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Centre interuniversitaire de recherche sur le cycle de vie des produits, procédés et services

DDI8003 – Week 6

Multifunctional systems

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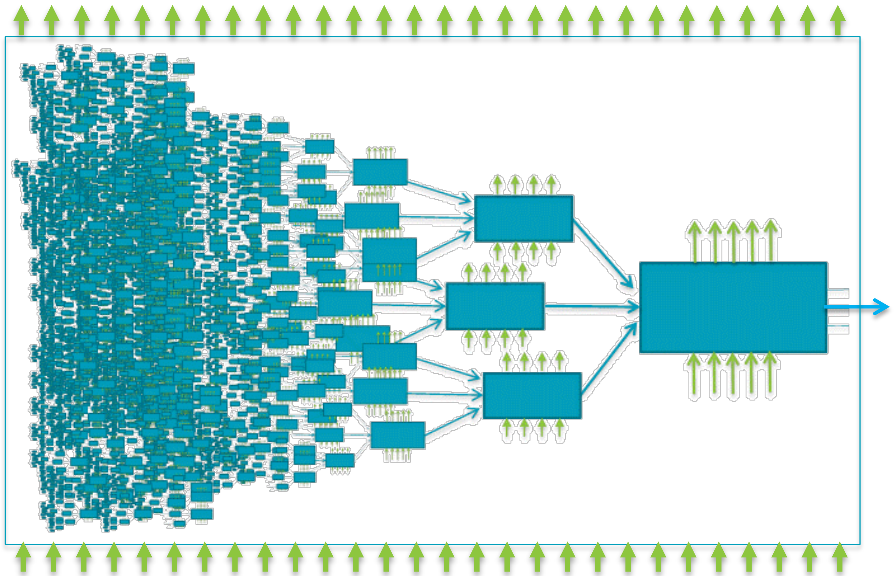
POLYTECHNIQUE MONTRÉAL

WORLD-CLASS ENGINEERING

Recap: System boundary

- In theory, the only economic flows that cross the system boundary in the study are directly associated to the function (final demand flow)
- The other economic flows are entirely consumed by the other unit processes
- All other flows that cross the system boundary are elementary flows



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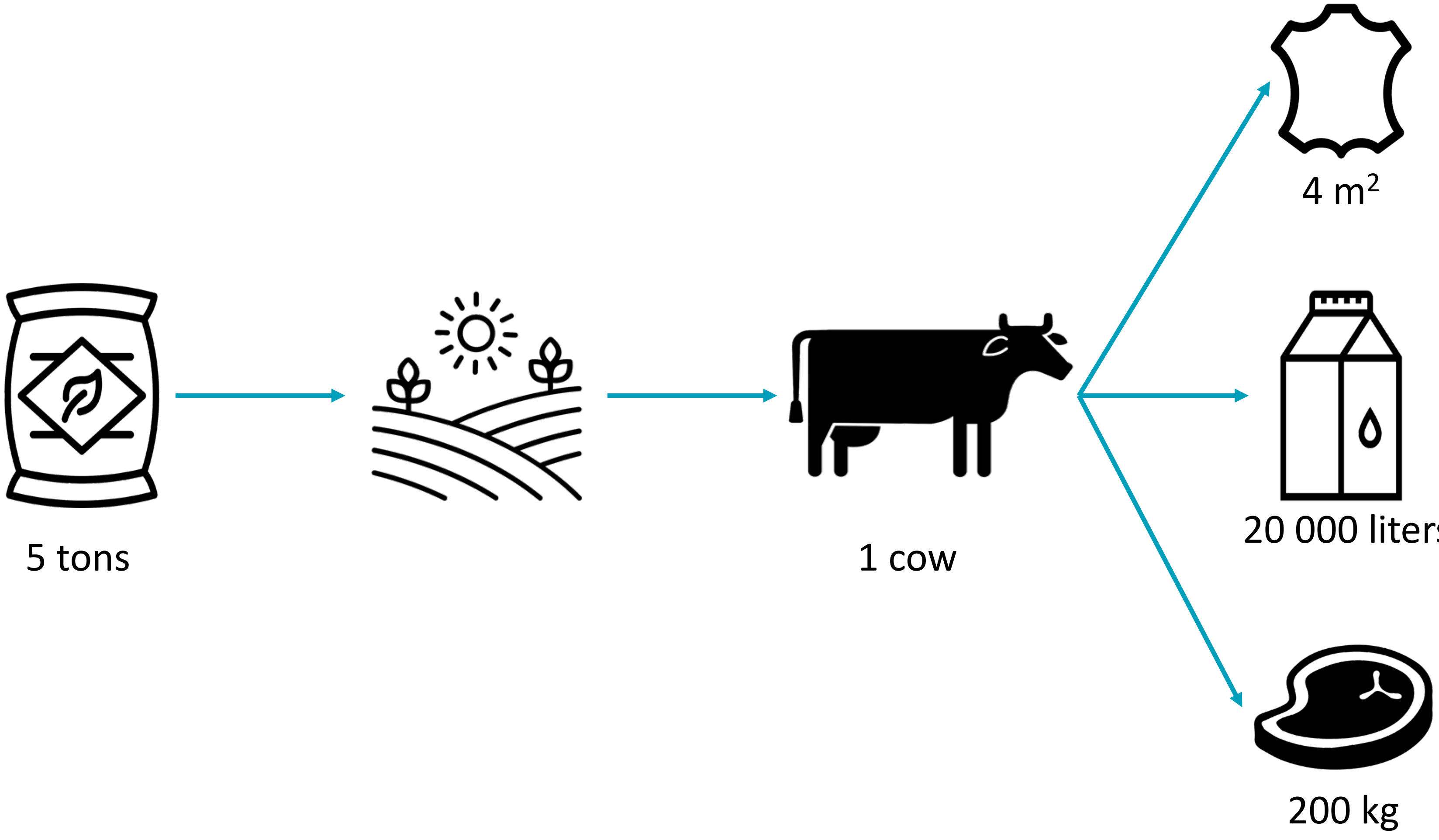
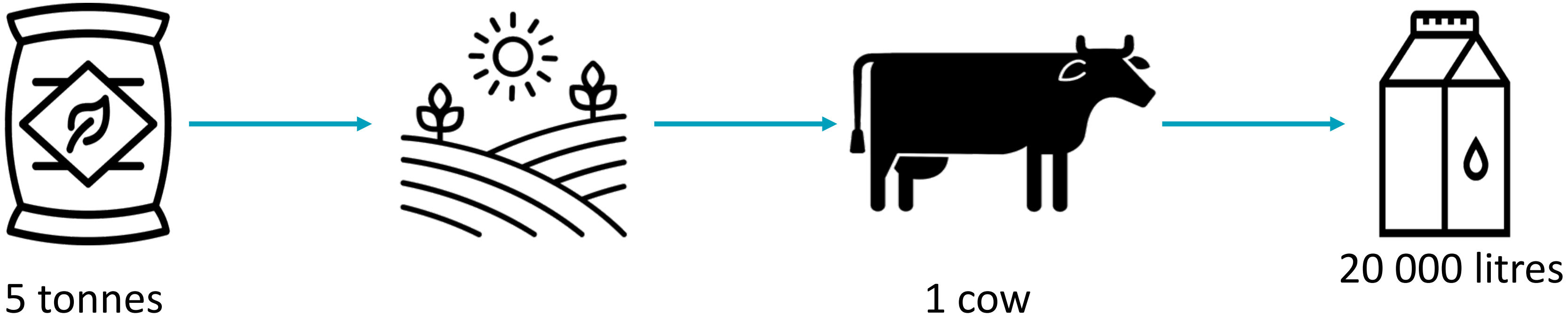
Multifunctional processes – the example of a cow



Processus multifonctionnels

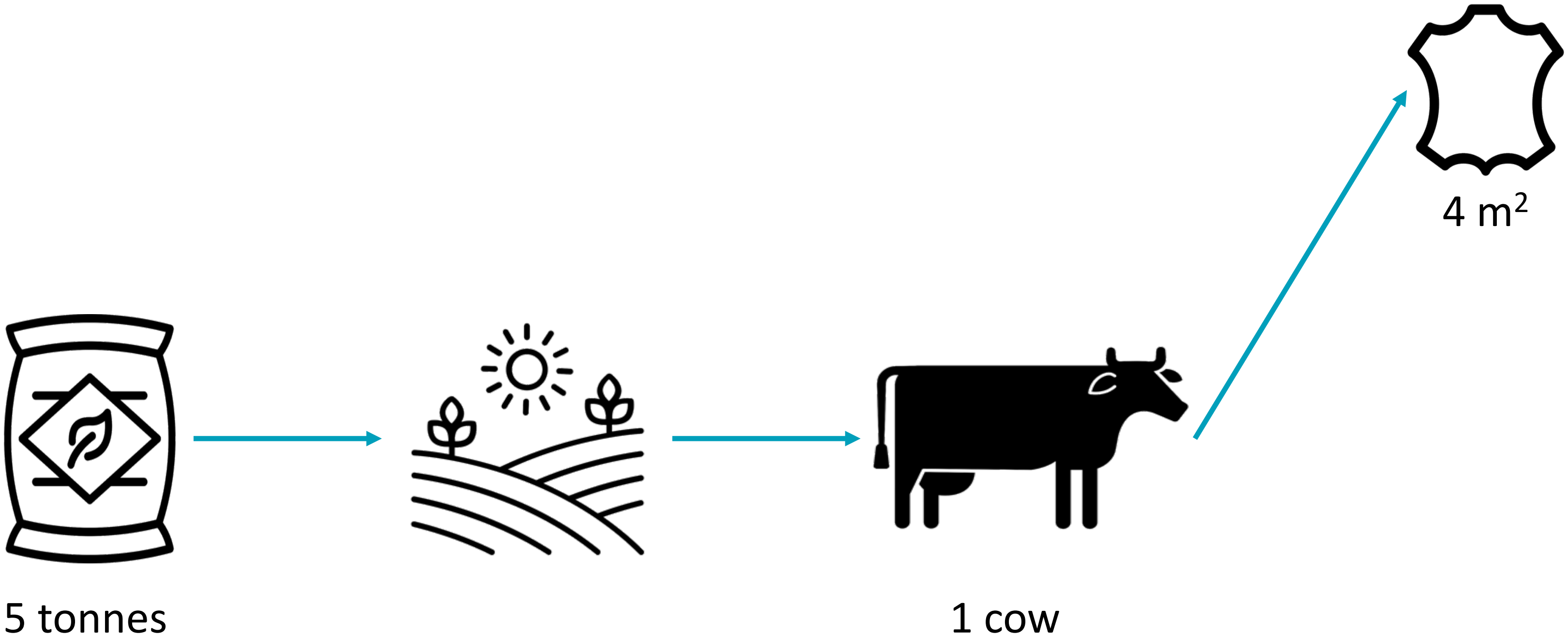
- Imagine the following situation: an almost deserted island is home to a field that can support a cow for the rest of her life.
- During this time, 5 tons of fertilizer were used. During her lifetime, the cow produces a few thousand liters of milk. At its death, 4 m2 of leather and a couple of hundreds kg of meat are produced.
- An LCA is performed on the milk produced. A process tree is used to identify the processes involved in applying the fertilizer as part of the product system.
  - **After calculation, it is determined that 5 tons of fertilizer are needed to produce the milk.**
  - **A second LCA is performed on the leather produced. Again, it is identified that the fertilizer application should be accounted for. After calculation, it is concluded that 5 tons of fertilizer are needed to produce the leather.**
- You make a simple addition, 5 tons + 5 tons = 10 tons of fertilizer. Now, you know, as the manager of the island, that you used 5 tons... Find the mistake.

Multifunctional processes



5 tonnes of fertilizer for the milk

Multifunctional processes



5 tonnes of fertilizer for the milk
+ 5 tonnes of fertilizer for the leather

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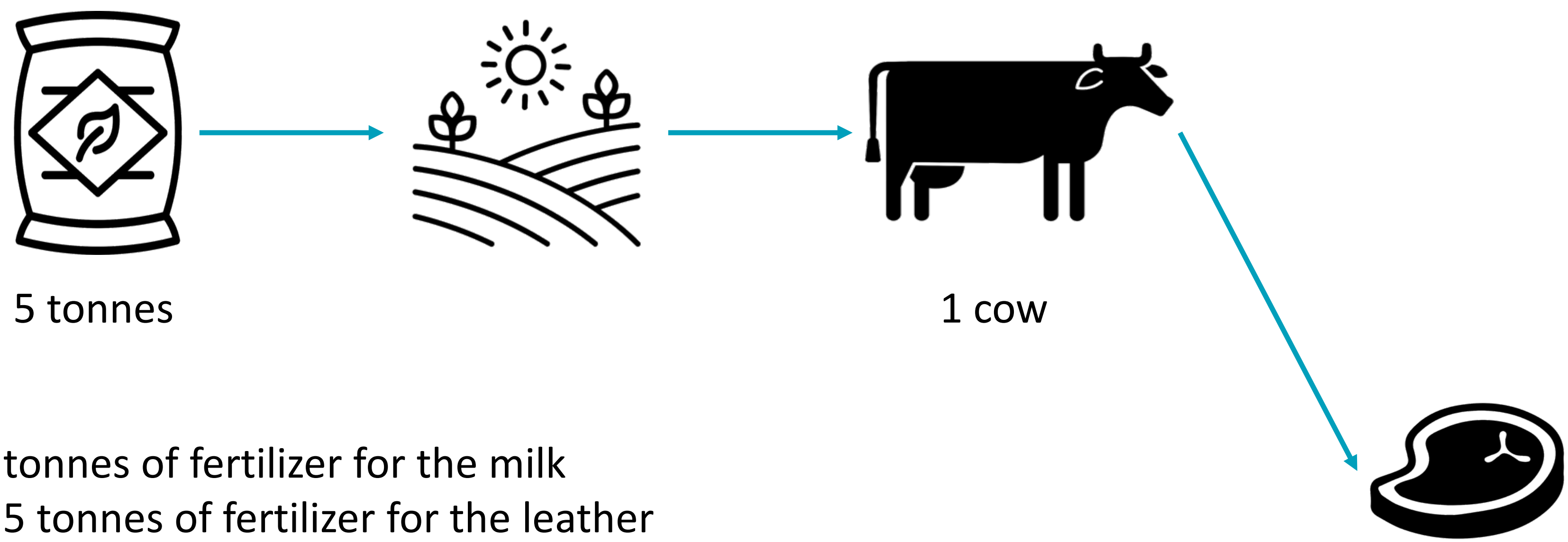
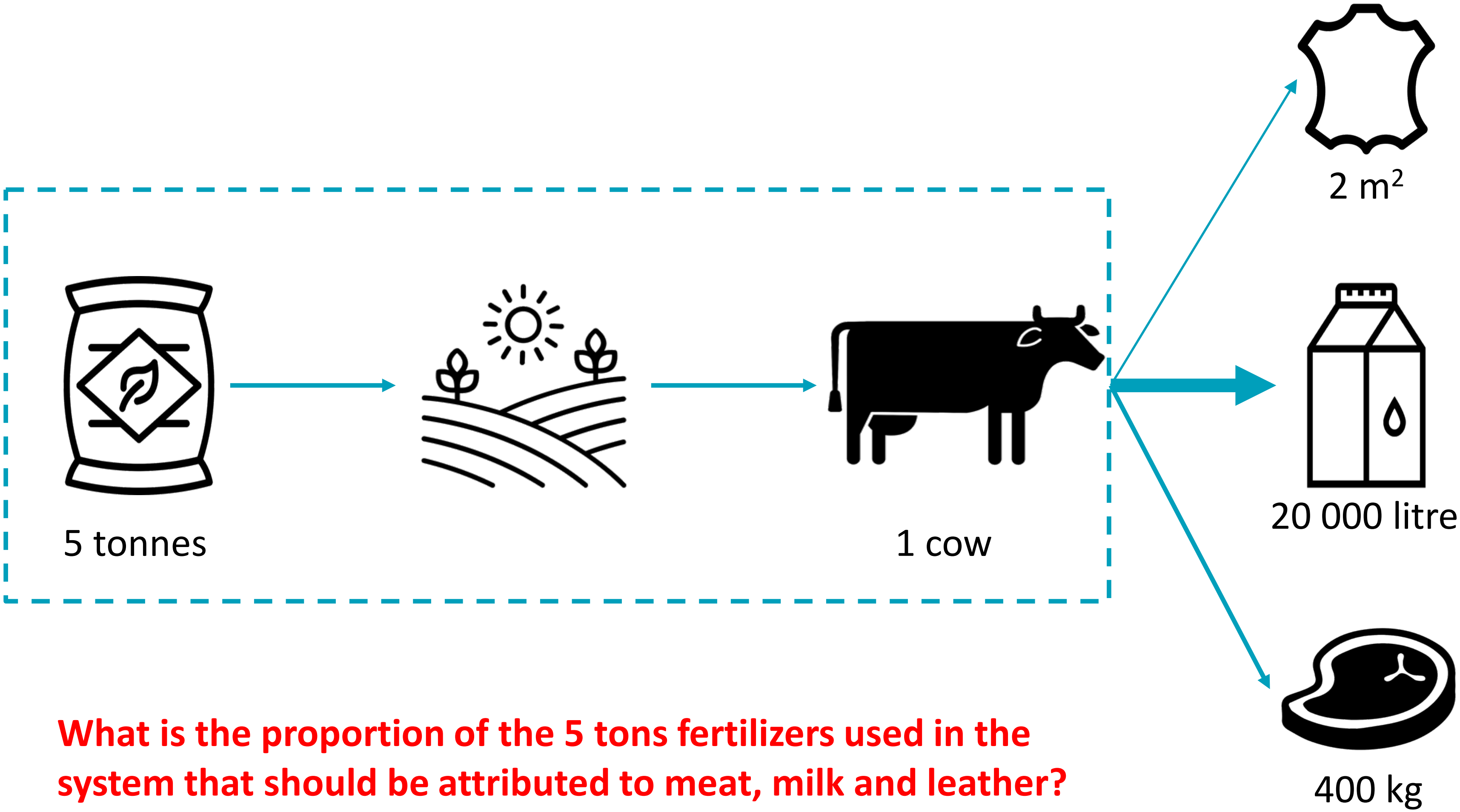
Multifunctional processes



