Multi-functionality in LCA and brightway

Bernhard Steubing

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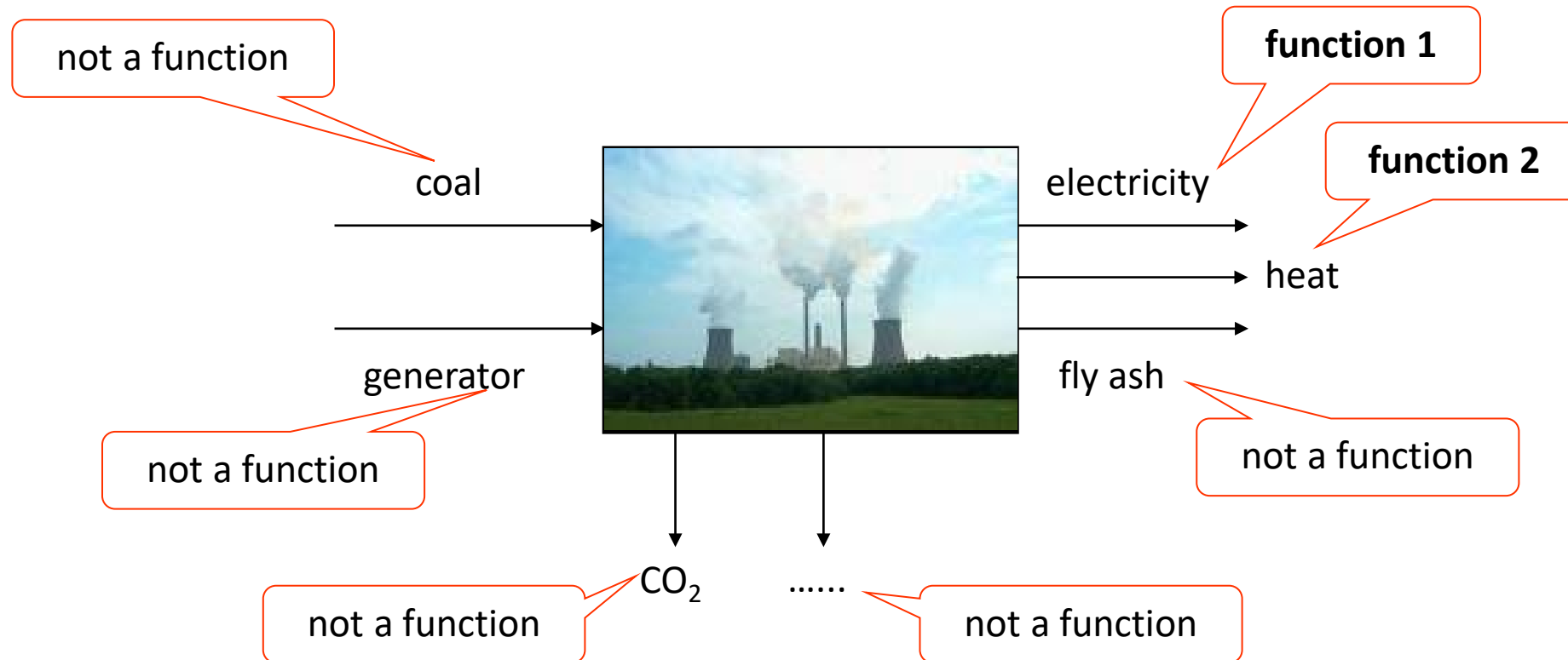
Universiteit Leiden
The Netherlands

CML
Institute of Environmental Sciences

The problem

- There are processes which have more than one function
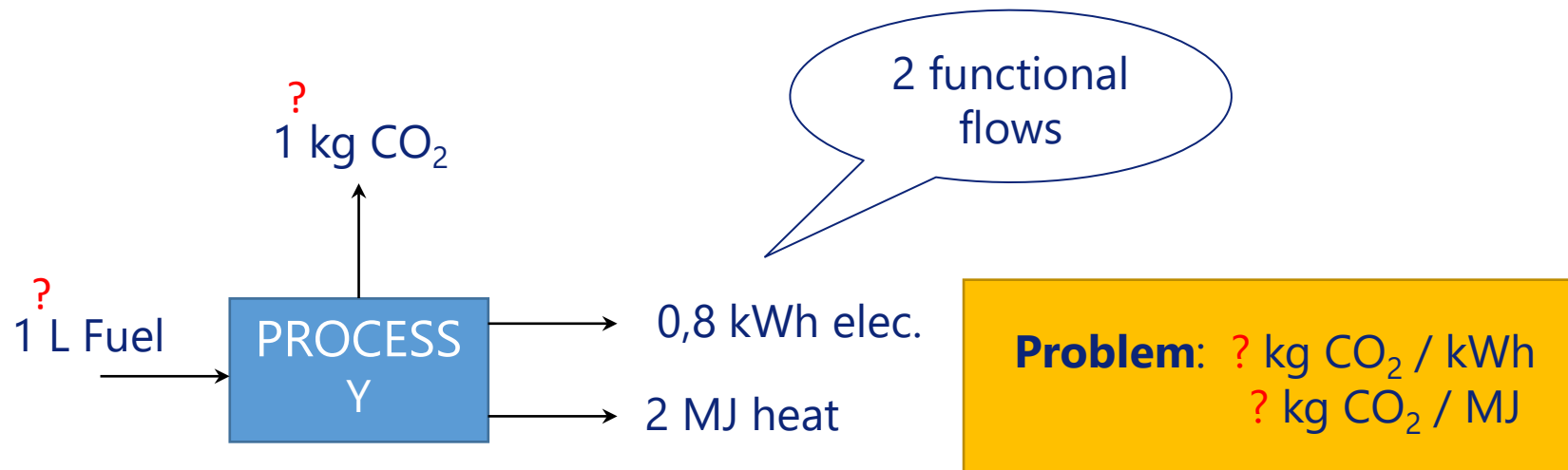 - "multifunctional processes"

