Life Cycle Assessment 2

- LCA cause-effect relations

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Tuesday 8th November 2011, 8:30-12:00

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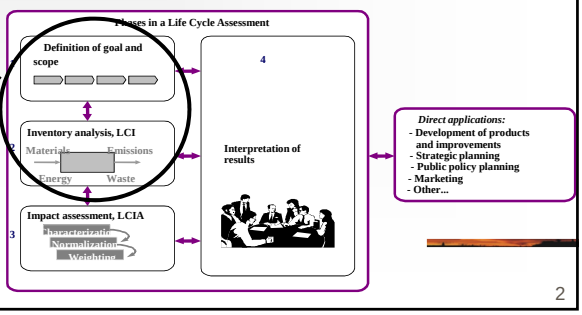
Content of the LCA course (within Tools course)

Lesson 1: LCA introduction (SL)

Today Lesson 2: LCA cause-effect relations (JS)

Lesson 3: Carbon footprintint (SL)

Lesson 4: LCA biofuels land-use (JS)



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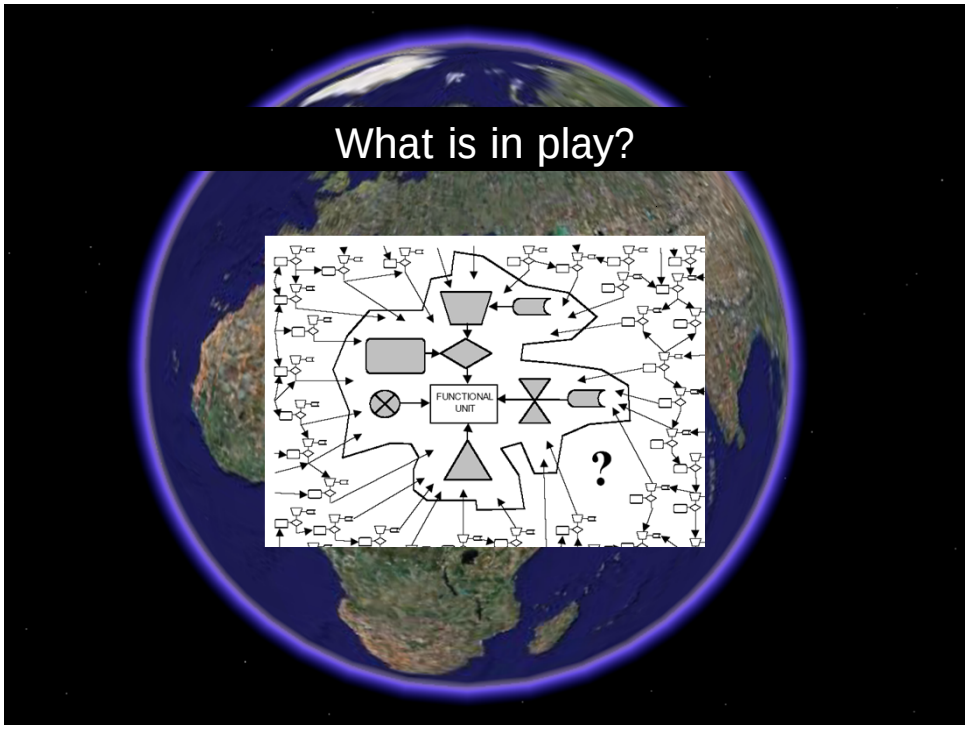
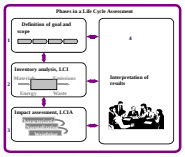
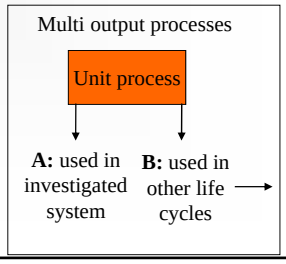
- **Why is system delimitation important?**
- Approaches to system delimitation
- Consequential system boundaries
- Co-product allocation in LCA
- Exercise



What are system boundaries?

- ISO 14044: System boundary is a "... a set of criteria specifying which unit processes are part of a product system"
- What is system delimitation?
  - Choices made in goal and scope phase
  - Carried out in practice in the inventory phase
  - Setting of system boundaries: - what unit processes are to be included? (cut-off)
    - which suppliers are affected?
  - Procedures for handling co-product problems





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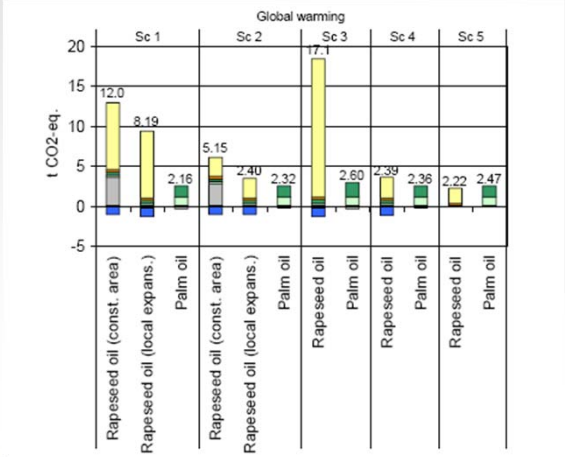
Why is it important?