5 tonnes of fertilizer for the milk
+ 5 tonnes of fertilizer for the leather
+ 5 tonnes de fertilizer for the meat
= 15t!! → **ERROR!**

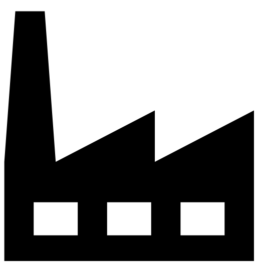
Multifunctional processes



What is the proportion of the 5 tons fertilizers used in the system that should be attributed to meat, milk and leather?

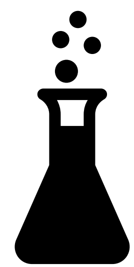
Multifunctional processes

- When a process provides more than one function (co-products, multiple services, etc.) we need to « distribute » the inputs and outputs to each of the functions to avoid double-counting.
- These processes are omnipresent:



Thermal electric power:
Electricity + heat

Sawmill:
construction wood, wood chips



Production of NaOH by electroysis of an NaCl solution:
NaOH, Cl_2, H_2

Transport: several products transported

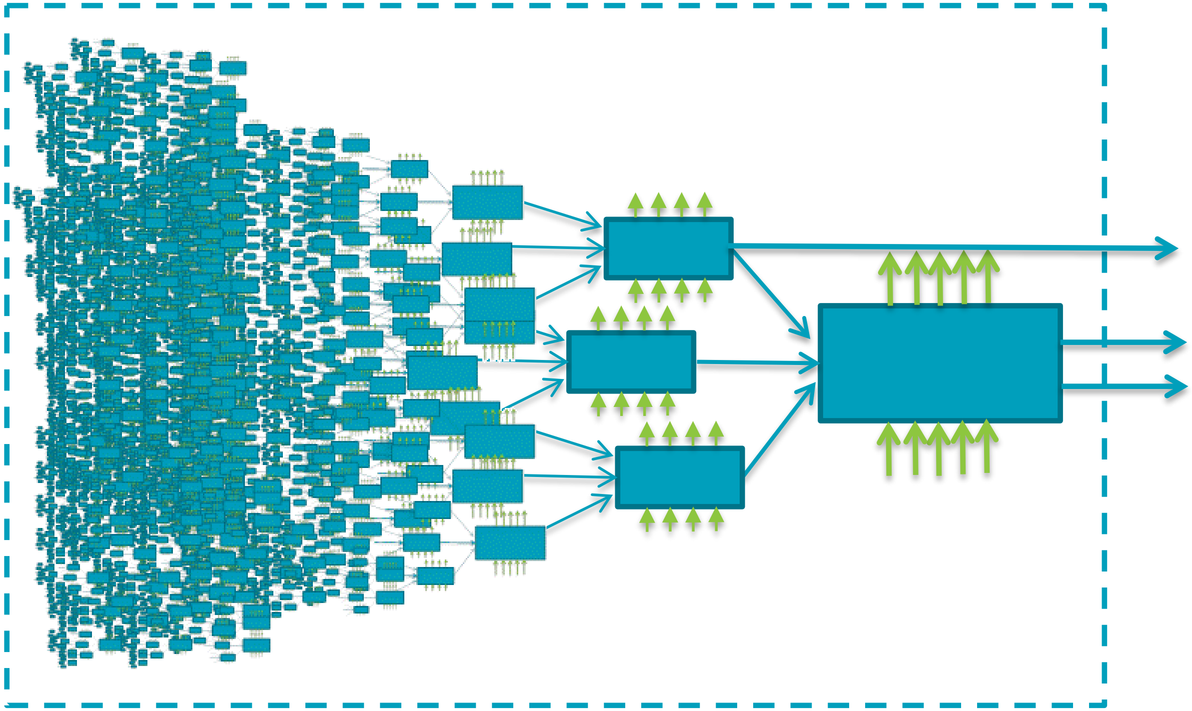
Multifunctional processes

- When a process provides more than one function (co-products, multiple services, etc.) we need to « distribute » the inputs and outputs to each of the functions to avoid double-counting.
- These processes are omnipresent:
  - **Wheat cultivation: straw, wheat grain**
  - **Raising cows: meat, milk, leather**
  - **Thermal electric power plant: electricity, heat**
  - **Production of NaOH by electroysis of an NaCl solution: NaOH, Cl_2, H_2**
  - **Transportation: many products transported in the same truck**
  - **Refining petroleum: carboreactor (aviation fuel), gasoline, diesel, propane, etc.**
  - **Sawmill: construction wood, wood chips for paper production, wood waste for energy production**

Why multifonctionality set a problem?

Problem of « double counting »

Only one intermediary flow can cross the system boundary



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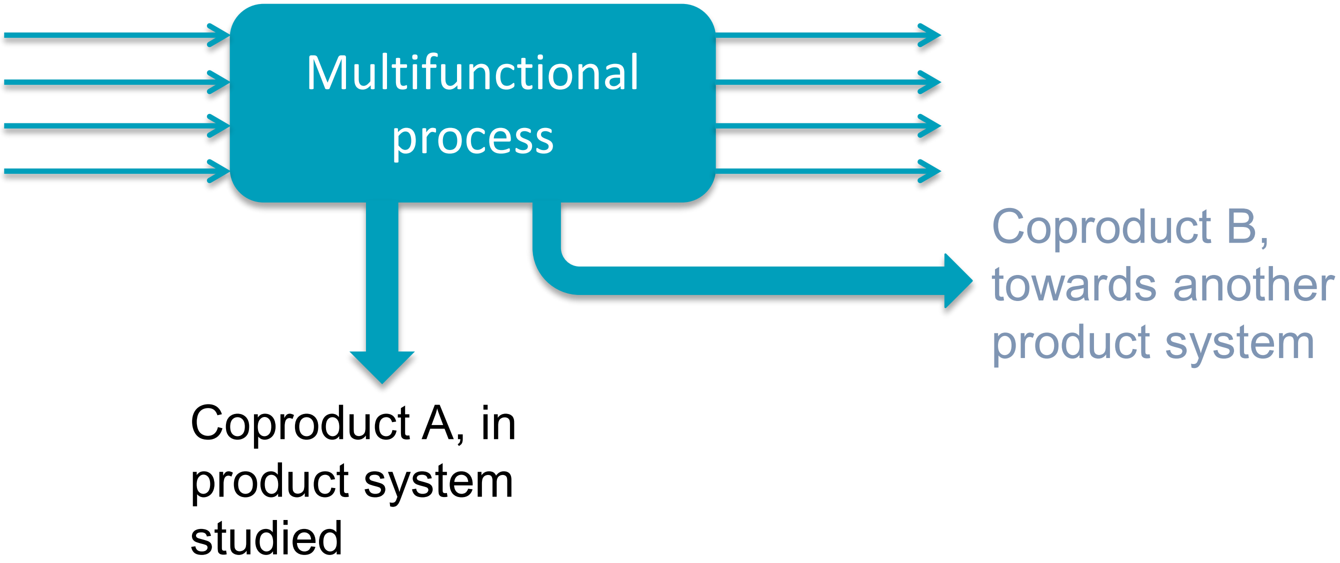
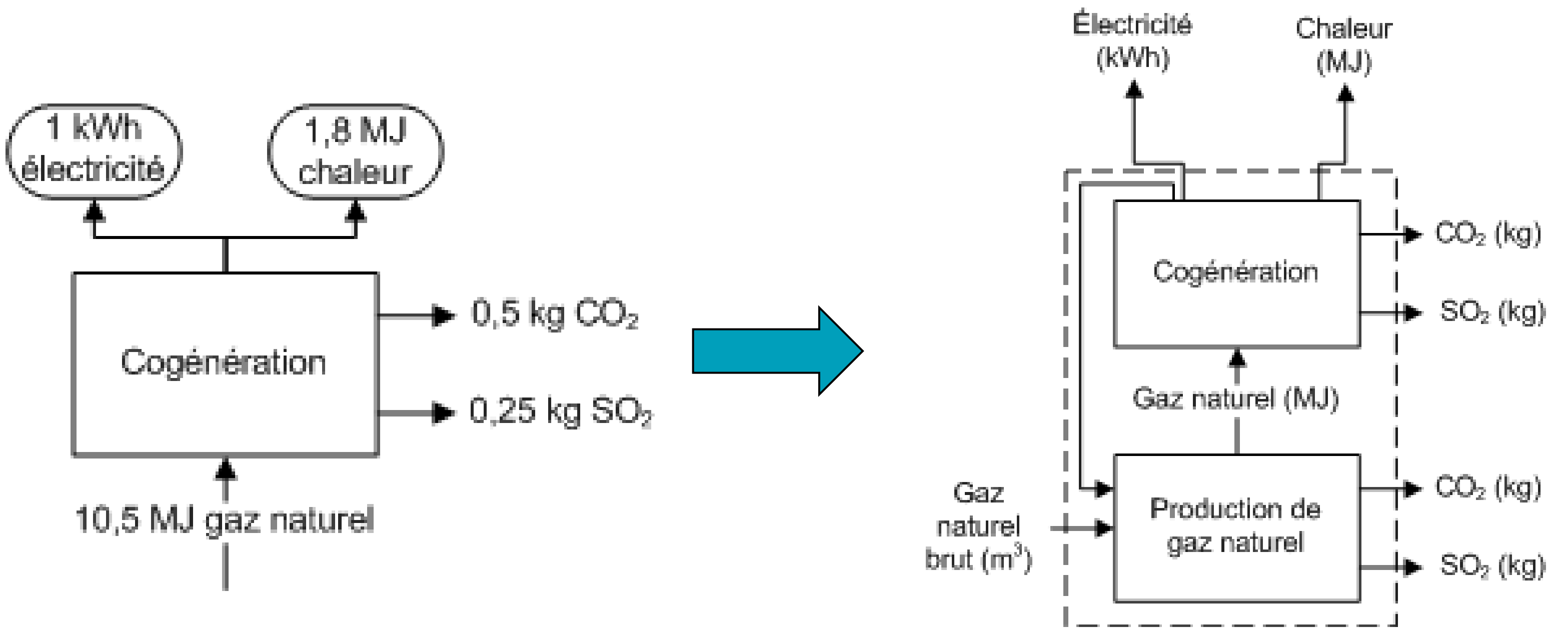
Multifunctionality problem



Problem: What proportion of impacts associated to the inputs and outputs of the multifunctional process should be attributed to coproduct A?

Multifunctional processes

- The only economic flow that may cross the system boundary is the one directly associated to the functional unit!
- With multifunctional processes, supplementary economic flows cross the system boundary: the system has more than one function!!!



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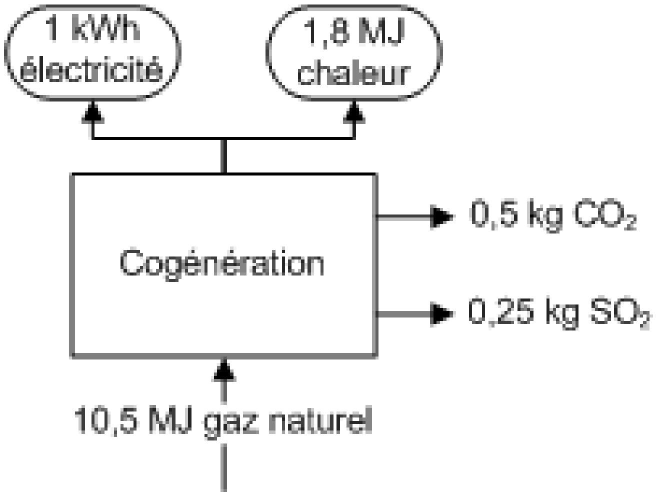
Multifunctional processes

- The only economic flow that may cross the system boundary is the one directly associated to the functional unit!
- With multifunctional processes, we will also have non-inversible **A** matrices (not square)…



	p_{cogen}	p_{GN}	
Electricity (kWh)	1	-2,5	**A**
Natural gas (MJ)	-10,5	1000	
Heat (MJ)	1,8	0	
Raw natural gas (m^3)	0	-25	**B**
CO_2 (kg)	0,5	10	
SO_2 (kg)	0,25	0,01	

How to solve multifunctionality in LCA?

Subdivision

System expansion

Underlying physical relationship

Allocation

Multifunctional processes and ISO 14044

ISO 14044, section 4.3.4.2: The study must identify the processes shared with other product systems and follow the step-by-step procedure presented here:

Step 1: Avoid allocation as much as possible by:

- **Subdividing the unit process by creating two sub-processes or more;**
- **Extend the system boundary of the product system**

Step 2: Allocate the inputs and outputs in a way that reflects underlying physical relationships existing between them.

Step 3: Allocate inputs and outputs in a way that reflects other mutual relationships (mass, economic, etc.)

