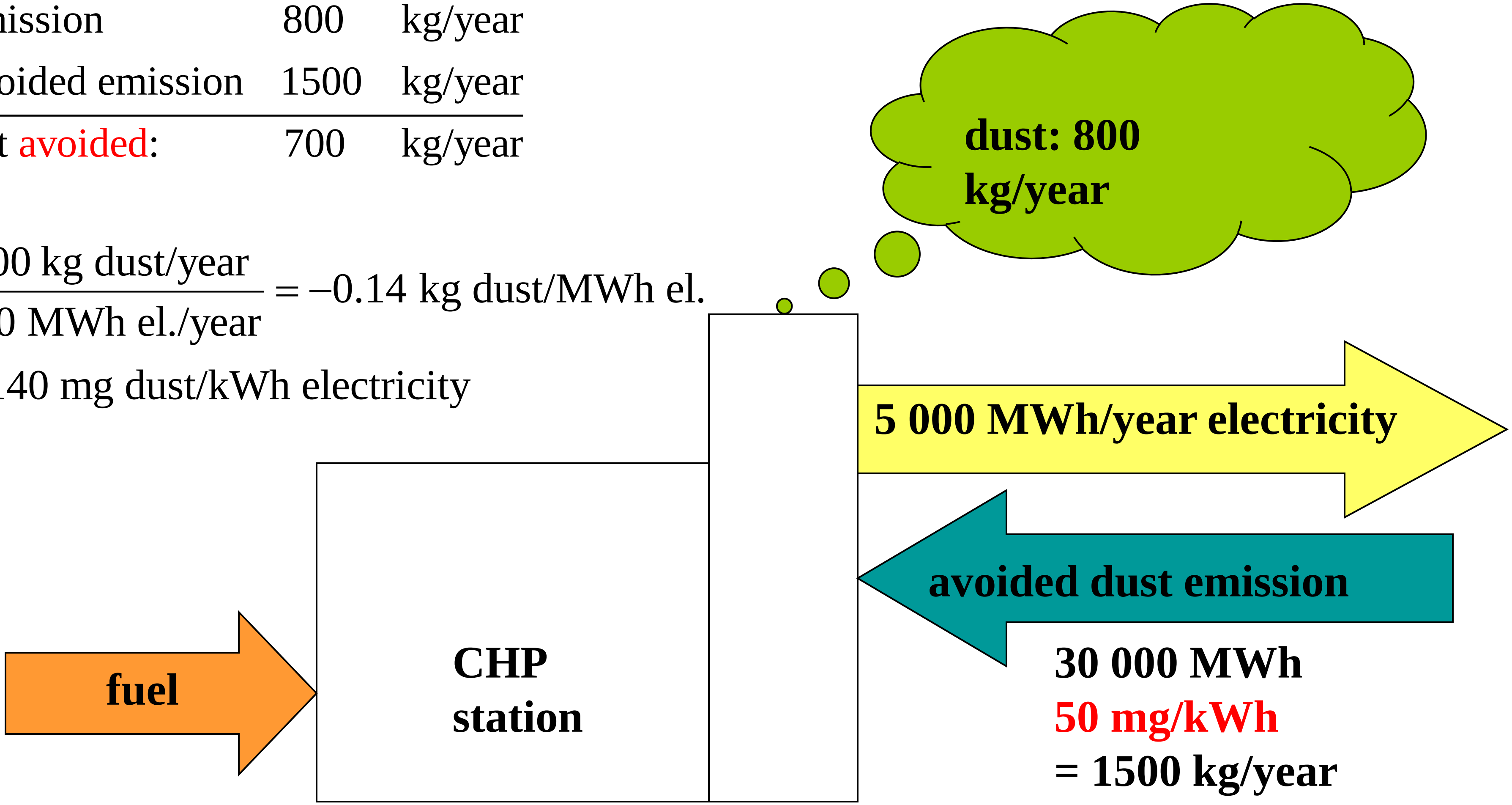
4. System expansion (2/2)

emission	800	kg/year
avoided emission	1500	kg/year
net avoided:	700	kg/year

$$\frac{-700 \text{ kg dust/year}}{5000 \text{ MWh el./year}} = -0.14 \text{ kg dust/MWh el.}$$

$$= -140 \text{ mg dust/kWh electricity}$$



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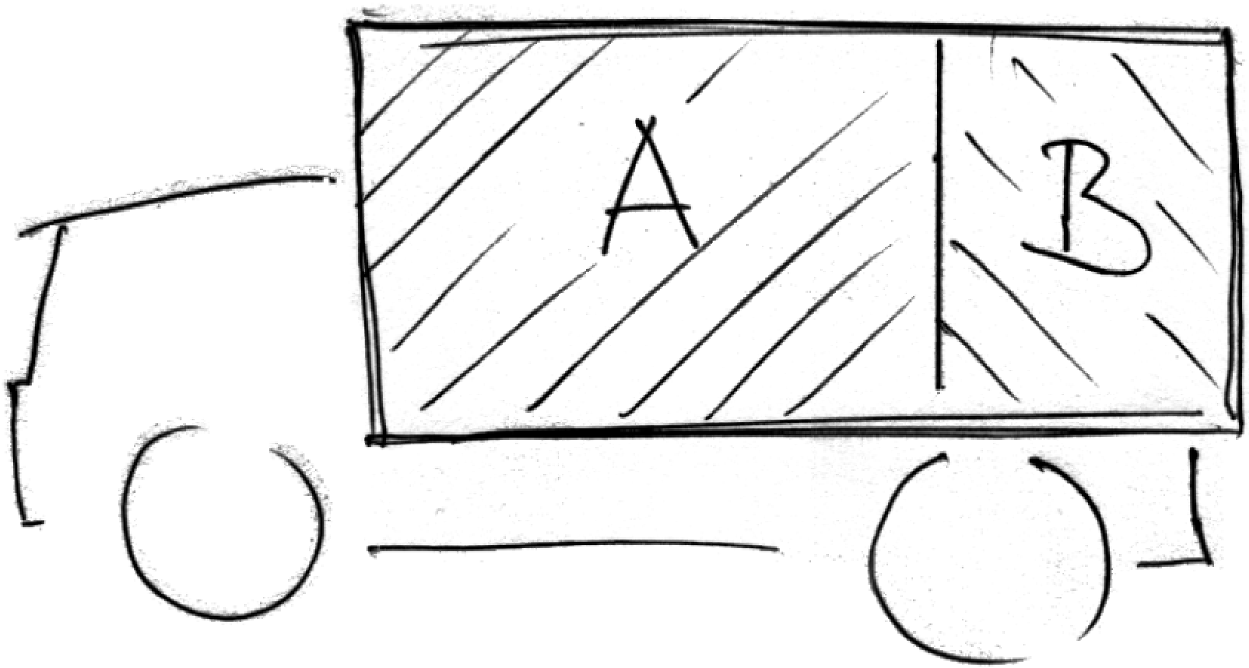
Allocation (1/3)