- Results and conclusions may depend on system delimitation!!!



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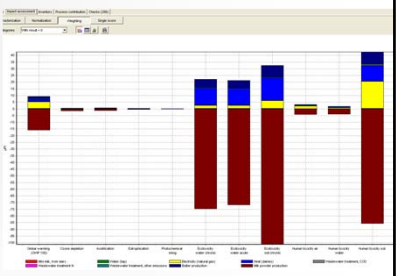
Surprising LCA results!

- Butter from dairy: Environmental impact = 0!
  - Milk from dairy: Impact = negative!
- 2nd generation biofuels a bad idea
- Rapeseed oil is worse than palm oil for biodiversity
- …



(Data from LCAfood, 2005)

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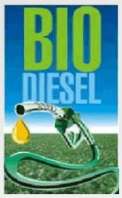
Important questions can be asked – and answered…?

- Biodiesel from rapeseed oil



- Organic farming

- Re-establishment of nature in DK

do we clear the rainforest?

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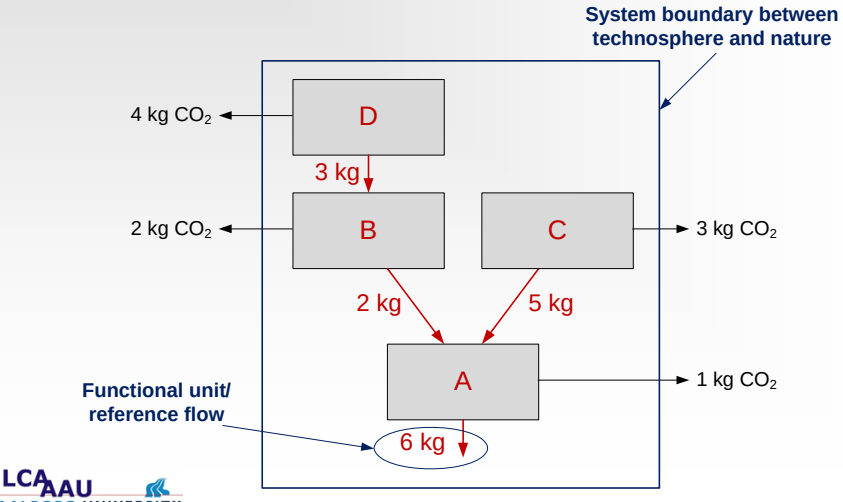
From product flow diagram to matrix
- Product system

3.28
product system
collection of unit processes with elementary and product flows, performing one or more defined functions, that models the life cycle of a product



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From product flow diagram to matrix
- What is an LCA process?

LCA-process = activity with inputs and outputs

3.11
process
set of interrelated or interacting activities that transforms inputs into outputs

- Output: product (reference flow)

Other processes can link to this flow

- Output: co-products
- Input: products from other processes
- Output: waste sent to treatment/recycling

Inputs/outputs from other processes

- Emissions
- Resources

Exchanges with the environment

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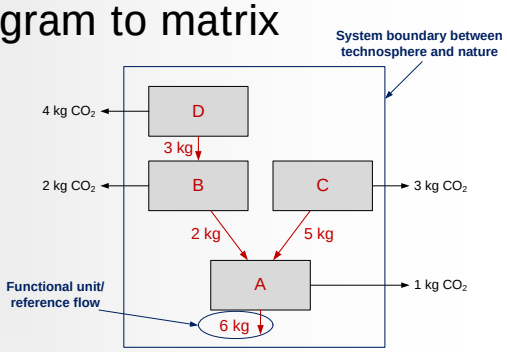
From product flow diagram to matrix
- no co-products

Process	A	B	C	D
Output	6	2	5	3
Inputs				
A				
B	2			
C	5			
D		3		
Emissions				
CO_2	1	2	3	4



Normalised

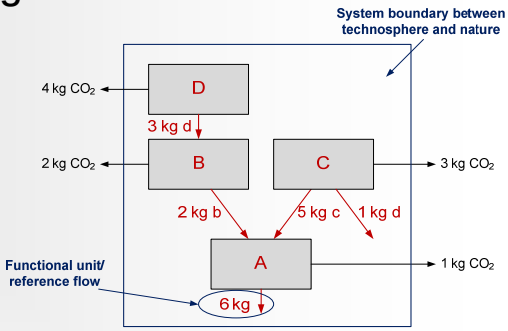
Process	A	B	C	D
Output	1	1	1	1
Inputs				
A				
B	0.33			
C	0.83			
D		1.50		
Emissions				
CO_2	0.17	1.00	0.60	1.33

Direct requirement coefficient matrix

$\tilde{Z}$

From product flow diagram to matrix
- with co-products

Process	A	B	C	D
Outputs				
A	6			
B		2		
C			5	
D			1	3
Inputs				
A				
B	2			
C	5			
D		3		
Emissions				
CO_2	1	2	3	4

