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UP FARMING

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“UP-FARMING - Updating sustainability application and communication in the livestock farming sector”

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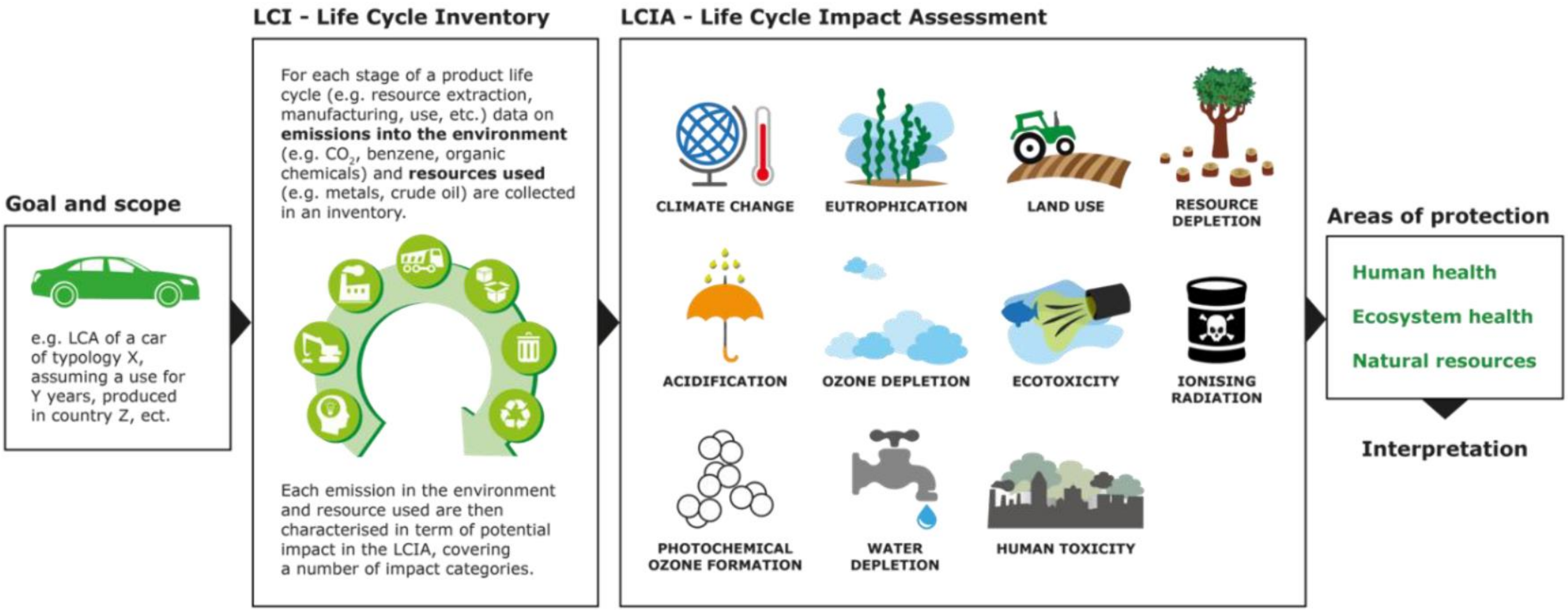
Life cycle assessment: from theory to practice

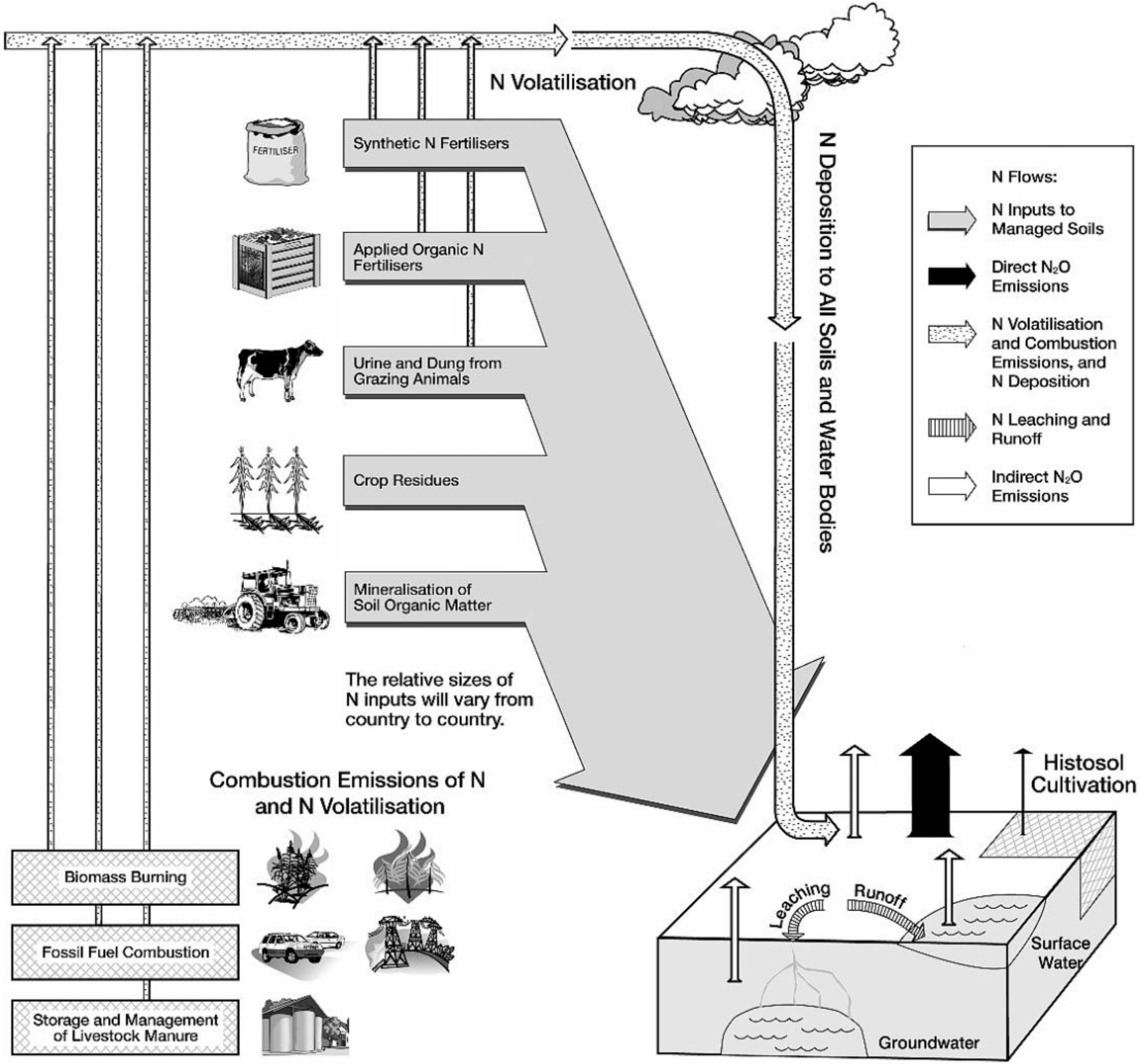
Simone Blanc

Outline

- *Introduction*
- *What is LCA?*
- *LCA applications*
- *LCA accounting*
- *Conclusion*



https://eplca.jrc.ec.europa.eu/lifecycleassessment.html



N Volatilisation
N Deposition to All Soils and Water Bodies
FERTILISER
Synthetic N Fertilisers
Applied Organic N Fertilisers
Urine and Dung from Grazing Animals
Crop Residues
Mineralisation of Soil Organic Matter
The relative sizes of N inputs will vary from country to country.
N Flows:
N Inputs to Managed Soils
Direct N_2O Emissions
N Volatilisation and Combustion Emissions, and N Deposition
N Leaching and Runoff
Indirect N_2O Emissions
Combustion Emissions of N and N Volatilisation
Biomass Burning
Fossil Fuel Combustion
Storage and Management of Livestock Manure
Histosol Cultivation
Leaching
Runoff
Surface Water
Groundwater

Introduction

Which tomato is better from an environmental perspective?

Introduction

Based on production data?

Open-field production LOW ENERGY CONS. (**5** MJ/m2)	Unheated greenhouse LOW ENERGY CONS. (**10** MJ/m2)	Heated greenhouse HIGH ENERGY CONS. (**25** MJ/m2)

Origin: ITALY

Origin: SPAIN

Origin: NETHERLANDS

Introduction

Based on production data?

Open-field production
LOW ENERGY CONS.
(**5** MJ/m2)

LOW CROP YIELD
(10 kg/m2)
0,5 MJ/kg

Unheated greenhouse
LOW ENERGY CONS.
(**10** MJ/m2)

MEDIUM CROP YIELD
(15 kg/m2)
0,6 MJ/kg

Heated greenhouse
HIGH ENERGY CONS.
(**25** MJ/m2)

HIGH CROP YIELD
(56,5 kg/m2)
0,44 MJ/kg

Introduction

But….

Which one consumes more water?

Which are the impacts of the greenhouse?

Which fertilizers did they apply?

Are thet produced organically?

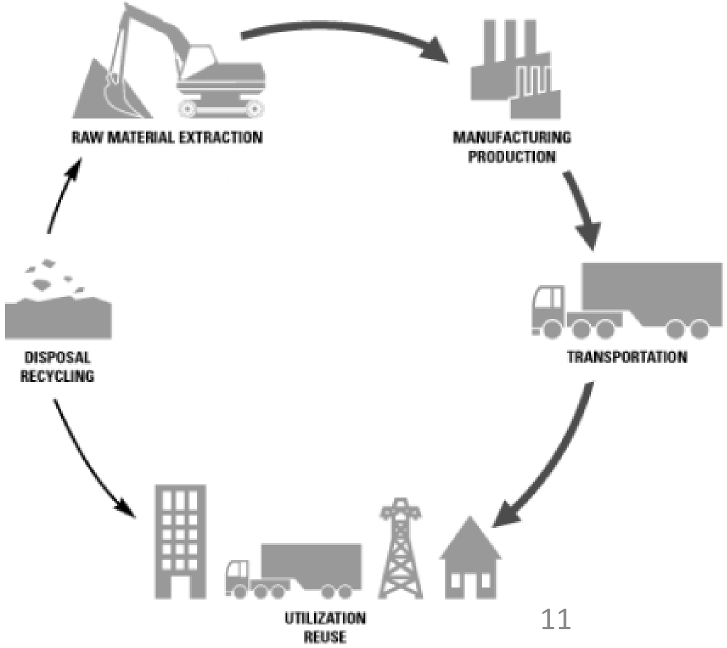
Introduction

Need for a quantitative method

- Life Cycle Assessment (LCA);
- The footprint family:
  - Carbon Footprint (PAS 2050)
  - Ecological Footprint
  - Water Footprint
  - Energy Footprint

What is LCA?