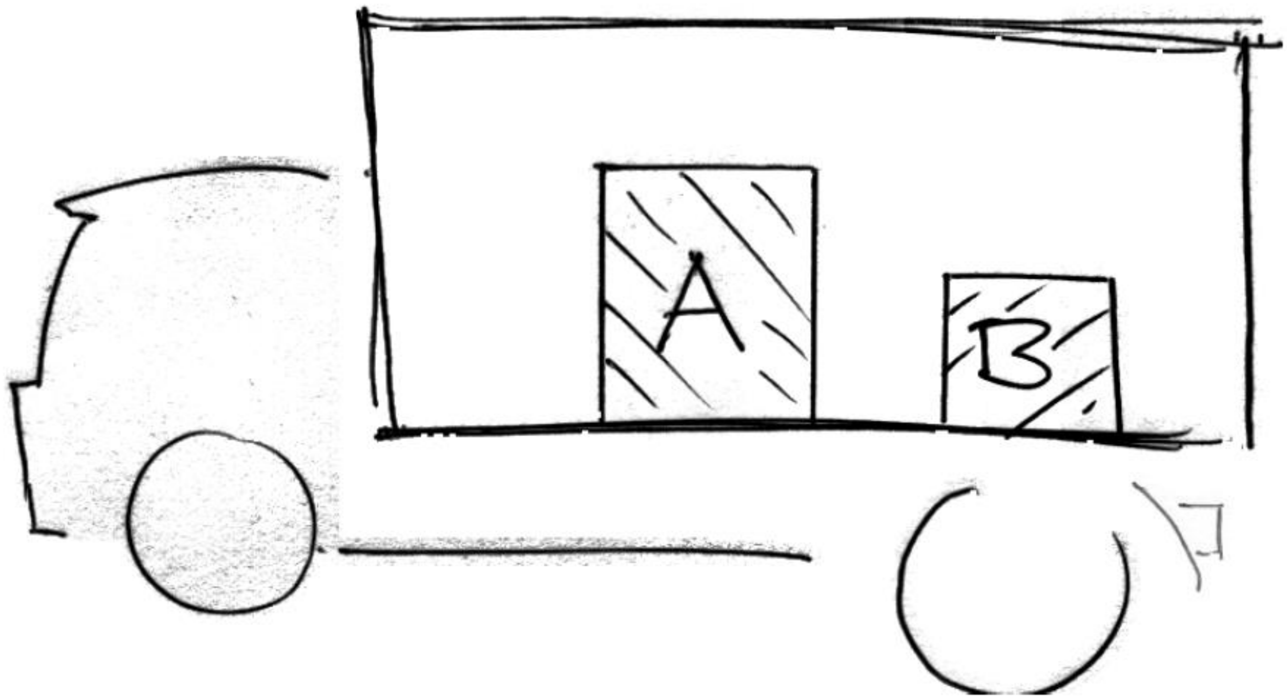
- Transport EPS (expanded polystyrene) over 40 km.
- Two types of EPS, type A and type B.
- Total energy (truck, full with EPS, 40 km) = 10 litres diesel

How much diesel for type A, how much for type B?

→ Answer:

For A: volume(A)/{volume(A) + volume(B)} * Total energy

Allocation (2/3)



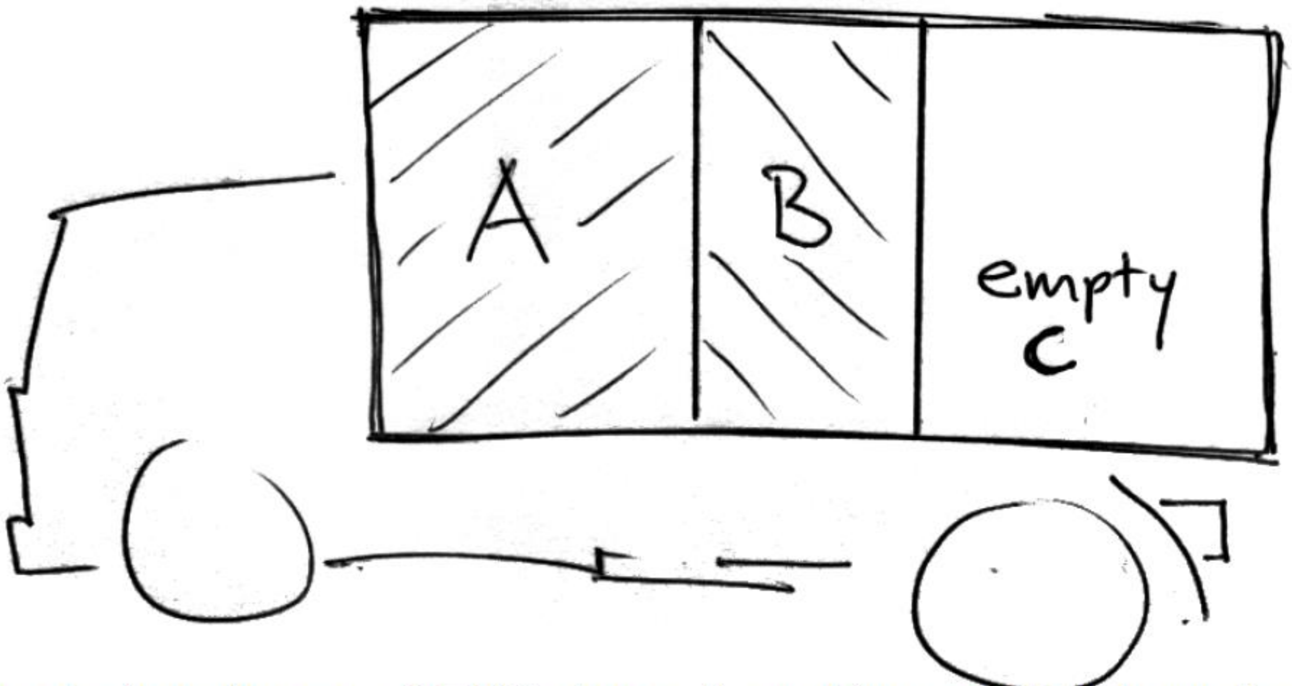
- Now for metal A and metal B.
- Maximum load of 20 t has been reached.

How much diesel for metal A, how much for metal B?

→ Answer:

For A: mass(A)/{mass(A) + mass(B)} * Total energy

Allocation (3/3)



Again two types of EPS, type A and type B but lorry is not full.