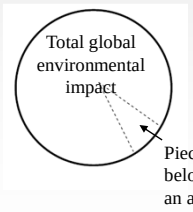


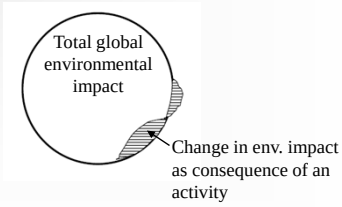
Direct requirement coefficient matrix depends on allocation/system expansion

- Why is system delimitation important?
- **Approaches to system delimitation**
- Consequential system boundaries
- Co-product allocation in LCA
- Exercise

Consequential vs. Attributional modelling

Traditional/attributional	Consequential
Information on physical-related flows	Information on consequences of actions
Average suppliers/technology	Marginal (=affected) suppliers/technology
Co-product allocation: Allocation factor	Co-product allocation: avoided
Seeks to cut out a piece related to an activity	Seeks to capture change in env. impact as a consequence of a certain activity





Ekvall and Weidema (2004), *System Boundaries and Input Data in Consequential LCI*, Int J LCA 9 (3) 161-171

Weidema (2003), *Market information in LCA*, Danish EPA

- Why is system delimitation important?
- Approaches to system delimitation
- **Consequential system boundaries**
- Co-product allocation in LCA
- Exercise

Consequential system boundaries

- **The concept in *Consequential system boundaries***
  - Include the actual AFFECTED processes
- **What is the difference in practise?**
  - **Attributional LCA:**
    - Average technology
    - Co-producing processes: allocation factor is applied
  - **Consequential LCA:**
    - Marginal technology
    - Co-product allocation is avoided by system expansion

Attributional vs. Consequential modelling

- Attributional system boundaries
  - E.g. Electricity use in Denmark

Fuel for electricity production	Share
Coal	47%
Natural gas	24%
Wind power	13%
Oil	10%
Other (biomass and waste)	6%

Average energy composition

- Consequential system boundaries
  - E.g. Electricity use in Denmark

Fuel for electricity production	Share
Coal	?
Natural gas	?
Wind power	?
Oil	?
Other (biomass and waste)	?

Which capacity installation will be affected as a consequence of a change in demand?

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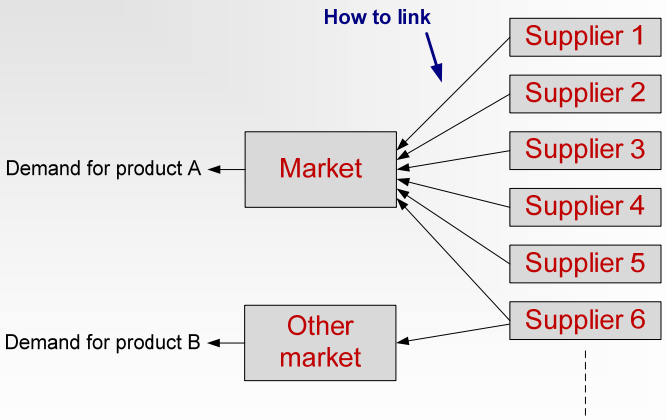
Demand for product A: The challenge of identifying the affected activity



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Identification of affected suppliers in consequential modelling

Identify affected suppliers: 4 steps

a. Scale and time horizon
b. Market delimitation
c. Trends in the volume of the market
d. Changes in supply and demand

Weidema et al. (2009) *Guidelines for applications of deepened and broadened LCA.* CALCAS project, pp 8-17

➡ a. Scale and time horizon
b. Market delimitation
c. Trends in the volume of the market
d. Changes in supply and demand

a. Scale of the studied decision

- The scale of the studied decision can be small or large
- Small scale is (unfortunately) the typical case
  - Small => Default assumption
- Large scale is seen when introducing new technologies and regulations on significant markets, e.g. ban on palm oil
  - Large => May affect the markets in which the change is taking place; non-linear, requires special analysis

a. Time horizon of the decision

- Relevant because background conditions may change over time, e.g. electricity, recycling rates, use of scarce materials
- Time horizon also concerns the distinction between short-term and long-term changes
- Short-term changes only affect current capacity utilisation
  - Short-term: Not the typical case; relevant where no capital invenstments are planned/affected, e.g. in declining markets, monopolised or highly regulated markets
- Long-term changes affects also capital investments
  - Long-term: Default assumption

b. Market delimitation

- Two cases: Decision affects specific supplier or market
- Specific supplier => this is the affected one (if it is not constrained)
- Supply from market; Markets are typically differentiated:
  - Geographically (natural geography, regulation, consumer culture)
  - Temporally (peak hours, rush hours, season)
  - In customer segments (obligatory properties: typically functionality, aesthetics, image)
  - => Default: Assume no limits

a. Scale and time horizon
b. Market delimitation
c. Trends in the volume of the market
d. Changes in supply and demand

c. Market trend (increasing/decreasing)