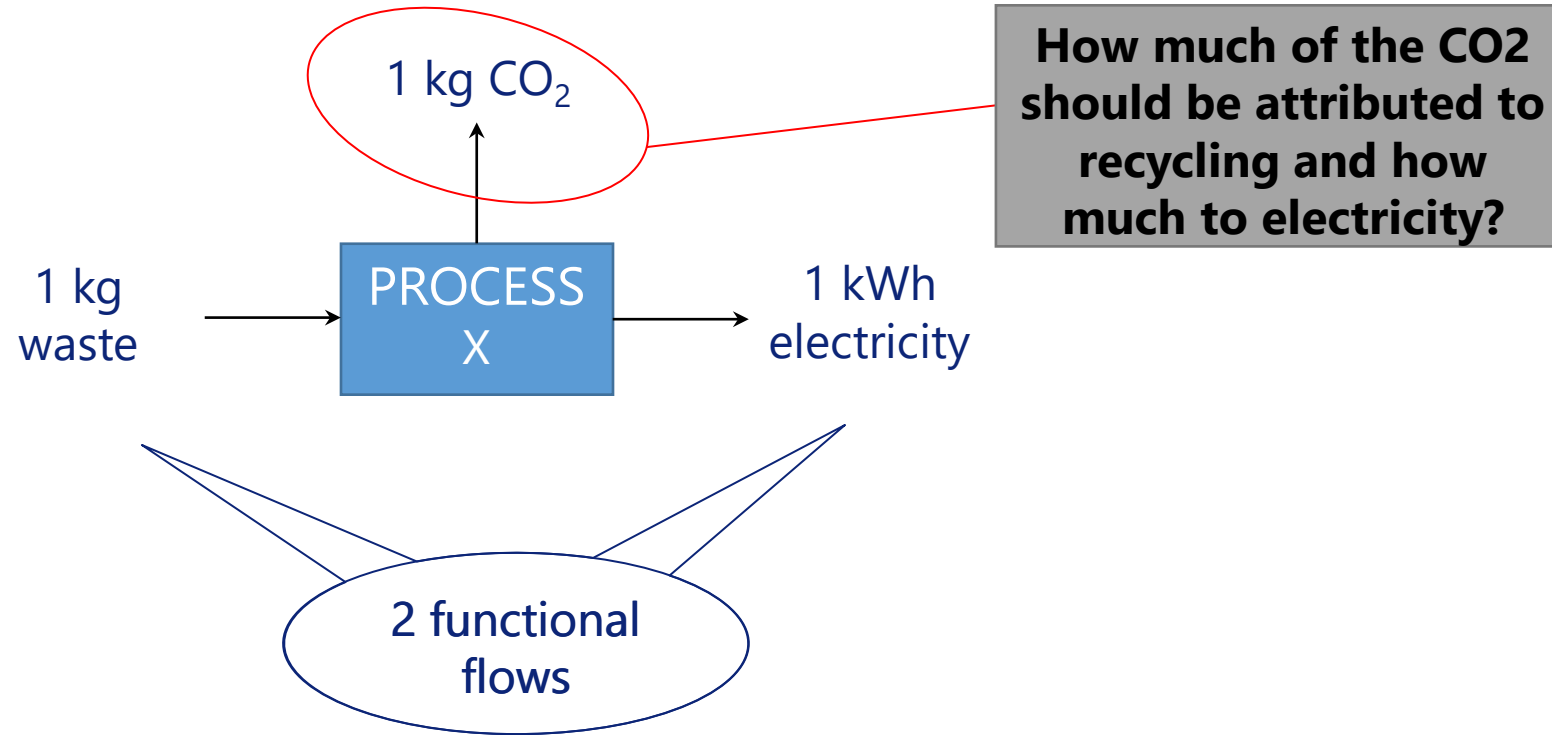Slide by Jeroen Guinée

Functional flows

Functional flows are any of the flows of a unit process that constitute its goal, e.g.

- *product outflows* of a production process
- *waste inflows* of a waste treatment process

- every process needs <u>at least one</u> functional flow

- A flow is not *intrinsically* a functional flow, but only with respect to a certain unit process

