THE UNIVERSITY OF BRITISH COLUMBIA

ENGR 544, Life Cycle Assessment and Management

School of Engineering, Faculty of Applied Science

The University of British Columbia (Okanagan)

Chapter 8, Scope Definition

Learning Objectives

- Define the scope of any LCA study.
- Explain each of the nine scope items and their relevance for the subsequent LCA phases.
- Define a functional unit for any kind of LCA study.
- Explain the fundamental characteristics of an **attributional** and a **consequential** modelling approach and how the decision context determines the choice between them.
- Explain how the iterative approach to LCA helps getting the **system boundaries** and completeness right.

1. Terminology and Key Concepts

Unit Process and Flows

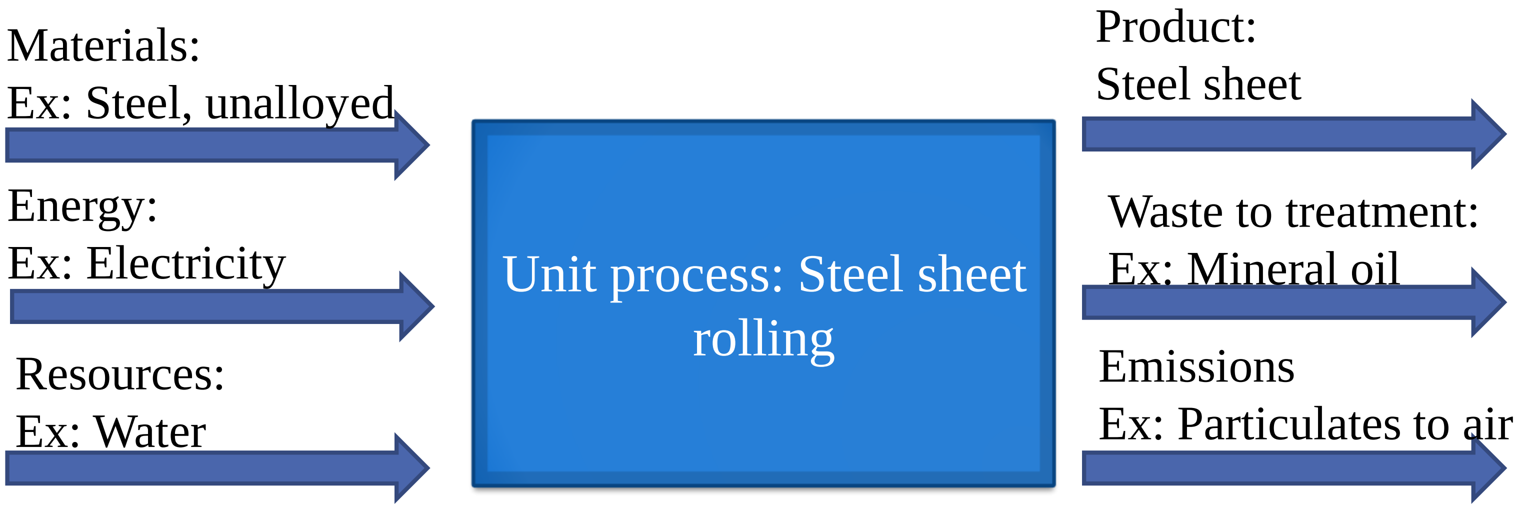
A **unit process** is the **smallest element** in a life cycle inventory model for which input and output data are quantified.

Input flows:

- ❑ 1. Materials
- ❑ 2. Energy
- ❑ 3. Resources

Output flows:

- ❑ 4. Products
- ❑ 5. Waste to treatment
- ❑ 6. Emissions.