→ Answer:

For A: volume(A)/{volume(A) + volume(B)} * Total energy

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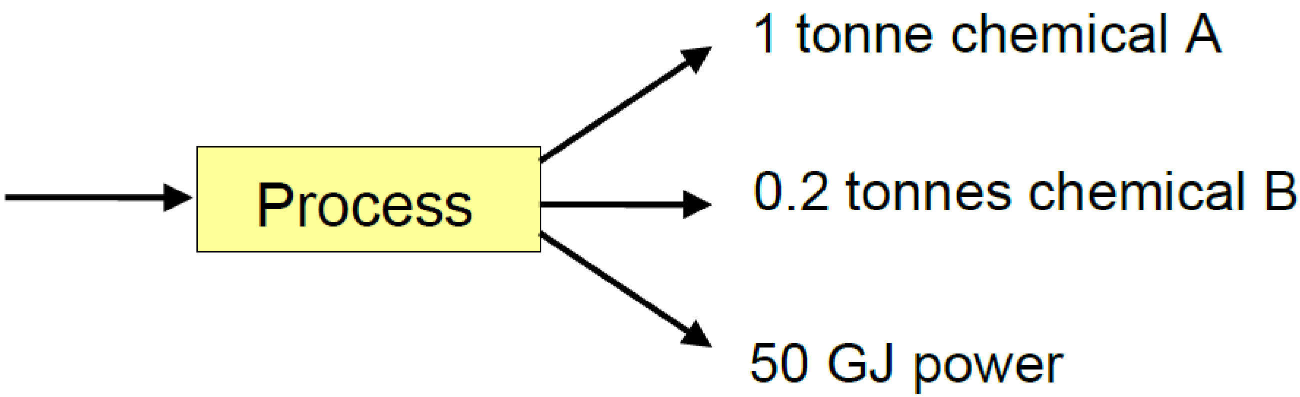
NOT: volume(A)/{volume(A) + volume(B) + volume(C)}

Allocation – cont'd. (1/3)

What is allocation?



Relevant options

a) Partitioning:

- Mass
- Economic value
- Energy content (calorific value)

b) System expansion:

- Credits for chemical B and for power

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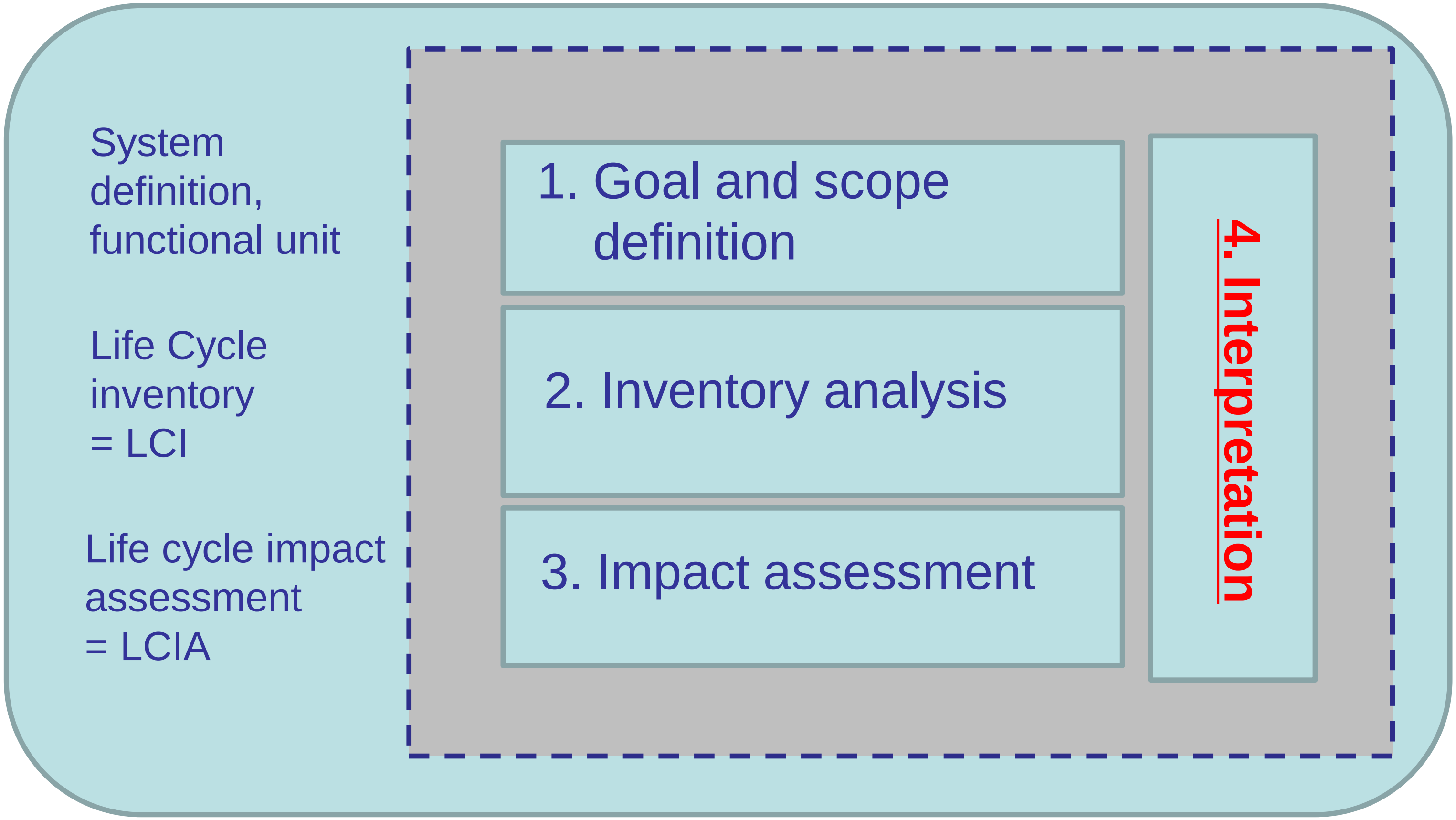
Attributional versus consequential LCA

Attributional	Consequential	Proposed or used by
Cause-oriented	Effect-oriented	Ekvall and Tillman (1997)
Accounting Retrospective	Change-oriented Prospective	Tillman (2000)
Descriptive	Change-oriented	Guinee (2001)
Attributional	Consequential	Ekvall and Weidema (2004), ILCD (2010)

Example: Land use change – iLUC factors
Potential further example: Carbon footprint of grid electricity generated with PV

Implementation:
* Attributional LCA: typically allocation, e.g. based on economic values
* Consequential LCA: typically system expansion

LCA – General framework



Applications:

- Product development & improvement ➔ eco-design
- Strategic planning
- Public policy making
- Marketing etc.

Source: ISO 14040 & 14044

Discussion and interpretation of the results

Discussion:

- For how many impact categories is new product/process better?
- By how much (in %)?
- Is this a lot or little in view of the uncertainties?

Further questions:

- What to conclude in the case of a mixed overall picture?
- Is a 50% reduction for one impact category as meaningful as a 50% reduction for another?
  →Normalisation

Impact category	Conventio-nal	New
Climate change.	20 kg CO_2/f.u.	10 kg CO_2/f.u.
Photochem. smog	40 units/f.u.	20 units /f.u.
Acidification	20 units/f.u.	20 units/f.u.
Human toxicity	20 units/ f.u.	30 units/ f.u.
Ecotoxicity	20 units/f.u.	40 units/f.u.
Eutrophication	20 units/f.u.	60 units/f.u
Ozone depletion	20 units/f.u.	5 units/f.u.
Winter smog	20 units/f.u.	20 units/f.u.