- The functions (and thus functional flows) are defined by the LCA practitioner

- Terminology: "Functional flow" is a better term than "reference product" or "product" as the functions can be either the *input* or the *output* of a process
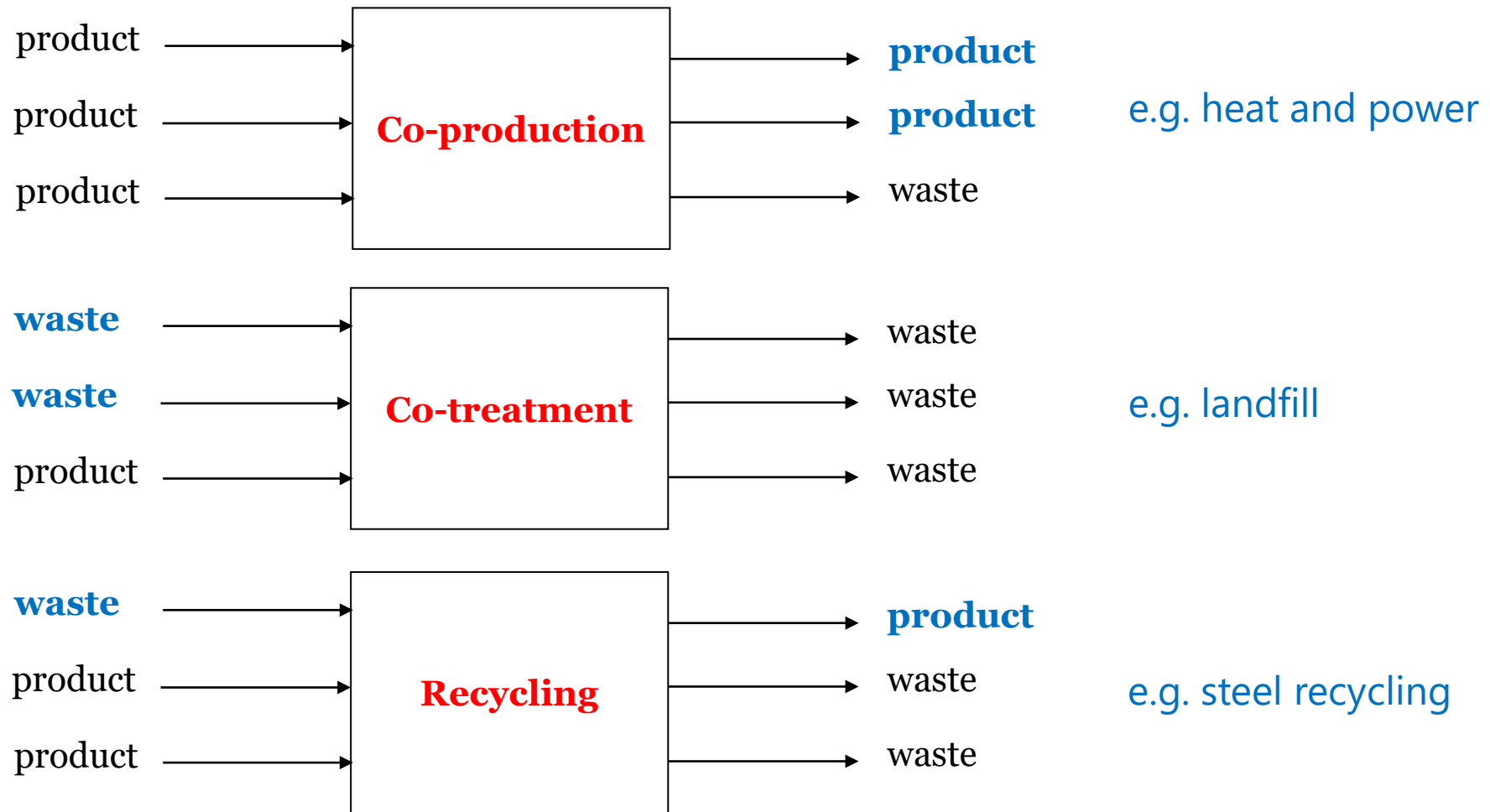
Multi-functionality problem is an *allocation problem*

?
1 kg CO$_2$

?
1 L Fuel → PROCESS Y → 0,8 kWh elec.

2 MJ heat

2 functional flows

Problem: ? kg CO$_2$ / kWh
? kg CO$_2$ / MJ

Multi-functionality occurs whenever there is *recycling*!

1 kg CO_2

How much of the CO2 should be attributed to recycling and how much to electricity?

1 kg waste → PROCESS X → 1 kWh electricity

2 functional flows

Typology of multi-functional processes

product → **Co-production** → **product**, **product**, waste   e.g. heat and power

waste, **waste**, product → **Co-treatment** → waste, waste, waste   e.g. landfill

waste, product, product → **Recycling** → **product**, waste, waste   e.g. steel recycling

Allocation procedure according to ISO 14044

1. Avoid MF by **sub-dividing processes** (often not possible)

2. **System expansion**

   a. ***Substitution** (avoided burdens approach)

3. **Partitioning**, e.g.:

   a. Physical (e.g. mass or energy based)

   b. Economic (e.g. revenue-based)

> accept extra functions as extra reference flow(s)

> get rid of extra functions by an extra modelling step

* Not mentioned by ISO

Is there one correct solution?

- Allocation problem is artefact of *wishing to isolate 1 function* when in reality there are several functions to a process

- Artefacts can only be cured in an artificial way; there is no "correct" way, even not in theory

- So what to do if different MF solutions result in highly different outcomes?
  - *sensitivity analysis*

How can brightway currently help?