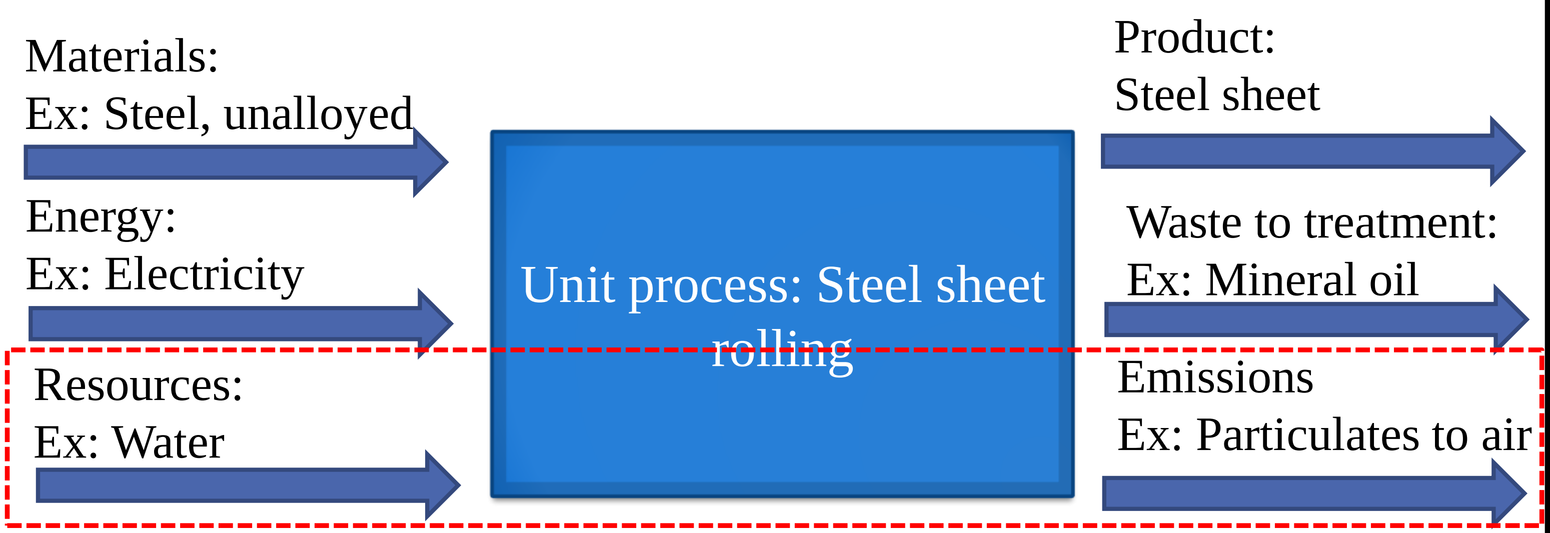


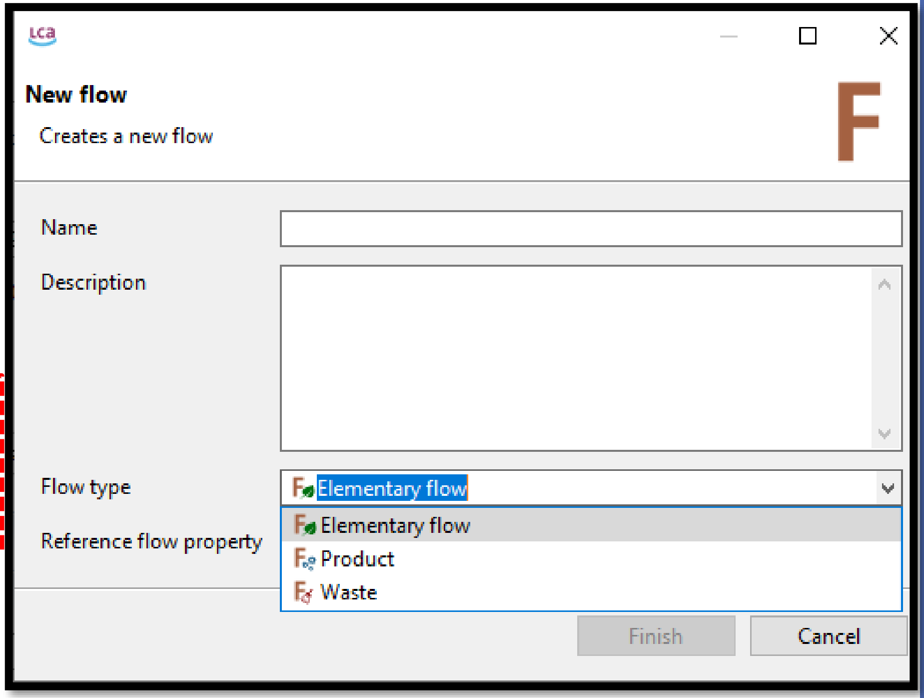
The unit process of steel sheet rolling and examples of flows. The actual unit process contains 86 flows [source: ecoinvent v3 (Weidema et al. 2013)]

❖ A unit process can represent a single process, e.g. the rolling of steel, but it can also represent an entire facility that contains many different processes.

Unit Process and Flows

- **Output flows** belonging to the **product** or **waste to treatment** categories from one unit process can act as **input flows** belonging to the categories materials and energy for **other unit processes** and this is *how unit processes are linked in a life cycle inventory model*.
- By comparison, **resources** and **emission** flows are not exchanged between unit processes. They are referred to as **elementary flows**.

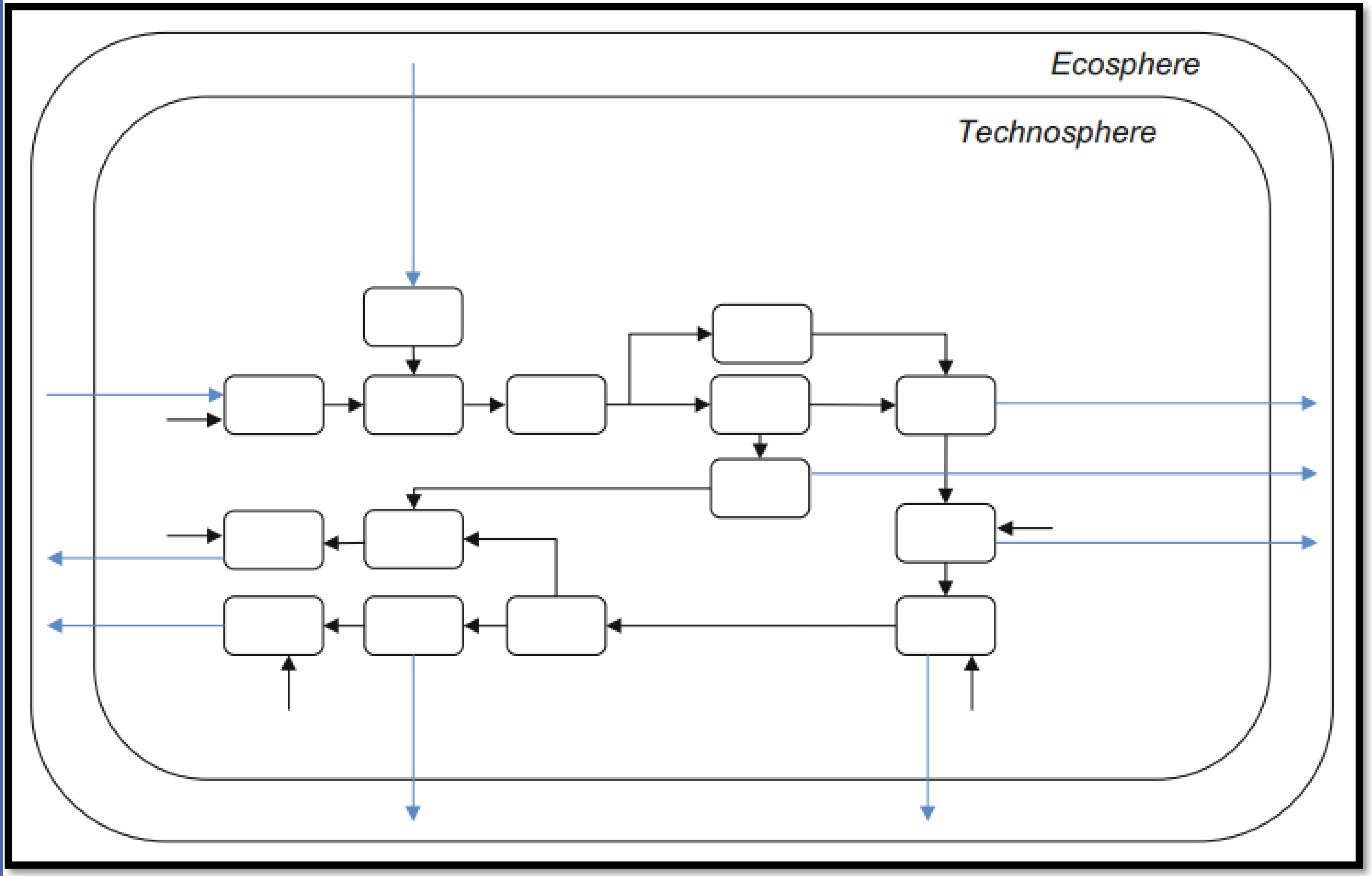


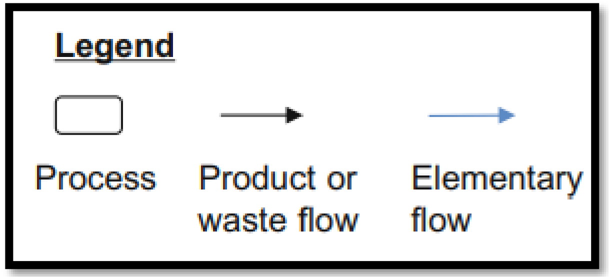


The unit process of steel sheet rolling and examples of flows. The actual unit process contains 86 flows [source: ecoinvent v3 (Weidema et al. 2013)]

The Technosphere and the Ecosphere

- The **technosphere** can be understood as **everything** that is intentionally "**man-made**".
- The **ecosphere** is sometimes referred to as "the **environment**" or "**nature**" and can be understood as everything which is not intentionally "man-made".





Division between ecosphere and technosphere for a generic product system. **Elementary flows are represented by blue arrows**, **while flows within the technosphere are in black**.