ISO calls them steps, but they are in fact 4 mutually exclusive options

Multifunctional processes and ISO 14044

ISO 14044, section 4.3.4.2: The study must identify the processes shared with other product systems and follow the step-by-step procedure presented here:

Step 1: Avoid allocation as much as possible by:

- **Subdivision** **process by creating two sub-processes or more;**
- **System extension** **oundary of the product system**

Step 2: Alloc **Allocation – Underlying physical relationship** cts underlying p

Step 3: All **Allocation – Other relationship** other mutual relat

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Multifunctional processes and ISO 14044

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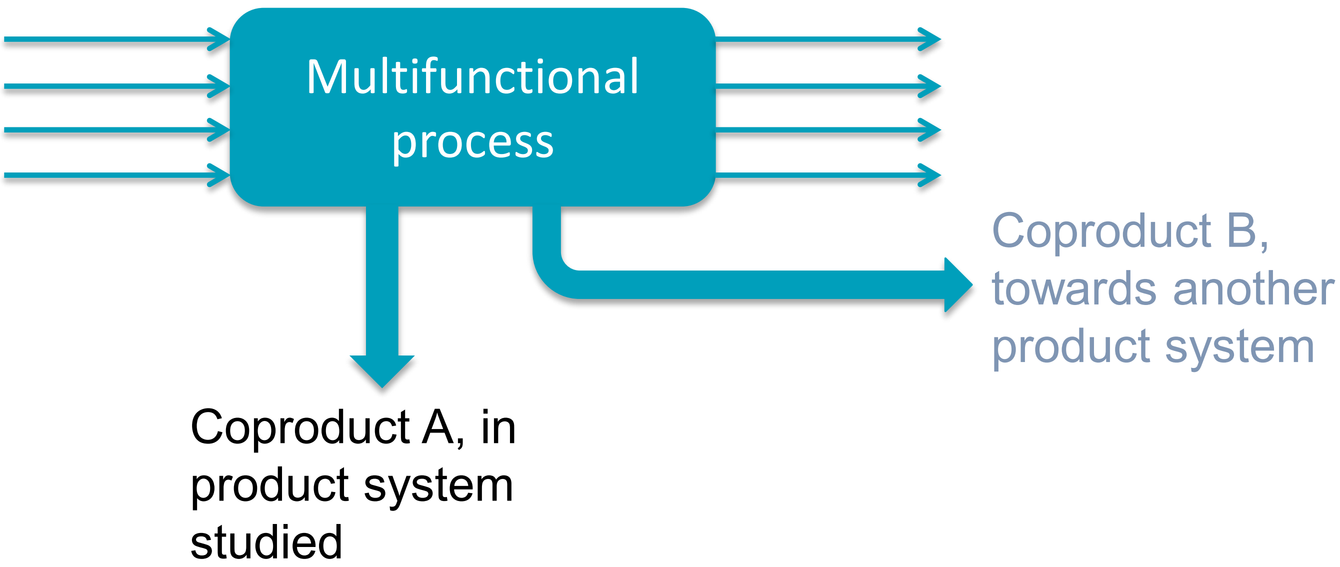
ISO 14044 Procedure– Step 1a: Subdivision



Step 1.1: Divide the process in sub-processes

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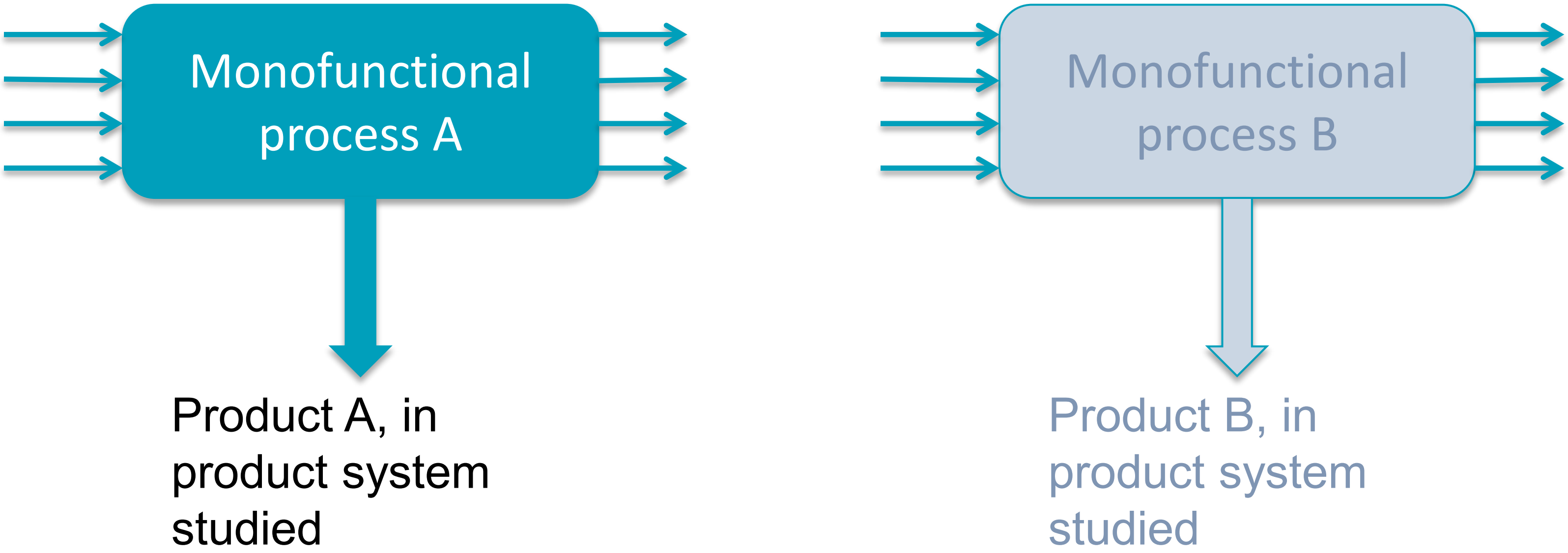
ISO 14044 Procedure– Step 1a: Subdivision



Step 1.1: Divide the process in sub-processes

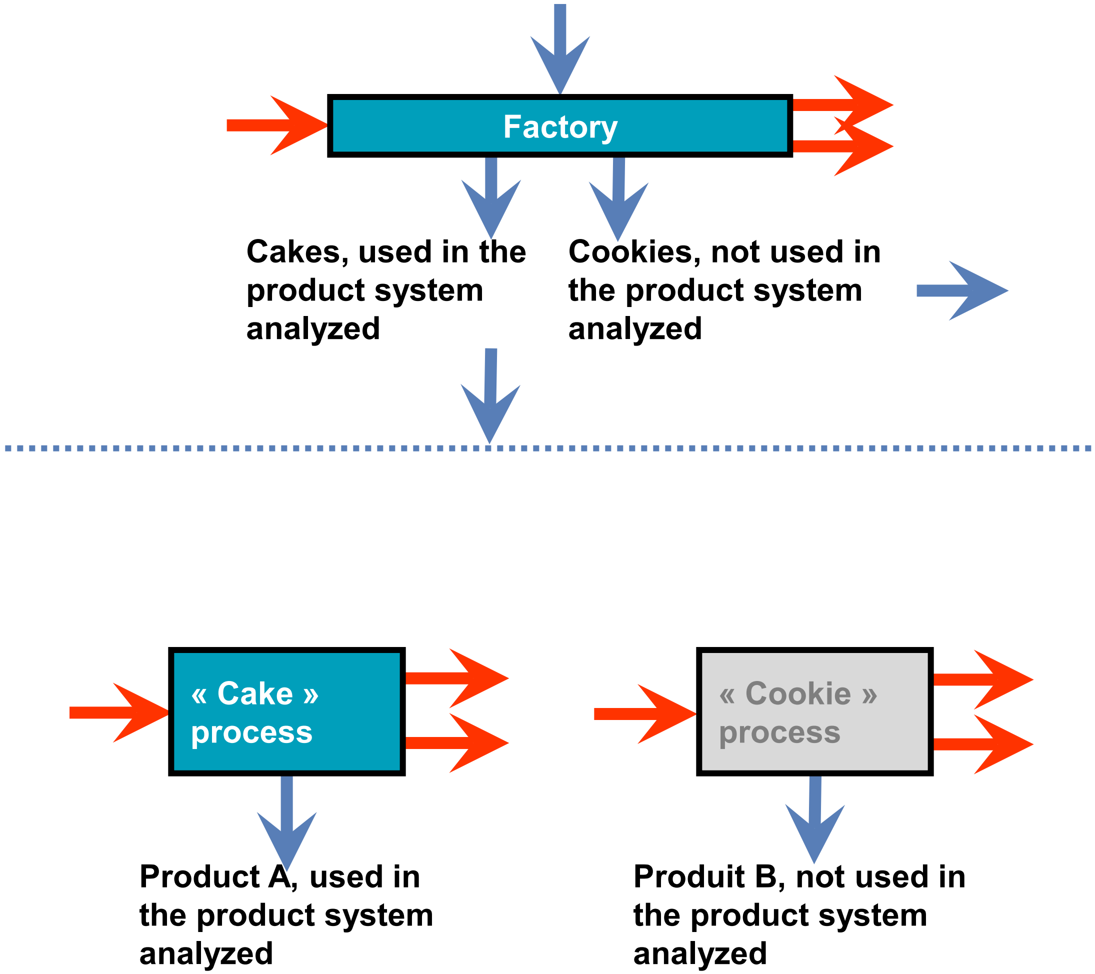
<u>Note</u>: only applicable if the process isn't actually multifunctional

ISO 14044 Procedure– Step 1a: Subdivision

- Example: LCA of cakes.

We have data for all inputs and outputs of a factory producing two products: cakes and cookies.

The data collection could be refined to distinguish the processes in the factory that are used for the cake and those used for the cookies.



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Multifunctional processes and ISO 14044

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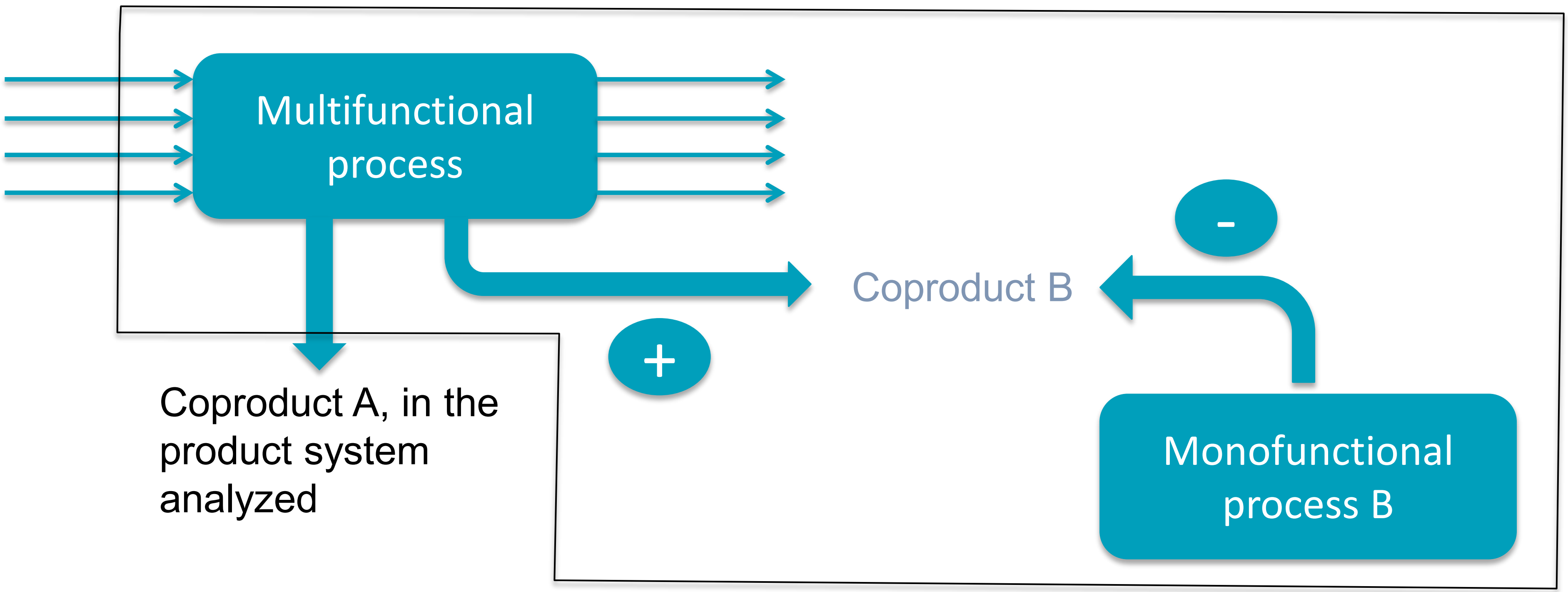
ISO 14044 Procedure– Step 1b: Expanding the system boundary



Step 1.2: Expand the system boundary

Only applicable if there is a process producing a functionally equivalent product to product B

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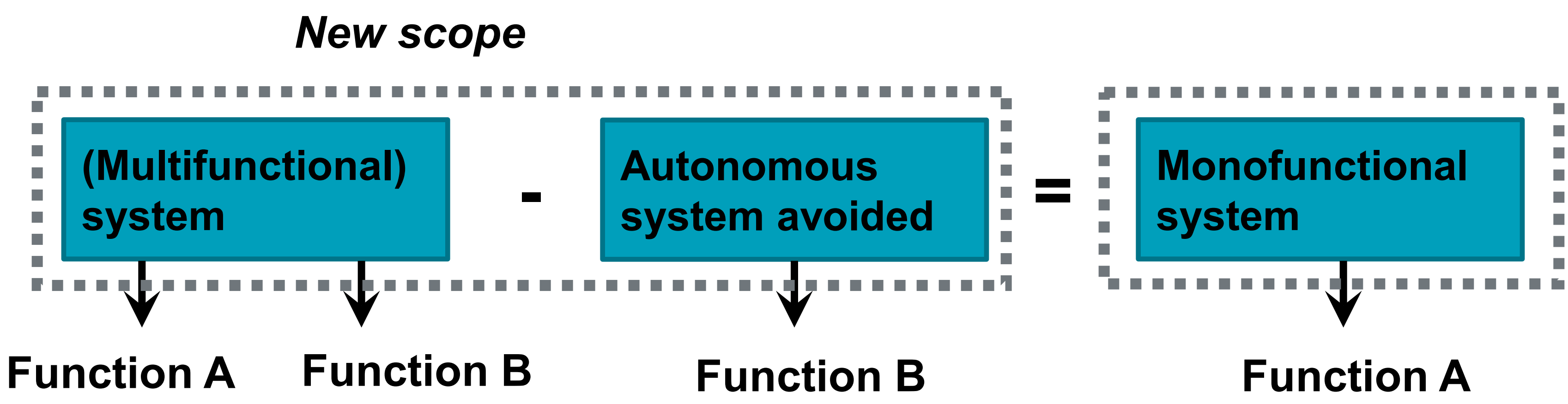
ISO 14044 Procedure– Step 1b: Expanding the system boundary

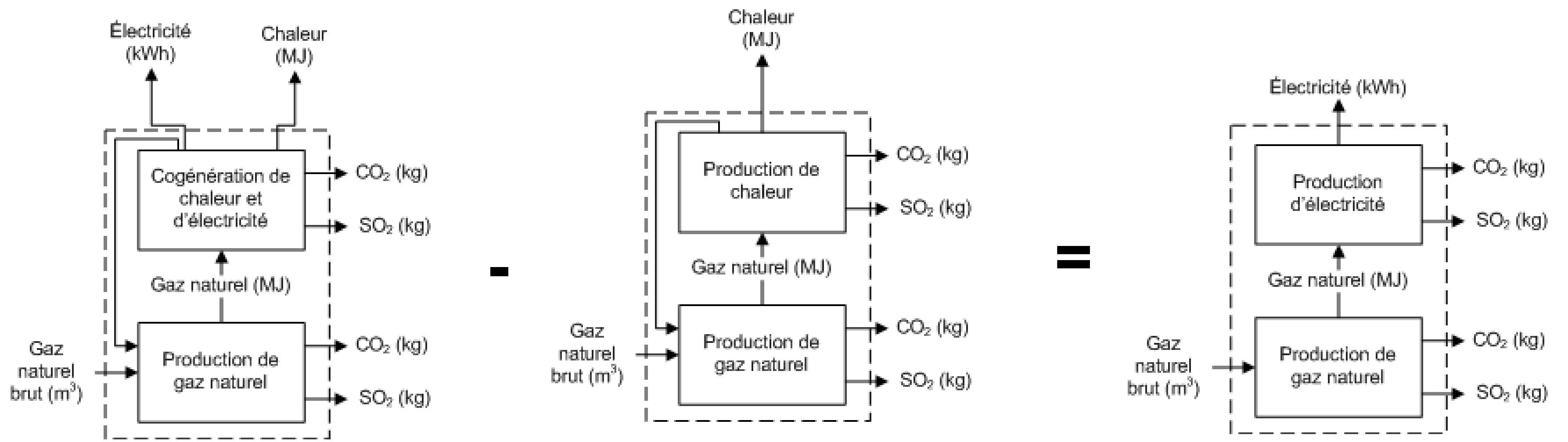
- In this approach, the product system is expanded to include avoided unit processes
  - LCA on function A, product system A and B
  - We take into account the avoided (negative) autonomous system, that represents an alternative way to produce B
    → substitution, displacement, avoidance
  - We consider then that the expanded system is equivalent to a product system that doesn't have function B as an output



ISO 14044 Procedure– Step 1b: Expanding the system boundary

To use system expansion, we need to be able to identify an alternative way to produce the co-product that does not belong to the functional unit of interest.