1. Avoid MF by **sub-dividing processes** (often not possible)

2. **System expansion**

   a. ***Substitution** (avoided burdens approach)

   In principle supported by brightway

3. **Partitioning**, e.g.:

   a. Physical (e.g. mass or energy based)

   b. Economic (e.g. revenue-based)

   Not really supported by brightway yet

* Not mentioned by ISO

Better support for MF in brightway

- **We need (better) support for modeling multi-functional processes in brightway!**

- MF processes are EVERYWHERE and increasingly so in a circular economy (recycling, bio-based economy, metals, …)

- For us at CML this is the single biggest problem we have with brightway and the reason why we are not using it yet for teaching LCA or for research where multi-functionality occurs…

Real world examples:

Carbon capture and use (CCU)
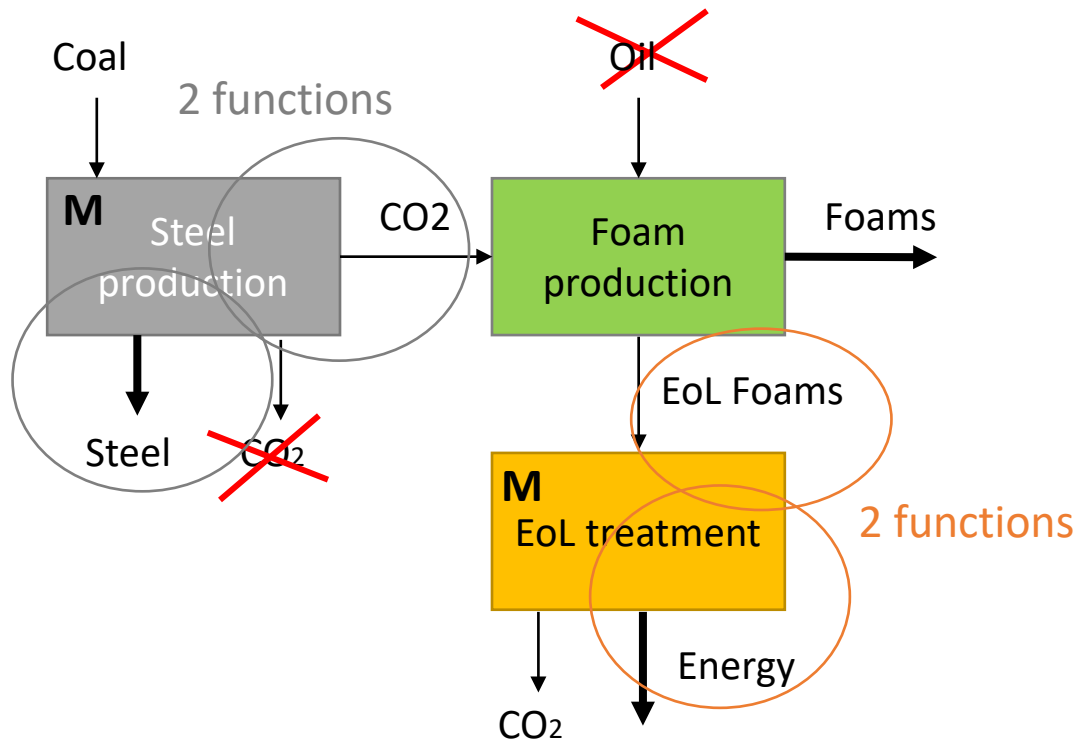
LCA on electric vehicles
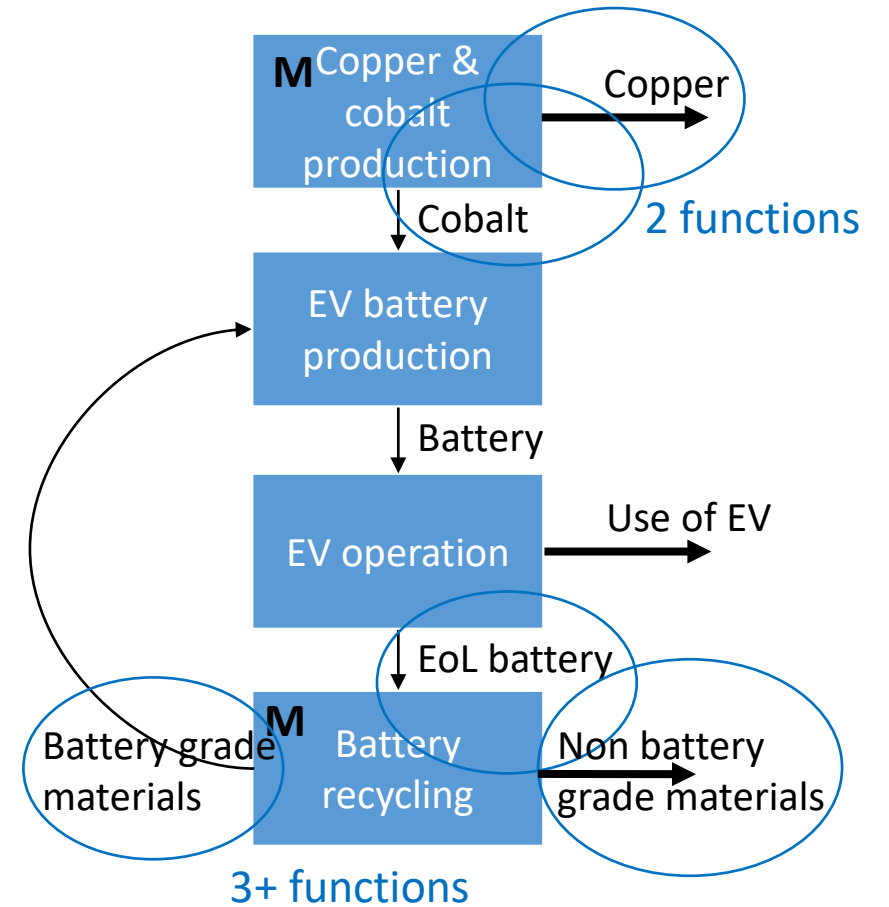
Suggestions for an implementation in brightway