- Two cases: Market trend can be increasing/stable or decreasing
- Increasing/stable market
  - => Default assumption: Typically modern and competitive suppliers are affected
- Decreasing market (decrease faster than replacement rate of capital equipment)
  - => Least competitive suppliers are affected

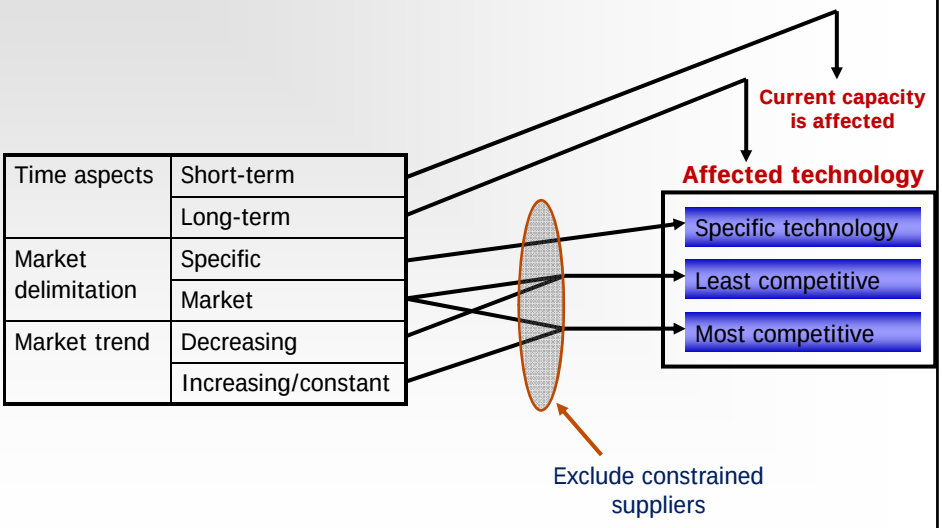
a. Scale and time horizon
b. Market delimitation
c. Trends in the volume of the market
d. Changes in supply and demand

d. Changes in supply and demand

- In LCA and IOA normal practise is to assume full elasticy of supply => demand for one unit leads to supply of one unit
- When suppliers are constrained or markets are imperfect (i.e. if producers can affect price), then
  - => modify the assumption of full elasticity, see below
- Constrined suppliers:
  - Regulatory constraints (max/min quotas, taxes, subsidies)
  - Political constraints
  - Availability of raw materials
  - Waste treatment capacity
  - Co-product constraints (determining co-product puts a constraint on the dependant co-products)
  - Default => if no data, assume no constraints. Questionable constraints should be analyzed in separate scenarios

Identification of affected suppliers in consequential modelling

Time aspects	Short-term
	Long-term
Market delimitation	Specific
	Market
Market trend	Decreasing
	Increasing/constant



Practical recommendations
- when is it important?

- We have average data for everything, e.g. in ecoinvent and many existing studies – does the issue of marginal suppliers make this useless?
- Areas where significant differences on marginal/average are present:
  - Electricity
  - Aluminium
  - Agricultural products (also depends on by-product utilisation)
  - By-products: manure, scrap, straw

Practical recommendations – literature references

- **Schmidt J H and Thrane M (2009)**, *Life cycle assessment of aluminium production in new Alcoa smelter in Greenland*. Government of Greenland. Chapter 4, 5, 6, and appendix 4 http://www.smv.gl/Baggrundsrapporter/lca_2009.pdf
- **Schmidt J H (2007),** *Life assessment of rapeseed oil and palm oil. Ph.D. thesis, Part 3: Life cycle inventory of rapeseed oil and palm oil*. Chapter 2, 3, and 5.4 http://vbn.aau.dk/fbspretrieve/10388016/inventory_report
- **Schmidt J H (2008)**, System delimitation in agricultural consequential LCA, Outline of methodology and illustrative case study of wheat in Denmark. *International Journal of Life Cycle Assessment*, 13 (4) 350-364 <DOI: 10.1007/s11367-008-0016-x>
- **Weidema (2003)**, *Market information in LCA*, Danish EPA, p 67-79, www.mst.dk/udgiv/Publications/2003/87-7972-991-6/pdf/87-7972-992-4.PDF

Practical recommendations – literature references

- You can see several examples on marginal technologies in:
  - Weidema (2003), *Market information in LCA*, Danish EPA, p 67-79 www.mst.dk/udgiv/Publications/2003/87-7972-991-6/pdf/87-7972-992-4.PDF
  - Schmidt J H, S Merciai, M Thrane and R Dalgaard (2011), Inventory of country specific electricity in LCA – Consequential and attributional scenarios. Methodology report v2. 2.-0 LCA consultants, Aalborg, Denmark http://www.lca-net.com/files/Inventory_of_country_specific_electricity_in_LCA_Methodology_report_20110909.pdf
  - Merciai S, J H Schmidt J H and R Dalgaard (2011), Inventory of country specific electricity in LCA - India. 2.-0 LCA consultants, Aalborg, Denmark http://www.lca-net.com/files/IN_-_India_20110909.pdf

Shift in the marginal supply of vegetable oil

Example: LCA of biodiesel in the global market

- Market segment: Most important oils? Substitutable?
- Market situation: Increasing/decreasing?
- Constraints: Are any of the important oils constrained?
- Most competitive oil?