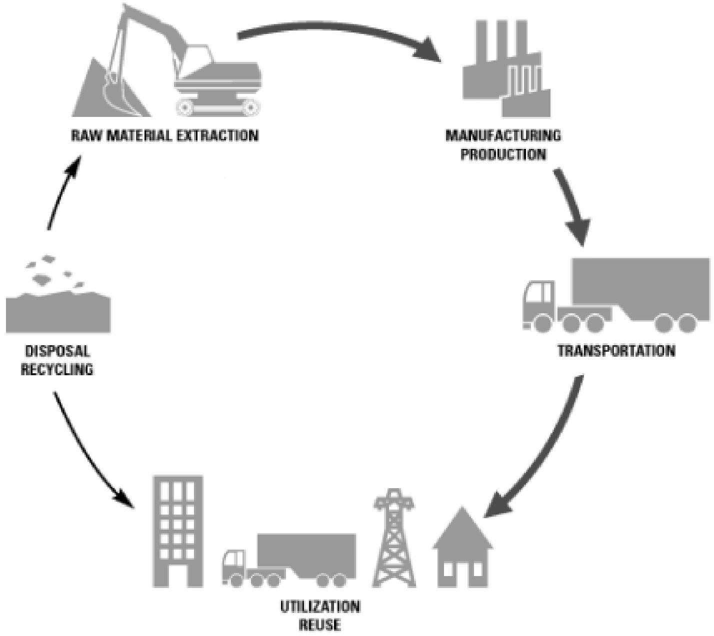
Life-Cycle Assessment (LCA) is an **objective** process to **evaluate the environmental burdens associated with a product, process, or activity** by identifyng and **quantifying energy and materials** used and **wastes released** to the environment; to asses the impact of those energy and materials used and released to the environment by considering **the entire life cycle of the products, process or activity** (SETAC, 1991).



What is LCA?

Life-Cycle Assessment (LCA) involves the **evaluation of some aspects of a product system through all stages of its life cycle.**

At **every stage of the life cycle there are emissions and consumption of resources**. The environmental impacts from the entire life cycle of products and services need to be addressed.



What is LCA?

https://www.youtube.com/watch?v=cYOC8_jJcII

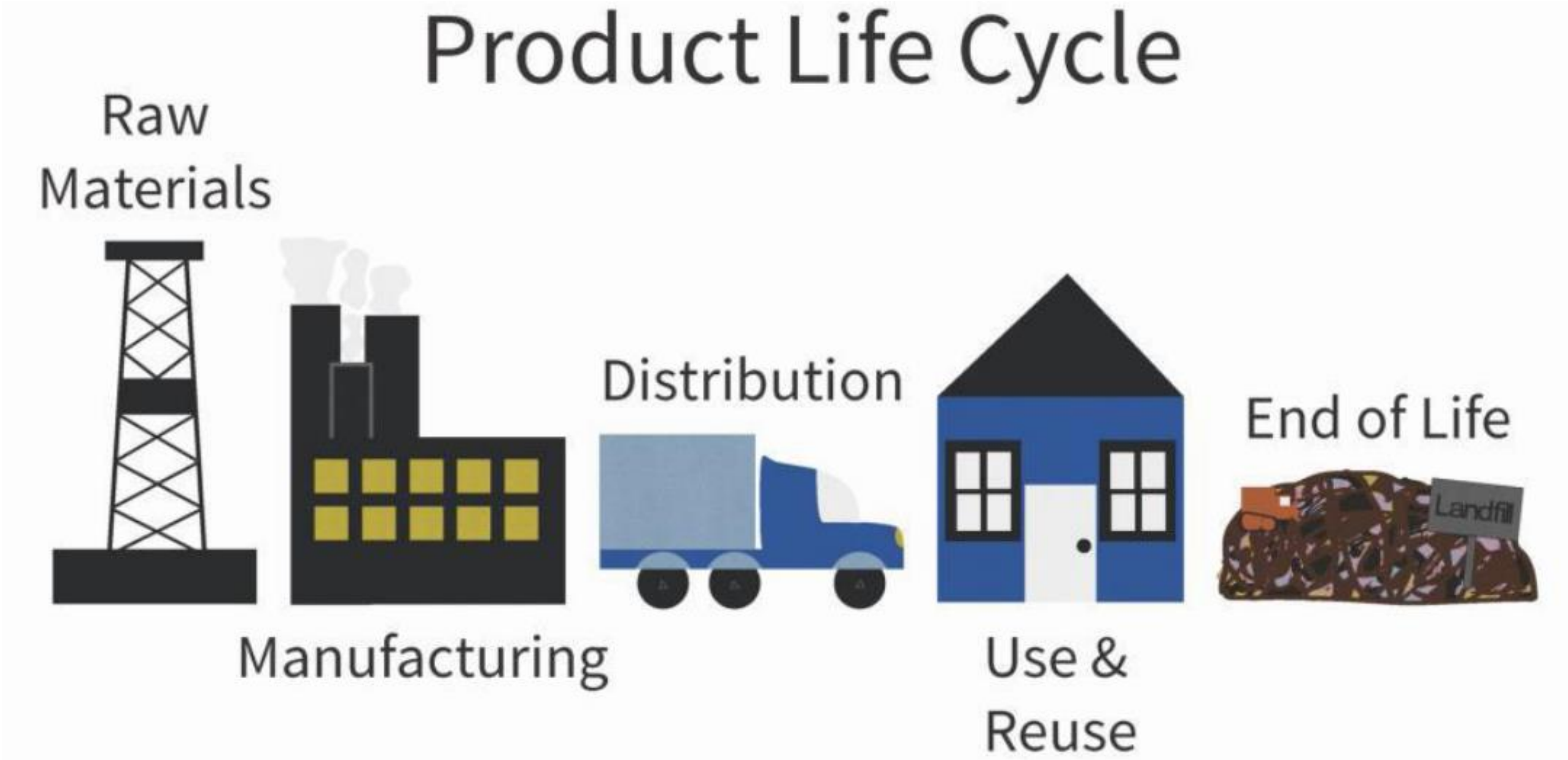
What is LCA?

LCA can assist in:

- Identifying opportunities to **improve the environmental performance** of products at various points in their life cycle
- **Informing decision-makers** in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign)
- The **selection of relevant indicators** of environmental performance, including measurement techniques
- **Marketing** (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration)

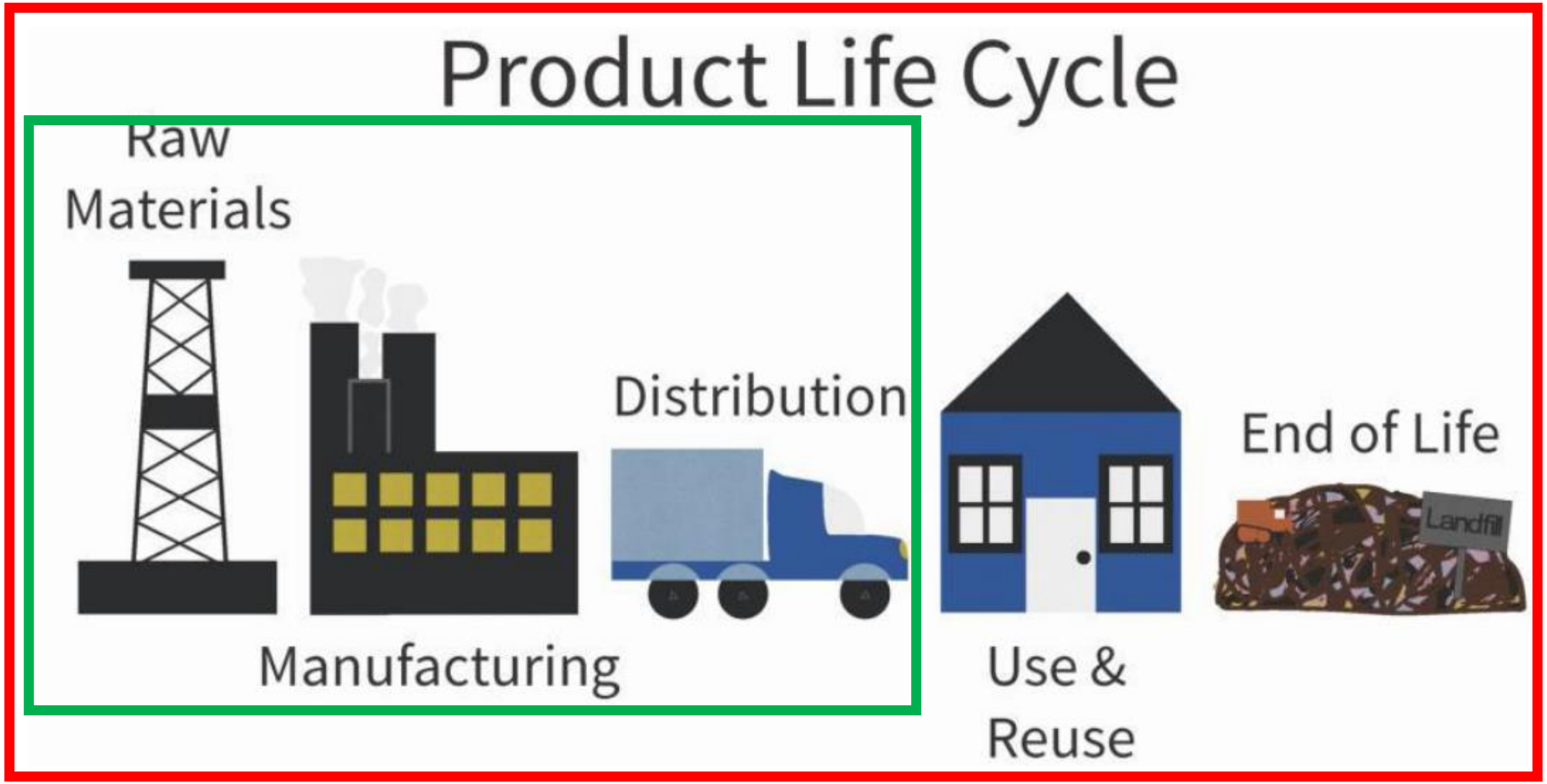
- Example: https://www.gruppogranarolo.it/il-nostro-impegno/i-progetti-per-la-comunita/lca

What is LCA?


Product Life Cycle
Raw Materials
Manufacturing
Distribution
Use & Reuse
End of Life
Landfill

What is LCA?

Cradle-to-grave



Cradle-to-gate

When the entire life cycle is considered…

Where is this tomato consumed?

How much the transport and packaging contributed to its environmental impact?