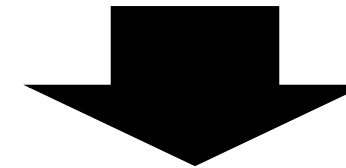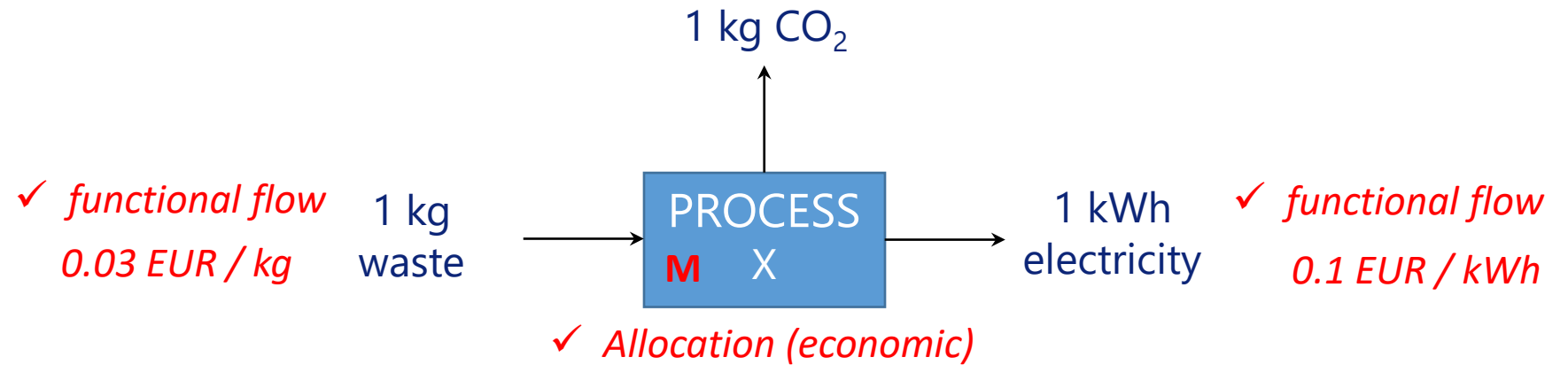# Proposition for an implementation of MF in brightway

1. User specifies *functional flows*
2. User specifies *how allocation shall be performed* and provides necessary information
3. Brightway stores MF processes in database
4. **Brightway resolves MF at the moment when LCA results are calculated** (when matrices are built)

- This is better than writing allocated processes to the database since:
  - It keeps information together that belongs together
  - you can easily go back and modify things
  - Other practitioners can see and understand the MF process (as it exists in the real world) and how MF is resolved (instead of trying to puzzle this information together from several allocated processes)

Example economic partitioning

1 kg CO_2

MF brightway database

Rectangular matrix

✓ *functional flow*

0.03 EUR / kg

1 kg waste

PROCESS **M** X

1 kWh electricity

✓ *functional flow*

0.1 EUR / kWh

✓ *Allocation (economic)*

Logic to deal with MF

x kg CO_2

1-x kg CO_2

In *technosphere matrix* generated for LCA calculations

Square matrix

1 kg waste

PROCESS X1

PROCESS X2

1 kWh electricity

Example substitution

MF brightway database

Rectangular matrix

1 kg CO_2

1 L fuel → PROCESS **M** X

*Substitute: **electricity** from wind power, NL*

✓ *functional flow*

→ 1 kWh electricity
→ 1 MJ heat ✓ *functional flow*

*Substitute: **heat** from heat pumps, NL*

✓ *Substitution*

Logic to deal with MF

In *technosphere matrix* generated for LCA calculations
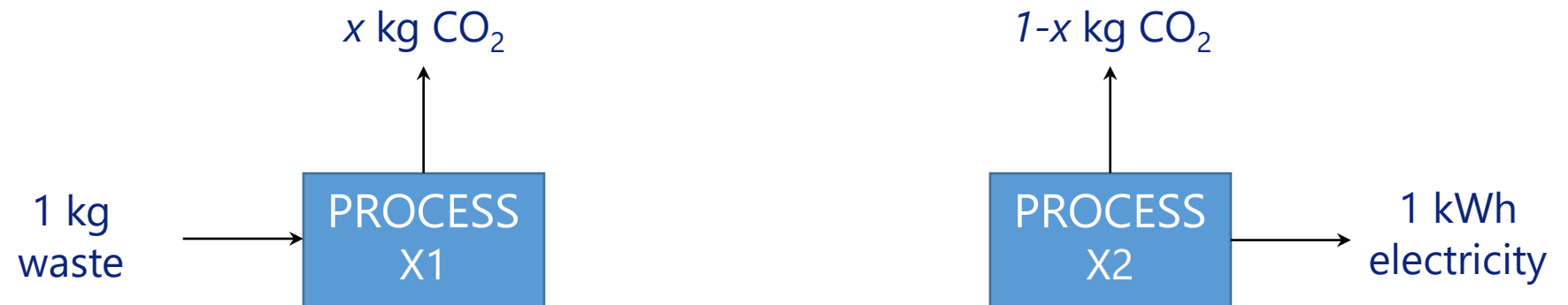
Square matrix