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Normalisation (LCA)

- = Optional step in an LCA
- Main aim: Better understand the relative importance of a value (or a Δ) for a given impact category
- Approach: Divide result by reference value, e.g.
  - total emissions or resource use for a given region
  - per capita emissions or resource use for a given region

Data for normalization

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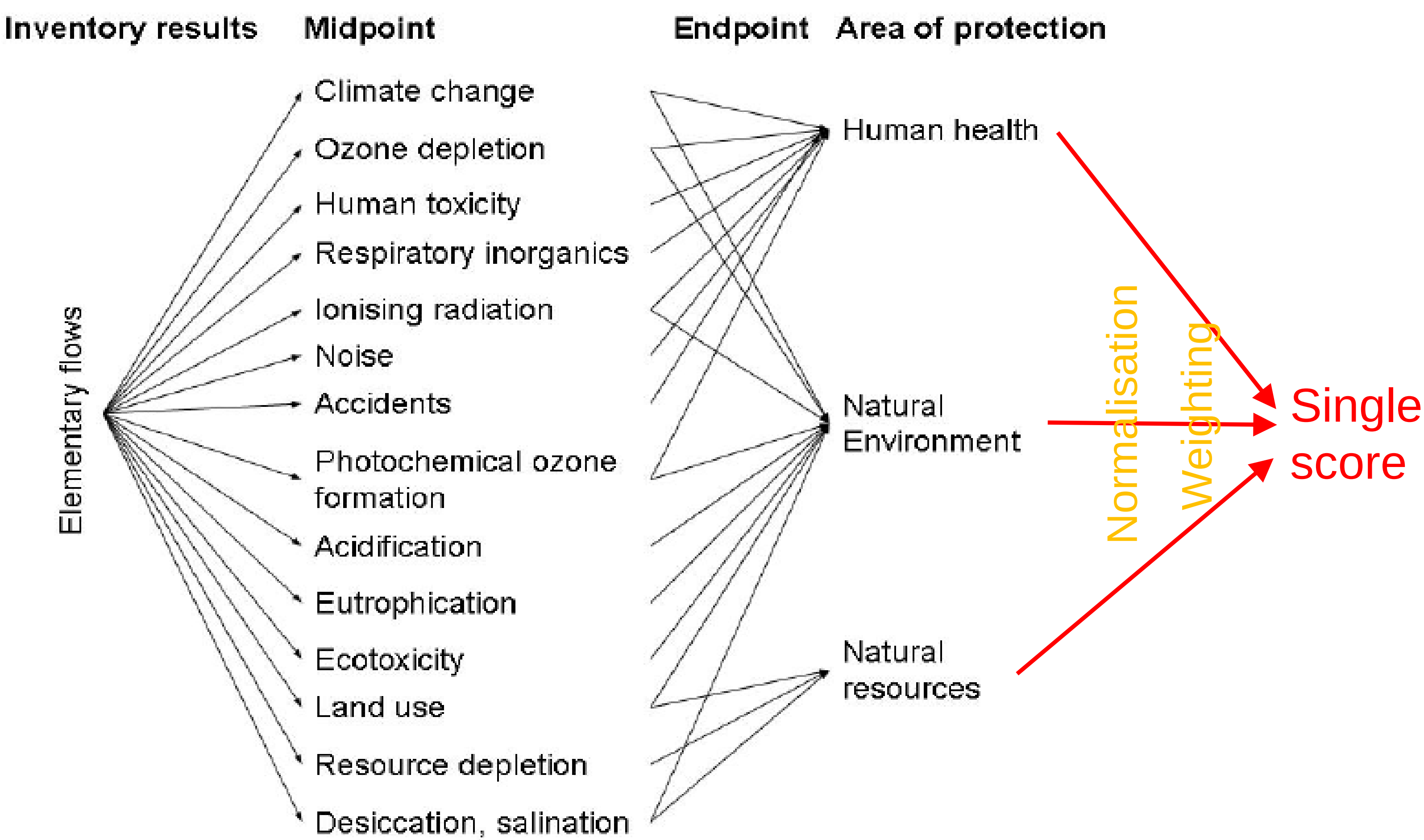
Table 4 – Normalisation factors

Impact category	Unit	EU_{25+3}	World	EU_{25+3} (% of world)
Climate change				
TH = 20 years	kg CO_2-eq.	6.57E+12	5.76E+13	11
TH = 100 years	kg CO_2-eq.	5.21E+12	4.18E+13	12
TH = 500 years	kg CO_2-eq.	4.49E+12	3.36E+13	13
Ozone depletion	kg CFC-11-eq.	6.79E+06	2.10E+08	3
Acidification				
TH = 20 years	kg SO_2-eq.	2.23E+10	3.01E+11	7
TH = 100 years	kg SO_2-eq.	2.36E+10	3.18E+11	7
TH = 100 years	kg SO_2-eq.	2.49E+10	3.36E+11	7
TH = 500 years	kg SO_2-eq.	2.84E+10	3.78E+11	8
Fresh water eutrophication	kg P-eq. (to fresh water)	3.47E+08	3.77E+09	9
Marine eutrophication	kg N-eq. (to fresh water)	5.89E+09	5.71E+10	10
Respiratory effects				
Photochemical oxidant formation	kg NMVOC-eq.	2.80E+10	3.51E+11	8
Particulate matter formation	kg PM_{10}-eq.	8.12E+09	9.92E+10	8
Human toxicity				
TH = 100 years	kg 1,4-DCB eq. (to urban air)	1.24E+11	1.20E+12	10
TH = infinite	kg 1,4-DCB eq. (to urban air)	2.27E+12	8.86E+12	26
Fresh water ecotoxicity				
TH = 100 years	kg 1,4-DCB eq. (to fresh water)	5.83E+09	2.94E+10	20
TH = infinite	kg 1,4-DCB eq. (to fresh water)	6.03E+09	3.07E+10	20
Marine ecotoxicity				
TH = 100 years	kg 1,4-DCB eq. (to seawater)	8.98E+09	2.85E+10	32
TH = infinite	kg 1,4-DCB eq. (to seawater)	1.78E+12	6.24E+12	29
Terrestrial ecotoxicity				
TH = 100 years	kg 1,4-DCB eq. (to industrial soil)	4.07E+09	3.72E+10	11
TH = infinite	kg 1,4-DCB eq. (to industrial soil)	6.37E+09	5.09E+10	13
Ionising radiation	kBq U-235 eq.(to air)	2.90E+12	7.97E+12	36
Agricultural land occupation	$m^2 \times$ year	2.10E+12	3.30E+13	6
Urban land occupation	$m^2 \times$ year	1.89E+11	4.71E+12	4
Fossil energy resource depletion	kg Sb eq.	7.23E+11	7.78E+12	9