The environmental impact of a plastic bottle…

Polyethylene terephthalate (PET)

Inputs from nature → **Injection molding and pre-form bowling** → Outputs to nature

PET bottle

The environmental impact of a plastic bottle…

LCA model **inputs** can belong to:

(i) **technosphere**, which describes inputs and outputs of technological systems, such as energy and material consumption;

(ii) **biosphere**, which gives interactions with the natural environment such as the consumption of natural resources or emissions to soil, water, or air;

Polymeritazion

↓

Input from technosphere - - - → Polyethylene terephthalate (PET)

↓

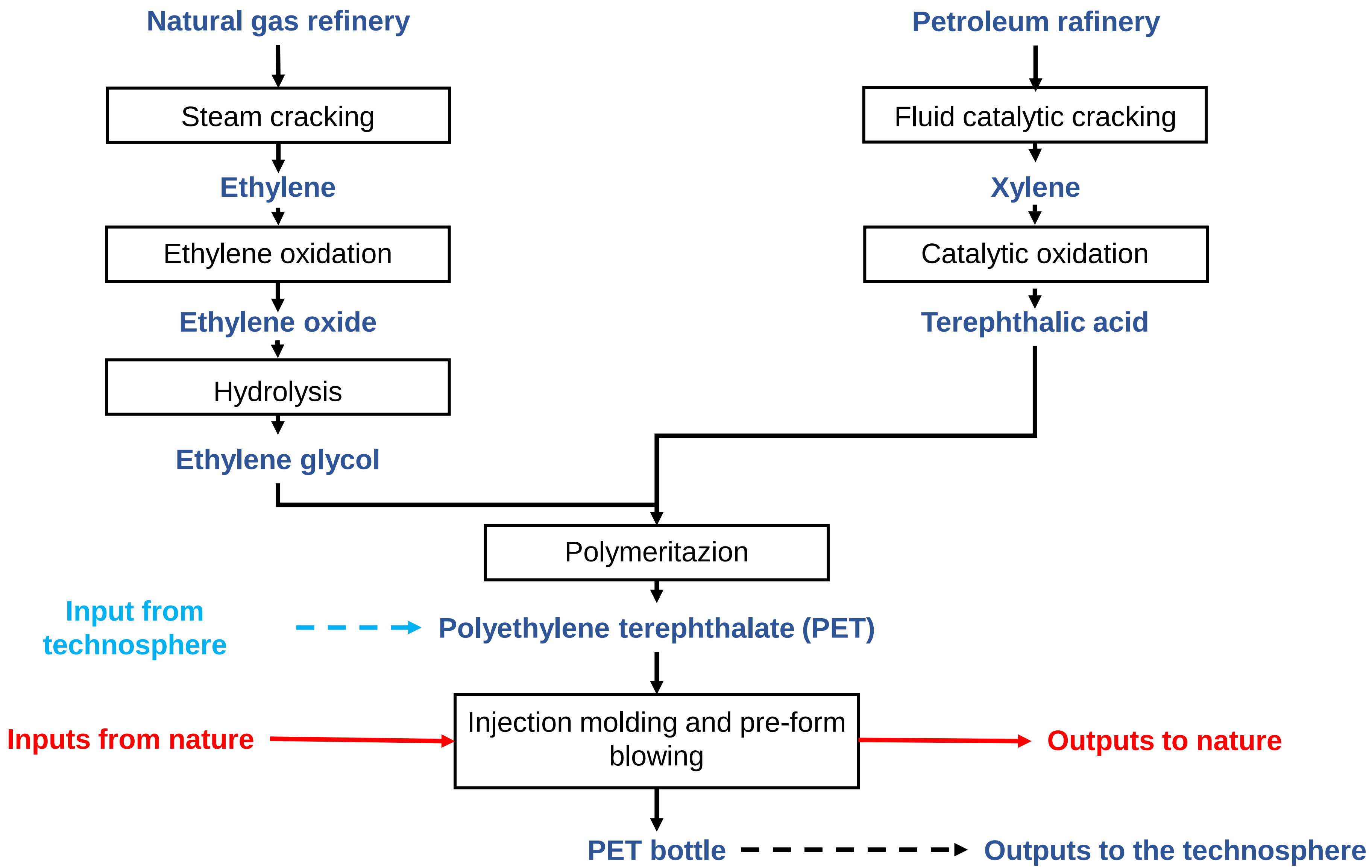
Inputs from nature → Injection molding and pre-form blowing → Outputs to nature

↓

PET bottle - - - - - - - → Outputs to the technosphere

A cradle to gate analysis considers the production steps + transport (not only the material)

The environmental impact of a plastic bottle…



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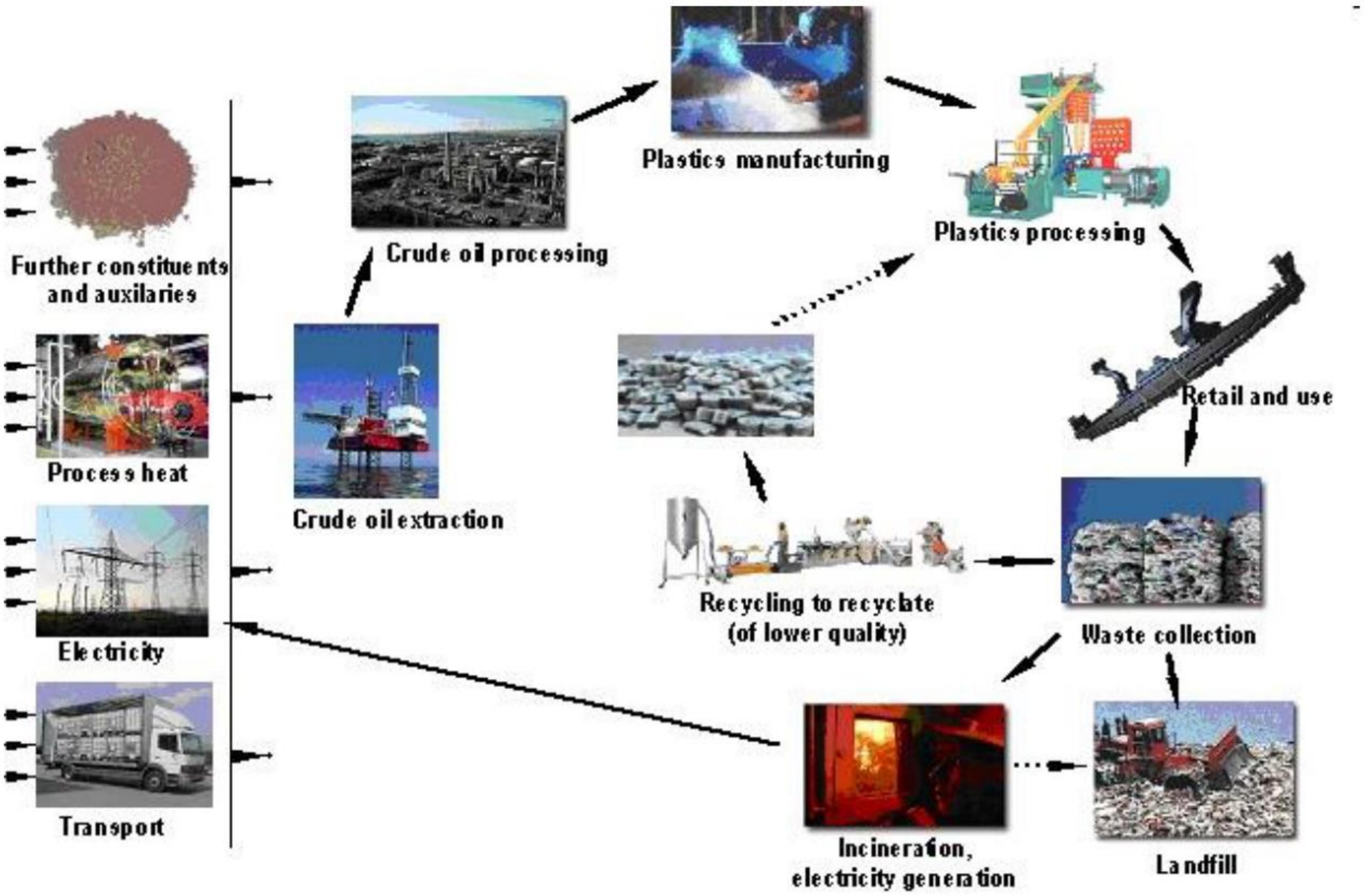
The environmental impact of a plastic bottle…



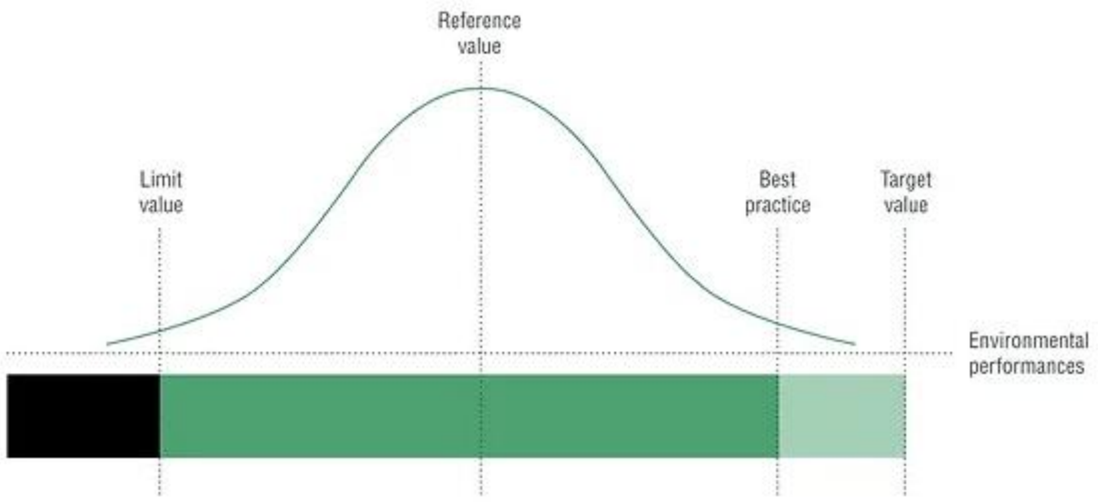
LCA applications

By manufacturers…

- Product development;
- Product improvement;
- Product comparison;
- Eco-design;
- Benchmarking;
- Communication;
- Consumer information;