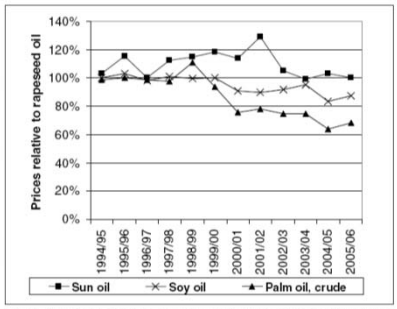
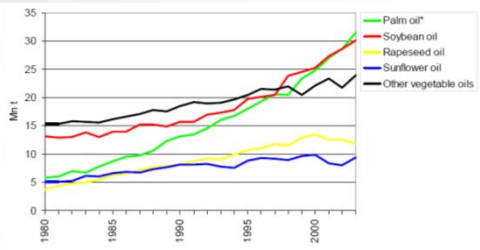


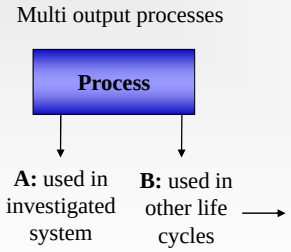
Fig. 2: Prices and price forecasts for sun oil, soy oil and palm oil relative to rapeseed oil. Figures for 05 and 06 are estimates. Source: Oil World (2005)



- Why is system delimitation important?
- Approaches to system delimitation
- Consequential system boundaries
- **Co-product allocation in LCA**
- Exercise

Co-product allocation in LCA

- **Co-product allocation:** ISO 14044 chapter 4.3.4
  - Relevant when more than one product output:



You use a certain amount of A, and B is a co-product
How to address inputs and outputs to product A?

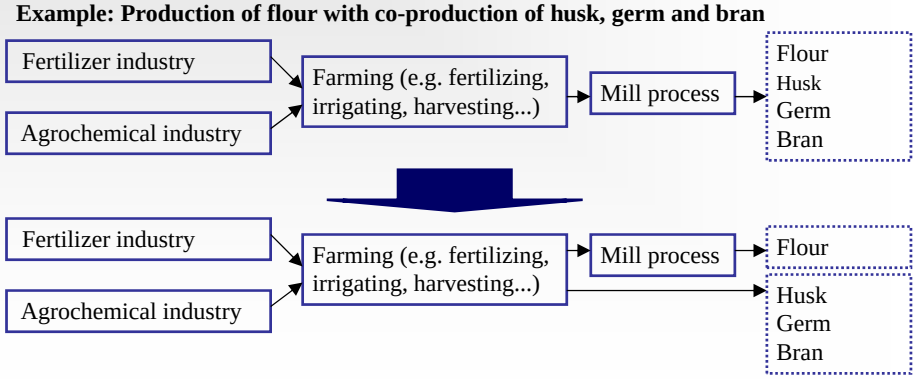
(ISO 14044, 2006)

Allocation according to ISO14044 –three steps

Step 1: Wherever possible avoid allocation

a) by subdivision of processes

Example: Production of flour with co-production of husk, germ and bran



(ISO 14044, 2006)

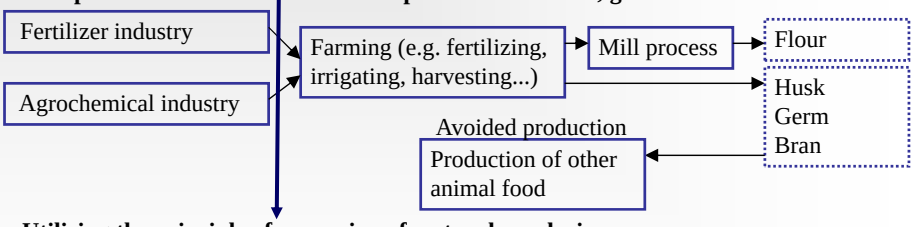
Allocation according to ISO14044 – three steps

Step 1: Wherever possible avoid allocation

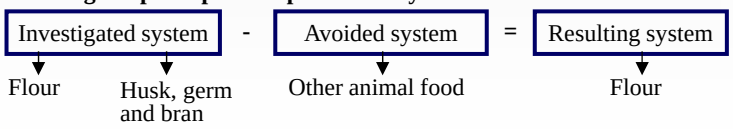
a) by subdivision of processes

b) by expansion of system boundaries

Example: Production of flour with co-production of husk, germ and bran



Utilizing the principle of expansion of system boundaries



Energy: 5 MJ - Energy: 2 MJ = Energy: 3 MJ

(ISO 14044, 2006)