ISO 14044 Procedure– Step 1b: Expanding the system boundary



Adjusted A-Matrix by system expansion

	p_{cogen}	p_{GN}	$p_{chaleur}$
Electricity (kWh)	1	-2,5	0
Natural gas (MJ)	-10,5	1000	-1.05
Heat (MJ)	1,8	0	1
Raw natural gas (m^3)	0	-25	0
CO_2 (kg)	0,5	10	0,06
SO_2 (kg)	0.25	0.01	6e-7

A→square!

B

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Multifunctional processes and ISO 14044

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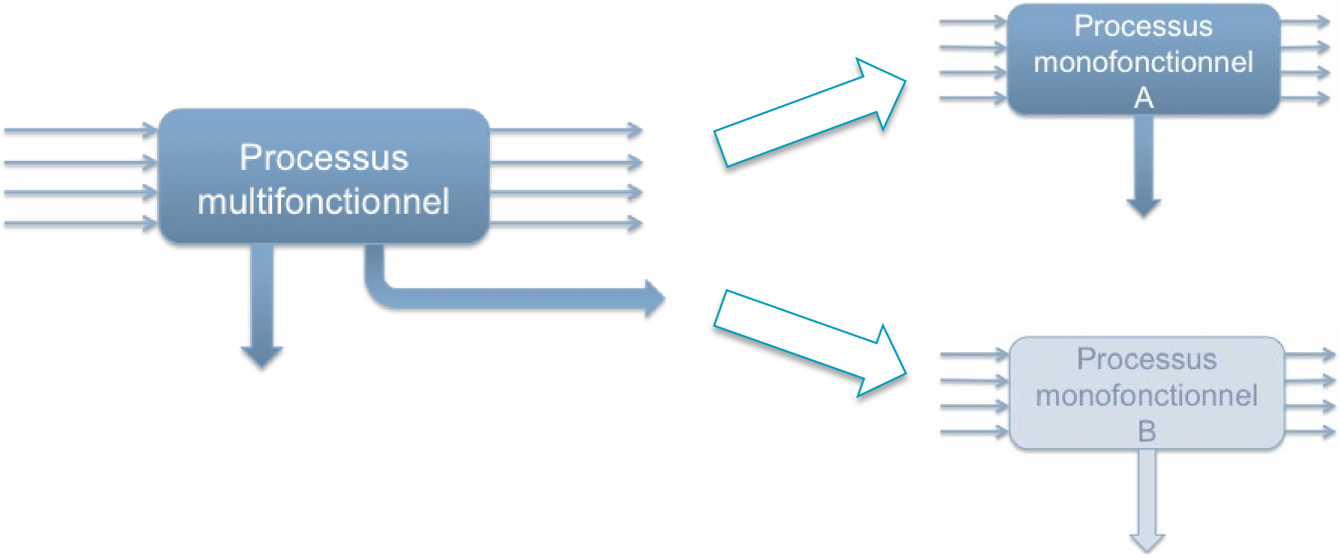
ISO 14044 Procedure – Step 2: underlying physical relationships



Step 2: Allocate between products in a way that reflects underlying physical relationships existing between them

Only applicable if we can vary the co-products independently (combined production)

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ISO 14044 Procedure – Step 2: underlying physical relationships

→ Applies to **combined productions**

- This method allows us to determine how the inputs and outputs are affected by an increase in production of one of the co-products.
- This information is used to estimate the inputs and outputs associated to one product only
- Coming back to LCA example of the factory producing cakes and cookies:
  - **If it's impossible to simply attribute the different unit processes inside the factory to those producing cakes, we could vary the quantity of cakes produced: this would affect the inputs and outputs of the factory**
  - **In this way, we could determine which inputs are directly attributable to cakes**
- Not be be confused with applying a physical property like mass (Step 3: allocation)!

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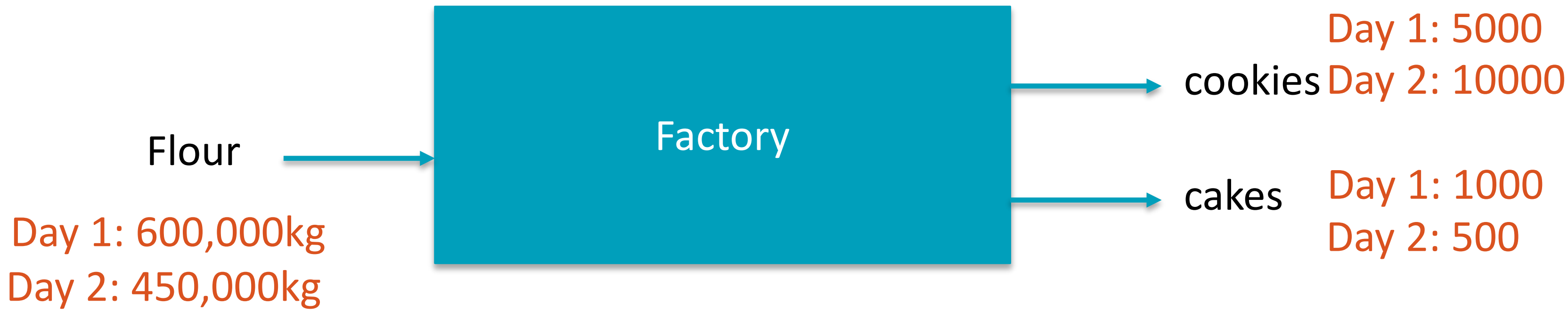
ISO 14044 Procedure – Step 2: underlying physical relationships



How much flour do I need per cookie (#flour/cookie) ? Per cake (#flour/cake) ?

For day1 (or 2) : #flour = #cookies*#flour/cookies + #cakes*#flour/cakes
For day 1- day2: Δflour=Δcookies*#flour/cookies + Δcakes*#flour/cakes

→ #flour/cake=500
→ #flour/cookie=20

Multifunctional processes and ISO 14044

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Step 3: Allocate inputs and outputs in a way that reflects other mutual relationships (mass, economic, etc.)

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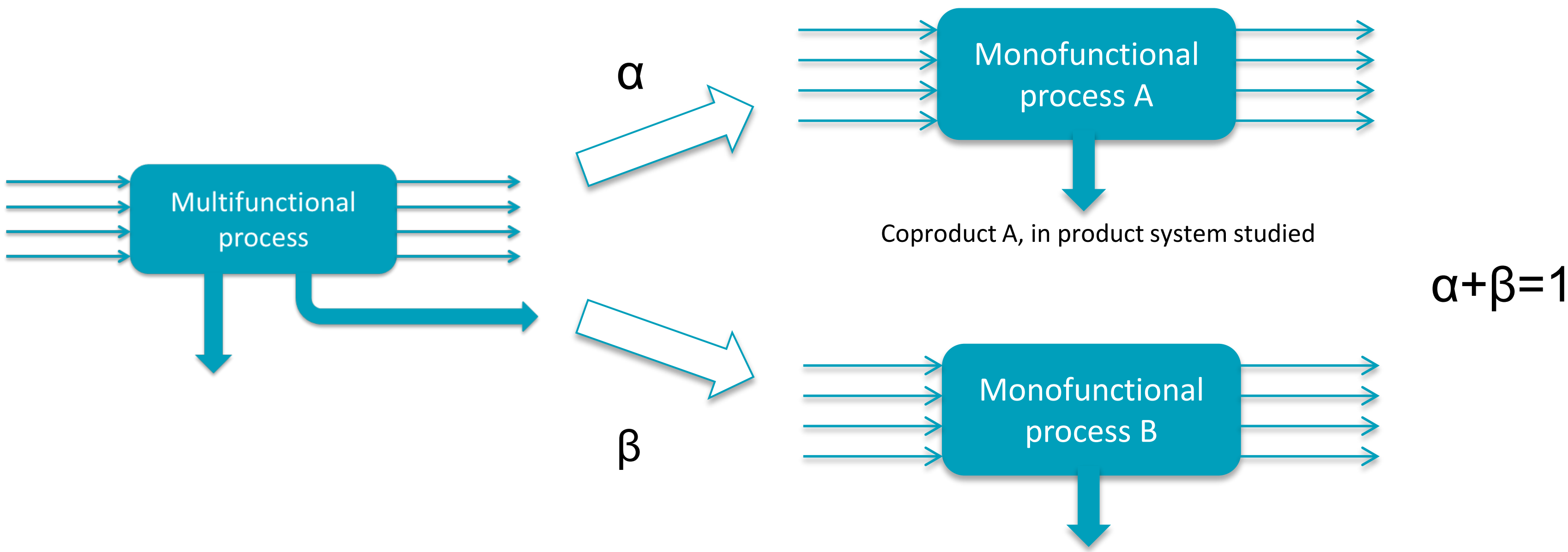
ISO 14044 Procedure – Step 3: Other relationship



Step 3: Attribute according to another mutual relationship (economic value, mass, surface, exergy, etc.)

Results are only valid for the chosen mutual relationship .
Useful for joint production.

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ISO 14044 Procedure – Step 3: Other relationship

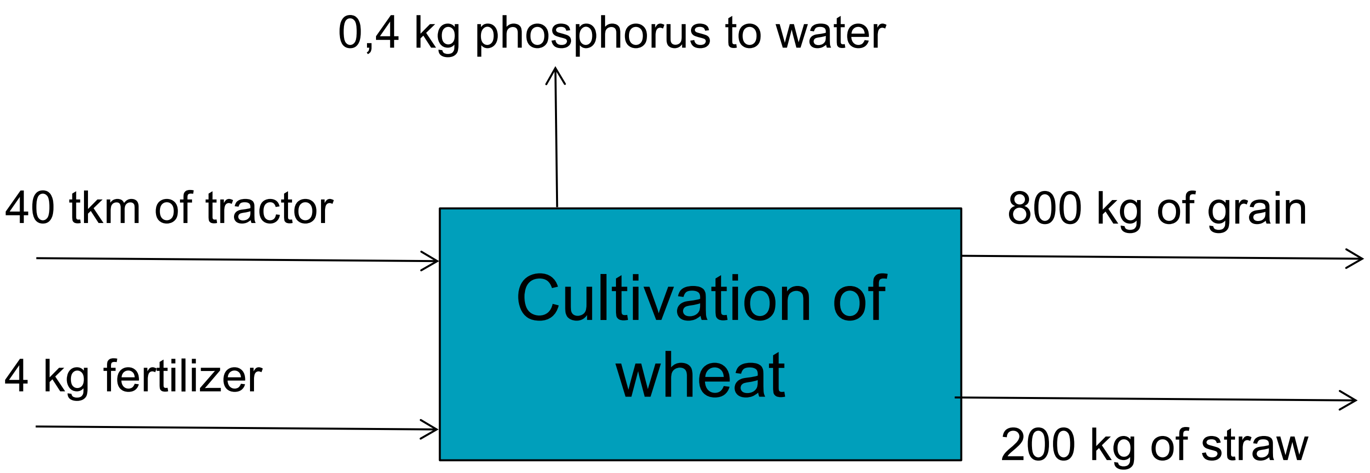
→ Applies to **joint productions**

- The inputs and outputs are allocated between the different products
  - **According to a physical property (e.g. mass, energy, surface)**
  - **According to economic value of the co-products**
  - **According to another valuable relationship**

- Causality principle : the factors used to allocate a flow to a product should reflect the degree of responsability of the product for generating that flow

ISO 14044 Procedure – Step 3: Other relationship

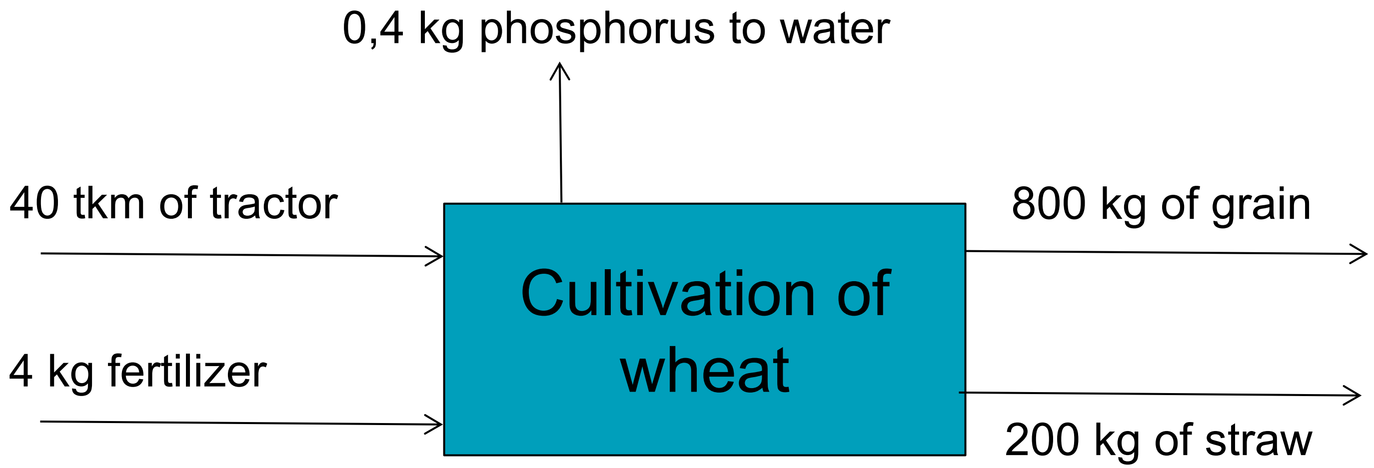
- Allocation example



- Choice of allocation base: mass? economic?