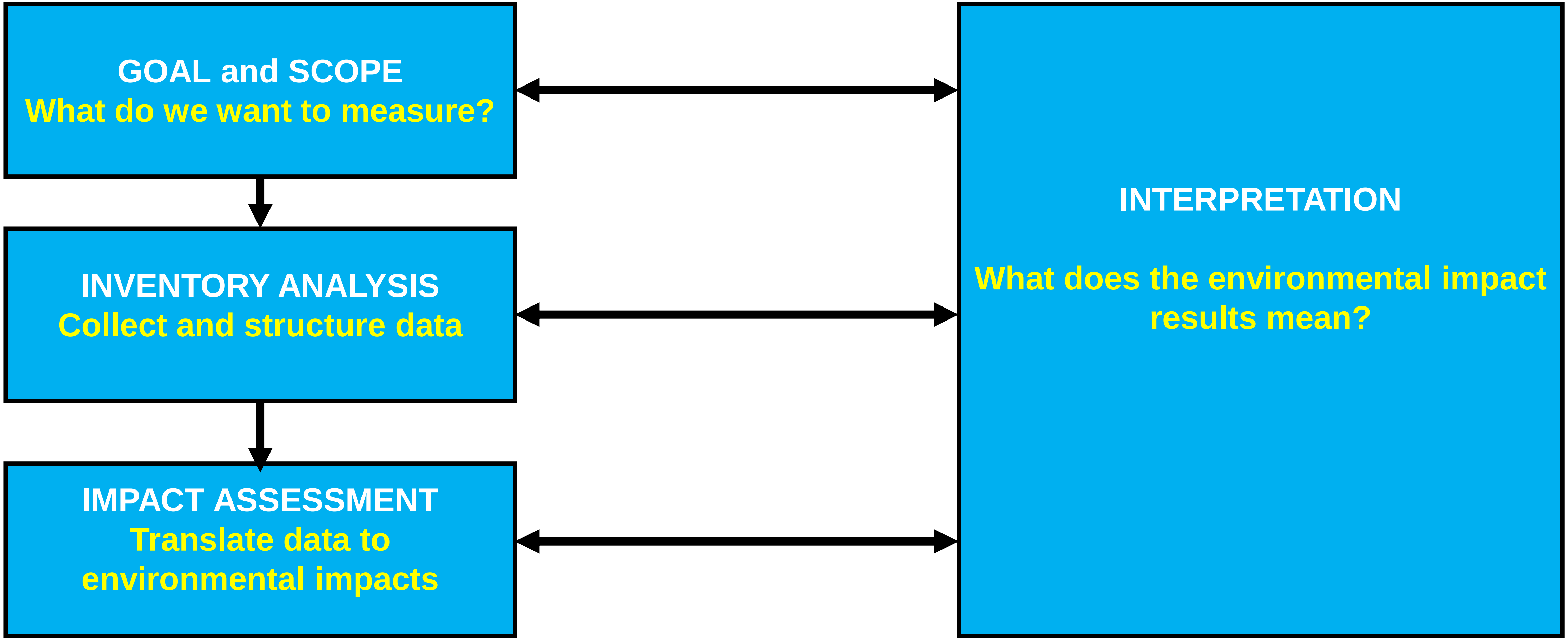
By policymakers…

- Eco-labelling;
- Subsidies and regulations;



LCA accounting

Life cycle assessment Framework



LCA accounting

GOAL and SCOPE

- The aim of the study and the intended audience
- Functions of the system and functional unit
- System boundaries
- Data sources and quality
- Assumptions and limitations
- Allocation procedures

INVENTORY ANALYSIS

- Data collection
- Data calculation
- Allocation of flows and releases

IMPACT ASSESSMENT

- Classification
- Characterisation
- Normalisation and valorisation (optionals)

INTERPRETATION

- The interpretation phase should deliver results that are consistent with the defined goal and scope and which reach **conclusions, explain limitations and provide recommendations**.
- Readily understandable, complete and consistent **presentation** of the results (tables and graphs).
- **Reviewing and revising** the scope of the LCA, as well as the nature and quality of the data collected in a way which is consistent with the defined goal (Sensivity assessment).

LCA accounting

GOAL and SCOPE

What do we want to measure?

The ISO 14040 standard states that the **goal** of the study should define:

- The intended application and the **reason** for carrying out the study
- The intended **audience**, i.e. to whom the results are intended to be communicated
- Whether the result is intended to be used in comparative assertions disclosed to the public

The **scope** should describe the **detail and depth of the study**, and show that the goal can be met with the actual extent of the limitations. When defining the scope of the study the following aspects should be considered and described:

The product system; The functions of the product system, the functional unit and reference flow: System boundary; Allocation procedures; Environmental impact assessment methodology and types of impacts, and interpretation to be performed; Data requirements; Assumptions and limitations; Data quality requirements; Critical review considerations

LCA accounting

GOAL and SCOPE

What do we want to measure?

- The scope of an LCA shall clearly specify the **functions** (performance characteristics) of the system being studied.

- One of the primary purposes of a functional unit is to **provide a reference to which the input and output data are normalized** (in a mathematical sense). Therefore the **functional unit** shall be sclearly defined and measurable.

- Comparisons between systems shall be made on the basis of the same function(s), quantified by the same functional unit(s) in the form of their **reference flows.**

LCA accounting

GOAL and SCOPE
What do we want to measure?

GOAL

- Identify the **hotspots** of a product/system/service:
  - Most impacting life cycle stages;
  - Most impacting inputs/outputs;
  - Identify potential strategies to improve the environmental profile;
- **Compare** different products/systems/services:
  - Local vs. imported products;
  - Products within sector;
  - Eco-designed vs. original products;
- **Compare** methodological aspects:
  - Inventory modeling;
  - Life Cycle Impact Assessment methods;

LCA accounting

GOAL and SCOPE

FUNCTIONAL UNIT

What is the functional unit of Wall Paint?

LCA accounting

GOAL and SCOPE

FUNCTIONAL UNIT

Function: to cover a certain area during a certain period of time with a certain quality

LCA accounting

GOAL and SCOPE

FUNCTIONAL UNIT

<u>Function</u>: to cover a certain area during a certain period of time with a certain quality

- 1 kg or 1 L of Paint
- 1 bucket
- The amount of Paint necessary to cover 1 m^2 of wall with 0,5 mm thickness during 5 years

Reference flows:

Paint A – 0,5 L

Paint B – 0,4 L

LCA accounting

GOAL and SCOPE

FUNCTIONAL UNIT

What is the function and the potential functional units for these examples:

1) To compare two garden chairs.

LCA accounting

GOAL and SCOPE

FUNCTIONAL UNIT

What is the function and the potential functional units for these examples:

1) To compare two garden chairs.

Function: to withstand the weight of one person

Functional unit: to withstand the weight of one person of 80 kg during 12 years in a terrace with Mediterranean climate (functional basis)

Reference flow:

Two white chairs

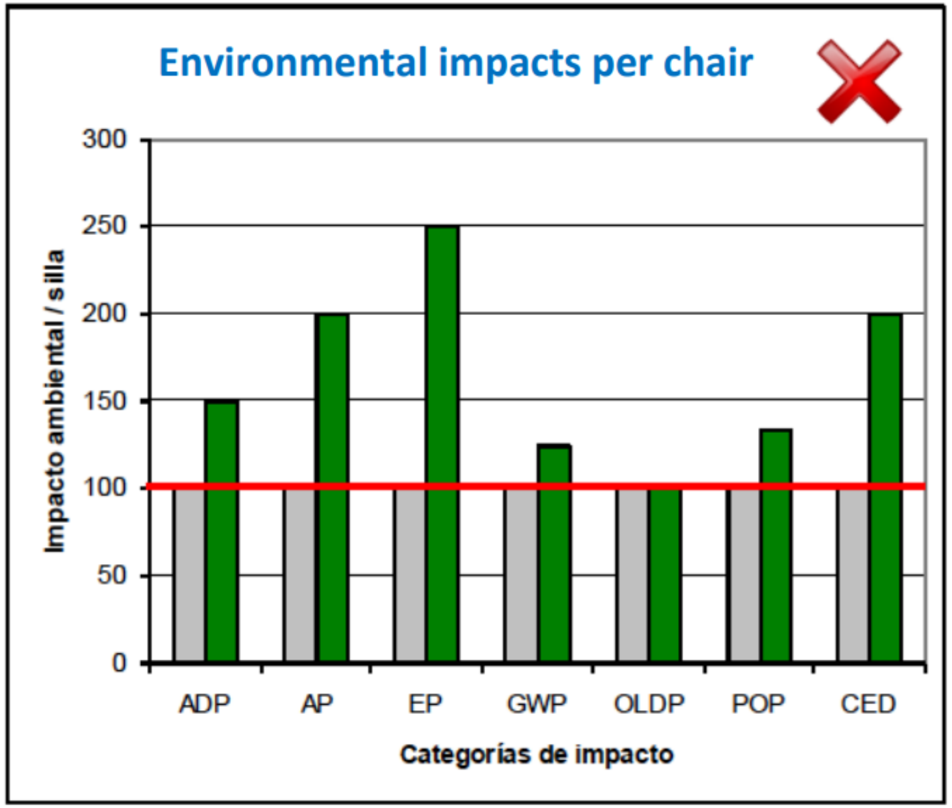
One Green chair

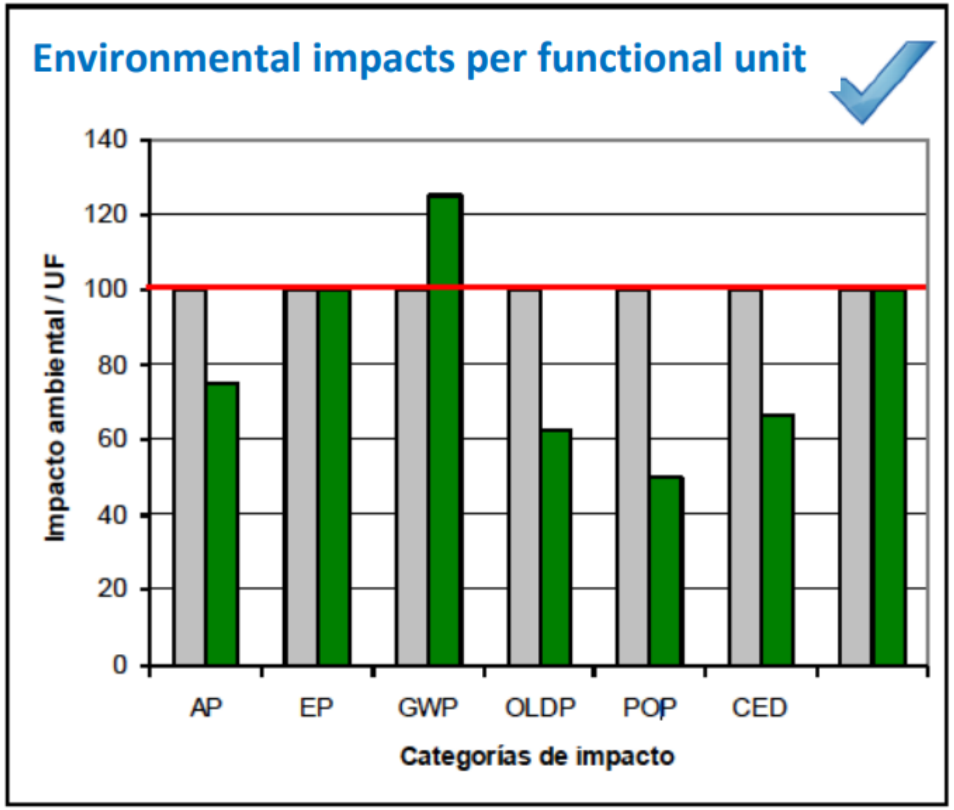
LCA accounting

GOAL and SCOPE

FUNCTIONAL UNIT

The functional unit will relevantly determine the results





Reference flow: Two white chairs vs One Green chair

LCA accounting

GOAL and SCOPE

FUNCTIONAL UNIT

Examples of FUs

- **Physical FUs**:
  - Area: 1 ha crop
  - Mass: 1 kg/t product
  - Energy: 1 MJ electricity
  - Volume: 1 m^3 water

- **Non-physical FUs (Services)**:
  - Delivery of 100 pizzas
  - Lighting a room for 10 years

LCA accounting

GOAL and SCOPE

SYSTEM BOUNDARIES

A LCA could be infinite, so the **system boundary determines wich unit processes shall be included within**. The criteria used in establishing the system boundary shall be identified and explained.