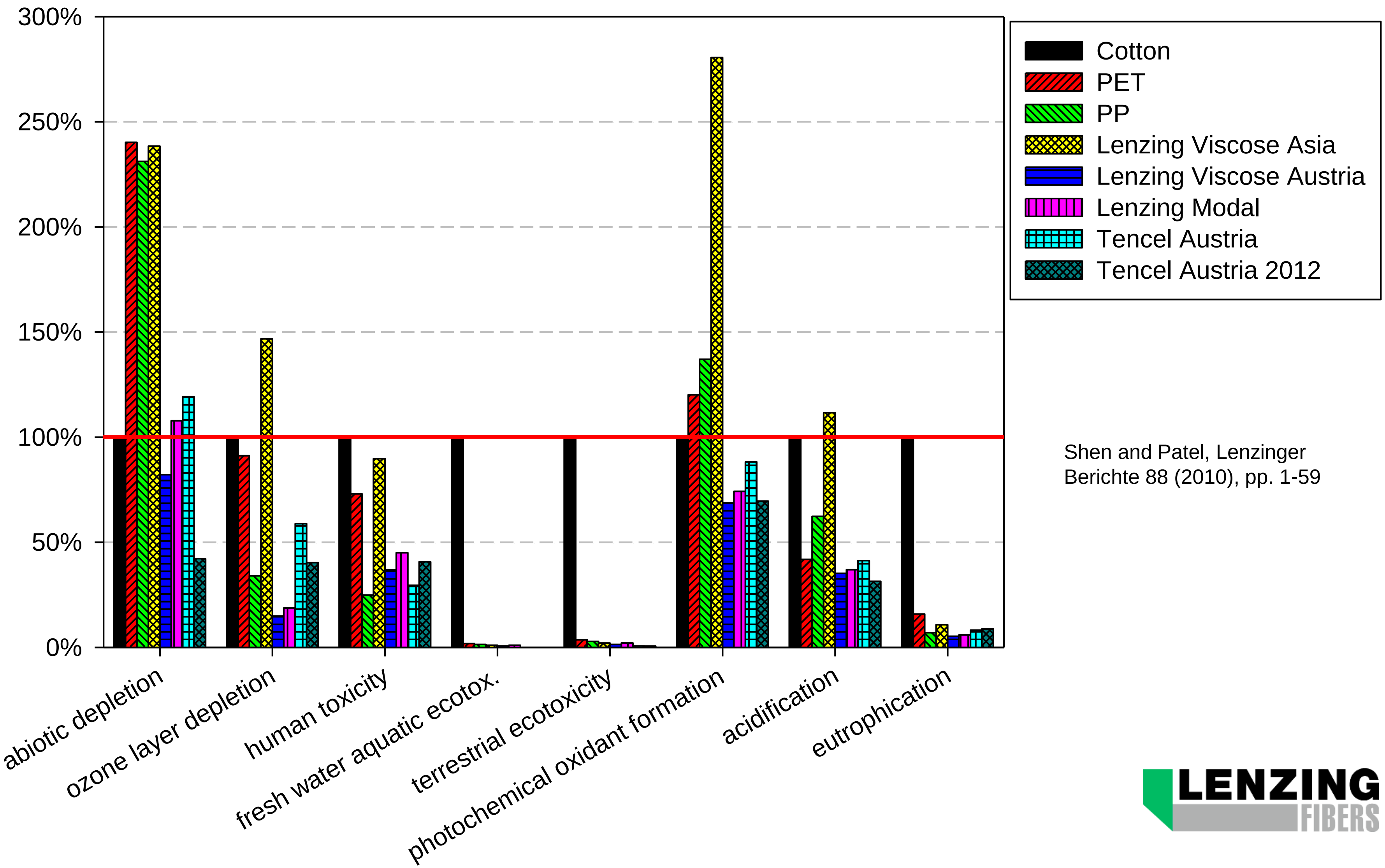
Sleeswijk et al.: Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. *Science of the Total Environment*, 2008

Midpoint versus Endpoint analysis



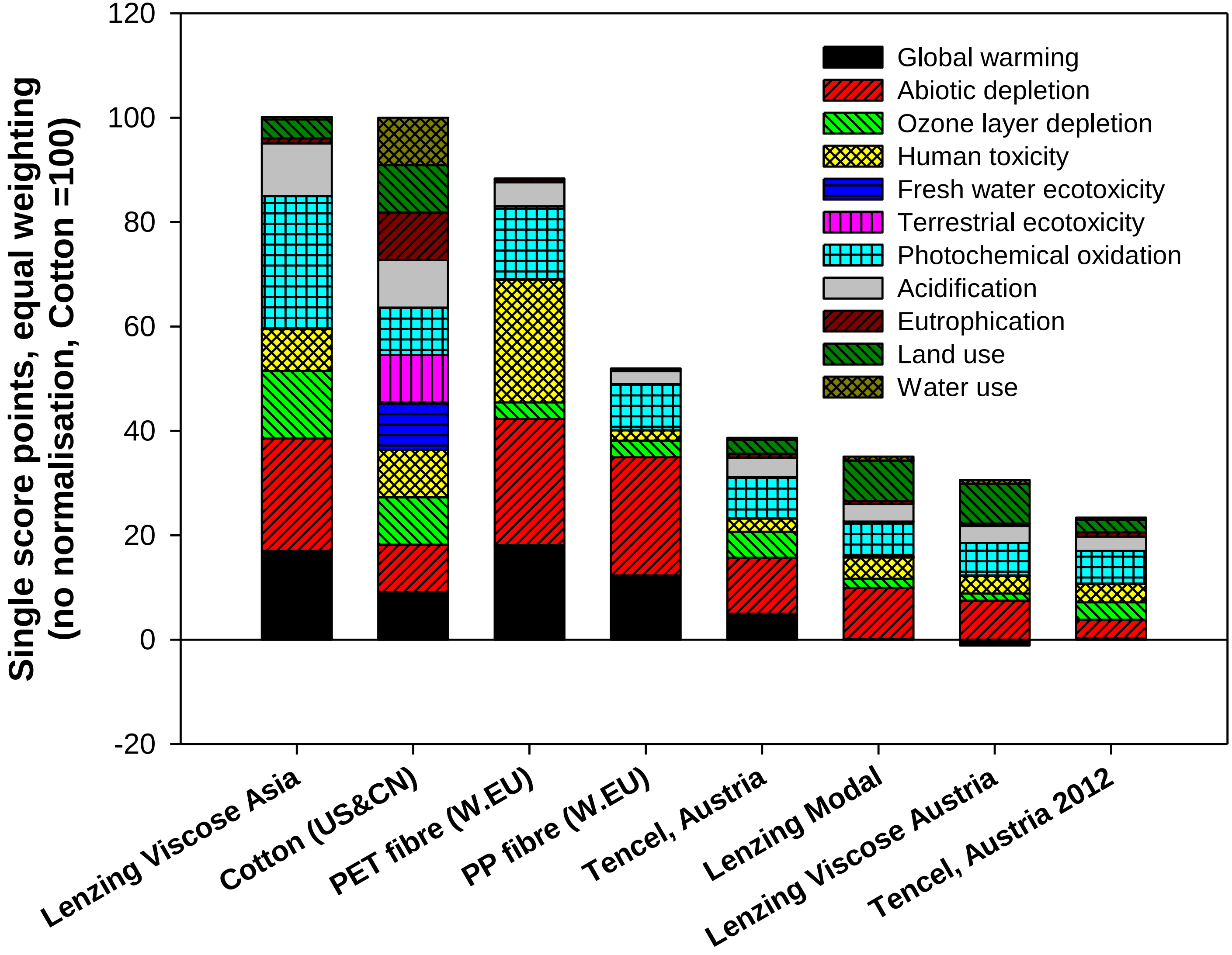
Source: ILCD Handbook

Environmental impact categories (CML)
Cradle-to-factory gate, 1 tonne fibre (cotton = 100)