ISO 14044 Procedure – Step 3: Other relationship

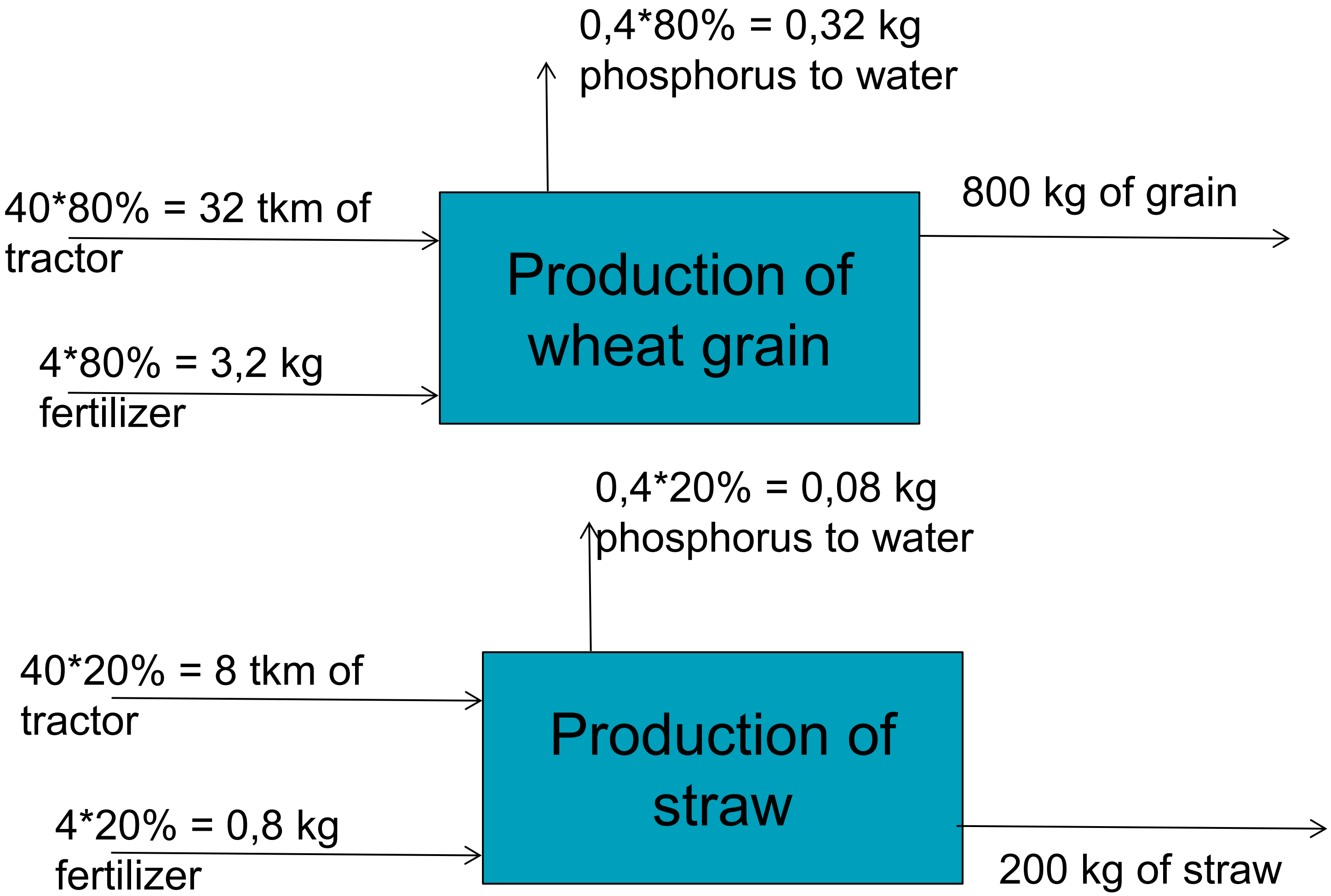
- Allocation example: mass



- Total mass produced: 800 + 200 = 1000 kg
- Allocation factor for grain = 800/1000 = 80%
- Allocation factor for straw = 200/1000 = 20%

ISO 14044 Procedure – Step 3: Other relationship

- Allocation example: mass



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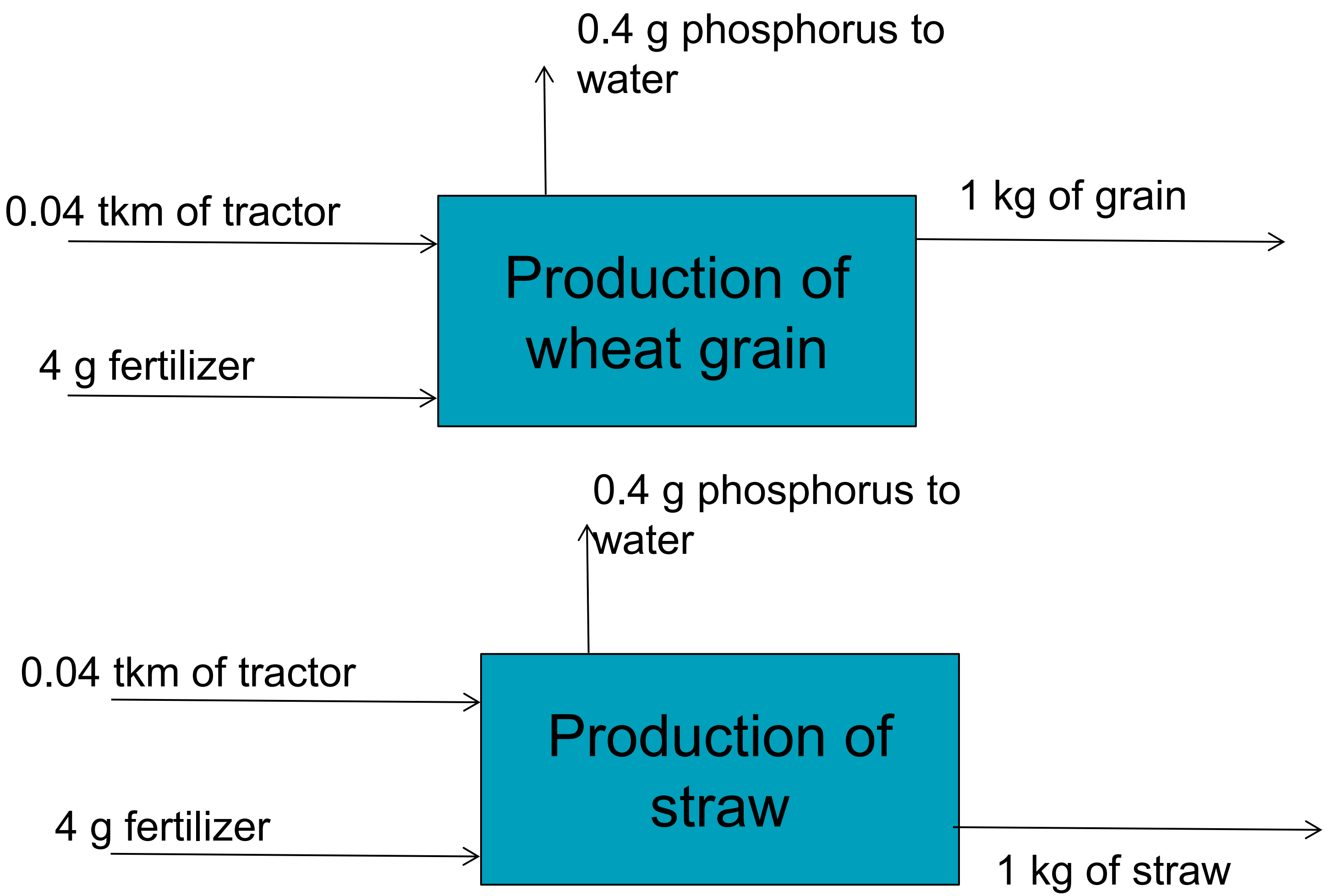
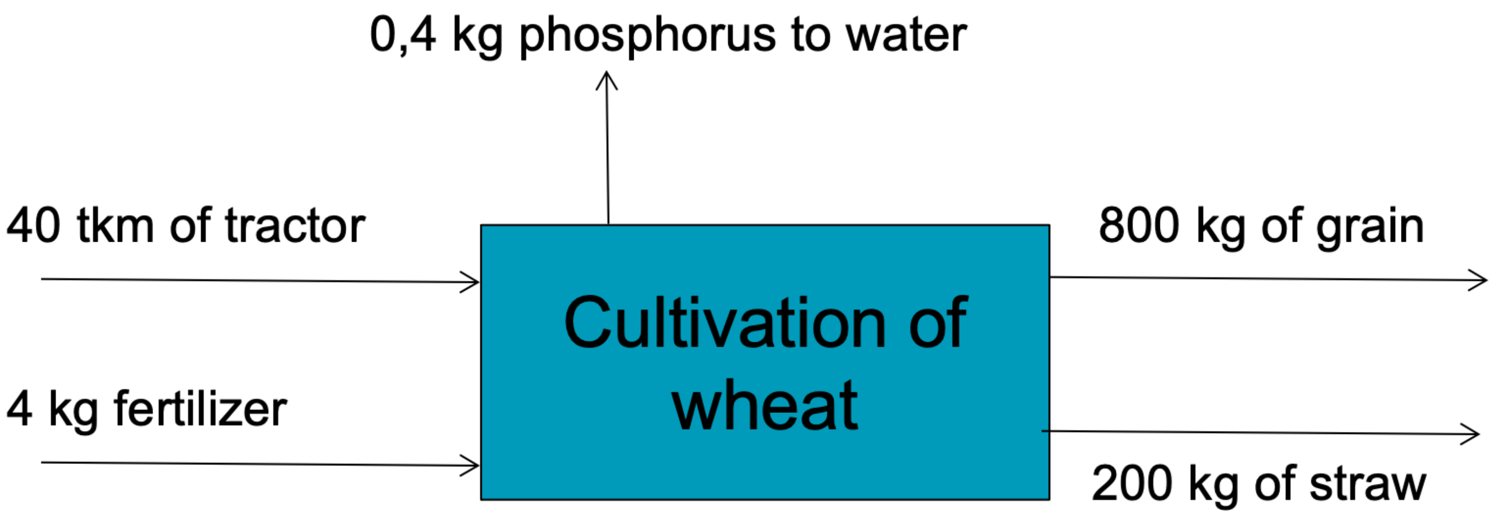
ISO 14044 Procedure – Step 3: Other relationship

- Allocation example: mass



ISO 14044 Procedure – Step 3: Other relationship

- Allocatin Example: economic allocation
  - **Let's take the same process, but let's use an economic allocation**
  - **Let's suppose the following prices:**
    - Wheat grains: 0,25$/kg
    - Straw: 0,1$/kg



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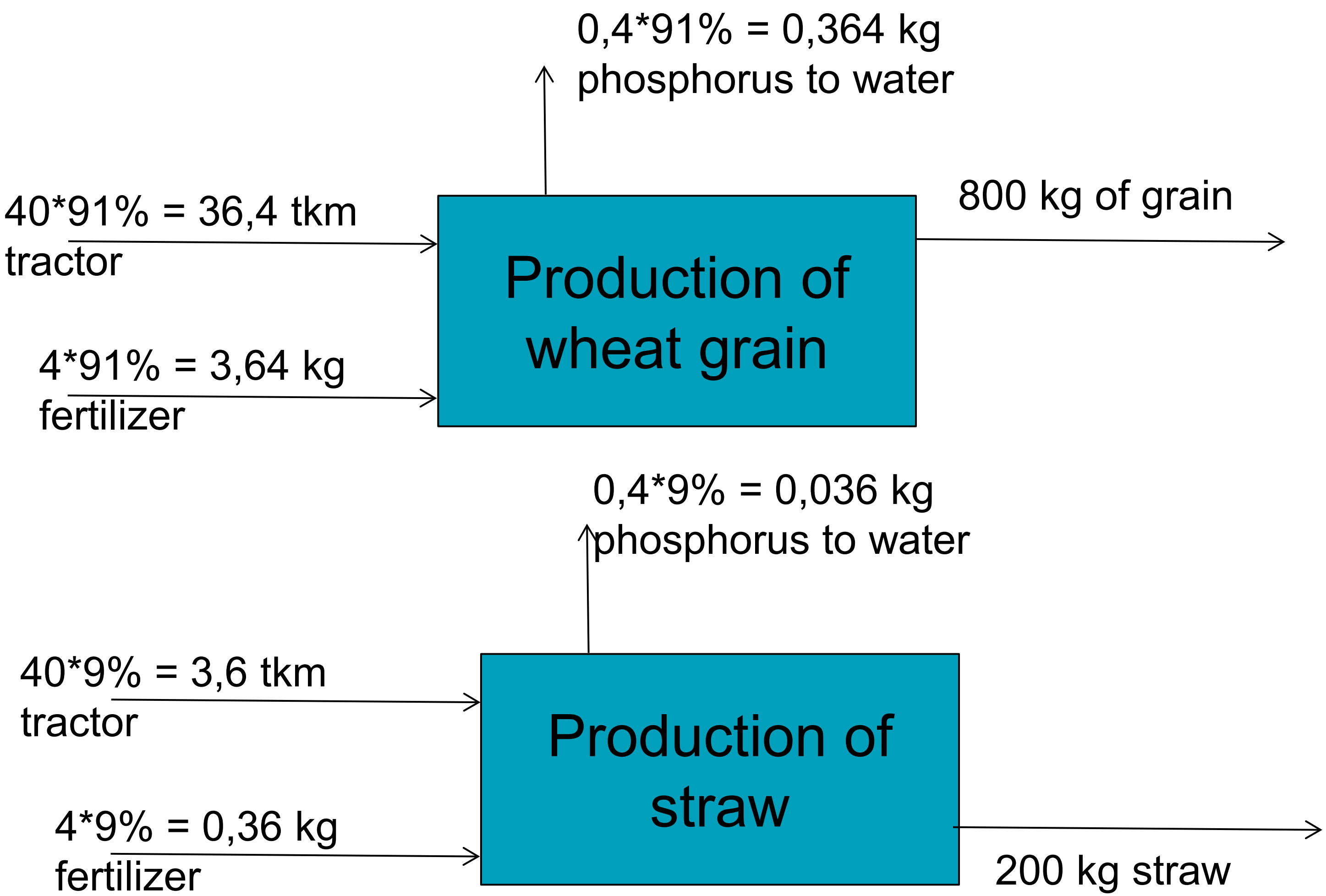
ISO 14044 Procedure – Step 3: Other relationship

- Example of economic allocation
  - **Let's take the same process, but let's use an economic allocation**
  - **Let's suppose the following prices:**
    - Wheat grains: 0,25$/kg
    - Straw: 0,1$/kg

- Total revenue: 800 kg * 0,25 $/kg + 200 kg * 0,1 $/kg = 220$
- Allocation factor for grain = 200/220 = 91%
- Allocation factor for straw = 20/220 = 9%