1 kg CO_2

1 L fuel → PROCESS X1 → 1 kWh electricity

-1 MJ ***heat** from heat pumps, NL*

1 kg CO_2

1 L fuel → PROCESS X2 → 1 MJ heat

-1 kWh ***electricity** from wind power, NL*
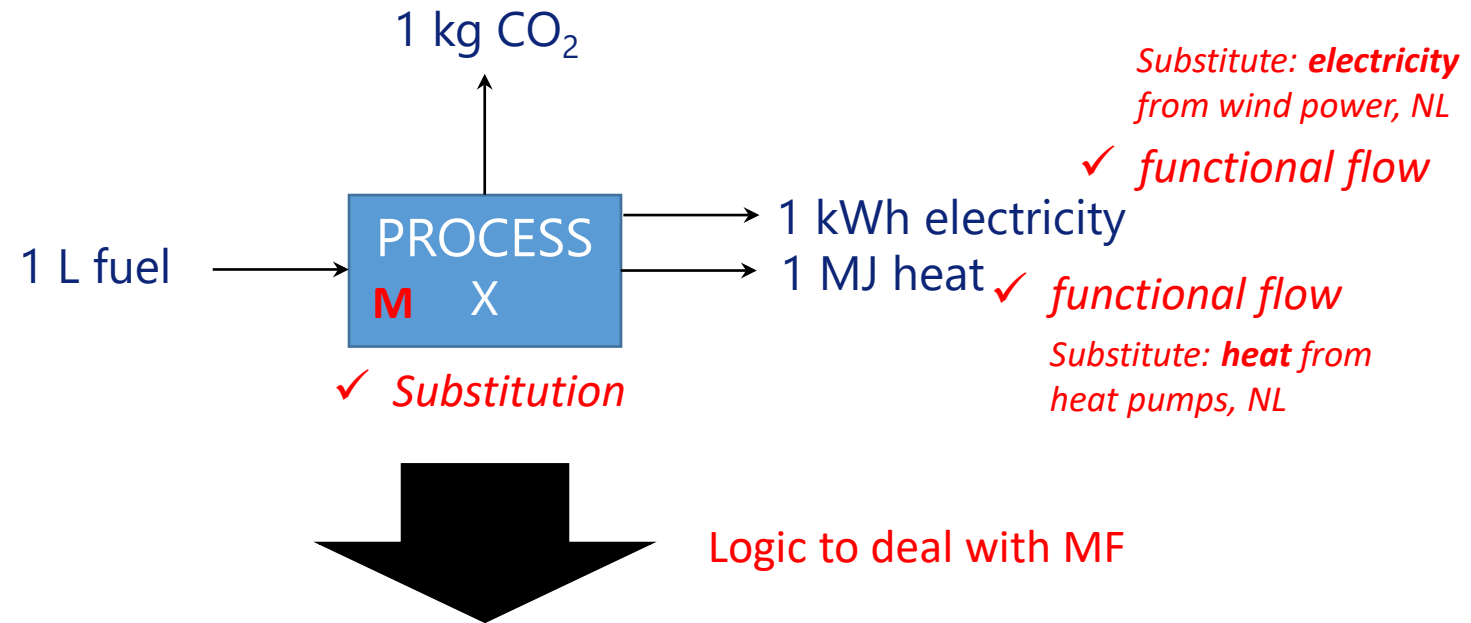
Which data is needed and at which level?

- **Flows**:
  - functional flow
  - flow properties necessary to resolve MF (e.g. prices; substitute flow)

- **Processes**:
  - solution to MF problem (e.g. economic allocation; substitution)
  - MF flag?