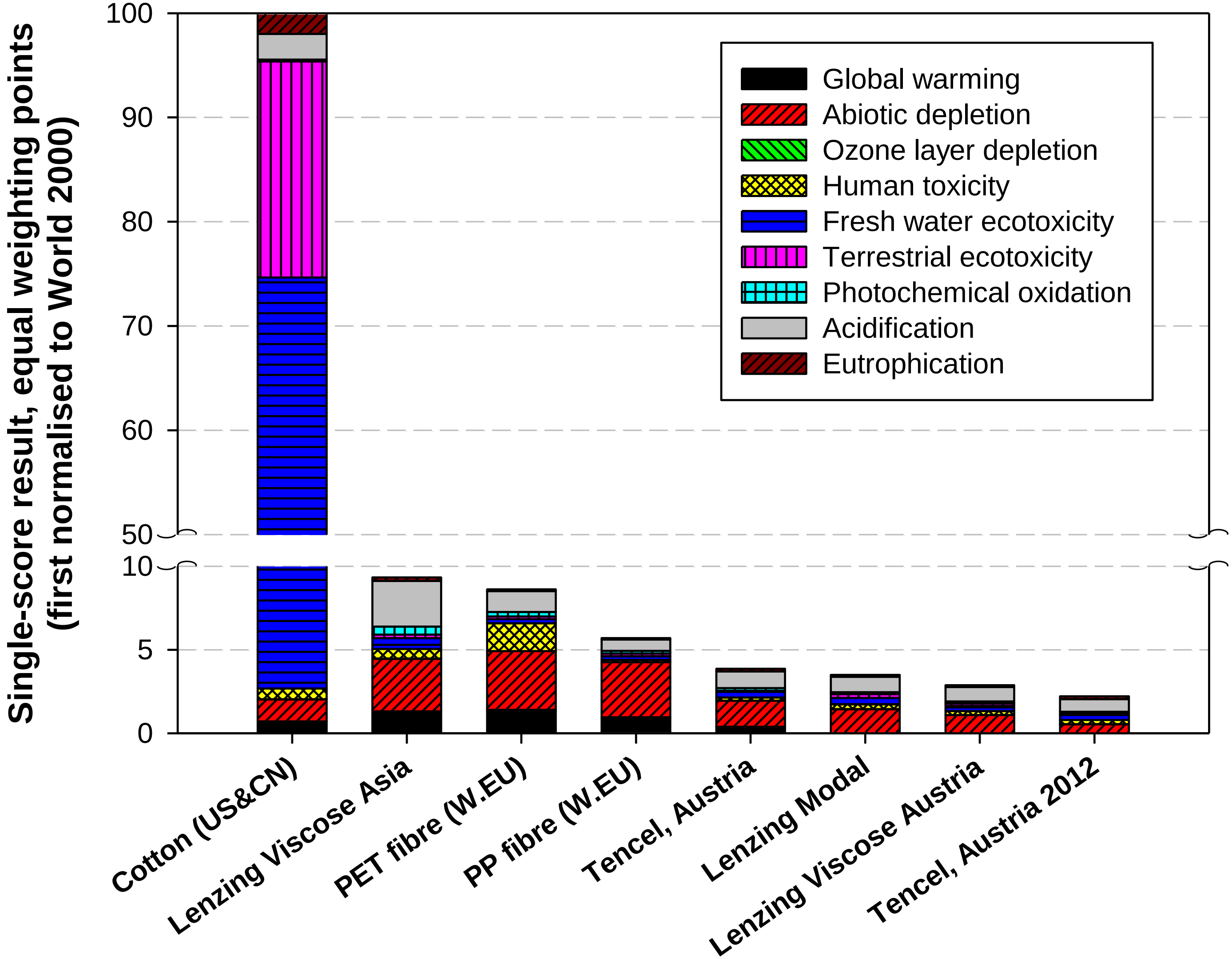
Shen and Patel, Lenzinger Berichte 88 (2010), pp. 1-59

Single-score result (I) - Equally weighted, Cotton = 100
1 tonne fibre, cradle-to-factory gate



Shen and Patel, Lenzinger Berichte 88 (2010), pp. 1-59

Single-score result (II)
Equally weighted, normalised to World 2000
1 tonne fibre, from cradle to factory gate, Cotton = 100



Shen and Patel, Lenzinger Berichte 88 (2010), pp. 1-59

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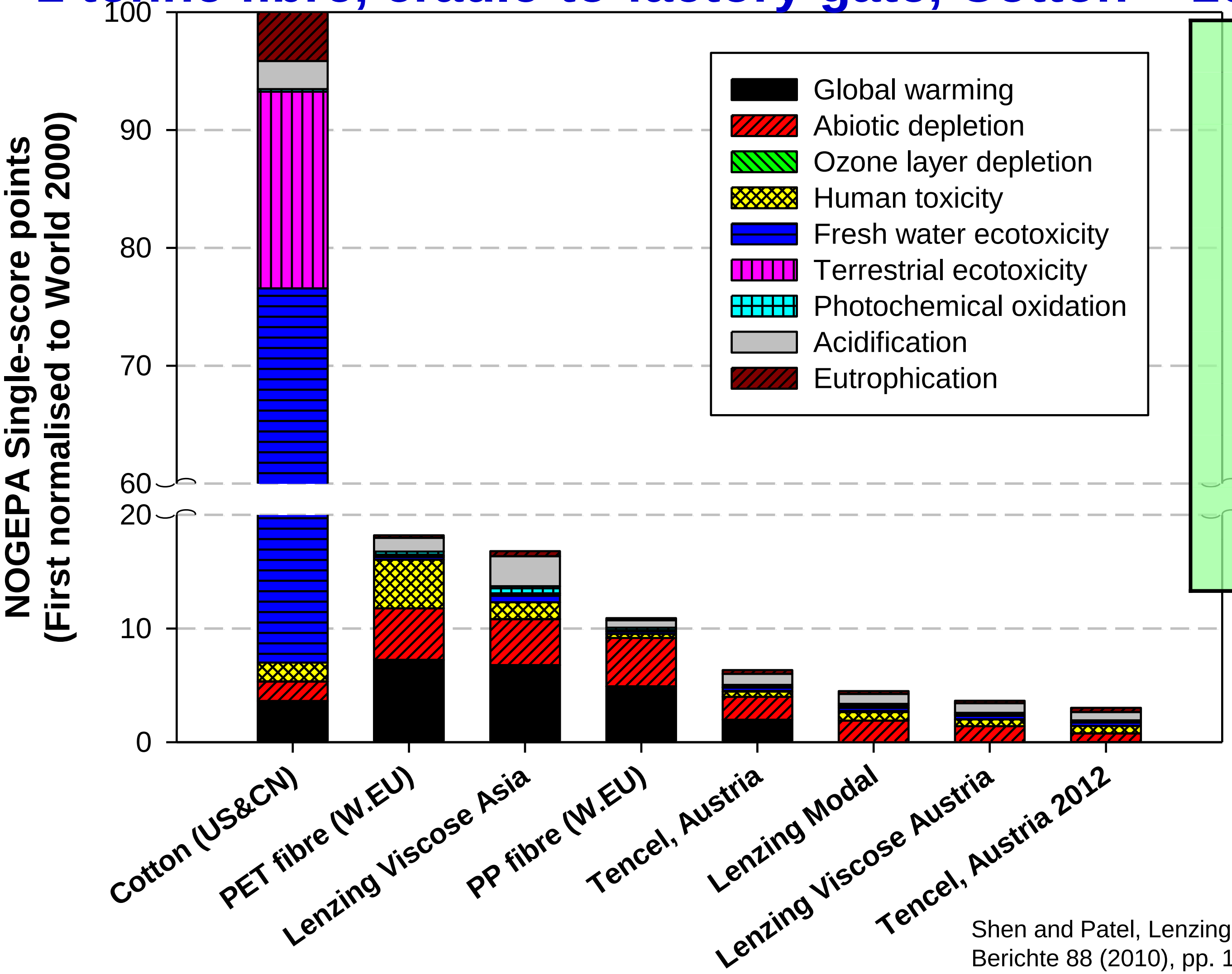
LENZING FIBERS