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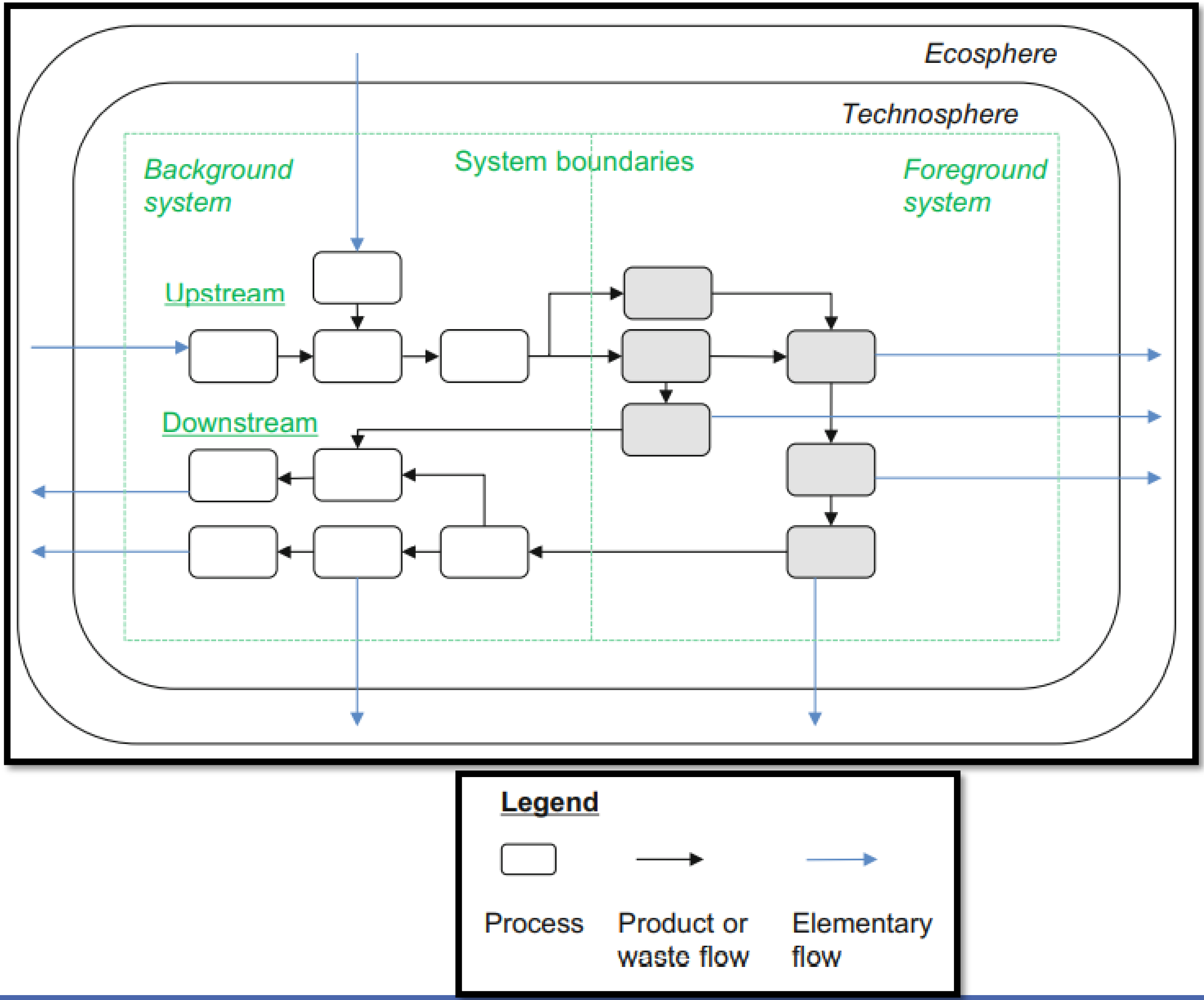
Foreground and Background System

- The green box represents the <u>boundaries of the product system</u> with the division between **foreground** and **background** systems indicated.
- **Unit processes** with **grey shading** belong to the **foreground processes**, while unit processes **without shading** belong to the **background system**.
- Part of the background system lies upstream in the value chain and **feeds into the foreground system**. Another part lies downstream and **receives input from the foreground system**.
- **Black arrows** between unit processes indicate **material**, **energy**, **product** or **waste flows**. **Blue arrows** represent elementary flows (**resources** and **emissions**).



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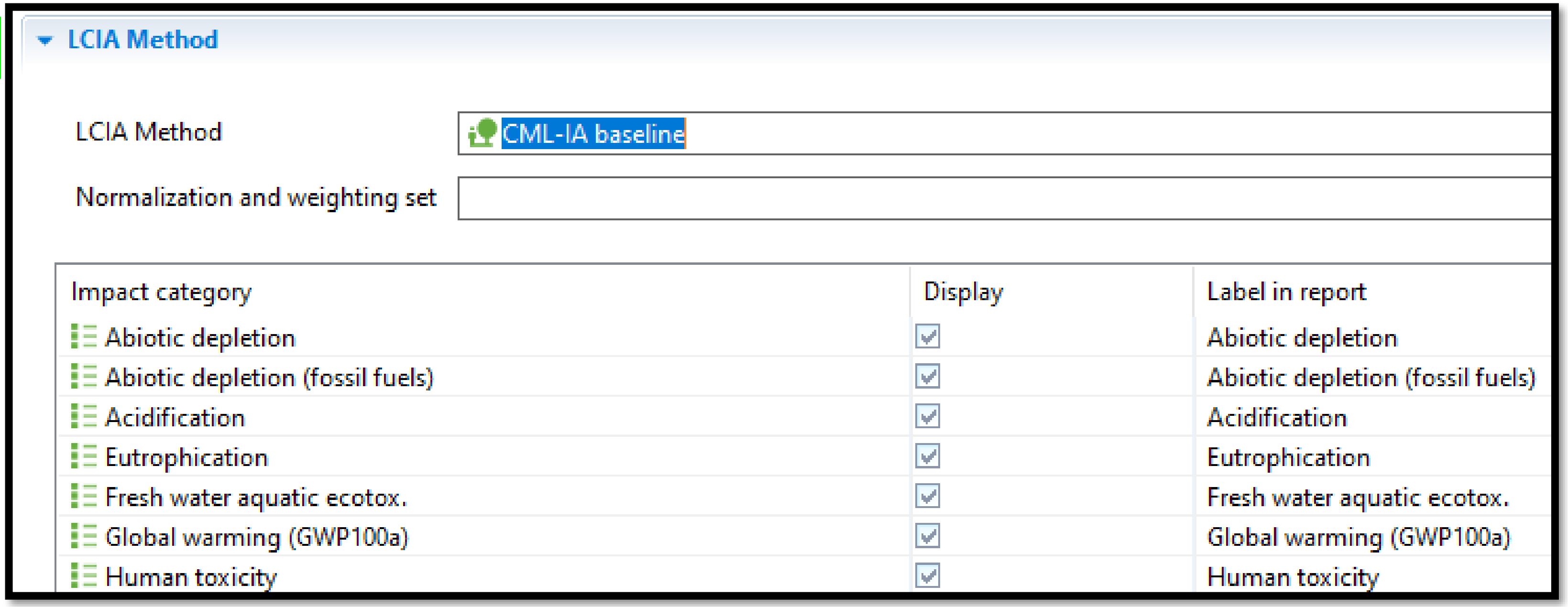
Life Cycle Impact Assessment (LCIA)

- LCIA is composed of **selection** of <u>impact categories</u>, <u>classification</u>, and <u>normalisation</u>.