ISO 14044 Procedure – Step 3: Other relationship

- Allocation example: economic



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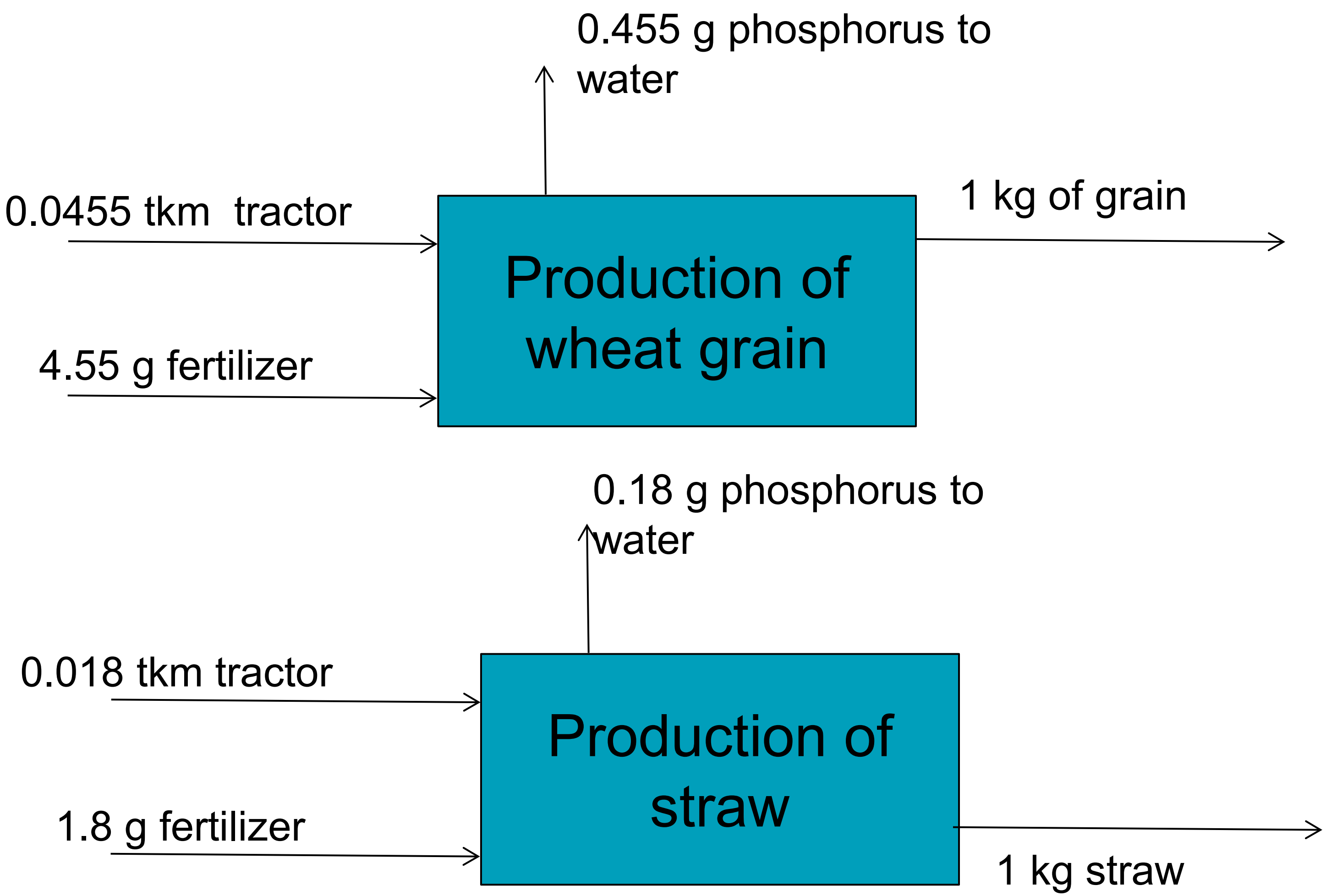
ISO 14044 Procedure – Step 3: Other relationship

- Allocation example: economic



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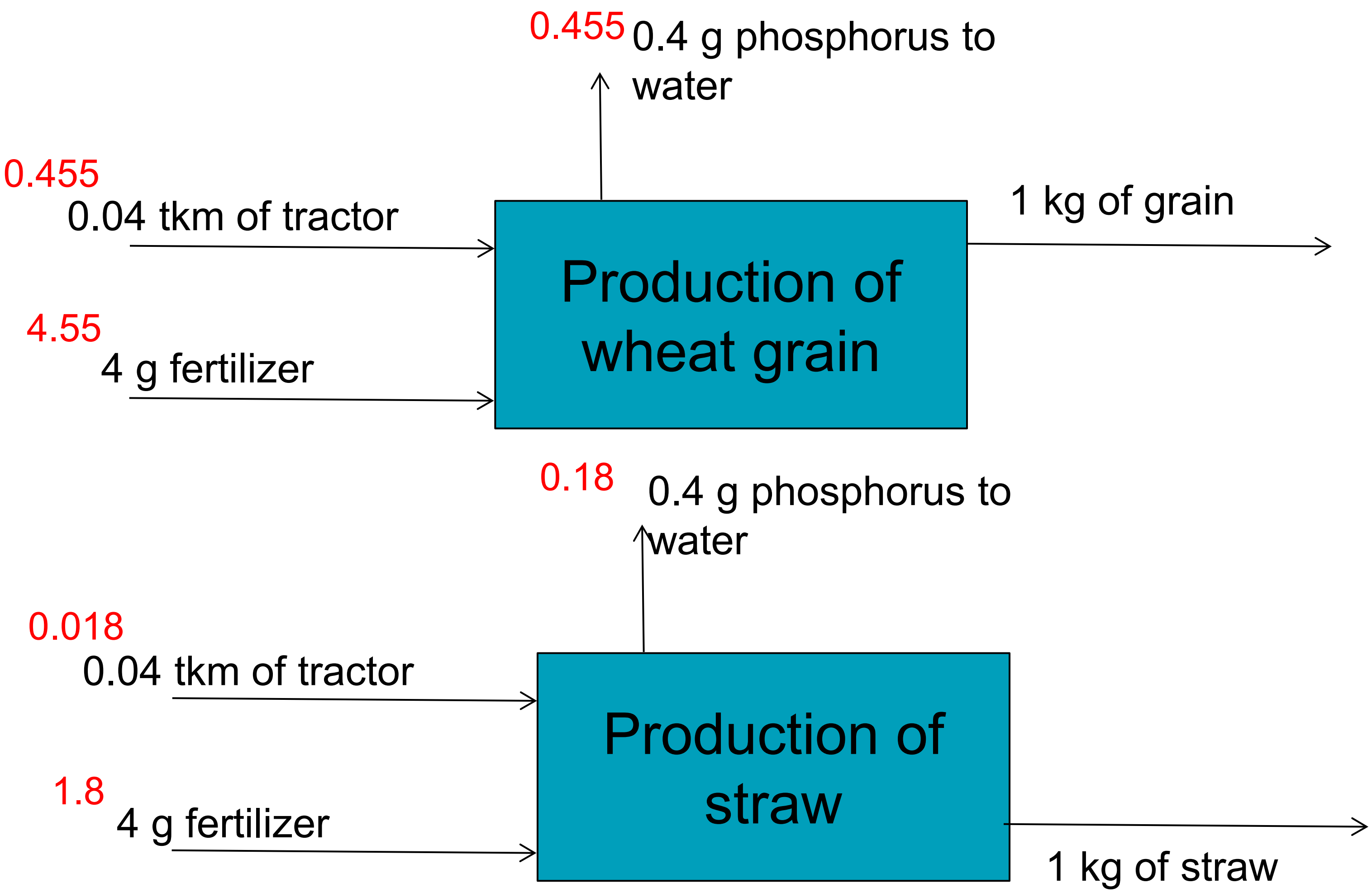
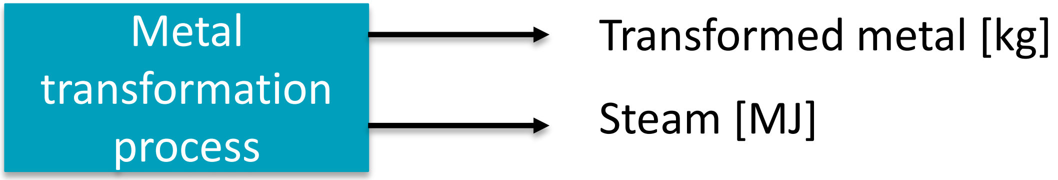
ISO 14044 Procedure – Step 3: Other relationship

- Allocation example: mass vs economic



ISO 14044 Procedure – Step 3: Other relationship

- Another example of economic allocation



- **A factory transforms metal with a process using heat. Heat is sold to a factory nearby under the form of steam.**
- **Inconsistent units → economic allocation.**
- **The factory sells metal at a price of 45 $/kg, and steam at 5 $/MJ**
- **Allocation factor for metal: 45 / (45 + 5) = 90% ?**
  - NO!!!!!! We cannot add the prices, but we could add the revenues.
- **Over one year, the factory produces 300 tonnes of metal and 800 GJ of steam**

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ISO 14044 Procedure – Step 3: Other relationship

- Example of economic allocation
  - **The factory sells metal at a price of 45 $/kg, and steam at 5 $/MJ**
  - **Over one year, the factory produces 300 tonnes of metal and 800 GJ of steam**

Product	Quantity	Price	Revenues	Allocation factor
Metal	300E3 kg	45$/kg	13500 k$	77,1%
Steam	800E3 MJ	5$/MJ	4000 k$	22,9%

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ISO 14044 Procedure – Step 3: Other relationship - examples

Raw

Gasoline [l]

Natural gas [m3]

Chemical products [kg]

Common property?

Machinery

Explosives

Combustibles

Gravel [tonnes]

Diamonds [g]

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ISO 14044 Procedure – Step 3: Other relationship - examples

Raw

Gasoline [l]

Natural gas [m3]

Chemical products [kg]

→ Volumic allocation would make no sense!

→ Economic value? Calorific value?

Machinery

Explosives

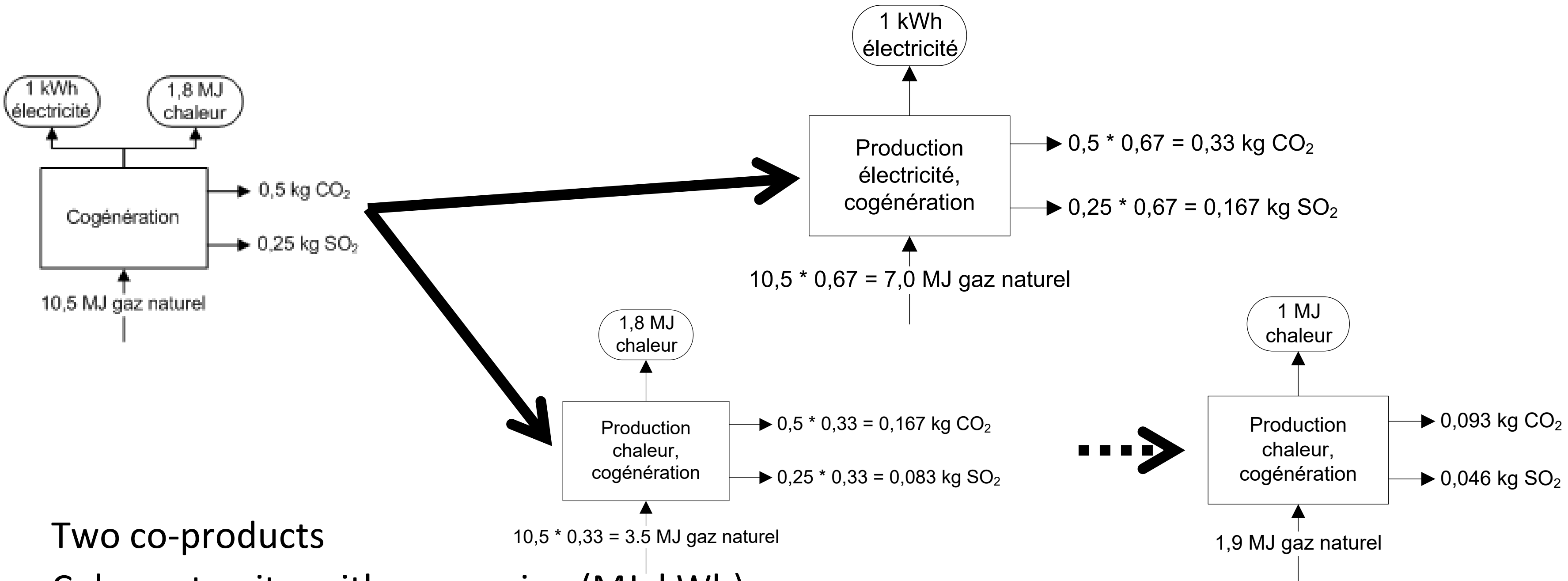
Combustibles

Gravel [tonnes]

Diamonds [g]

→ Diamond exploitation is the root of the process!

ISO 14044 Procedure – Step 3: Other relationship



- Two co-products
- Coherent units, with conversion (MJ, kWh)
- Are they comparable? Let's say yes...
- Basis of allocation chosen: Energy. We suppose that heat and electricity are both useful to do work (which is not necessarily true…→ exergy would be a better metric)
- Calculating the allocation factors:
  - **Total energy: 1 kWh * (3,6 MJ/kWh) + 1,8 MJ = 5,4 MJ**
  - **Allocation factor electricity: 3,6/5,4 = 0.67**
  - **Allocation factor heat: 1,8/5,4 = 0.33**
- Apply the factors
- Re-normalize, as needed

Multifunctional processes - Allocation

	p_{cogen}	p_{GN}
Electricity (kWh)	1	-2,5
Natural gas (MJ)	-10,5	1000
Heat (MJ)	1,8	0
Raw natural gas (m^3)	0	-25
CO_2 (kg)	0,5	10
SO_2 (kg)	0,25	0,01

A

B

Adjusted A-Matrix by allocation

	p_{elect}	p_{GN}	$p_{chaleur}$
Electricity (kWh)	1	-2,5	0
Natural gas (MJ)	-7	1000	-3,5
Heat (MJ)	0	0	1
Raw natural gas (m^3)	0	-25	0
CO_2 (kg)	0,33	10	0,17
SO_2 (kg)	0,167	0,01	0,083

A

Square!

B

How to choose the approach to address multifonctionality?

ISO 14044, section 4.3.4.2: The study must […] follow the step-by-step the procedure presented here:

Step 1: Avoid allocation as much as possible by:

- process by creating two sub-processes or

Subdivision

- oundary of the product system

Extension

Step 2: Allocate the inputs and outputs in a way that reflects underlying p

Allocation – Underlying physical relationship

Step 3: Allocate inputs and outputs in a way that reflects other mutual relat

Allocation – Other relationship

How to choose the approach to address multifunctionality?

According to the
UNEP Life Cycle Initiative (2016) …

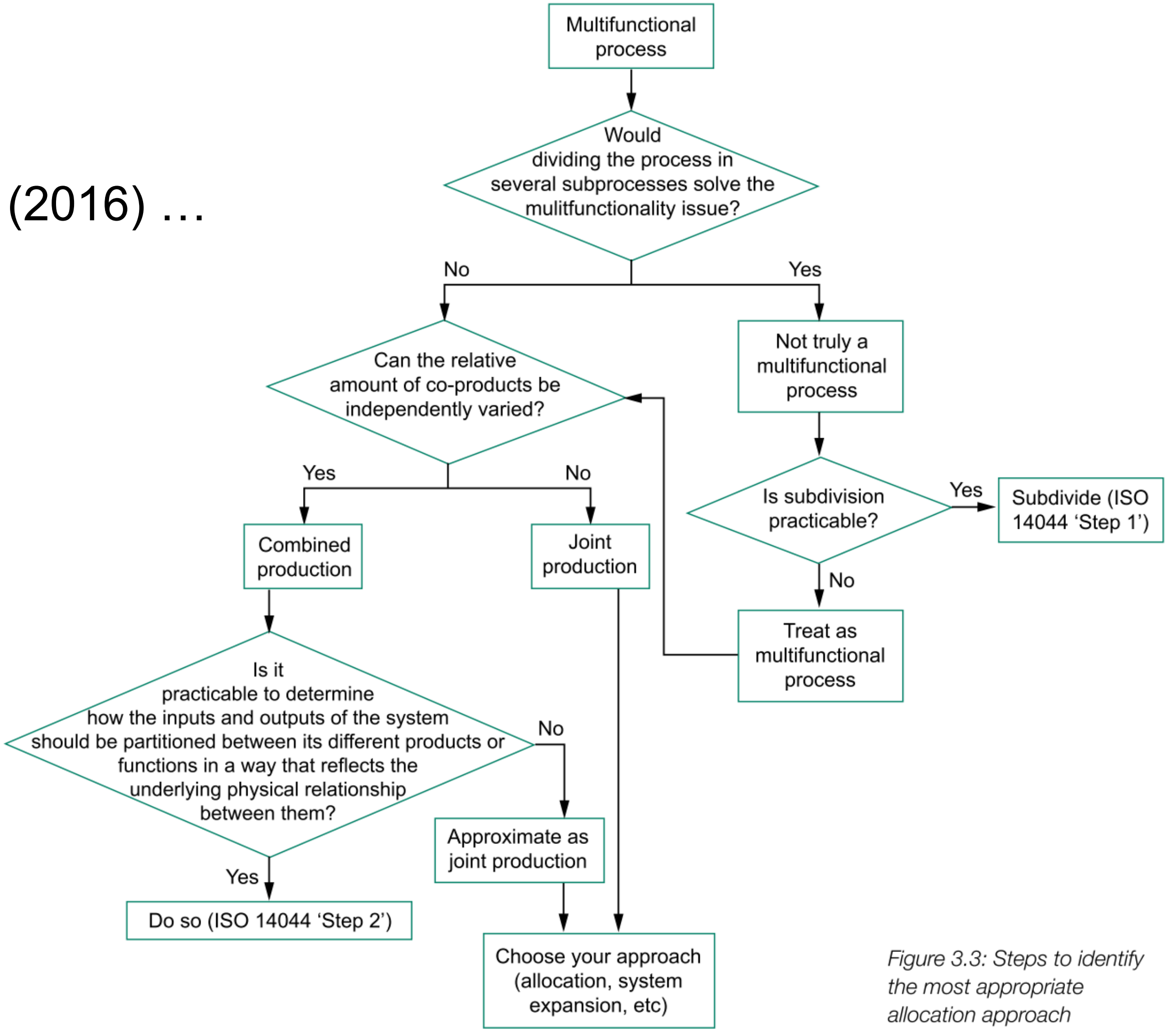


Figure 3.3: Steps to identify the most appropriate allocation approach

Life Cycle Initiative. (2016)
Steps to identify the most appropriate allocation approach.
Retrieved from: https://www.lifecycleinitiative.org/training-resources/global-guidance-principles-ggp-on-life-cycle-assessment-data-and-databases/

ISO 14044 Procedure - multifunctionality

- « Allocating impacts » to a co-product is entirely imaginary. In reality, the co-products will always be manufactured together. For this reason, **allocation is an arbitrary choice** subject to debate.