Single-score result (III)
NOGEPA weighting factors (normalised to world)
1 tonne fibre, cradle-to-factory gate, Cotton = 100



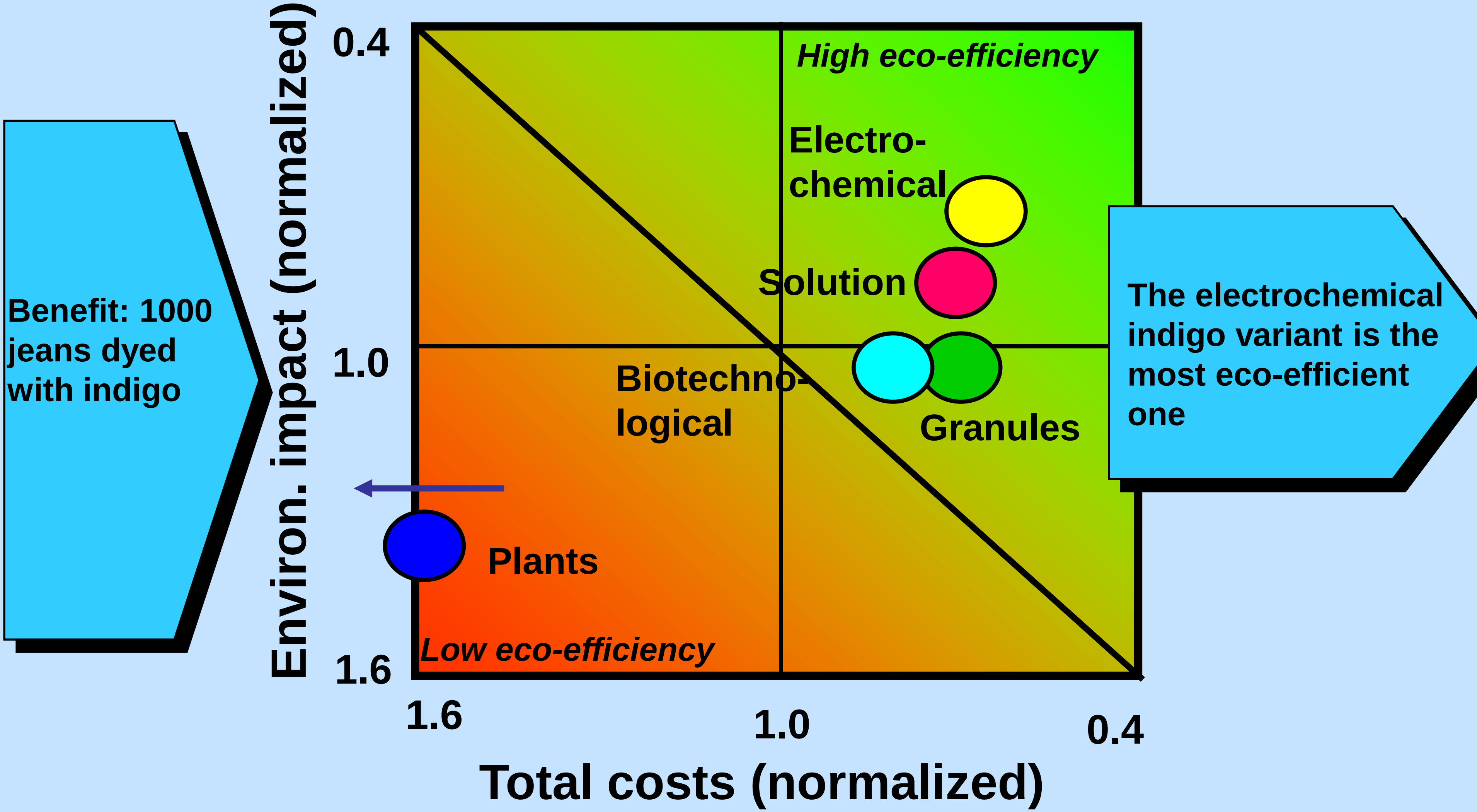
Shen and Patel, Lenzinger Berichte 88 (2010), pp. 1-59

Weighting factors (NOGEPA)	
Climate Change	32
Abiotic depletion*	8
Ozone layer depletion	5
Human toxicity	16
Fresh water ecotoxicity	6
Terrestrial ecotoxicity	5
Photochemical oxidation	8
Acidification	6
Eutrophication	13
Total	99

Source: Huppes et al (2003), except for abiotic depletion (marked with *), which is not excluded by Huppes et al. and is determined based on own estimation.

Caveat: possible bias caused by selected env. impact categories

In the ecoefficiency portfolio, the environmental impact is plotted against the costs



Contents

- LCA methodology
  - Goal and scope
  - Inventory analysis
  - Impact assessment
  - Interpretation
- Some case studies
- **Conclusions**

LCA – General wrap-up

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- Nowadays widely applied for policy making, company strategies and marketing
- Perhaps the most successful tool for assessing energy use, GHG emissions, envir. and health impacts
- Focus on products and services (and processes) but not on sectors
- Methods are evolving (e.g. consequential LCA, further impact categories, spatial analysis)
- Can be contentious
- “Assessment”, not “Analysis”
- Note: LCC and external costs are complementary approaches.