- **Databases**:
  - should store the MF processes

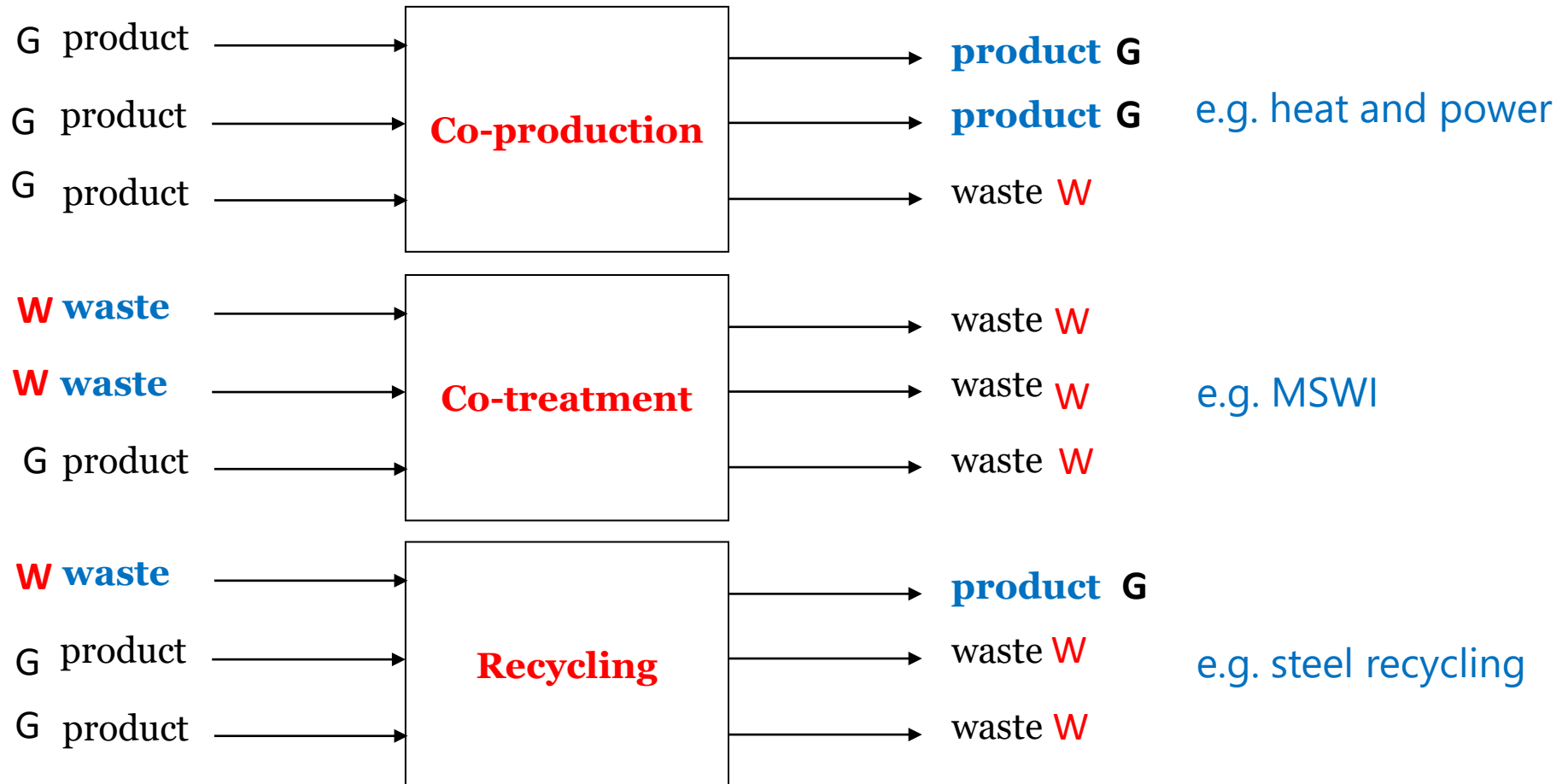# Proposition for a more advanced implementation of MF in brightway

1. User specifies ~~functional flows~~ whether flows are "goods" or "wastes", which determines whether a flow is a functional flow automatically

2. User specifies *how* allocation shall be performed and provides necessary information

3. Brightway stores MF processes in database

4. Brightway resolves MF at the moment when LCA results are calculated (when matrices are built)

Goods and wastes

a **good (G)** is a flow with an **economic value ≥ 0**
a **waste (W)** is a flow with an **economic value < 0**

Functional flows are:
- product *outputs* (**goods**)
- waste *inputs* (**wastes**)

G product → **Co-production** → **product G**
G product → **Co-production** → **product G**   e.g. heat and power
G product → **Co-production** → waste W

W **waste** → Co-treatment → waste W
W **waste** → Co-treatment → waste W   e.g. MSWI
G product → Co-treatment → waste W

W **waste** → **Recycling** → **product G**
G product → **Recycling** → waste W   e.g. steel recycling
G product → **Recycling** → waste W

Pros and cons to using the good/waste classification

Advantages

- Automatically identifies functional flows and thus MF processes

- Reduced risk for modeling errors (rectangular matrices/unsolvable systems)

- CMLCA has used this system for 20 years; it also works in conjunction with ecoinvent

Disadvantages

- Additional flow property

- Database-wide implementation required

Additional considerations

- If no information is provided how a MF process shall be dealt with, the LCA calculation SHOULD break by default and point the user to the process which needs additional information

- We can learn from existing LCA software implementations (e.g. CMLCA, OpenLCA)

- Unit conversion for physical allocation (e.g. "MJ to kWh" or "t to kg")

- Replacement rate for substitution
    - e.g. "1 kg HCl (20% conc)" replaces "2 kg HCl (10% conc)"

Vision

- MF processes can be conveniently modelled within BW and AB
- Different allocation methods are available and can be easily modified (at the process or even at the system level), e.g. for sensitivity analyses
- Existing MF activities can be easily identified (to analyze the importance of modeling choices)
- MF is part of the core bw libraries (not add-ons/extensions)

Also:

- Custom allocation methods can be added through functions
- AB Graph Explorer can show product systems with MF processes (e.g. showing recycling)
- Co-products could be quantified as part of LCA results
- …

Questions? Comments? Ideas?

First approach proposed by Chris:

https://gist.github.com/cmutel/939fd1f44a8a627f4682e3fe11ad7285

Reserve slides

Definitions and typologies

- Multi-functional process: a unit process yielding more than one functional flow
  - co-production: **more than one functional outflow** and **no functional inflow** (producing 2 or more *goods*)
  - combined waste processing: **no functional outflow** and **more than one functional inflow** (processing 2 or more *wastes*)
  - recycling: producing ≥1 good(s) + processing ≥1 waste(s)

Slide by Jeroen Guinée

How to determine if flow is G or W:
the price criterion

- a **good** is a flow between two processes with an **economic value ≥ 0**

- a **waste** is a flow between two processes with an **economic value < 0**

- Price/direction determines:
  - Which processes are included in the product system
  - If a process is multi-functional
  - Extent to which a process in included in case of multi-functionality
    - price<0: exclude
    - price>0: include a bit
    - price>>0: include a lot

- Is there any other principle than "price" for determining if a flow is functional or not? (yes, but the economic logic often makes most sense)

Slide by Jeroen Guinée

"**functional flows**":

- These are the flows of an activity/process that are the reasons for carrying out this process.