- The **first step** of LCIA involves **selecting the impact categories** and classifying the elementary flows of the LCI results into the impact categories.

- The **classification** is based on the identification of the environmental issues that each elementary flow can contribute to, such as **water depletion**, **non-renewable resource depletion**, **climate change** or **freshwater eutrophication**.

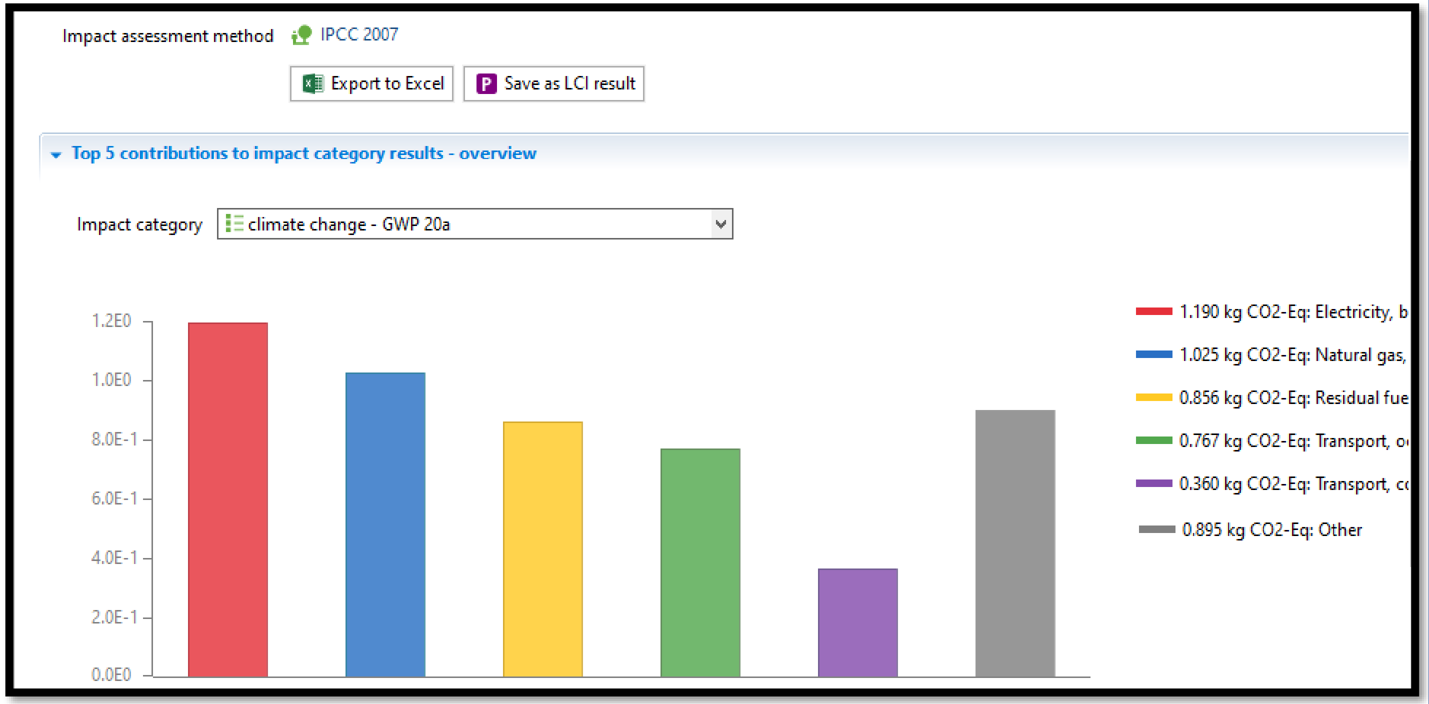


2. Deliverables

Deliverables

- LCA studies have **two deliverables**, the **life cycle inventory (LCI) results** and the **life cycle impact assessment (LCIA) results**.
- LCI collects information about the physical flows in terms of
  - input of resources,
  - materials, semi-products and products,
  - output of emissions, waste and valuable products for the product system.

- In the LCIA phase, the life cycle inventory's information on elementary flows is **translated into** environmental impact scores.



3. Object of the Assessment

Functions

- An LCA study should **first define the functions** from the perspective of the user.
  - Functions are especially **important** to understand when **comparing two or more product systems** because a comparison is only **fair and meaningful** if the compared systems provide the same function(s) to the user.

- For example:

- A **tablet** and a **newspaper** both provide the function of a **news media**. However, a direct comparison of environmental impacts of a newspaper and a tablet would not be meaningful since the tablet provides **more functions** (access to other websites, word processing and other software).

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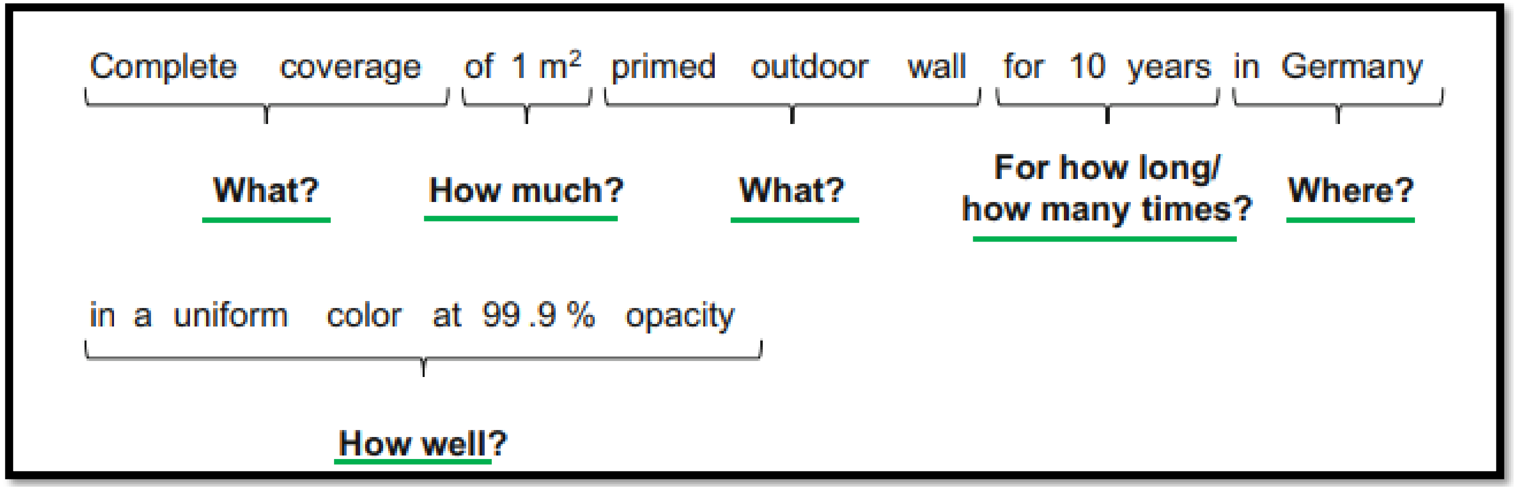
Functional Unit