The deletion of life cycle stages, processes, inputs or outputs is only permitted if it does **not significantly change the overall conclusions of the study**. Any decisions to omit life cycle stages, processes, inputs or outputs shall be clearly stated, and the reasons and implications for their omission shall be explained.

LCA accounting

GOAL and SCOPE

SYSTEM BOUNDARIES

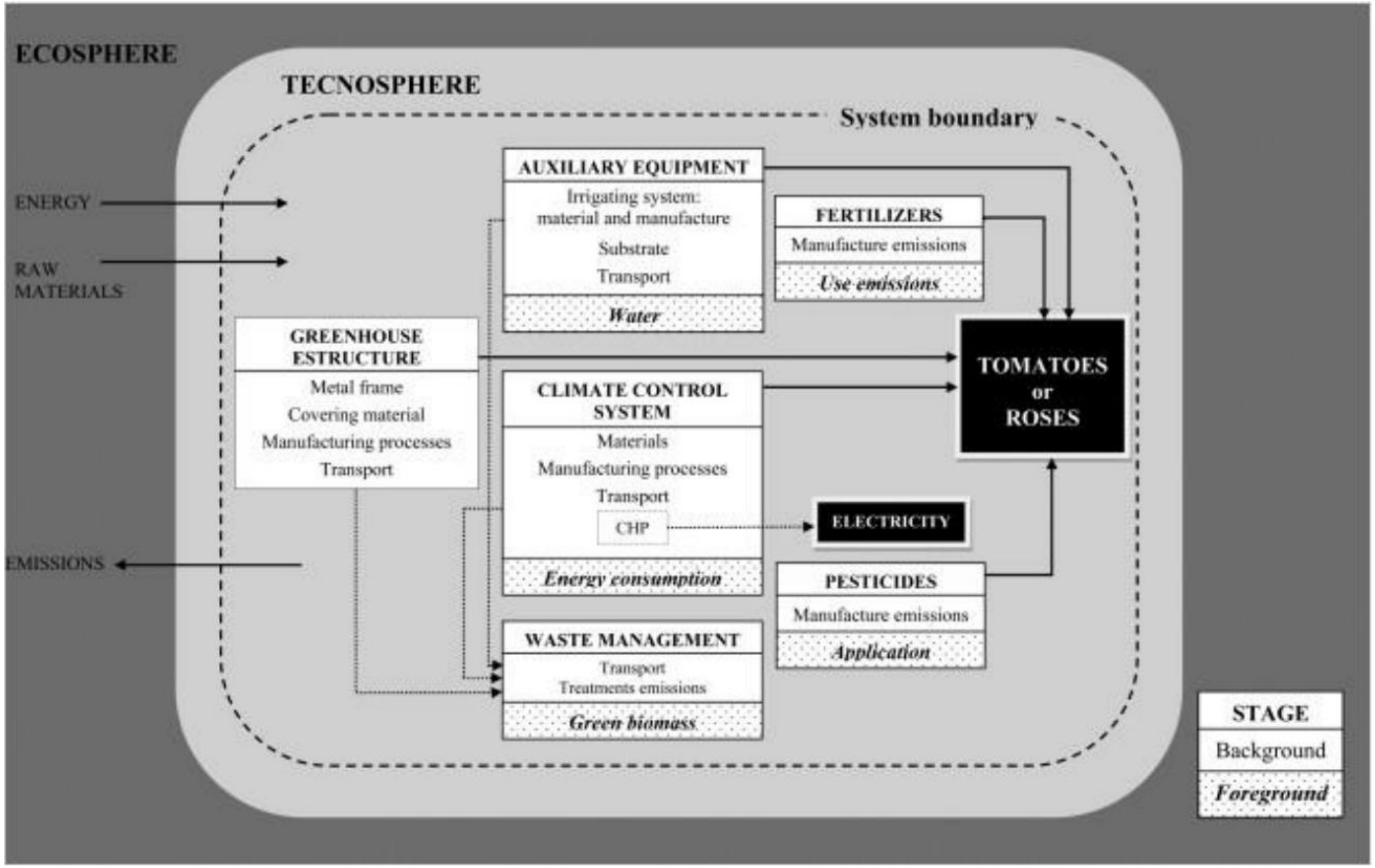
Several **factors** to decide the boundaries:

- The **goal** of the study and the audience;
- The main **hypothesis**;
- The exclusion (**cut-off**) criteria;
- The **data available**;

LCA accounting

GOAL and SCOPE

SYSTEM BOUNDARIES



LCA accounting

INVENTORY ANALYSIS
Collect and structure data

A **life cycle inventory (LCI)** is a process of **quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes**, and other releases for the **entire life cycle** of a product, process, or activity.

Results can be segregated by life cycle **stages**, by **media** (air, water, land), by **specific processes**, etc.

LCA accounting

INVENTORY ANALYSIS

DATA COLLECTION

Data collection consists on **finding and filling in a flow diagram and worksheets with numerical data**. Data can be difficult or impossible to obtain, and the available difficult to convert to the functional unit needed.

Therefore, the **system boundaries** or data quality **goals** of the study may have to be **refined based on data availability**. This iterative process is common for most LCAs. Data can be obtained from:

- Research;
- Site-visits and direct contact with experts which generate large quantities of data;
- Electronic database or spreadsheet can be useful to hold and manipulate the data. Also there are available LCA software packages;

Often **80% of the data needed is background information readily available in databases, or literature or internet**.

LCA accounting

INVENTORY ANALYSIS

DATA COLLECTION

Process **inputs can be divided** into two kinds:

- Inputs of **raw materials and energy resources** (environmental input).
- Inputs of **products, semi-finished products or energy**, wich are outputs from other processes (economic input from technosphere).

Similarly, there are two kinds of **outputs**:

- Outputs of **emissions** (environmental output).
- Outputs of **a product, a semi-finished product or energy** (economic output to technosphere).

LCA accounting

INVENTORY ANALYSIS

DATA STRUCTURE

The outcome is a **list containing the quantities of pollutants released** to the environment and the amount of energy and materials consumed.

The information can be organized by life cycle stage, by media (air, water, land), by specific process, or any combination consistent with the Goal Definition and Scoping, for reporting requirements.

LCA accounting

INVENTORY ANALYSIS

ALLOCATION

In many processes **more than one product** is produced. In such a case all inputs and outputs of the process have to be allocated to the different products.

Allocation is the partitioning and relating of inputs and outputs of a process to the relevant products and byproducts. The allocation to different products can be done according to one of the rules defined below.

- **Allocation by Mass**: the inputs and outputs of a process are assigned to all of its products proportionally to their mass
- **Allocation by Heating Value**: the inputs and outputs of a process are assigned to all of its products according to their heating value. This allocation method is often used for production processes of fuels.
- **Allocation by Market Value**: the inputs and outputs of a process are assigned to all of its products according to their market value.
- **Allocation by Other Rules**: this can include exergy, substance content, etc.