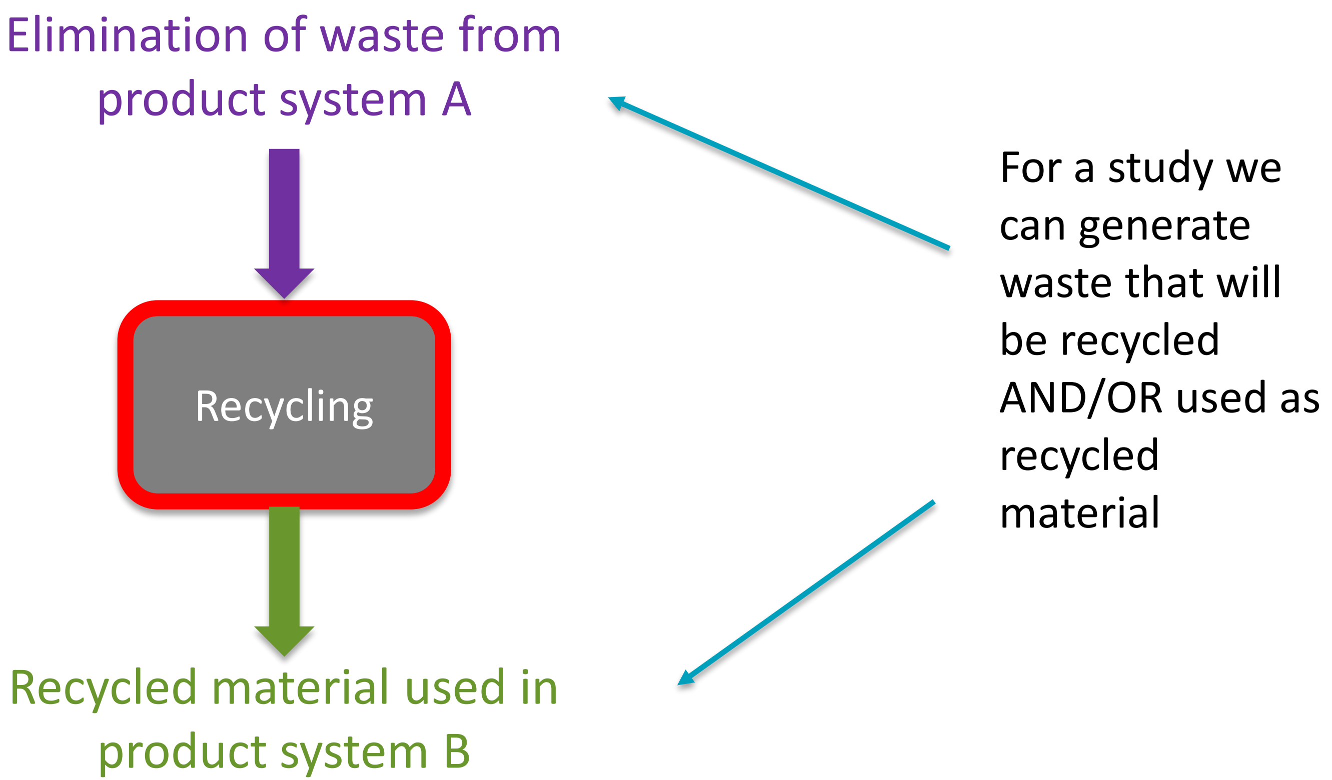
The choice of allocation approach can change the results and the conclusion of a study!!!

- **transparency** is necessary (like anytime, for any assumption in LCA)
- When in doubt, or if controversy arises on the best method to use, perform a **scenario/sensitivity analysis**

Multifunctionality and recycling

Open-loop recycling

Open-loop recycling has two functions, each associated to its respective product system



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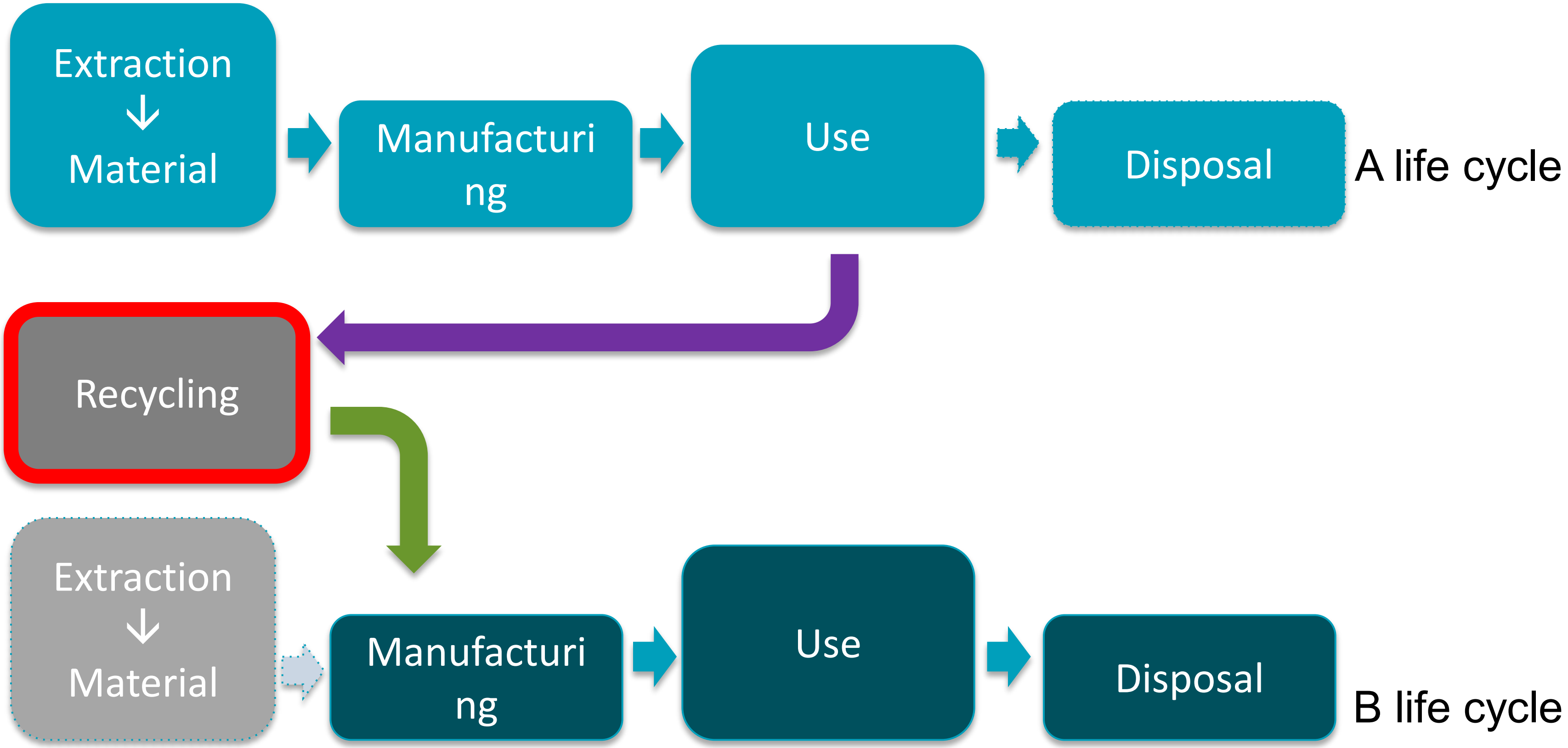
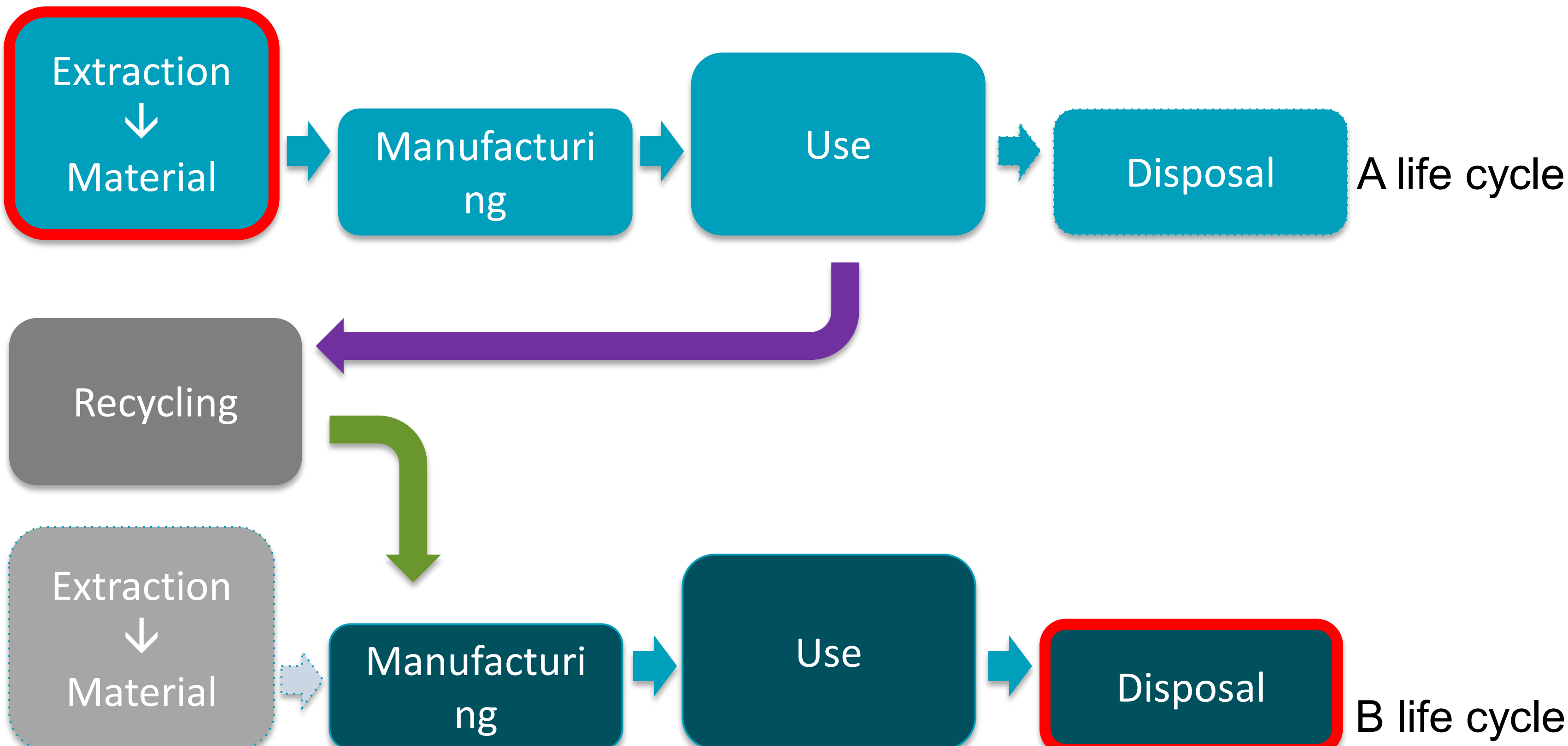
Open-loop recycling

Who is responsible for the impacts of recycling?



Open-loop recycling

Who is responsible for the impacts of the production of initial virgin material?
Who is responsible for the impacts of the final disposal?



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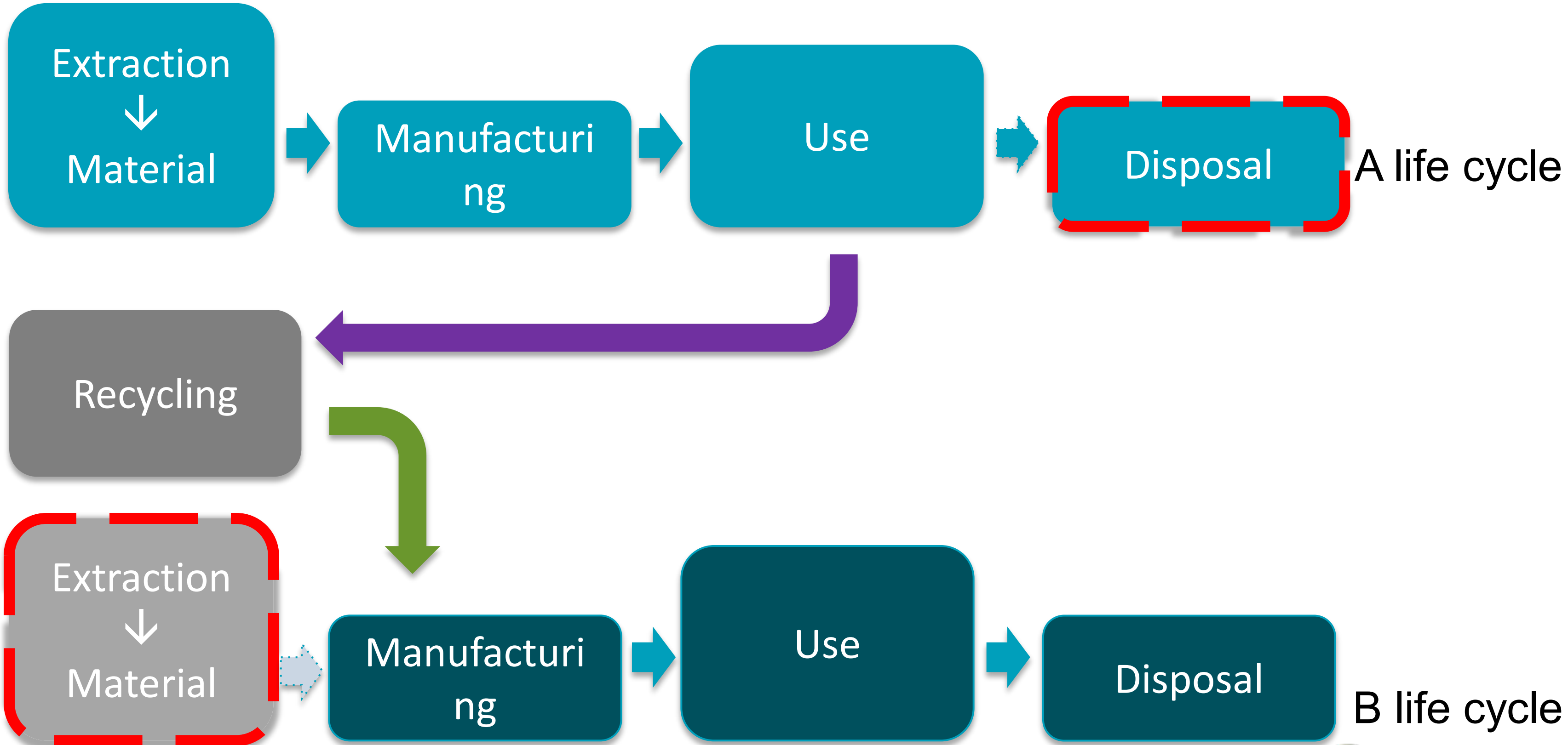
Open-loop recycling

Who takes credits for the avoided impacts of disposal?
Who take credits for the avoided impacts of the production of virgin raw material?