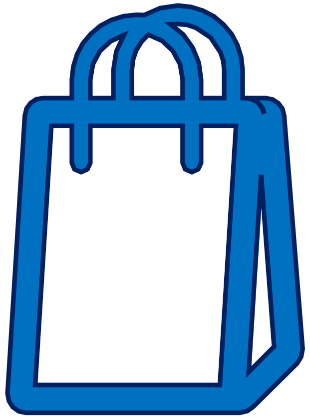
- A **functional unit** defines the **qualitative aspects** and quantifies the **quantitative aspects** of the function.

- For example, a **comparison of outdoor paints** may be based on the functional unit: "Complete coverage of 1 m2 wall for 10 years in Germany in a uniform colour at 99.9% opacity".



- **It is important** to understand that the **functional unit** should always include **a function** and not simply be a physical quantity, such as 1 kg or 1L. For example, it would be wrong to compare paints on the basis of a functional unit of "1L paint".

Example of a Functional Unit



Shopping bags:

- How much/many? <u>volume</u>.
- How long/many times? <u>the number of shopping trips</u> that the bag should be used for.
- How well? strength, i.e. the weight that can be carried.

- For products that **are not in use all the time** (e.g. clothes, mobile phones) the "how long/many times?" question should instead be addressed by specifying the intensity of the use, for example, **the total duration of use** (e.g. 1000 h).

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Common Types of Mistakes When Defining the Functional Unit

Assuming that same **physical quantity of product** equals the **same function**:

Example: “1 kg of packaging material”

Explanation:

- A physical quantity, such as mass, is not a function.
- As an example, **glass** and **PET** in beverage packaging have different **densities** and **physical properties**.

Reference Flows

- A reference flow is the product flow to which all input and output flows for the processes in the product system must be quantitatively related.

- The **reference flow** is the amount of **product** needed **to realise** **the functional unit**.

- In the example of painting, **0.67 L of paint A** is required to realise the functional unit, while the same functional unit is realised with **0.15 L of paint B**.

- Functional unit complete coverage of 1 m2 primed outdoor wall for 10 years in Germany at a uniform colour at 99.9% opacity.

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Class Participation 5

- ❑ Choose a **product** and define its **functional unit** and **reference flows** by answering the following questions:

- ❖ How much/many?
- ❖ How long/many times?
- ❖ How well?

4. LCI Modelling Framework and Handling of Multifunctional Processes

Secondary Functions and Multifunctional Processes

- In addition to **primary functions**, **secondary functions** can also emerge in the life cycle of a product system.
- Secondary functions are unintended functions that usually have low or no relevance to the users of a product.
- An example of a multifunctional process that both deliver more than one product output and provide more than one service is waste incineration.
- The **secondary functions** of a product disposed by **incineration** are the production of **heat** and **electricity**.

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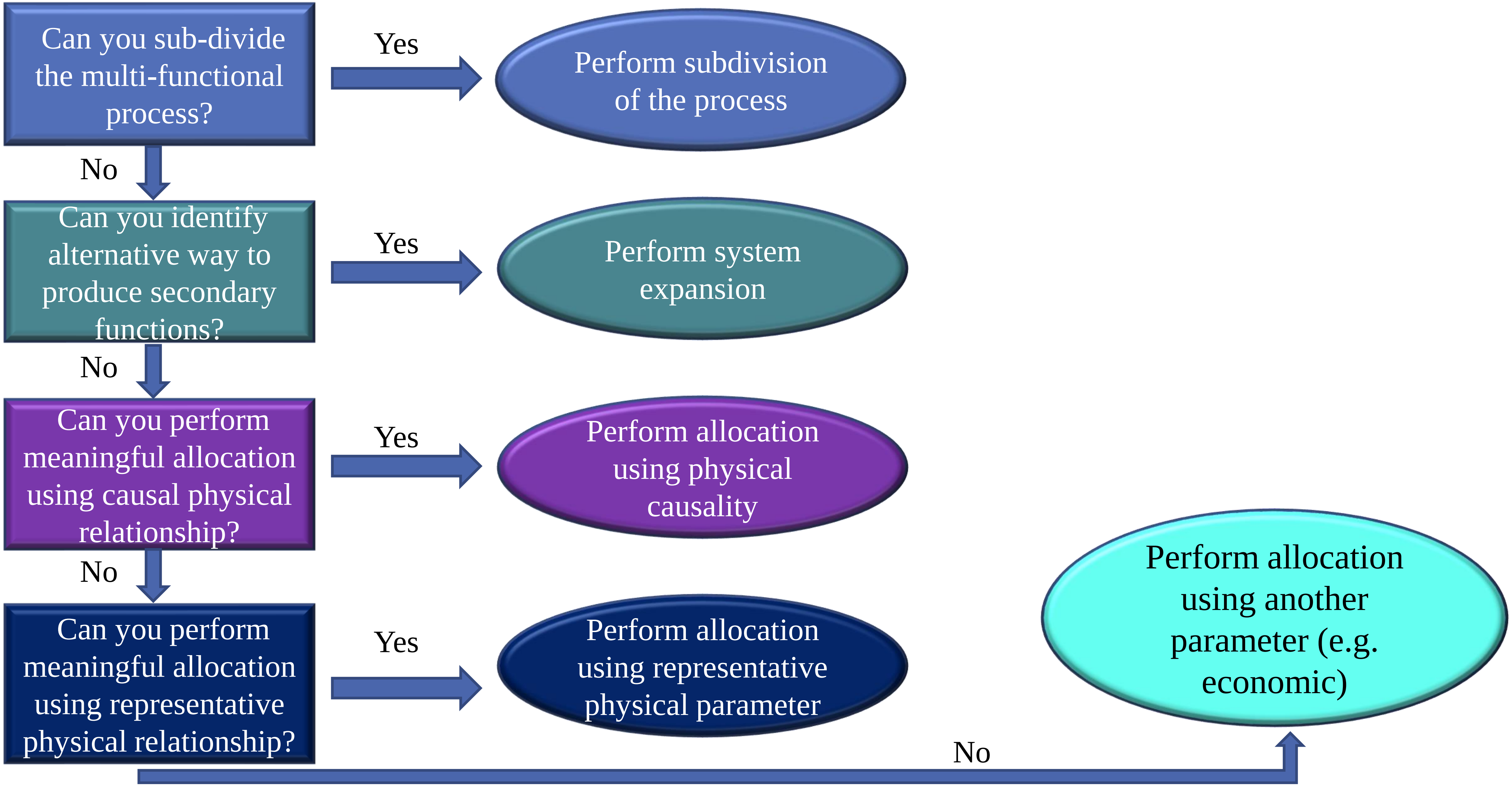
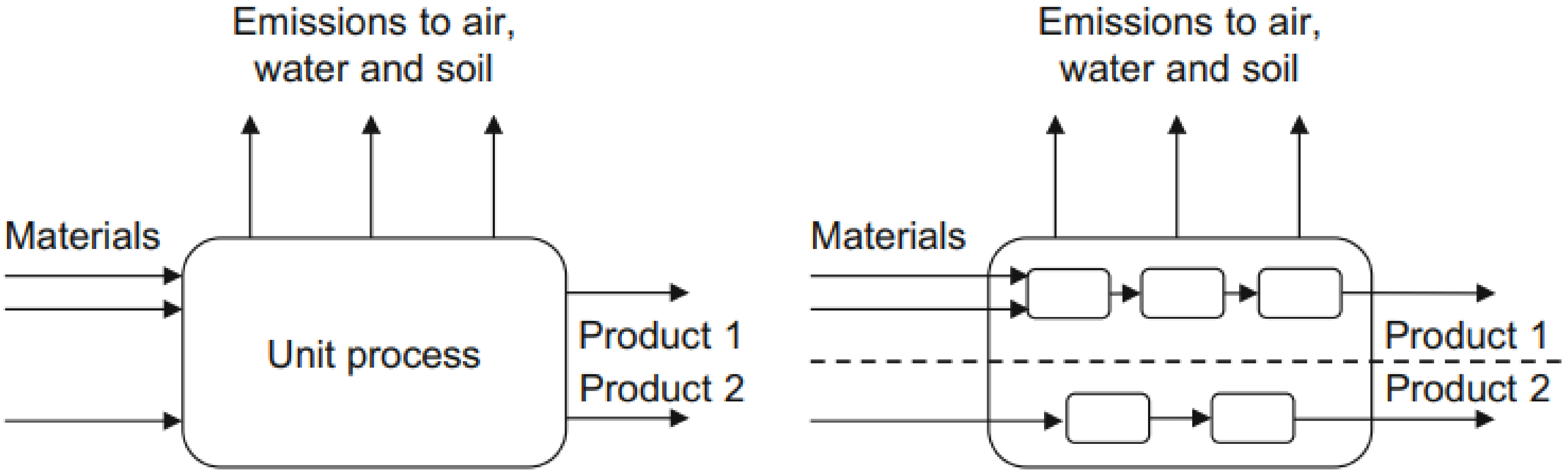
The ISO 14044 Hierarchy to Solving Multifunctionality