Allocation according to ISO14044 – three steps

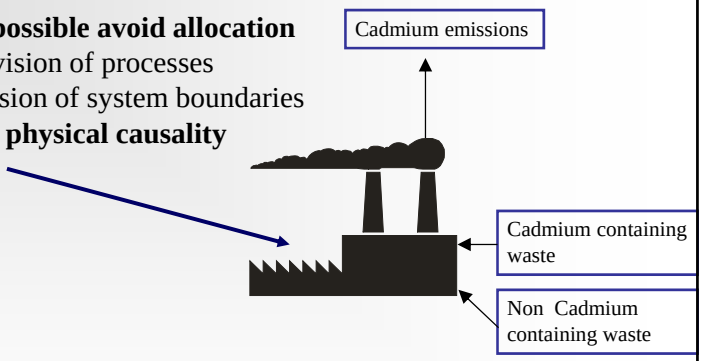
Step 1: Wherever possible avoid allocation

a) by subdivision of processes

b) by expansion of system boundaries

Step 2: Allocate by physical causality

- mass flow

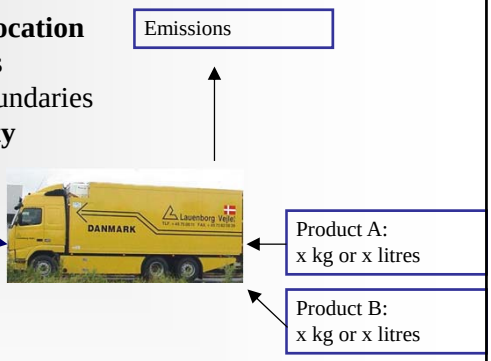


Cadmium emissions are ascribed to content of cadmium in waste

(ISO 14044, 2006)

Allocation according to ISO14044 – three steps

Step 1: Wherever possible avoid allocation
a) by subdivision of processes
b) by expansion of system boundaries
Step 2: Allocate by physical causality
- mass flow
- capacity

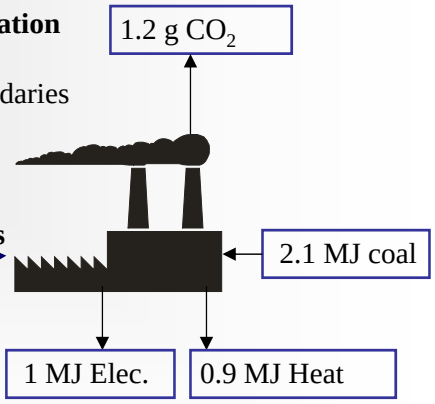


Emissions ascribed to product A are allocated by:
- weight, if weight is the limiting factor for loading the truck
- volume, if volume is the limiting factor for loading the truck

(ISO 14044, 2006)

Allocation according to ISO14044 – three steps

Step 1: Wherever possible avoid allocation
a) by subdivision of processes
b) by expansion of system boundaries
Step 2: Allocate by physical causality
- mass flow
- capacity
Step 3: Allocate by other relationships
- energy



1 MJ Elec. →
CO_2: $\frac{1}{1+0.9}$ x 1.2 g = 0.63 g
Coal: $\frac{1}{1+0.9}$ x 2.1 MJ = 1.10 MJ

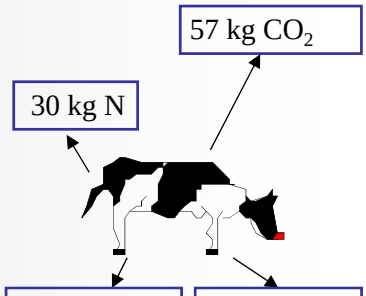
(ISO 14044, 2006)

Allocation according to ISO14044 – three steps

Step 1: Wherever possible avoid allocation
- a) by subdivision of processes
- b) by expansion of system boundaries

Step 2: Allocate by physical causality
- mass flow
- capacity

Step 3: Allocate by other relationships
- energy
- economic value



Beef: 200 DKK/kg
Minced: 50 DKK/kg

10000 DKK | 15000 DKK

50 kg beef → CO_2: $\frac{10000}{10000 + 15000}$ x 57 kg = <u>23 kg</u>

N: $\frac{10000}{10000 + 15000}$ x 30 kg = <u>12 kg</u>

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(ISO 14044, 2006)

Allocation according to ISO14044 – three steps

Step 1: Wherever possible avoid allocation
- a) by subdivision of processes
- b) by expansion of system boundaries

Step 2: Allocate by physical causality
- mass flow
- capacity

Step 3: Allocate by other relationships
- energy
- economic value
- mass
- exergy
- volume
- incentive for driving the process (100% and 0%)
- other…

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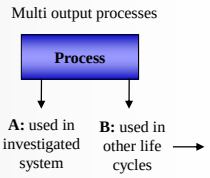
Handling of co-products in consequential modelling

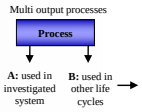
- Distinguish between:
  - A and B are produced independently
  - Production A depends on demand for B
  - Production B depends on demand for A
- See next three slides!