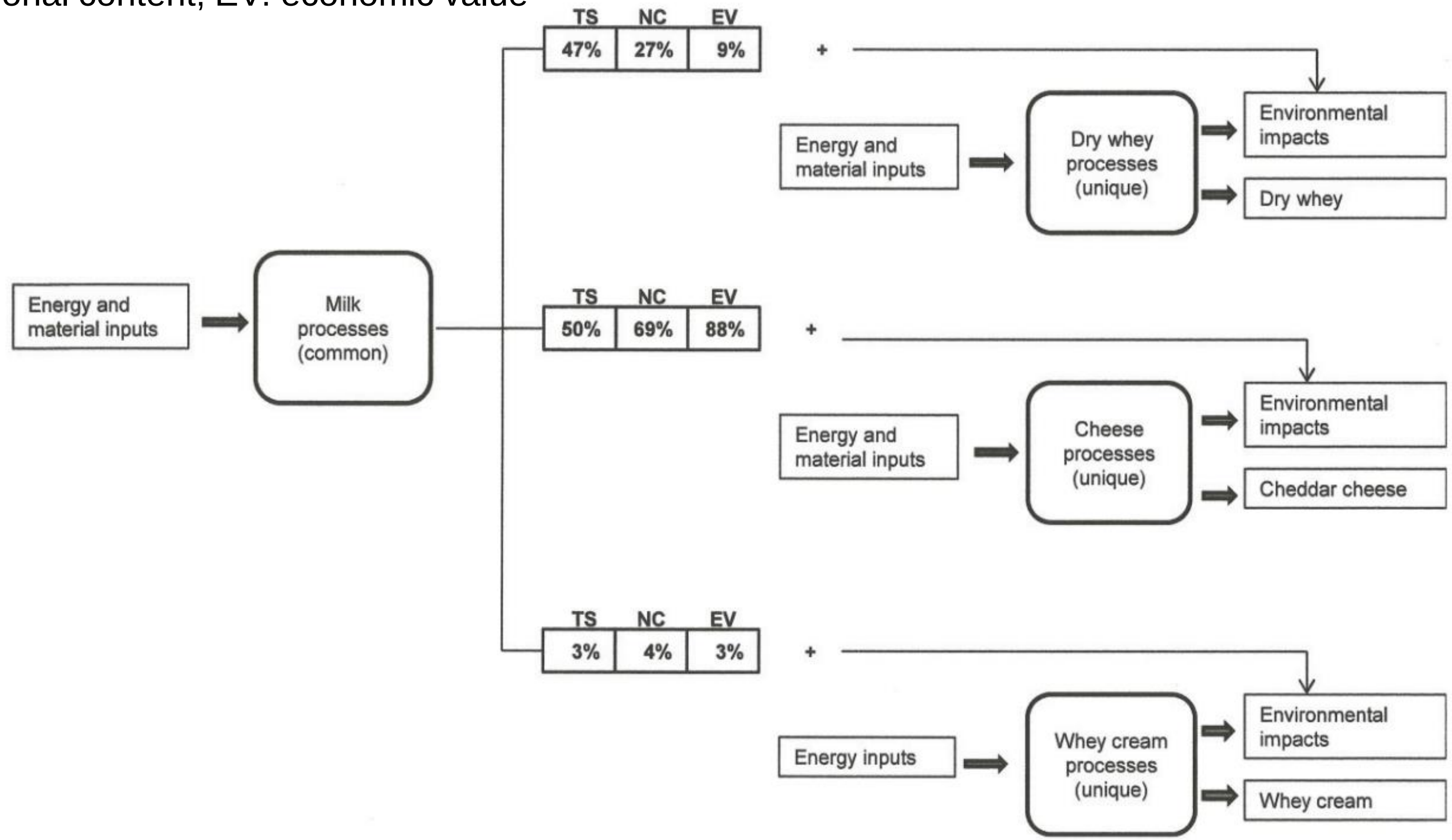
LCA accounting

INVENTORY ANALYSIS

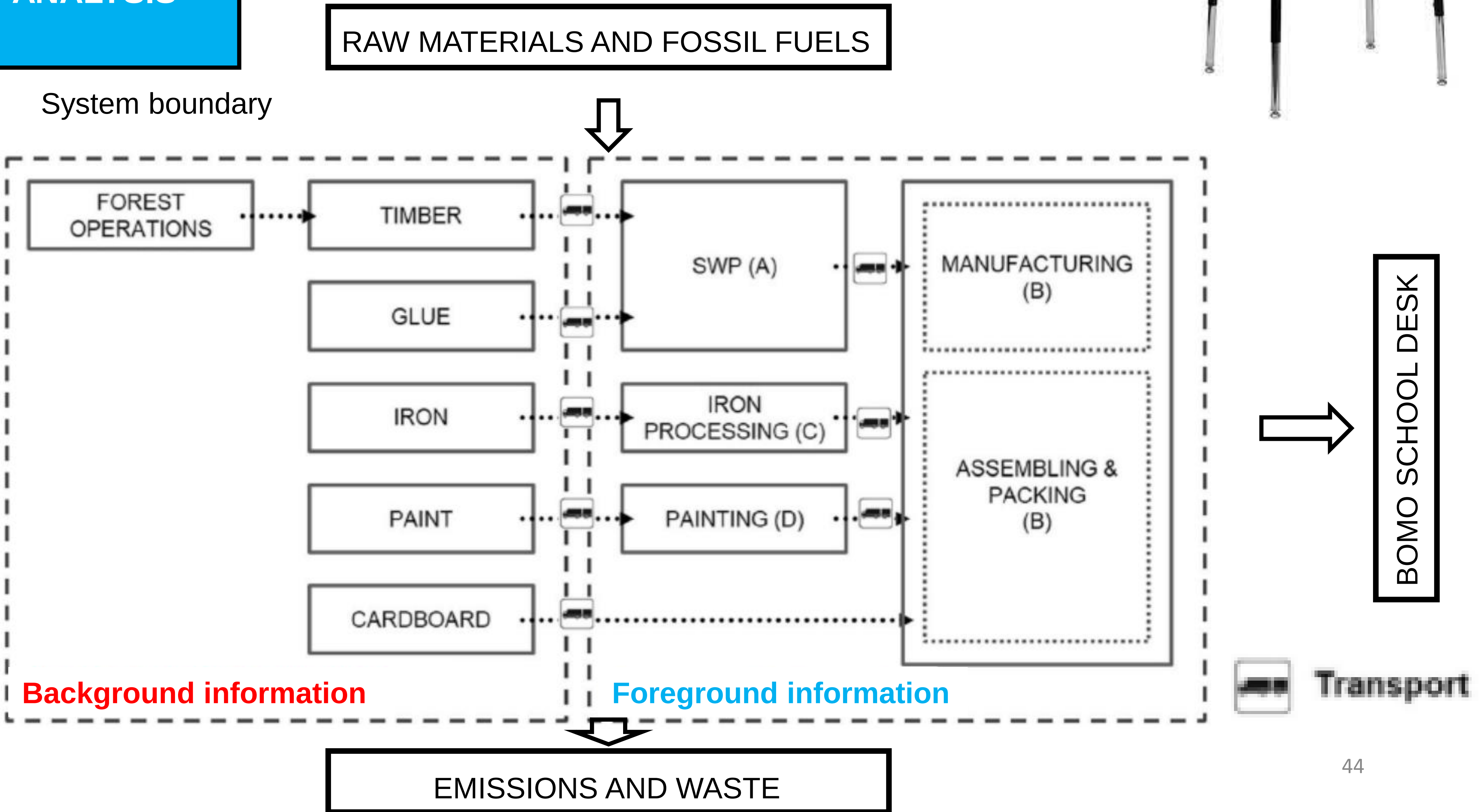
ALLOCATION

Possible allocation methods

TS: total solids; NC: nutricional content; EV: economic value



INVENTORY ANALYSIS



LCA accounting

IMPACT ASSESSMENT
Translate data to environmental impacts

Life Cycle Impact Analysis (LCIA) is the evaluation of **potential human health and environmental impacts** of the environmental resources and releases identified during the life cycle inventory.

Impact assessment should address **ecological and human health effects**; it can also address resource depletion.

A life cycle impact assessment attemps to estabilish **a linkage between the product or process and its potential environmental impacts.**

LCA accounting

IMPACT ASSESSMENT

CLASSIFICATION

The aim is to **organize** and possibly **combine the LCI results into environmental impact categories** (i.e carbon dioxide (CO_2) emissions can be classified into the global warming category).

For substances contributing to two or more different impact categories:

- **Allocate a representative portion of the LCI results to the impact categories to which they contribute**. This is typically allowed in cases when the effects are dependent on each other.

ie. SO_2 can impact to the ground **or** atmosphere, it can affect either human health **or** acidification (but not both at the same time). Therefore, SO_2 emissions can be divided between those two impact categories (e.g. 50% allocated to acidification).

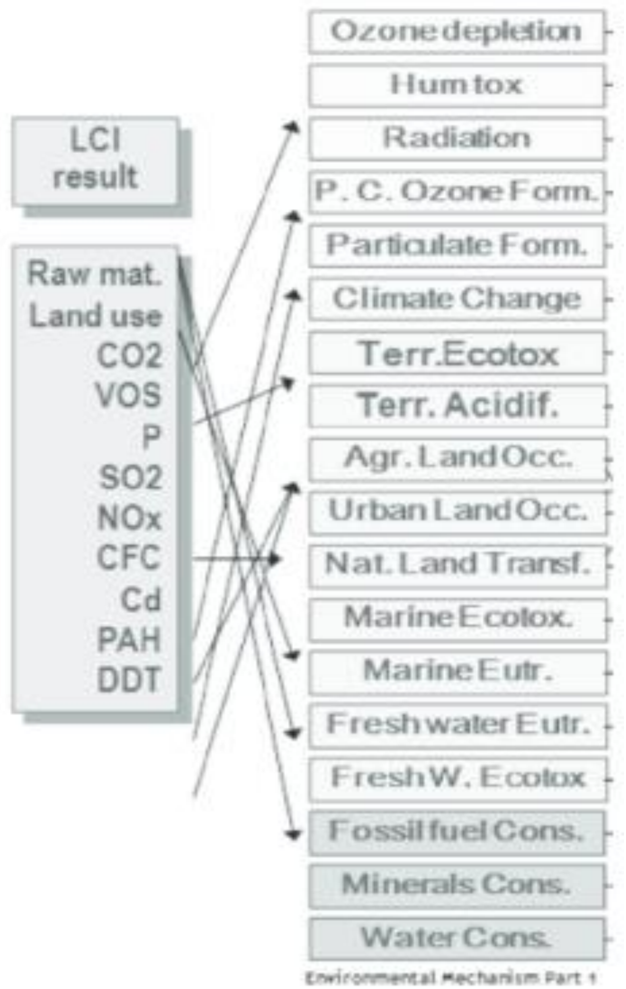
- **Assign all LCI results to all impact categories to which they contribute**. This is typically allowed when the effects are independent of each other.

ie. NO_2 can affect ground level ozone formation and acidification (at the same time), the entire quantity of NO_2 would be allocated to both impact categories (e.g. 100% to ground level ozone and 100% to acidification).

LCA accounting

IMPACT ASSESSMENT

CLASSIFICATION



Classification requires assigning the material/ energy inputs and outputs inventoried to the relevant impact category.

For example, during the classification phase, all inputs/ outputs that result in emissions of greenhouse gasses (e.g. CO2, methane, etc.) are assigned to the climate change impact category.

For example:

Ammonia (NH_3) contributes to:

- acidification
- eutrophication

https://eplca.jrc.ec.europa.eu/lifecycleassessment.html

LCA accounting

IMPACT ASSESSMENT

CHARACTERISATION

Characterization or equivalence factors are used to **convert and combine the LCI results into representative indicators of impacts to human and ecological health**. Characterization helps compare the LCI results within each impact category.