Subdivision of Unit Process

- **Solving the multifunctionality** problem by increasing the modelling resolution and **sub-dividing the process into minor units**.



- The **processes** needed for the production of the **first product** are physically **separated from** the processes needed for the production of the **second product**.

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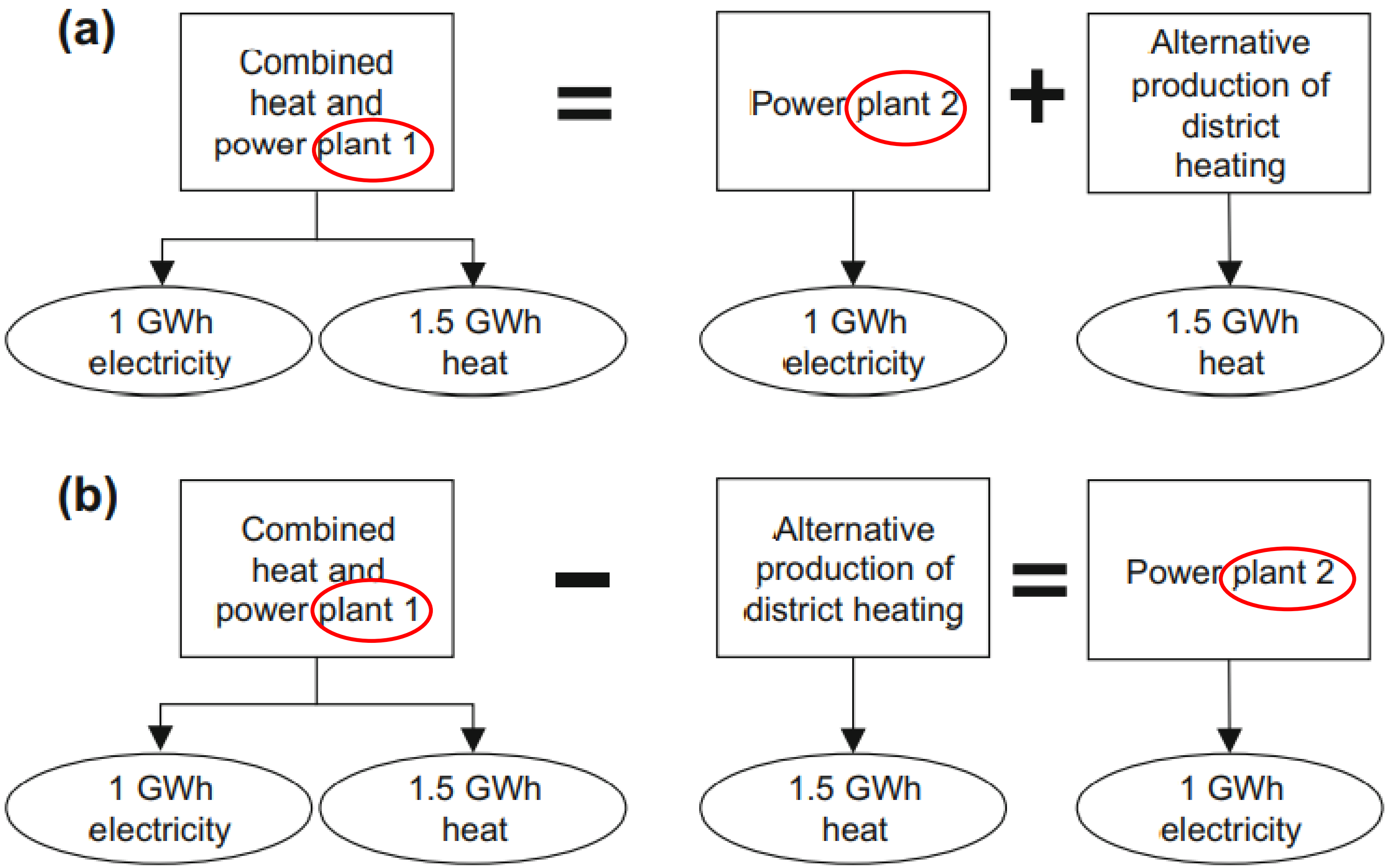
System Expansion

Equivalent modelling approach when dealing with **multifunctionality**.