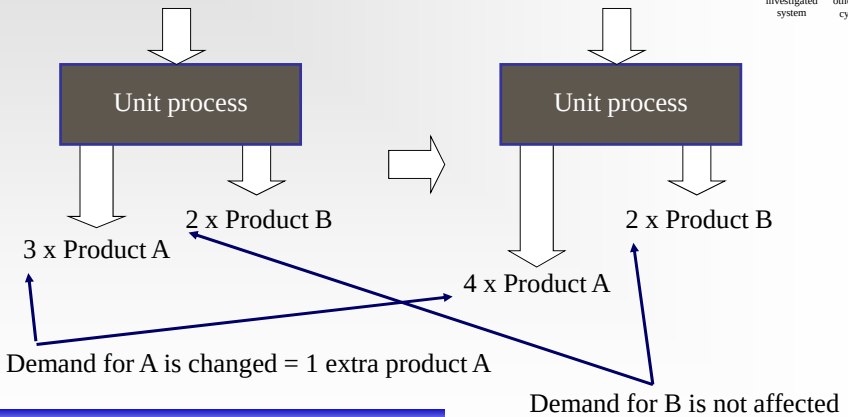
Ekvall and Weidema (2004), *System Boundaries and Input Data in Consequential LCI*, Int J LCA 9 (3) 161-171

Weidema (2001): *Avoiding Co-Product Allocation in LCA*

Handling of co-products in consequential modelling
- A and B are produced independently



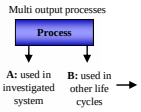
- Changed demand for product A:



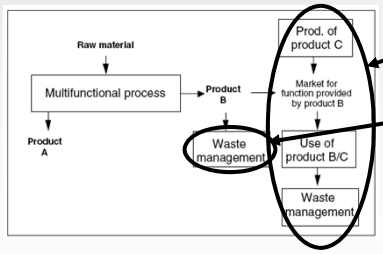
Allocate by physical, causal relationships

Example: Transport painting two products

Handling of co-products in consequential modelling
- Use of determining co-products

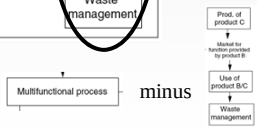


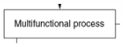
- Method: **Avoid allocation by system expansion**
  - Example: Oilseed meal
  - Include the co-producing process
  - Include the processes affected by a change in production of B



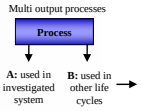
1) If B is fully utilized

2) If B is not fully utilized

1) If B is fully utilized:  minus = Impact allocated to A

2) If B is not fully utilized:  plus  = Impact allocated to A

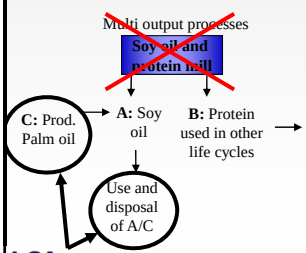
Handling of co-products in consequential modelling
- Use of dependant co-product



- Method: **Avoid allocation by system expansion**
  - Exclude the co-producing process
  - Include what is affected by a change in the use of A

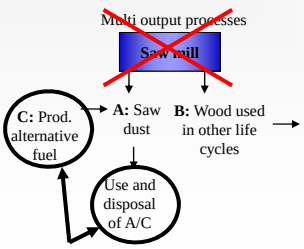
1 2 3

Increased use of A, cause increase in production of other products



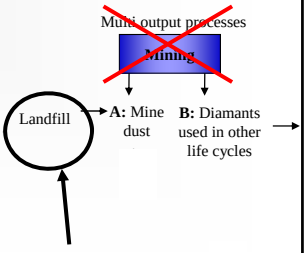
Example: Soy oil

Increased use of A, cause decrease in A, available for other purposes.



Example: Saw dust

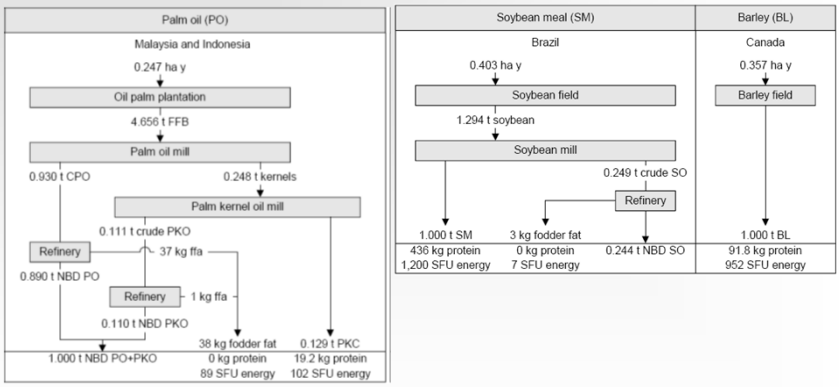
Increased use of A, cause decrease in waste management for A