Impact indicators are typically characterized using the following equation:

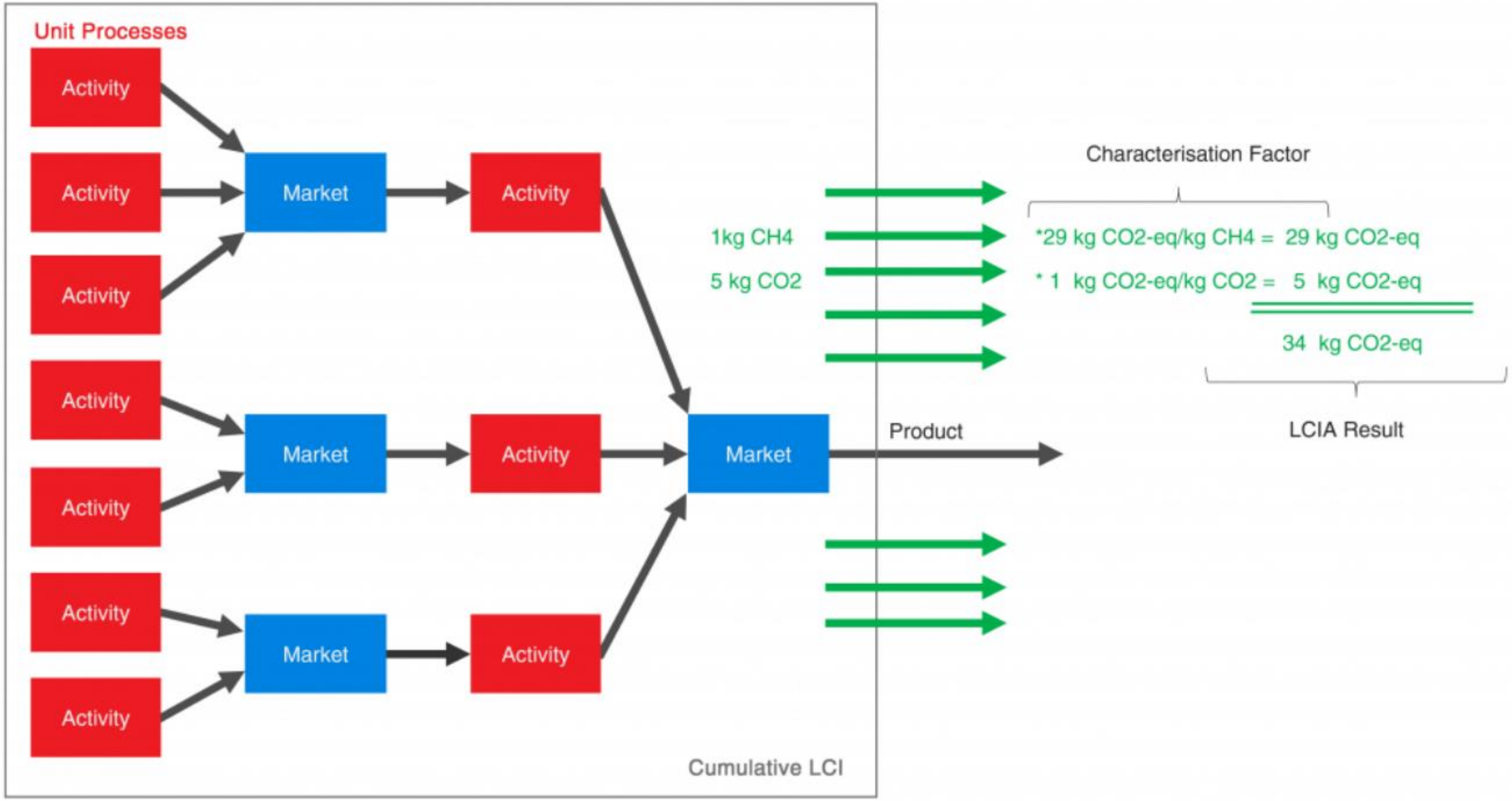
Inventory Data x Characterization Factor = Impact Indicators

Species	Chemical formula	Characterisation of GWP^{100}
Carbon dioxide	CO_2	1 kg CO_2 - eq
Methane	CH_4	25 kg CO_2 - eq
Nitrous oxide	N_2O	298 kg CO_2 - eq
HFCs	-	124 – 14,800 kg CO_2 - eq
Sulphur hexafluoride	SF_6	22,800 kg CO_2 - eq
PFCs	-	7,390 – 12,200 kg CO_2 - eq

LCA accounting

IMPACT ASSESSMENT

CHARACTERISATION

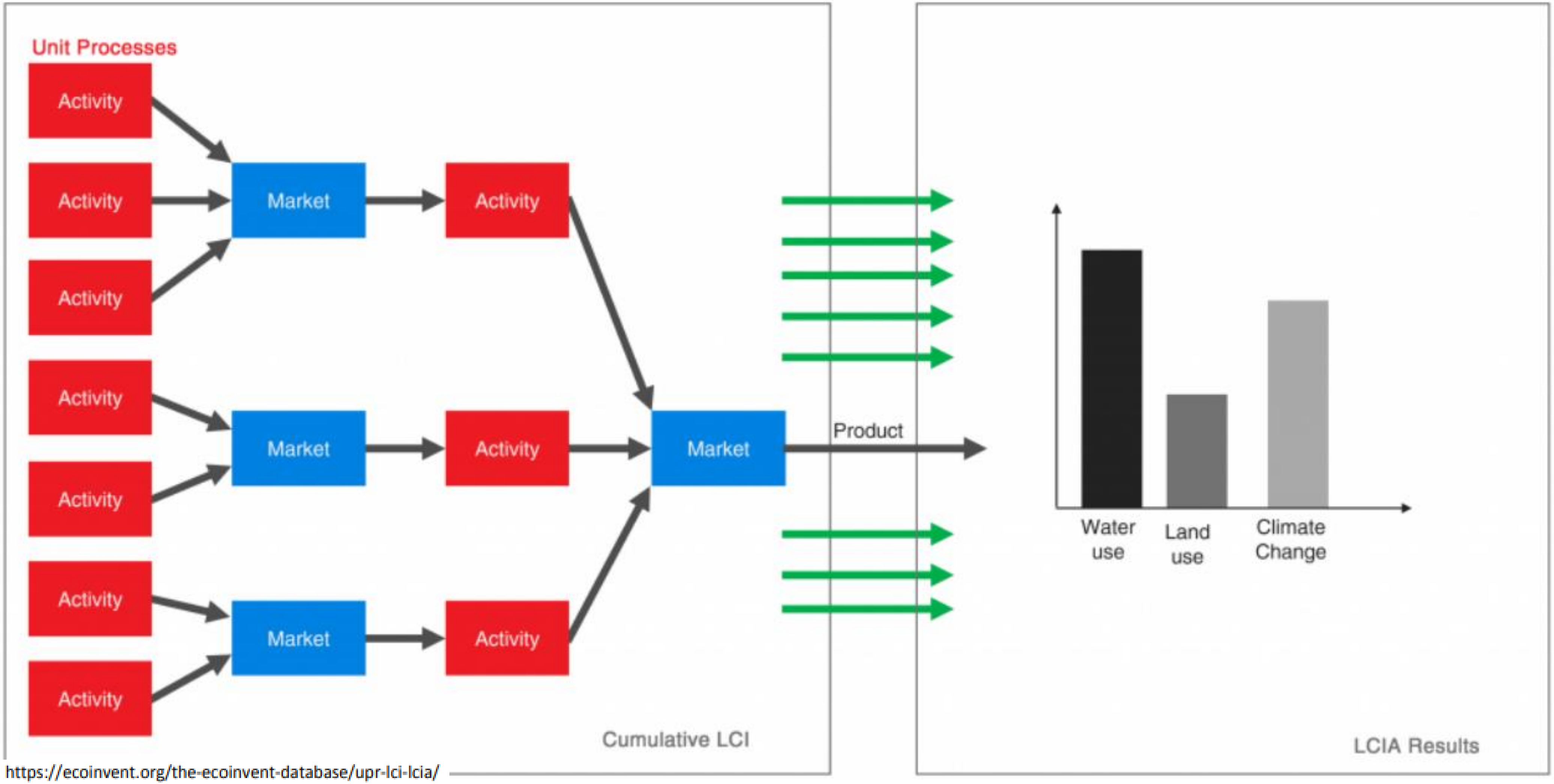


https://ecoinvent.org/the-ecoinvent-database/upr-lci-lcia/

LCA accounting

IMPACT ASSESSMENT

CHARACTERISATION



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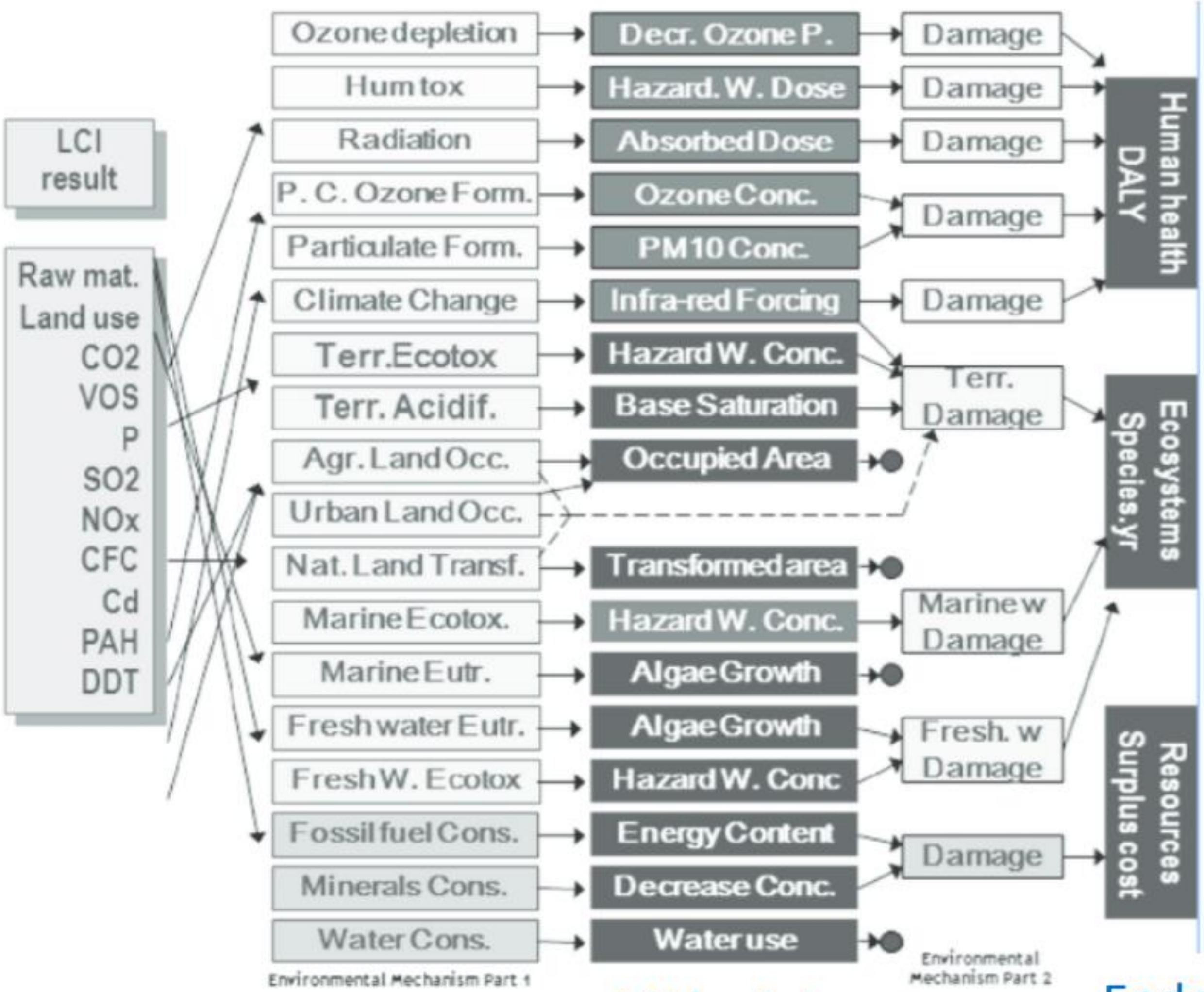
IMPACT ASSESSMENT

LCA accounting

CHARACTERISATION

Endpoints are to understood as issues of environmental concern, like human health, extinction of species, availability of resources for future generation etc.