(a) **System expansion**: to ensure equal functionality system 2 is expanded to include the secondary function of system 1.

(b) **Crediting**: system 1 is credited for the production of the secondary function, in order to have equal functionality of system 2.



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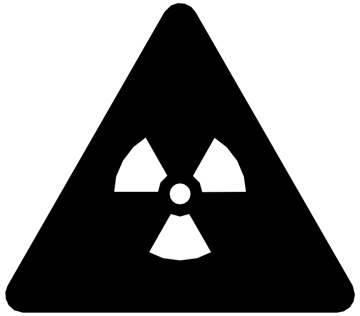
Allocation Using a Causal Physical Relationship

- Sometimes it is **not feasible** to obtain complete **functional equivalency between the compared systems** or to isolate the primary function of a process from the secondary functions through system expansion.
- A classic example of such a multi-output process is a **petrochemical refinery** with a **variety** of different organic substances as **output**.
- When **system expansion is not feasible**, the ISO 14044 recommends **dividing the inputs and outputs** of the multifunctional system between the different **products or functions**.
- The allocation should be based on the causal physical relationships between the quantities of input and output.

- For example, in the case of a **waste incineration** plant that incinerates **batteries** and **plastic**, emissions of the **toxic metal cadmium** from the process will originate entirely from the batteries, given that the plastic stream contains no cadmium.



Allocation Using a Representative Parameters

- In the absence of a **causal physical relationship** between the products, the ISO standard recommends performing the allocation according to **representative parameters**.
- This is possible when **co-products** provide **identical** or **similar functions**.
- In the example of an **agricultural process** that produces both **wheat** and **straw**, the **energy content** of the two flows can only be used as a **representative parameter** if they are both intended as animal fodder (a common function).
- Note: If the wheat is intended as food for humans this choice of representative parameter would be wrong. Why?

> Answer: Food for humans deliver many more functions than energy, e.g. vitamins and taste.

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Allocation Using an Economic Relationship

- When **no common representative physical parameter** can be identified for the different outputs, another relationship must be found between them.
- As an example, the ISO standard mentions an **economic relationship**, which is a frequently applied allocation parameter.
- In economic allocation, the **inputs and outputs** of the process are divided between its products systems according to **their respective economic values**, e.g. determined as their long-term average market prices.

- A justification for the use of economic allocation is that products are produced due to **an incentive of financial income**, and that a co-product with a market value close to 0 should be allocated a **low share** of a process, compared to a primary product with a high market value.

LCI Modelling Framework: Attributional LCI modelling

There are two main LCI modelling frameworks: **attributional** and **consequential** modelling.

- **Attributional modelling:** The overall aim of attributional modelling is to represent **a product system** in **isolation** from the rest of the **technosphere**.

The questions addressed by attributional LCI modelling:

What environmental impact can be attributed to product X?

- This separation is artificial because many product systems interact with other products systems through multifunctional processes, meaning that they cannot be described as physical entities in isolation.

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LCI Modelling Framework: Consequential LCI modelling

- **Consequential modelling:** The overall aim of **consequential modelling** is to describe the **changes** to the **economy** caused by the **product system's consequence**.

The question addressed by Consequential LCI modelling:

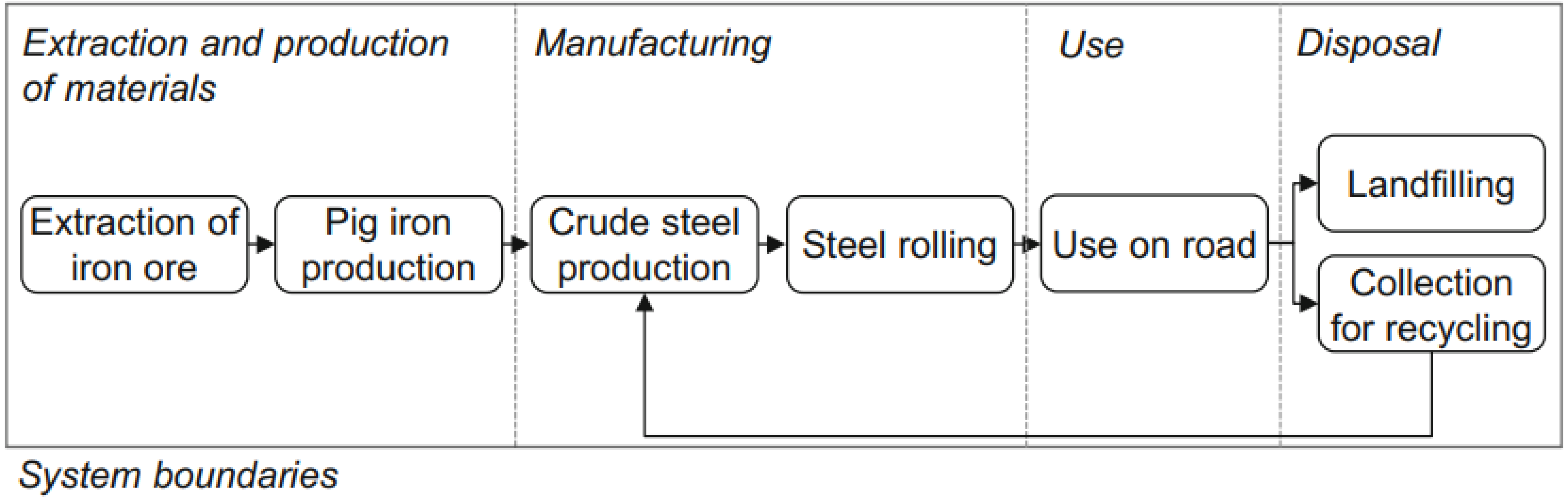
What are the environmental consequences of consuming X?

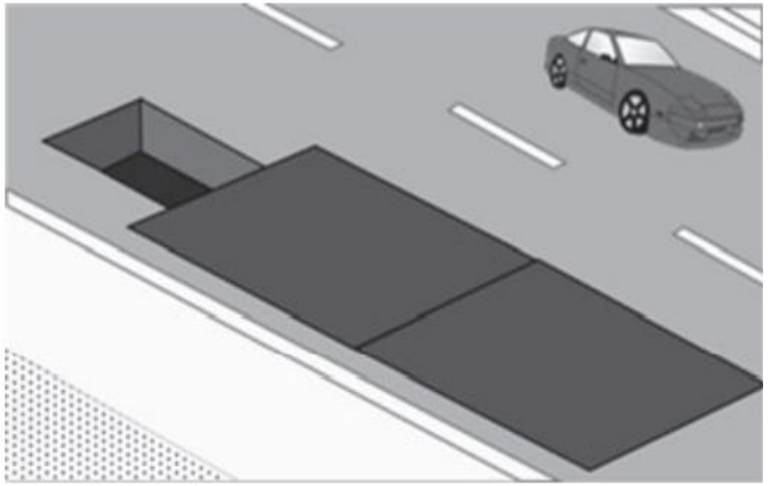
- The conversion of natural land happens as an indirect consequence of increases in the production of biofuel crops , i.e. **forest is being cleared** to make room for the for **biofuel crops**.