Example: Mine dust

Avoiding allocation in LCA of palm oil

- Production of 1 t palm oil



Avoiding allocation in LCA of palm oil

- Production of 1 t palm oil

$$t\,PO \cdot \begin{bmatrix} 1\text{ t oil/t PO} \\ 19.2\text{ kg prot./t PO} \\ 191\text{ SFU/t PO} \end{bmatrix} + t\,SM \cdot \begin{bmatrix} 0.244\text{ t oil/t SM} \\ 436\text{ kg prot./t SM} \\ 1{,}207\text{ SFU/t SM} \end{bmatrix} + t\,BL \cdot \begin{bmatrix} 0\text{ t oil/t BL} \\ 91.8\text{ kg prot./t BL} \\ 952\text{ SFU/t BL} \end{bmatrix} = \begin{bmatrix} 1\text{ t oil} \\ 0\text{ kg prot.} \\ 0\text{ SFU} \end{bmatrix}$$

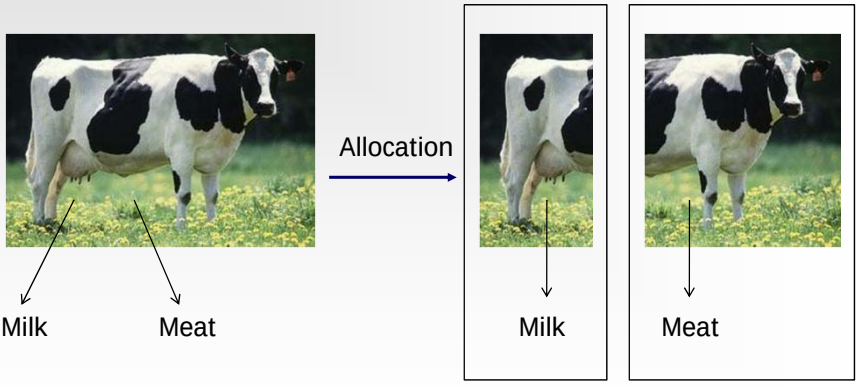
$$\Downarrow$$

$$t\,PO = 1.001$$

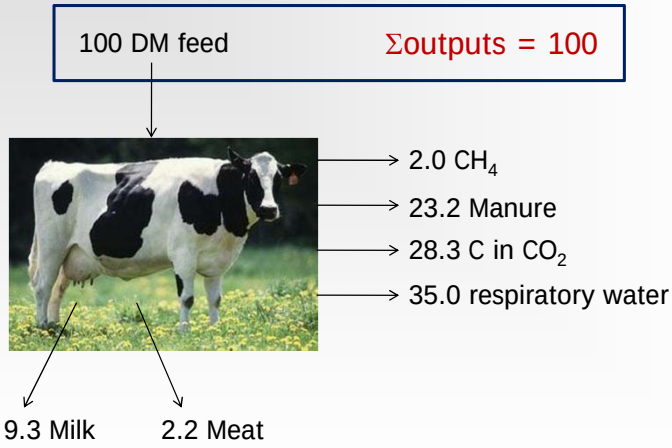
$$t\,SM = -0.00245$$

$$t\,BL = -0.198$$

Why system expansion
- Allocation – impossible processes are created

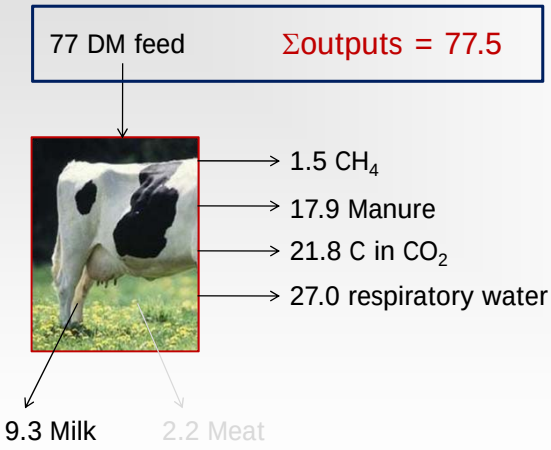


Why system expansion
- Unallocated milking cow (per 100 DM feed)



Milk: 77% of economic turnover
Meat: 23% of economic turnover

Why system expansion
Allocated milking cow (economic allocation: milk 77%)



Milk: 77% of economic turnover
Meat: 23% of economic turnover

- Why is system delimitation important?
- Approaches to system delimitation
- Consequential system boundaries
- Co-product allocation in LCA
- **Exercise**

Exercise 1: Define functional unit/reference flow

Define FU/ref. flows for the following activities

- Electricity from power plant
- Heat from CHP plant
- Natural gas

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Exercise 2: Establish LCA activities

Establish the following three LCA activities

- Electricity from power plant (natural gas fired)
- Heat from CHP plant (natural gas fired)
- Natural gas

Information:

>Each activity consists of a 'three story' column:

1. product outputs
2. product inputs
3. emissions

>Consider only product transactions of electricity, heat and natural gas

>PP efficiency = 40% electricity, CHP efficiency = 60% heat and 30% elec.

>Estimate emissions using EF_{gas} = 57 kg CO_2/GJ

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Exercise 3: Why consequential modelling

- Explain why consequential modelling should be preferred

Exercise 4: Problems of consequential modelling

- Explain which problems are related to consequential modelling:
  - Conceptual problems
  - Practical problems
  - Cognitive problems (is it difficult to understand… does it produce surprising results…)