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Most common approaches

- **Recycled content method**
- **End of life recycling method**

- There are more:
  - **Circular Footprint Formula (CFF)**
    https://ec.europa.eu/environment/eussd/pdf/Webinar%20CFF%20Circular%20Footprint%20Formula_final-shown_8Oct2019.pdf
  - **Method of number of uses (usually used for paper, but not covered in this course)**
  - **Methods based on the quality of the recycled material**
  - **50-50 method**
  - **…**

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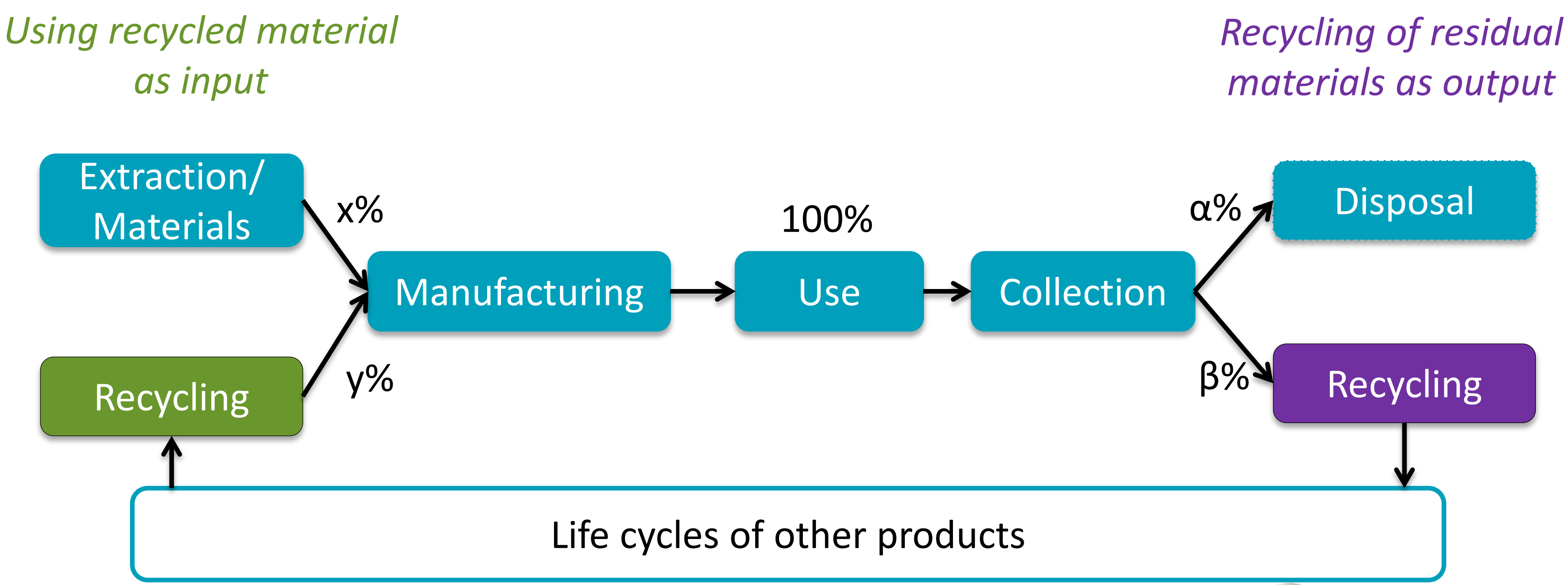
Example: description of the case implying recycling

- Let's assume a product composed of 1kg of material
  - **Is manufactured from x% virgin material and y% recycled material**
  - **At the end of its life, α% of the collected material goes to final disposal (e.g. landfill) and β% is recycled**



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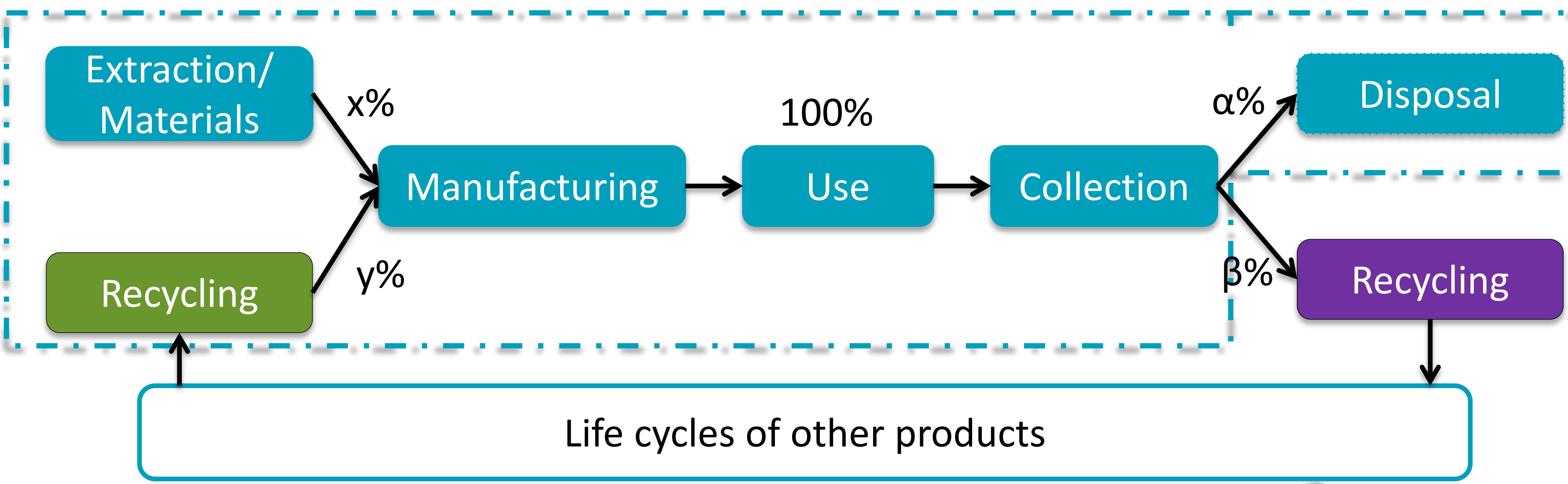
Example: "Recycled content" approach

- Recycled content approach (cut-off):
  - **Recycling is attributed to the life cycle that uses the recycled material**
  - **Recycling at end of life is simply excluded from the system (no credits, but no impacts of end of life treatment either)**



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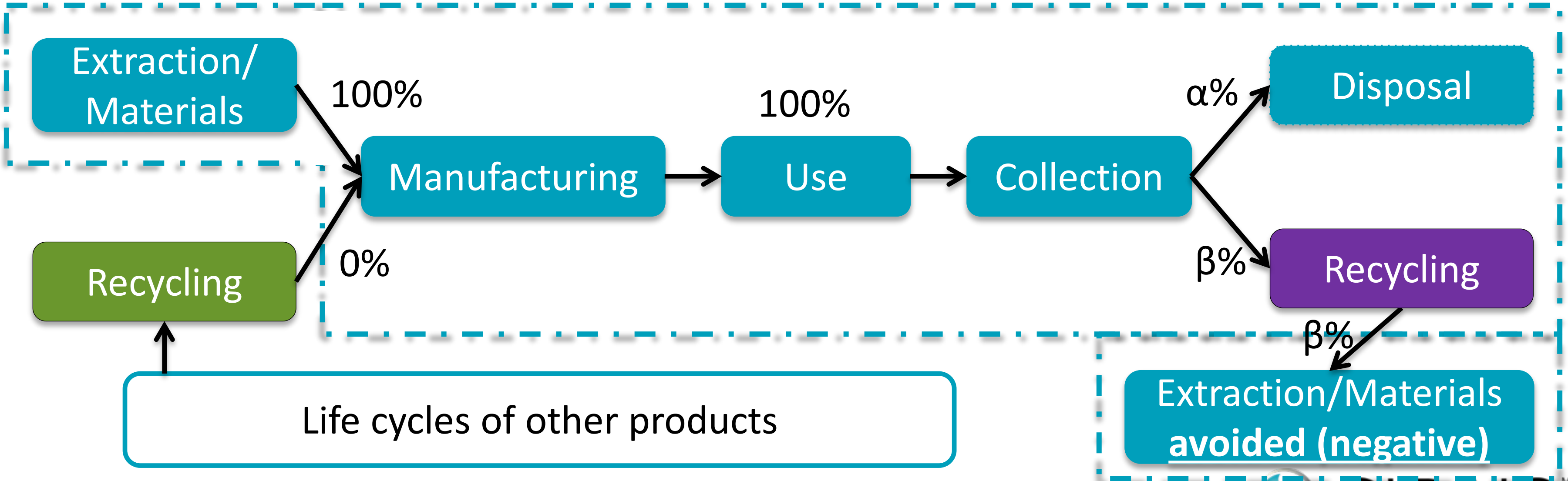
Example: “End of life recycling” approach

- End of life recycling approach
  - **Materials used by the life cycle are assumed as 100% virgin, regardless of the recycled content (assumed 0%)**
  - **Recycling at the end of life avoids producing raw materials (substitution, system boundary expansion)**



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Main approaches – what do they imply?

Recycled content approach:

- **Boosts the use of recycled materials**
  - If impacts of recycling < impacts of initial production of virgin materials
- **Encourages (though weak) recycling at the end of life**
  - Recycled material isn't associated to impacts of final disposal

Main approaches – what do they imply?

End of life recycling approach:

- Doesn't encourage the use of recycled materials
  - All input materials are associated to impacts of virgin materials, regardless of their recycled content
- Encourages recycling at end of life (Design for Recycling)
  - Recycling → « credit »
  - (must obviously take into account the modification of inherent properties of the materials)
- Discourages dissipation of materials
  - If they can't be collected, it's impossible to recycle them

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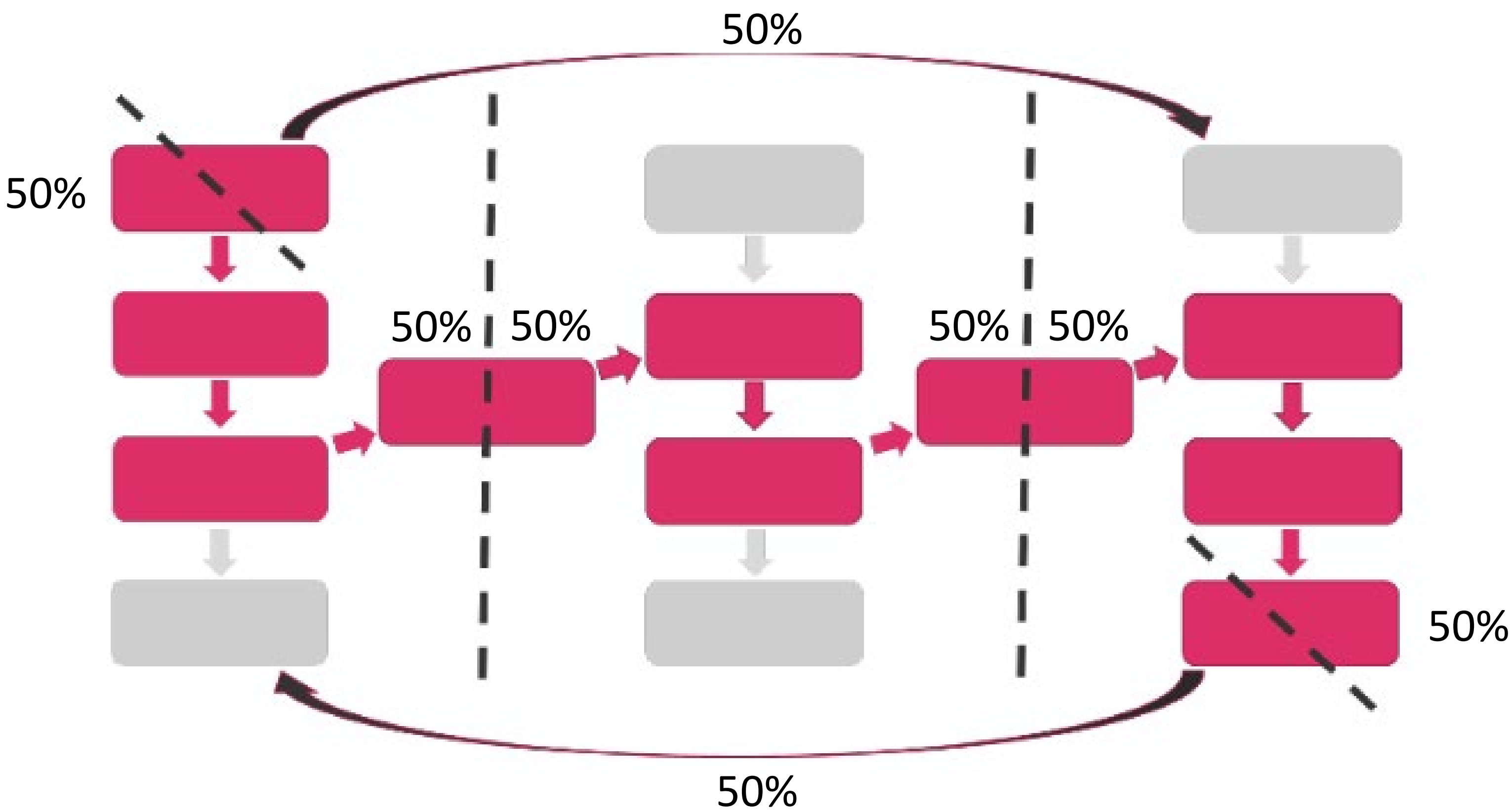
50/50 Approach for recycling

The lesser of the two evils?



Concretely, for your projects

For “significant” multifunctional processes and for recycling:

- **Choose, justify and document your approach**
- **Identify the other justifiable approaches**
- **Perform a sensitivity analysis with alternative allocation approaches**

To explore further how to model recycling in LCA

Final project report

Modeling recycling in life cycle assessment

Authors: Tomas Ekvall, Anna Björklund, Gustav Sandin, Kristian Jelse, Jenny Lagergren, Maria Rydberg

Project period: 2018-11-15 – 2020-05-31

Project number: 47270-1

https://www.lifecyclecenter.se/wp-content/uploads/2020_05_Modeling-recyling-in-life-cycle-assessment-1.pdf

The PEF approach: introducing the single end-of-life formula?

ARTICLES / MODELLING END-OF-LIFE IN THE PEF APPROACH

Modelling end-of-life in the PEF approach

Introducing the single Environmental Footprint end-of-life formula

https://pre-sustainability.com/articles/pef-series-end-of-life-modelling/

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The Circular Footprint Formula (CFF) approach

sphera maki Consulting GmbH Life cycle expert services SGS

The Circular Footprint Formula (CFF) and its practical application

Training; Environmental Footprint (EF) transition phase

10 November 2020

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https://ec.europa.eu/environment/eussd/smgp/pdf/TrainingCFF%20Circular%20Footprint%20Formula10Nov2020_final_corr.pdf

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