LCA – General learnings
- Contribution of steps to overall envir. impact

- Production of bulk materials often dominant
- Assembly often minor
- For products using energy during use phase: Use phase often dominates (e.g., cars, appliances), otherwise production usually dominates
- For energy intensive production processes: impacts related to investment goods negligible
- Transportation: often small contribution
- Waste management: usually rather small contribution

The Hitch Hiker's Guide to LCA, p. 278 (extended: waste)

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TO DOs for tomorrow

- **Bring your laptop.**
- **Try out connection to virtual machine (e-mail from Julien Michellod)**
- **Watch a tutorial of openLCA using the YouTube link provided in the exercise.**

Additional slides

Allocation acc. to ISO

ISO 14044: Environmental management — Life cycle assessment — Requirements and guidelines

4.3.4.2 Allocation procedure

The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure presented below.

a) Step 1*: Wherever possible, allocation should be avoided by*

1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or

2) expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 4.2.3.3.

b), c): Step2 & 3: Allocation

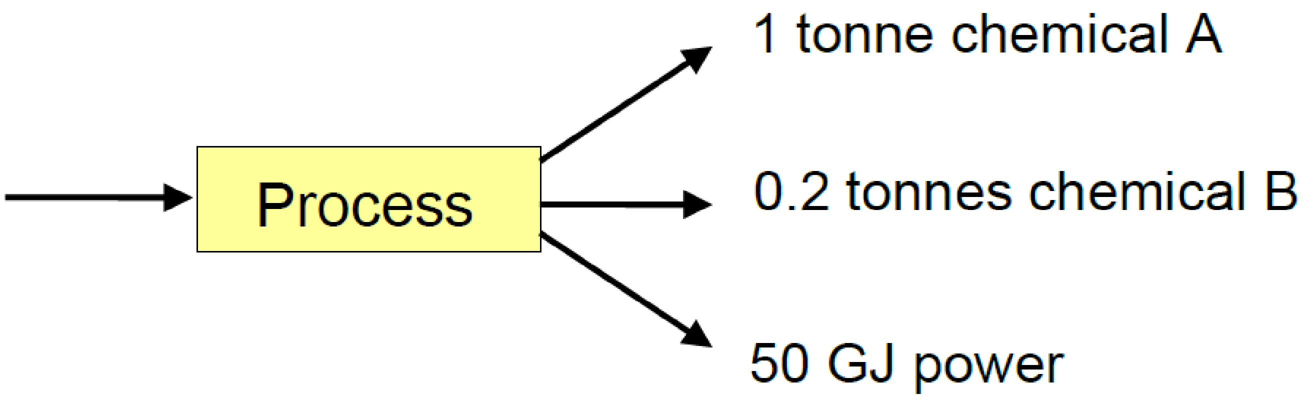
Caveat

- "Weighting […] shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public"
- "Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choices. It may include aggregation of the weighted indicator results."

Source: ISO 14044: Environmental management - Life cycle assessment - Requirements and guidelines, 2006

Allocation – cont'd. (1/3)

What is allocation?



Relevant options

a) Partitioning:

- Mass
- Economic value
- Energy content (calorific value)

b) System expansion:

- Credits for chemical B and for power

Allocation – cont'd. (2/3)

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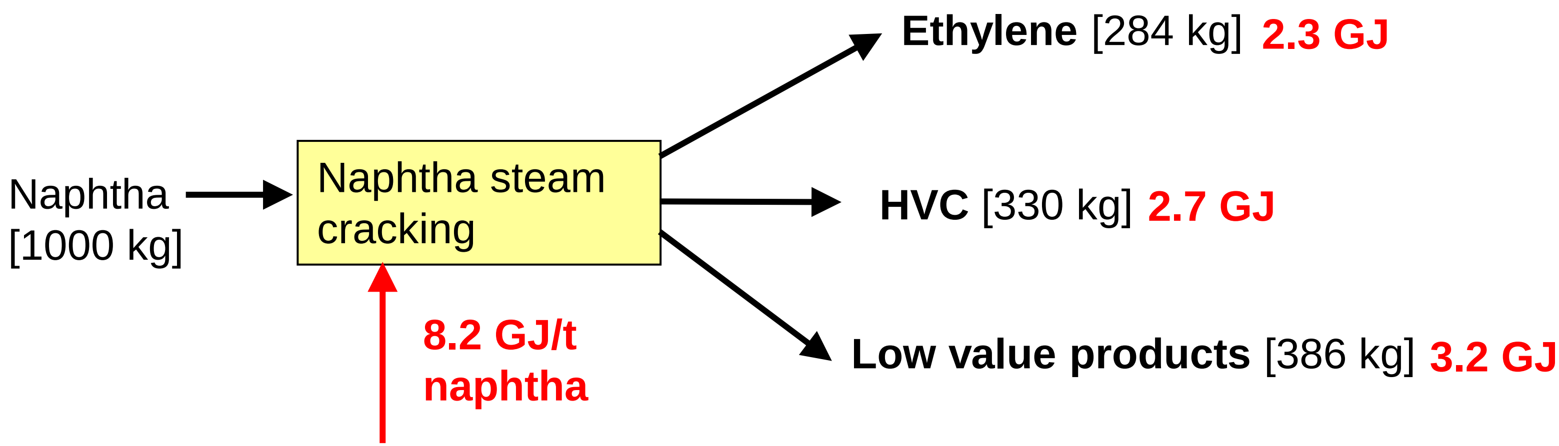
Example of allocation procedure (Steam cracking of naphtha)



Input	tonnes	Output	tonnes
Naphtha	1.000	Ethylene	0.284
		HVC*)	0.33
		Low value products	0.386
Total	**1.000**	**Total**	**1.000**

Mass allocation		
Mass-%	GJ/t input	GJ/t output
28%	GJ/t naphtha	GJ/t ethylene
33%	GJ/t naphtha	GJ/t HVC *)
39%	GJ/t naphtha	GJ/t Low val. pr.
100%	GJ/t naphtha	---

*) HVC = (Other) High value chemicals

Allocation – cont'd. (3/3)

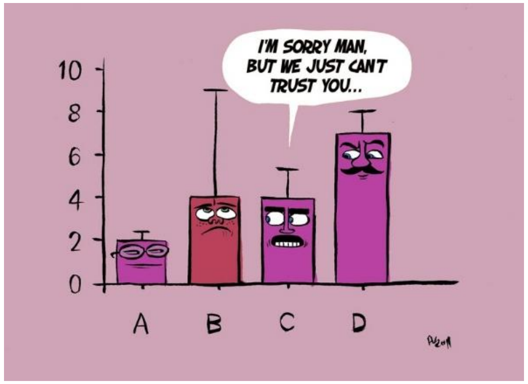
Example of allocation procedure (Steam cracking of naphtha)

Input	tonnes	Output	tonnes
Naphtha	1.000	Ethylene	0.284
		HVC*)	0.33
		Low value products	0.386
Total	**1.000**	**Total**	**1.000**

*) HVC = (Other) High value chemicals

Output	Price per tonne of each output EUR/t	Value of output EUR	%	Econ. allocation GJ/t input	Econ. allocation GJ/t output
Ethylene	1000	284	40%	GJ/t naphtha	GJ/t ethylene
HVC*)	900	297	41%	GJ/t naphtha	GJ/t HVC *)
Low v. pr.	350	135	19%	GJ/t naphtha	GJ/t Low val. pr.
Total		716	100%	GJ/t naphtha	---

LCA - Pitfalls and limitations



- Limited data availability
- Representativeness of LCA results
- Variability in LCA

- Only evaluation of potential impacts
- Results are very dependent on:
  - Assumptions (system boundaries, FU…)
  - Data quality (availability, confidentiality…)
- Recommendations emerging from LCA could be in conflict with other interests (economic, society…)