- This is a better term than "reference product" or "product" as the functions can be either the input or the output of a process.

- The functions (and thus functional flows) are defined by the LCA practitioner
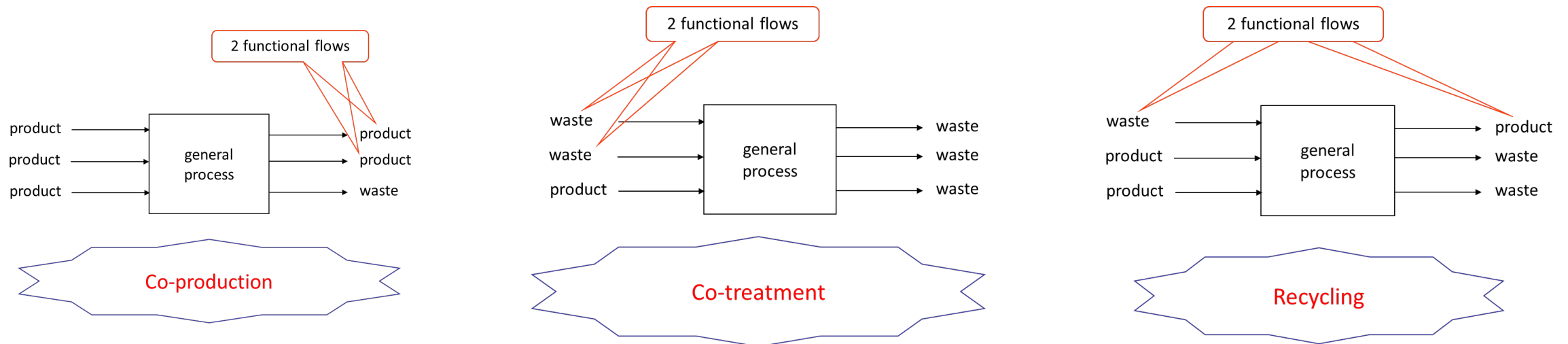
G and W flows: *the price criterion*
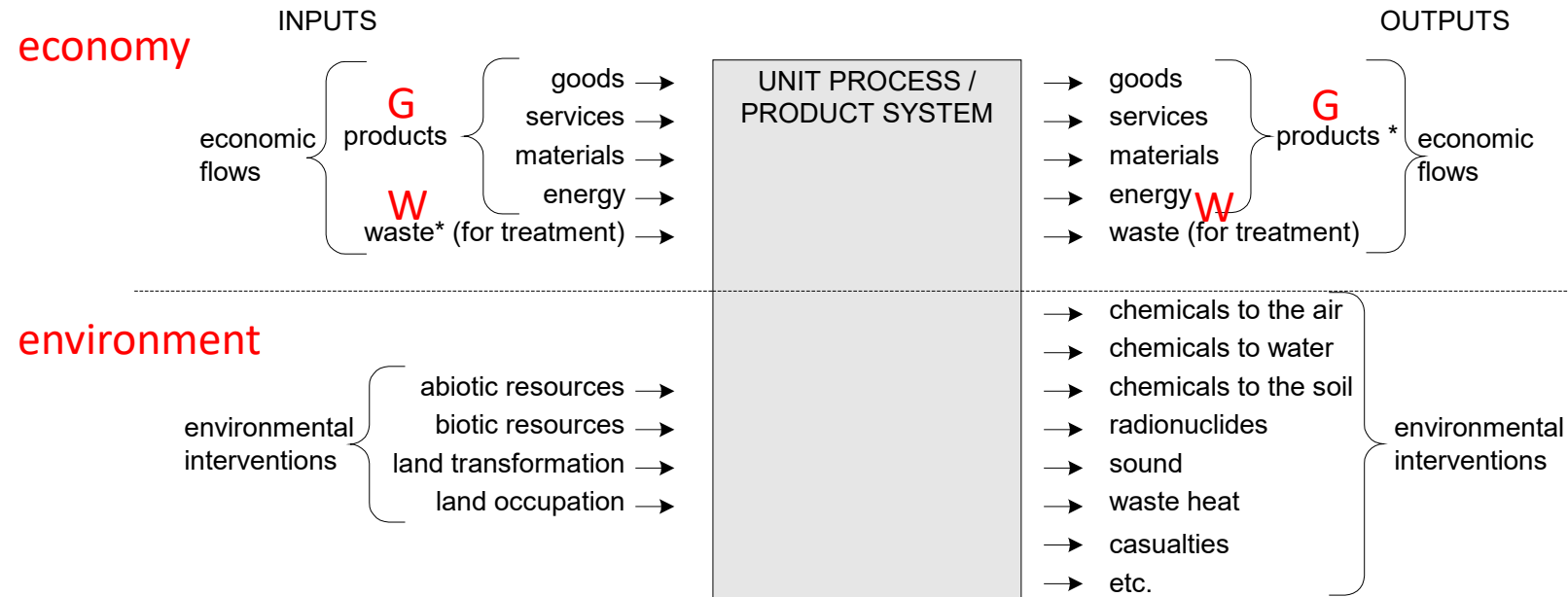
* the functional flows of the process

- *Between two processes*:
  - Good/product (G) is a flow with an economic value ≥ 0
  - Waste is a flow with an economic value < 0