5. System Boundaries and Completeness Requirements

System Boundaries and Completeness Requirements

- System boundaries **demarcate** the boundaries between the **studied product system** and (1) the **surrounding economy** (technosphere) and (2) **the environment** (ecosphere).
- "Completeness requirements": What processes should be included within the system boundaries to reach the degree of completeness in the product system modelling?





Example of system boundaries diagram for the life cycle of a **steel sheet** used to prevent accidents **during roadworks**.

Class Participation 6

1. Based on your background (Civil or Mechanical Engineering), select two additional cases and describe the completeness requirements for each, specifying the processes that should be included within the system boundaries.

2. Engage in a class discussion to share your perspectives, and then upload it on Canvas.

6. Representativeness of LCI Data

Representativeness of LCI Data

- The objectives of LCA model is to represent
  - what actually happens or has happened to the product system?
- The unit processes must be representative of the processes which are actually used in the analysed product system.
- The most important parts of a foreground system will be based on data (e.g., elementary flows) collected first-hand by the LCA practitioner.
- **Representativeness** of **LCI data** can be understood in **three** interrelated dimensions:
  - Geographical
  - Time-related
  - Technological

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Geographical Representativeness

- Geographical representativeness is important to consider two processes delivering the same product output, but taking place in two different locations (e.g. nations).
- They **can be different** in terms of **elementary flows**, **energy flows**, **material flows** and waste to treatment.
- Differences between unit processes can be caused by local climate and proximity to natural resources, and regulatory differences, such as energy taxes and emission thresholds.
- For example, the **electricity** mixes of **Denmark** (mainly coal and wind power) and **Sweden** (mainly nuclear and hydropower) vary quite a lot.
- **Sweden** has mountains, and therefore a potential for **generating hydropower**, but **Denmark** is flat.
- In aspect of social and political differences; Sweden has nuclear power plants, but Denmark does not due to public resistance.

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Time-Related Representativeness

- ❑ Two processes delivering the same product output can be **different** if they occur at **different times**.

- ❑ This is due to **technological innovation** and **development**, which often tends to lead to more efficient processes over time.
- ❑ In **comparative studies,** it is important to investigate whether there is a risk that differences in time-related representativeness for the compared alternatives can lead to a bias that favours one product system over the others.

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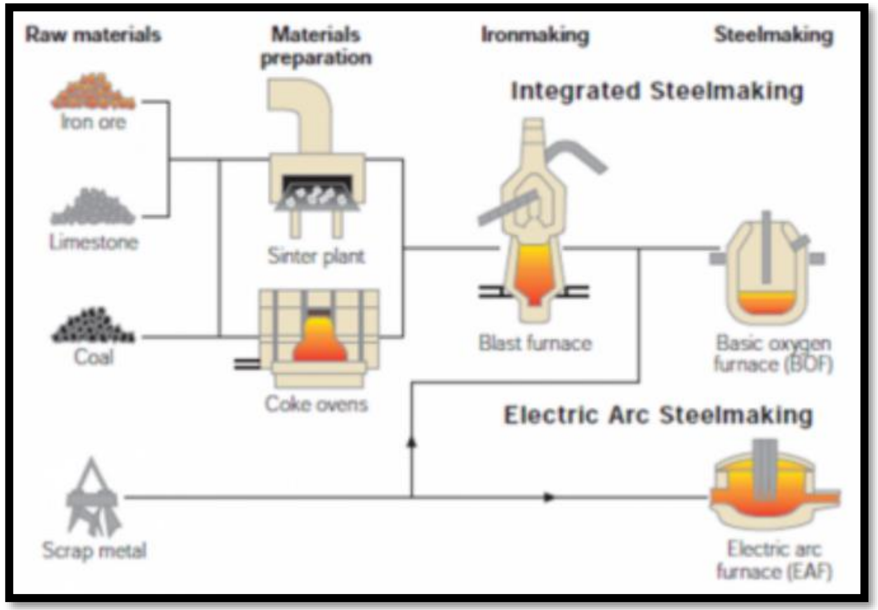
Technological Representativeness

- Two identical products can be produced using two different technologies with different unit processes and related flows.
- For example, **crude steel** can be produced using an **electric arc furnace (EAF)** or a basic oxygen furnace (BOF).
- The LCA practitioner must use his or her knowledge about the product system to ensure that it is modelled using unit processes that reflect the actual technologies involved.
- The product output of one process should meet the quality requirements for input materials of the next process in the system. For example, if a unit process requires steel that is stainless and heat resistant as material input, then it is incompatible with the product of a unit process producing basic grade steel without these properties.



Source from BOF and EAF Steels: What are the Differences? – Economics 243 Fall 2018 (wlu.edu)

Class Participation 7

1. Use the following link to compare steel production utilizing electric arc furnace (EAF) and basic oxygen furnace (BOF).

[BOF and EAF Steels: What are the Differences? – Economics 243 Fall 2018 (wlu.edu)]

2. Upload your summary on Canvas.

7. Preparation of the Basis for the Impact Assessment

Selection of LCIA Methods

To support the choice between alternative LCIA methods, s International Life Cycle Data System (ILCD) has developed some criteria for evaluating the methods:

- **Completeness of scope**:
  - How well does the indicator and the characterisation model cover the environmental mechanisms associated with the impact category under assessment?
- **Environmental relevance**:
  - To what extent are the critical parts of the impact pathway included and modelled in accordance with the current state of the art?
- **Applicability**:
  - Are characterisation factors provided for the important elementary flows for this impact category in a form that is straightforward to apply?
- **Stakeholders' acceptance**:
  - Has the model been endorsed by competent authorities, are the model principles and applied metric understandable for users of the LCA results in a business and policy contexts?

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8. Special Requirements for System Comparisons

Special Requirements for System Comparisons

The ISO 14044 standard poses a number of special requirements for the scope definition of comparative studies

- Systems shall be compared using the **same functional unit** and **equivalent methodological considerations**, such as *performance*, *system boundary*, *data quality*, *allocation procedures*, decision rules on evaluating inputs, and outputs and impact assessment.

- In the case where the goal definition prescribes a **comparison based on a single indicator** (e.g. **carbon footprint**) the **LCA study must highlight** that the comparison is not suitable to identify other environmental alternatives, as it only covers the climate change.

9. Planning Reporting of Results

Planning the Reporting of Results

To reduce the risk of erroneous and misleading use of the LCA, it is essential that the reporting is transparent with a clear indication of

- **What has and what has not been included in the study?**
- **Which conclusions and recommendations the outcome supports?**

Depending on whether the study is comparative and public, the ILCD guideline identifies three reporting levels:

1. **Internal use** by the commissioner of study;

2. **External use** by the third party, i.e. a limited, well-defined list of recipients with at least one organisation that has not participated in the study.

3. **Comparative studies** to be disclosed to the public.

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