Midpoint indicators

Endpoint indicators

LCA accounting

CHARACTERISATION

Characterisation

Characterisation refers to the calculation of the magnitude of the contribution of each classified input and output to their respective impact categories, and aggregation of the contributions within each category.
This is carried out by multiplying the inventoried values by the relevant characterisation factor for each impact category considered. The characterisation factors are substance- or resource-specific. They represent the impact intensity of a substance relative to a common reference substance for an impact category (and used to calculate the relative impact category indicator(s)).

For example, when calculating climate change impacts, all the greenhouse gas emissions previously inventoried in the LCI are weighted in terms of their impact intensity relative to carbon dioxide (expressed as kg of CO_2 equivalents).

LCA accounting

IMPACT ASSESSMENT

NORMALISATION

By normalization the indicator results by **dividing the value by a selected reference value**.

There are numerous methods of selecting a reference value, including:

- The **total emissions or resource use** for a given area that may be **global, regional or local**.
- The **total emissions or resource use** for a given area on a **per capita** basis.
- The **ratio of one alternative to another** (i.e., the baseline).
- The **highest value among all options**.

Normalized data can only be compared within an impact category.

For example, the effects of acidification cannot be directly compared with those of aquatic toxicity because the characterization factors were calculated using different scientific methods.

LCA accounting

IMPACT ASSESSMENT

NORMALISATION

Normalisation

Normalisation is the step in which the life cycle impact assessment results are multiplied by normalisation factors to calculate and compare the magnitude of their contributions to the impact categories, relatively to a reference unit. As a result, dimensionless, normalised results are obtained. These reflect the burdens attributable to a product relative to the reference unit. According the ISO 14040 standard, normalization is an optional phase. **Within the PEF / OEF methods** (Product Environmental Footprint and Organisation Environmental Footprint *methods*), **the normalisation phase is mandatory.**

In the PEF (Product Environmental Footprint) the normalization factors are expressed as impact per capita, based on a global value. For example, the factor for climate change is $8.1 \cdot 10^3$ kg CO_2eq./person.

LCA accounting

IMPACT ASSESSMENT

NORMALISATION

Weighting

Weighting supports the interpretation and communication of the results of the analysis. In this step, normalised results are multiplied by a set of weighting factors (in %) which reflect the perceived relative importance of the life cycle impact categories considered. Weighted results of different impact categories may then be compared to assess their relative importance. They may also be aggregated across life cycle impact categories to obtain a single overall score. **According the ISO 14040 standard, weighting is an also optional phase. Within the PEF / OEF methods, the weighting phase is mandatory.**

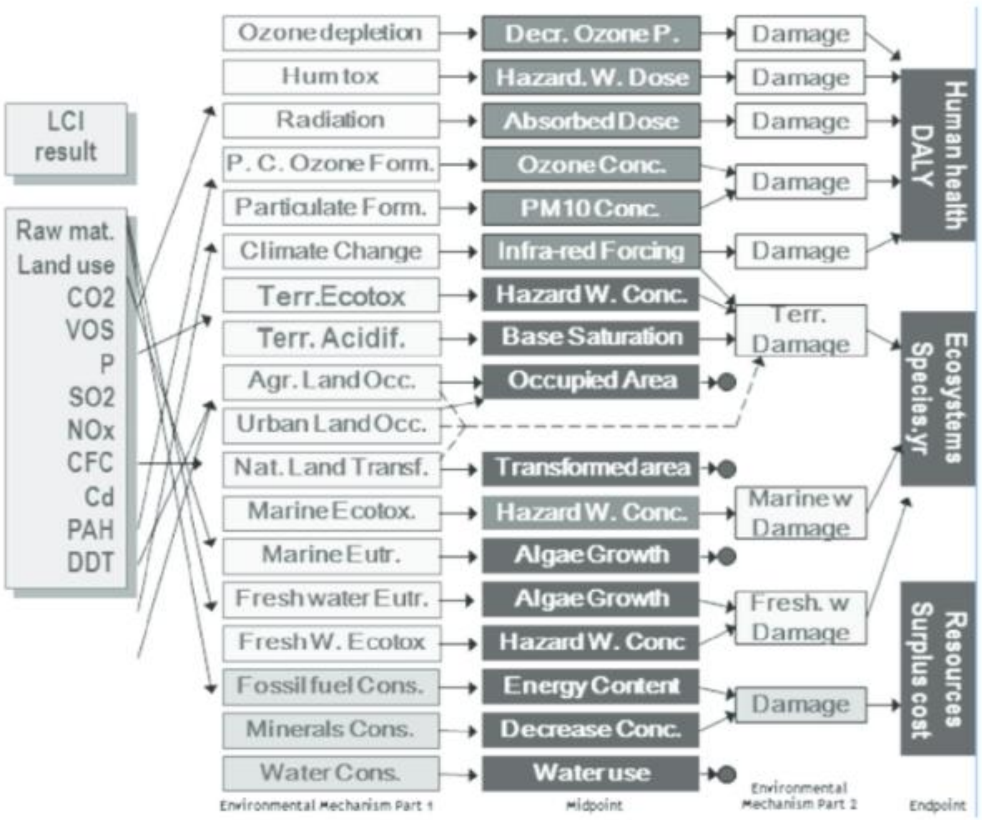
For example, the weighting factor in the PEF for climate change is about 21%, representing the relative relevance of this impact compared to the other categories.

LCA accounting

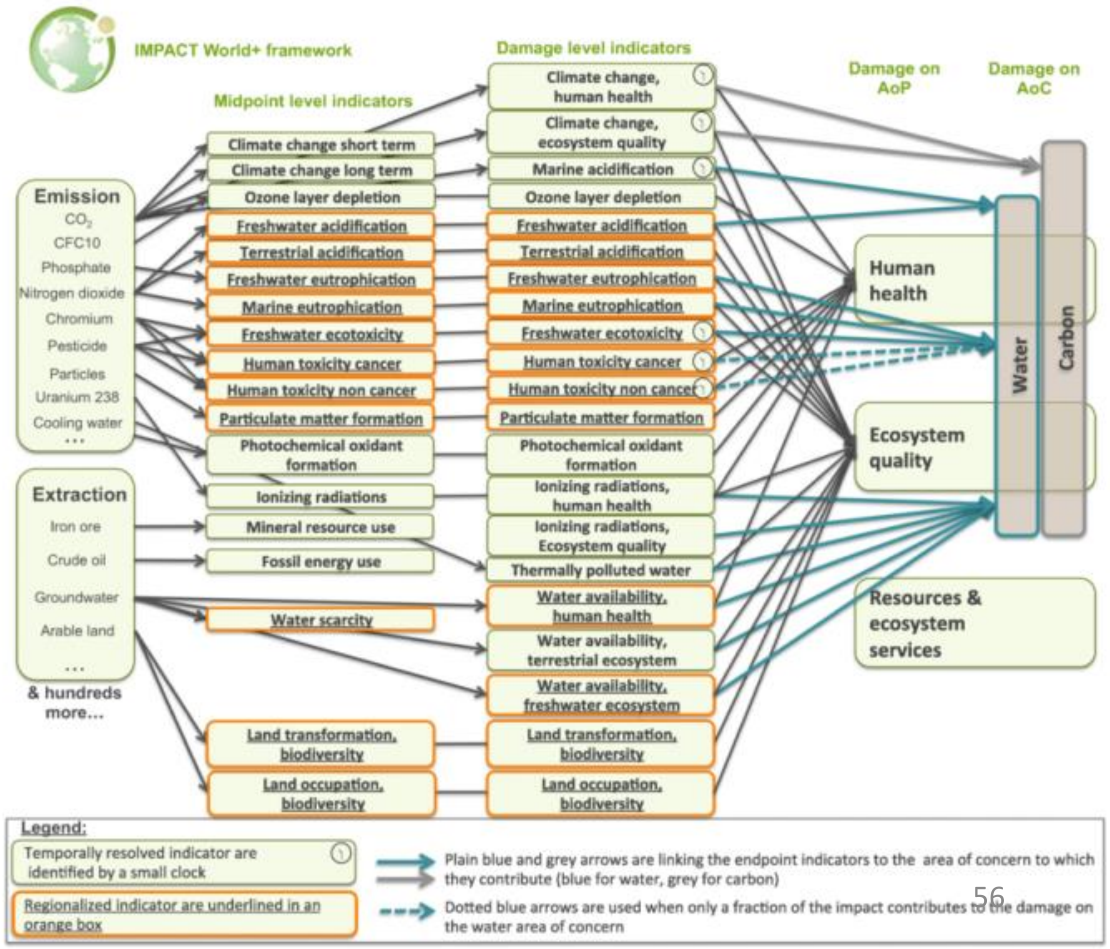
IMPACT ASSESSMENT

The most used LCIA method – ReCIPe but there are others i.e. IMPACTWorld+

ReCiPe (2016)



ImpactWorld+(2020)



LCA accounting

INTERPRETATION
What does the environmental impact results mean?

The **International Organization for Standardization** (ISO) has defined the following **two objects** of life cycle interpretation:

1) **Analyze results, reach conclusions, explain limitations and provide recommendations** based on the findings of the preceding phases of the LCA and to report the results of the life cycle interpretation in a transparent manner;
2) **Provide a readily understandable, complete, and consistent presentation of the results** of an LCA study, in accordance with the goal and scope of the study (ISO 1998b)

LCA accounting

INTERPRETATION

The steps to conducting a life cycle interpretation are identified and discussed:

1) Identify significant issues:
   - The **contribution of the life cycle stages** or groups of processes are compared **to the total** result and examined for relevance;
   - Based on previous experience**, unusual or surprising deviations** from expected or normal results are observed and examined for relevance (i.e. Energy use, emissions)
2) Evaluate the Completeness, Sensitivity and Consistency of the Data
   - To ensure that **all relevant information** and data needed for the interpretation are **available and complete**.
   - To evaluate the **reliability of the results** by determining whether the uncertainty in the significant issues identified affect to drawn comparative conclusions
   - Determine whether the **assumptions, methods and data** used throughout the LCA process are **consistent with the goal and scope of the study**, and for each product/process evaluated.
3) Draw Conclusions and Recommendations

Conclusion

Life Cycle Assessment (LCA) aims at **evaluating a product system or service through all stages of its life cycle**.

The most common applications are to:

- Identify improvements through the LC
- Inform decision makers (priority setting, redesing)
- Select relevant indicators
- Marketing (for environmental claims, environmental product declarations)

Life cycle assessment Framework

LCA accounting has the following steps: