

# Lecture 07

## Life-cycle assessment



CIVIL-239: Engineering a  
sustainable built  
environment  
Andrew Sonta

# Housekeeping

- Assignment 4 out today; due in 3 weeks
- Exam grades to be released next week

# Outline

- Introduction to environmental LCA
  - Standards and definitions
- Understand key steps of LCA
  - Defining purpose
  - Functional units
  - System boundaries
  - Interpretation
  - Dealing with uncertainty
- Process-based LCA vs EIO-LCA
- Attributional vs consequential LCA
- Understand how LCAs can be used to drive decision-making
- Be able to critique LCAs

## Materials, structures, and life-cycle assessment

9	5-Nov	Life-cycle assessment	Environmental LCA
10	12-Nov	<b>Guest lecture:</b> Embodied carbon emissions and materials	The phases of infrastructure life cycles

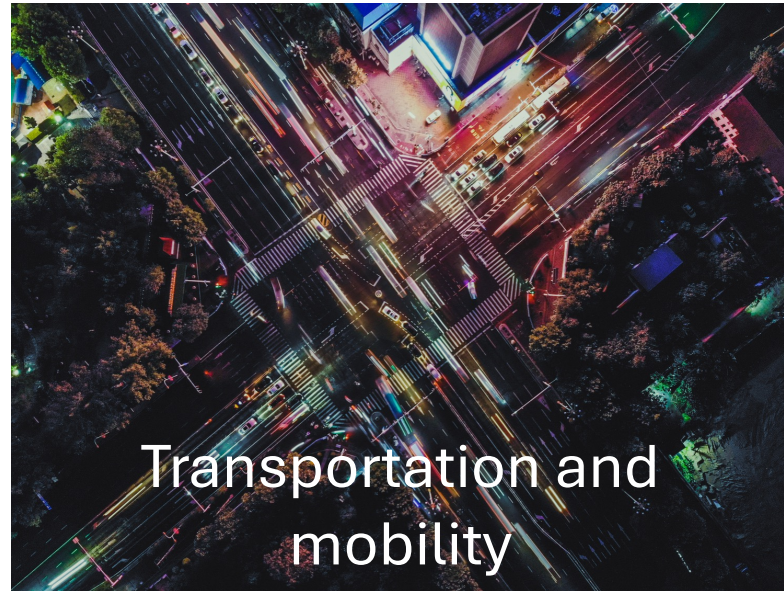
## Civil engineering and natural systems

11	19-Nov	Engineering with natural systems; geotechnical engineering, water resources engineering	Multi-criteria decision-making, resilience, sensitivity analysis, nature-based solutions	
12	26-Nov	<b>Guest lecture:</b> Assigning value to natural systems	Sustainability in natural systems; Engineering and sustainability valuation/economics	Assignment 4

## Sustainability in the civil engineering profession

13	3-Dec	Safety and reliability in civil engineering	Load combinations, safety and reliability, safety factors	
14	10-Dec	<b>Guest lecture:</b> Sustainable engineering in the industry	Practical issues	
15	17-Dec	Course wrap up Class debate		Assignment 5

# Subdisciplines of civil engineering



# Which building material is greener?



Timber



Steel



Adobe



Concrete

# How sustainable is biogas?



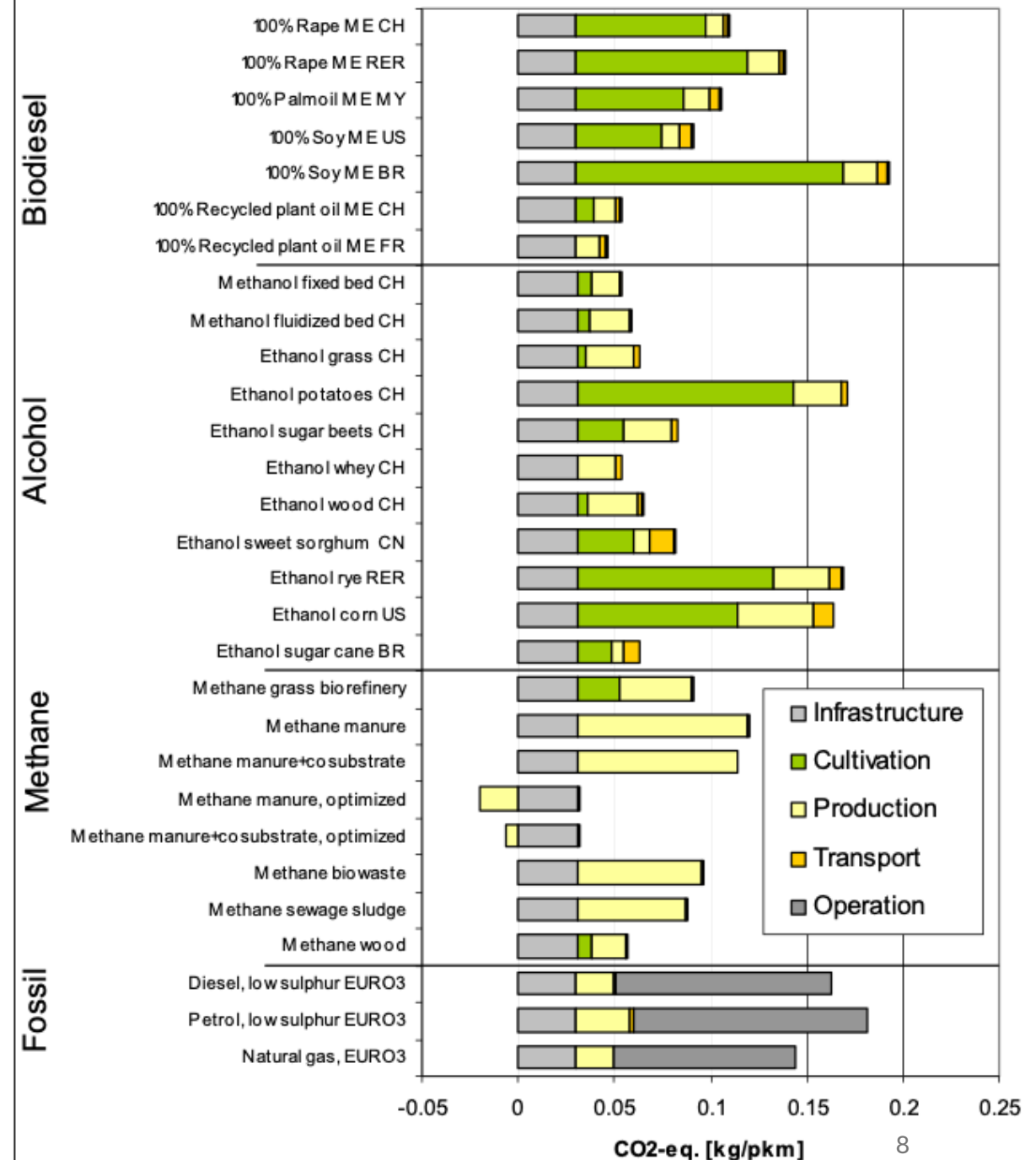
Biogas



Petroleum

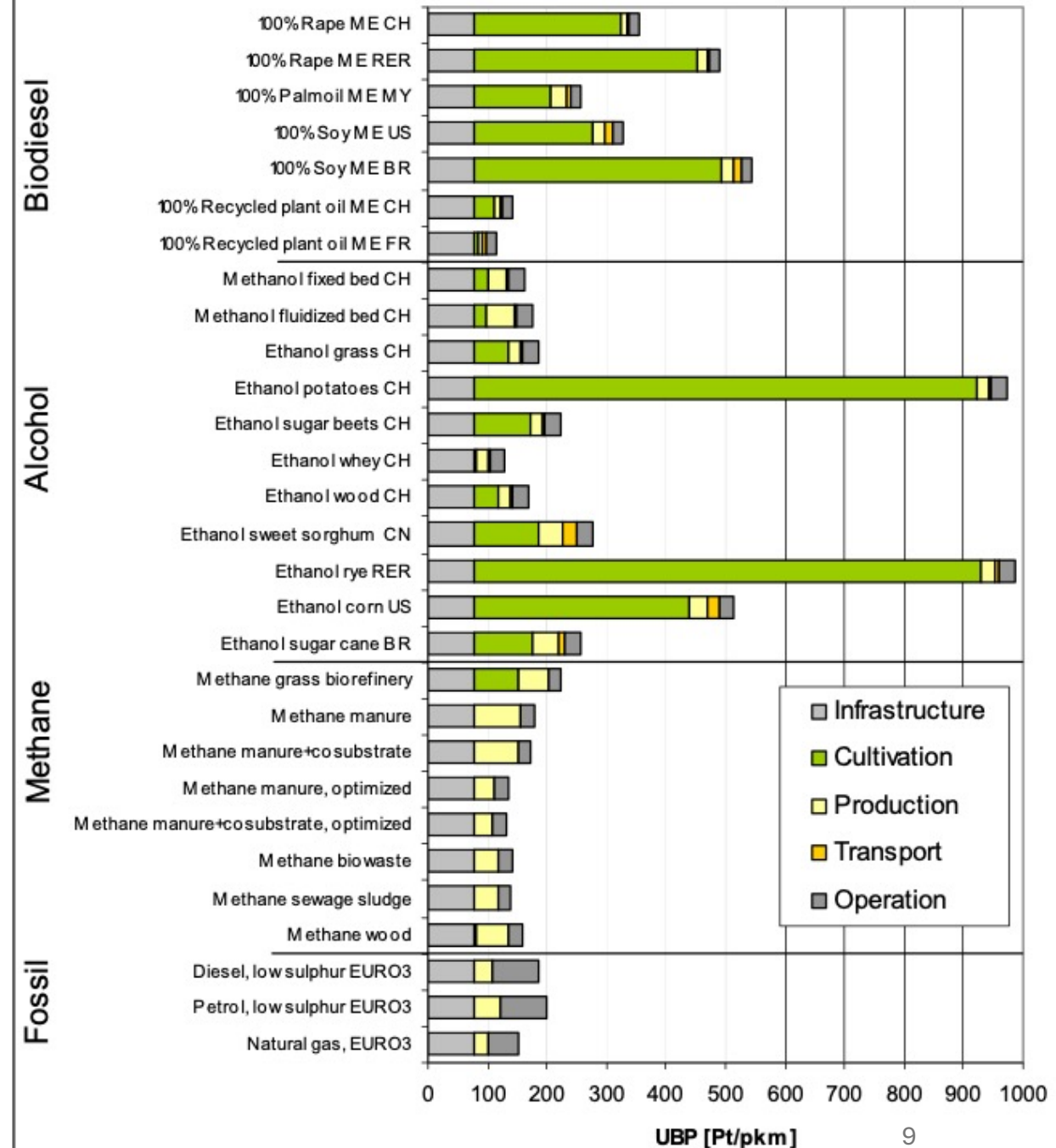
# LCA of biofuels vs. fossil fuels

- Greenhouse gas emissions
  - Up to 80% savings are possible
  - Large variation
  - Significant GHG emissions from cultivation
    - Machines
    - Fertilizer and pesticides
    - Direct emissions (e.g. nitrous oxides)
  - No emissions during operation stage (all released CO<sub>2</sub> was absorbed during plant growth)

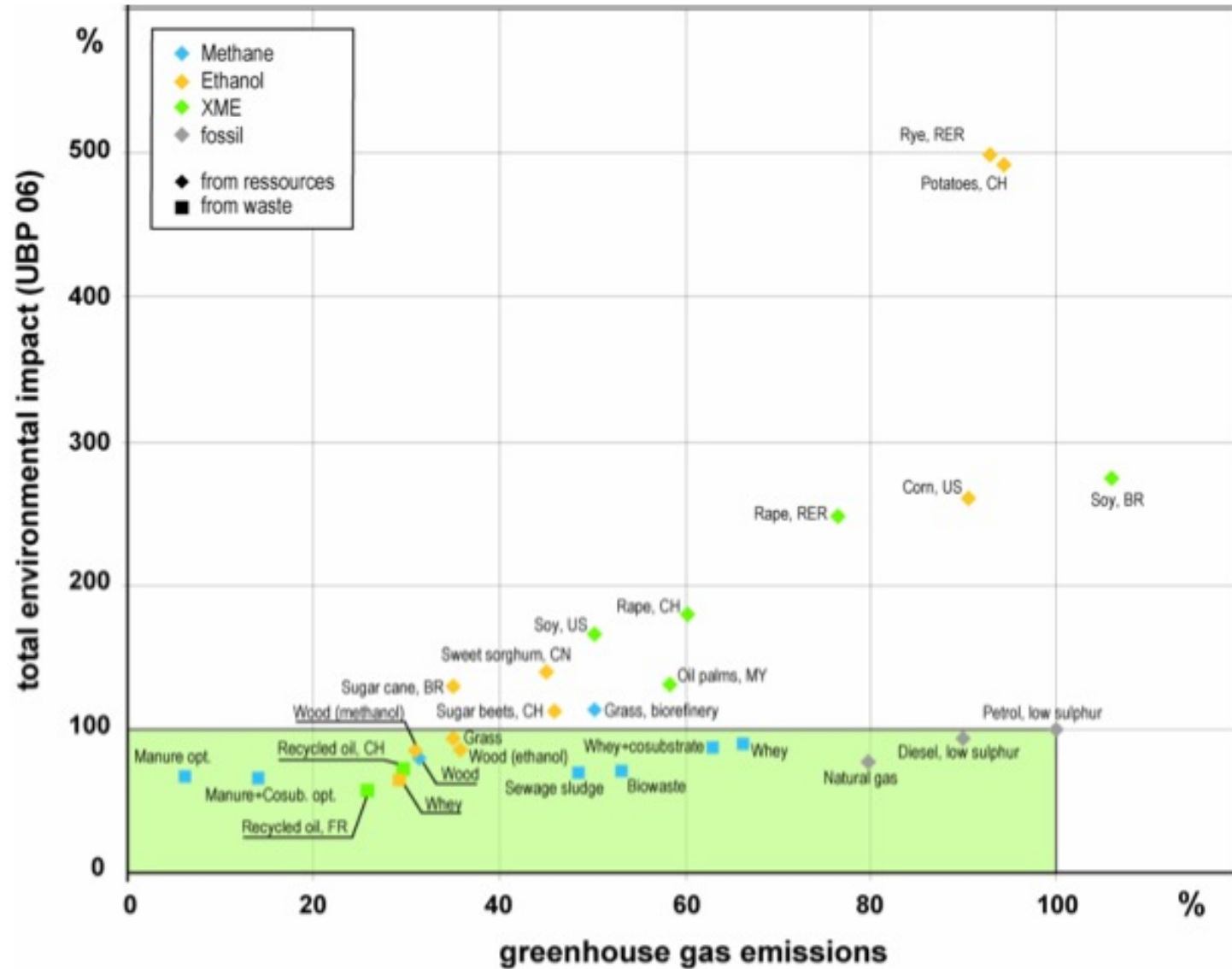


# LCA of biofuels vs. fossil fuels

- Aggregated environmental impact
  - Uses method of ecological scarcity (UBP 06) which is a composite indicator
  - Largest impacts in Switzerland are from soil acidification and excessive fertilizer use



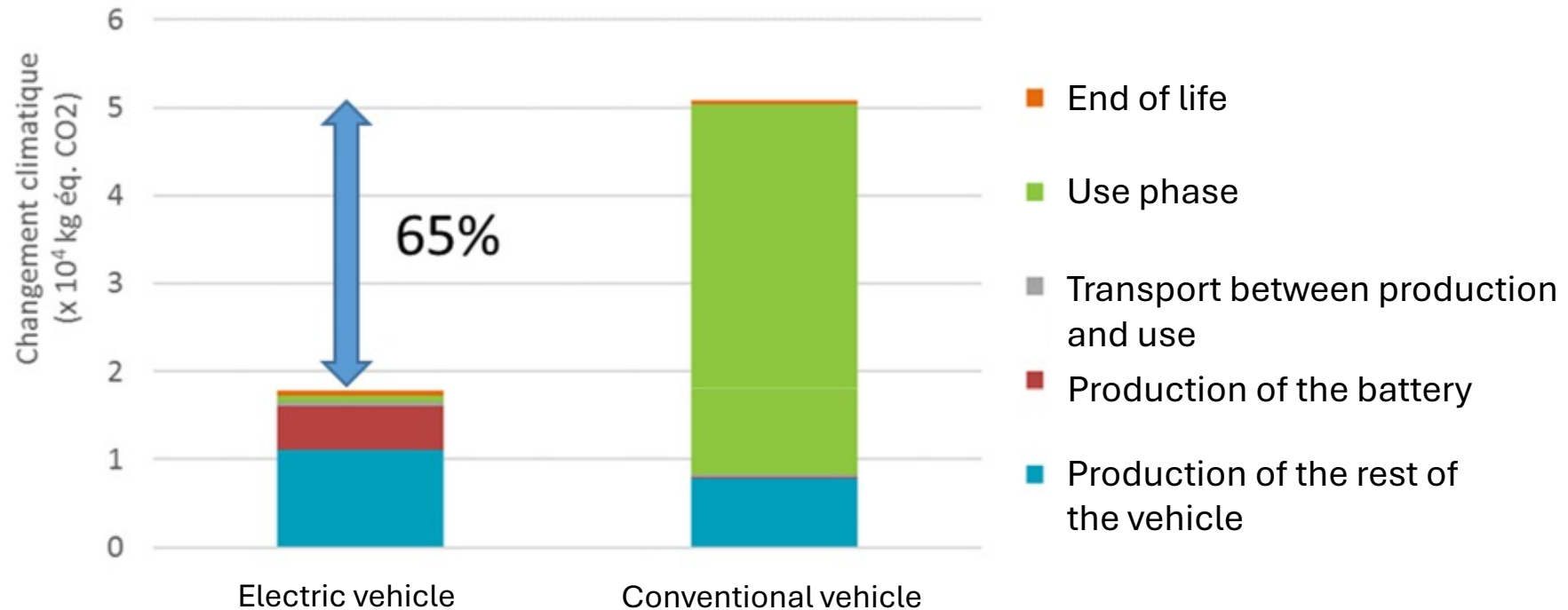
# LCA of biofuels vs. fossil fuels



# Electric vehicles vs. internal combustion engine vehicles (ICE)



# Electric vehicles vs. internal combustion engine vehicles (ICE) – Montreal case study





**VS.**







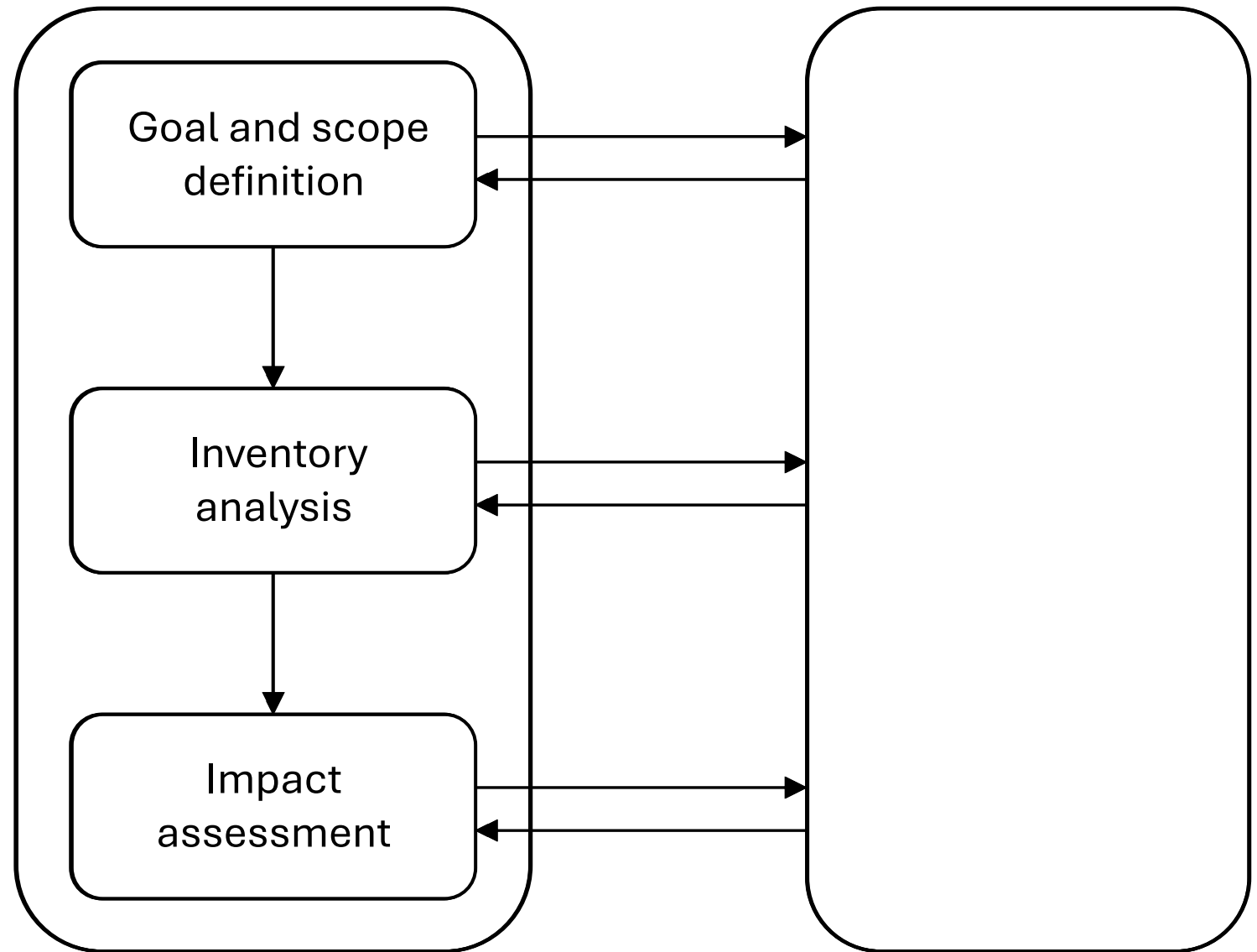
# LCA Definition

- LCA is a technique for assessing the **environmental aspects and potential impacts** associated with a product, by
  - compiling an **inventory** of relevant inputs and outputs of a product system
  - **evaluating** the potential environmental impacts associated with those inputs and outputs
  - **interpreting** the results of the inventory analysis and impact assessment phases in relation to the objectives of the study
- [International Organization for Standardization (ISO) 14040]

# Common LCA Applications

- Product or process development and improvement
- Strategic planning
- Public policy
- “Eco-marketing”

# LCA Framework



**goal  
and  
scope**

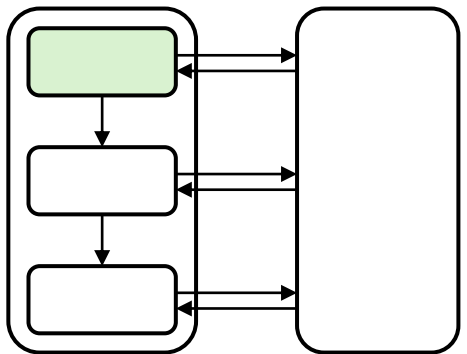


Intended application

Purpose

Intended audience

Whether the results will be used for  
comparative assertions



VS.



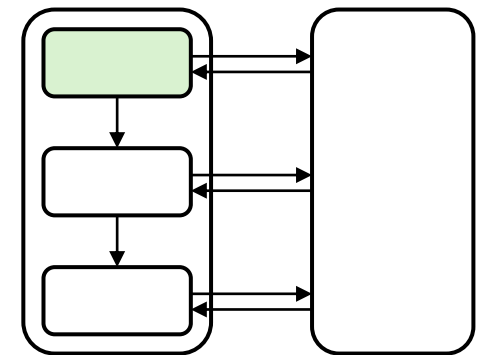
goal  
and  
**scope**

Product or service

Function and functional unit

System boundaries

Data requirements / assumptions /  
limitations



# goal and scope

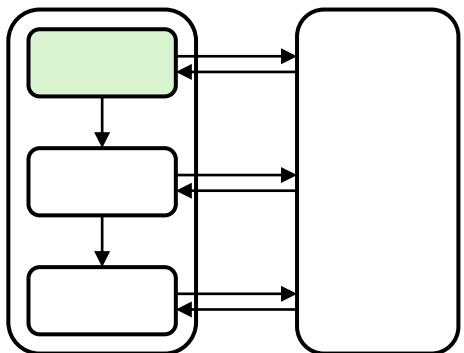
## Function and functional unit

### Function

- Service provided by system
- Performance characteristics

### Functional unit

- Means for quantifying the product function
- Basis for the LCA
- Same across all scenarios



goal  
and  
**scope**

# Function and functional unit



vs.

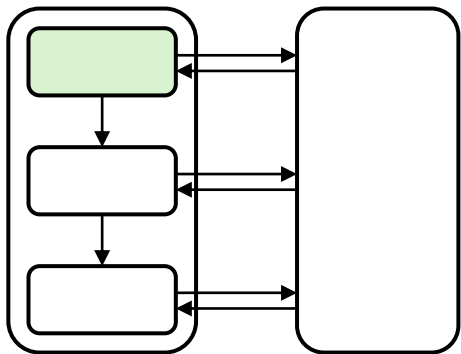


Function

Drying hands

Functional  
unit

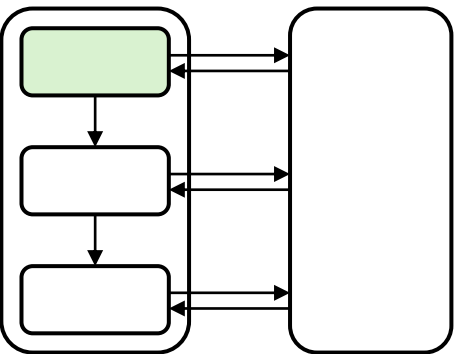
One pair of hands dried  
through each system



# goal and scope

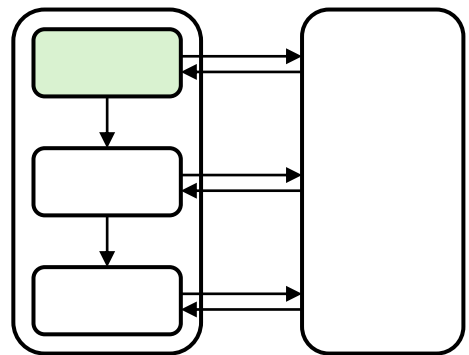
## Function and functional unit

- The functional unit should answer the following questions:
  - What?
  - How much?
  - For how long / how many times?
  - Where?
  - When?
  - With what quality?
- Example: Commute transportation for one person in Lausanne over 5km for one year in 2024

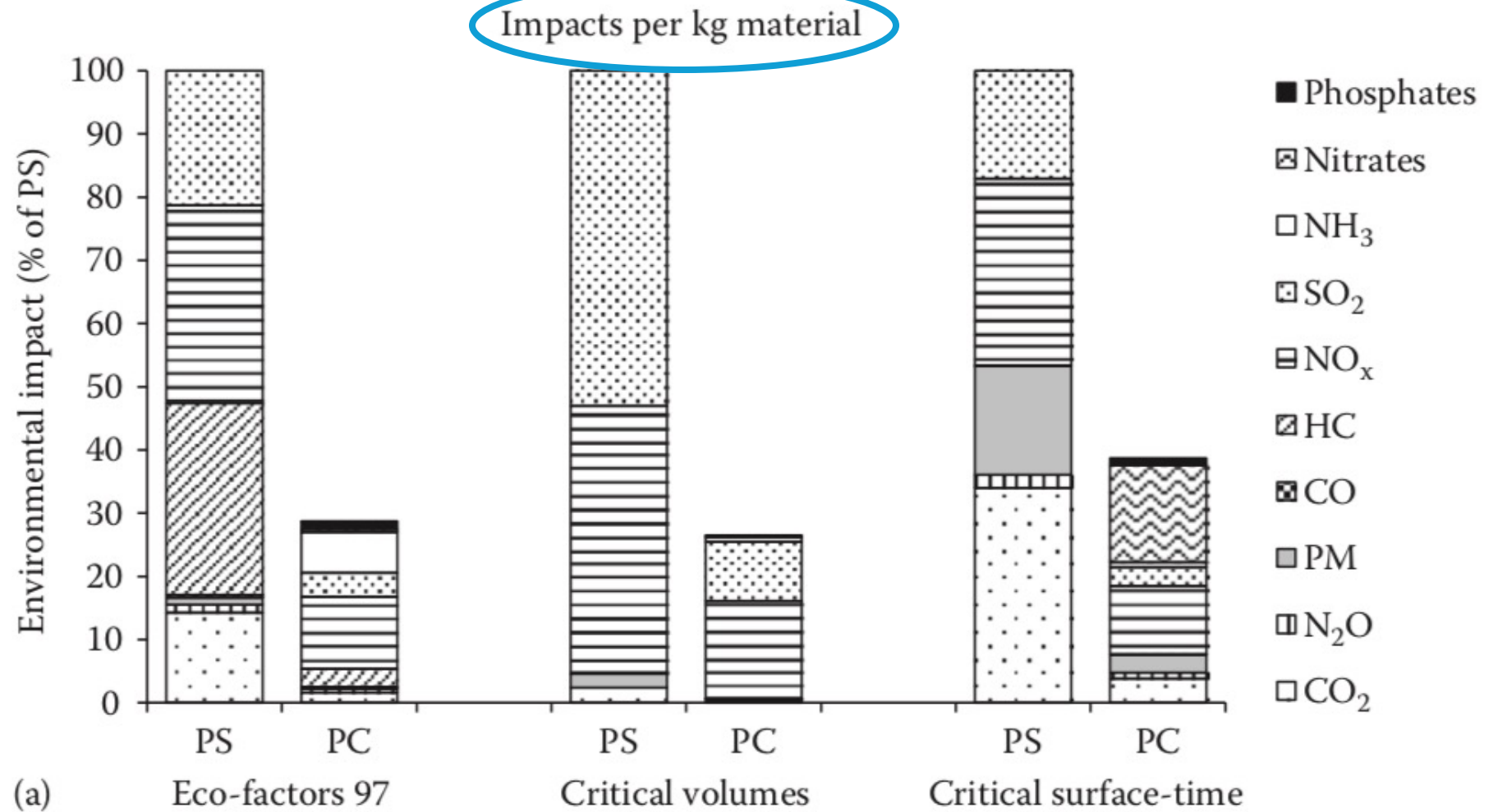


# goal and scope

PS: Polystyrene  
PC: Popcorn

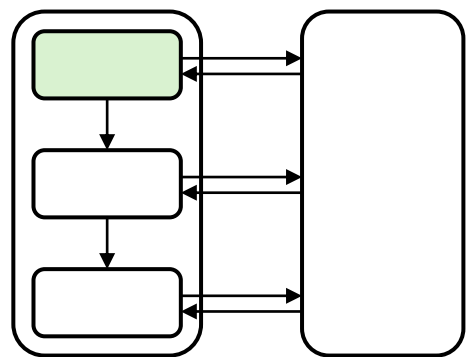


## Polystyrene (PS) vs. Popcorn (PC) for packaging



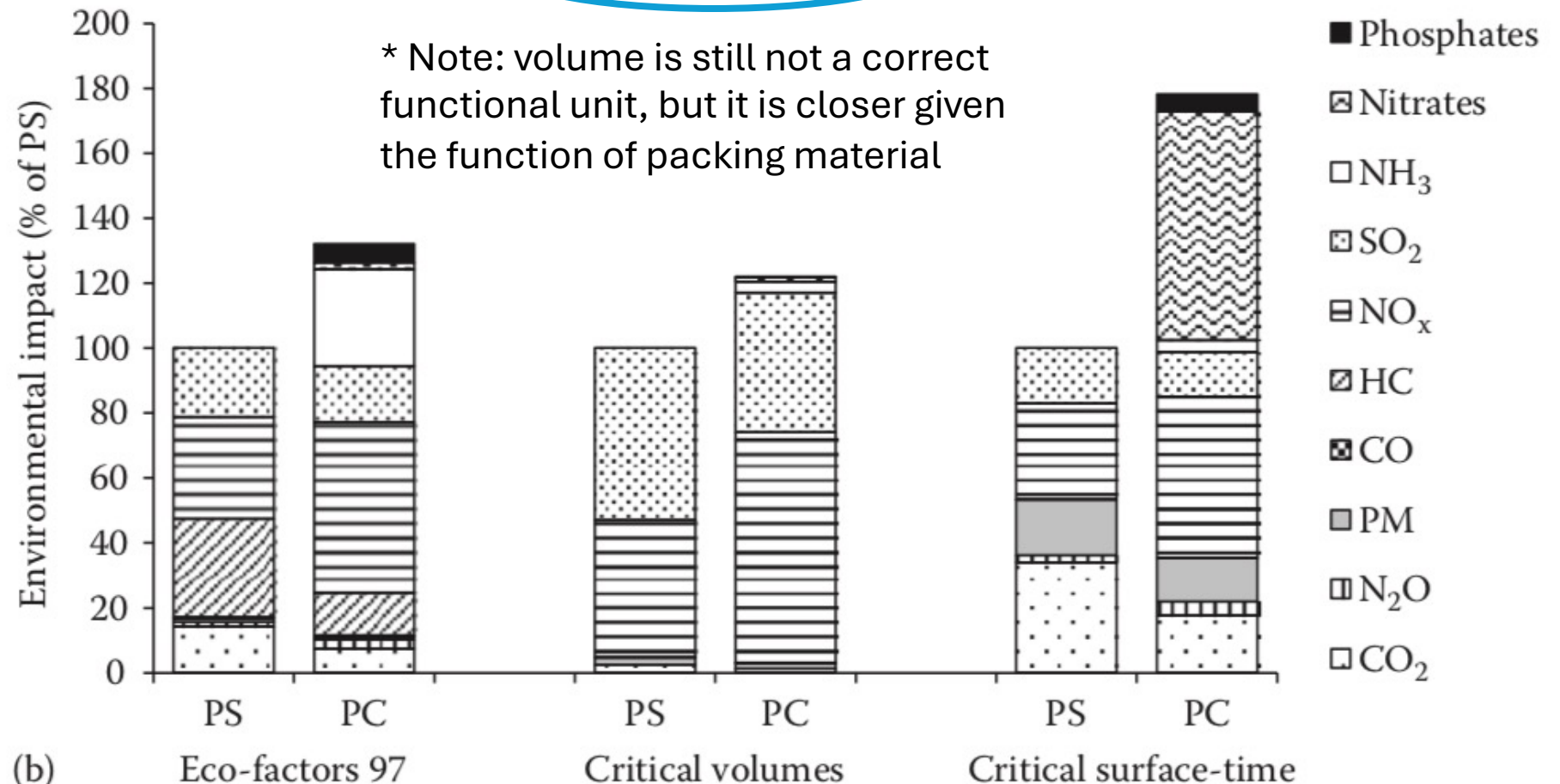
# goal and scope

PS: Polystyrene  
PC: Popcorn



## Polystyrene (PS) vs. Popcorn (PC) for packaging

Impacts per m<sup>3</sup> material



(b)

Eco-factors 97

Critical volumes

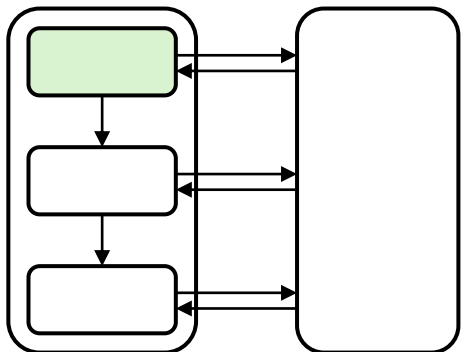
Critical surface-time

# Functional unit exercise

goal  
and  
**scope**

PS: Polystyrene  
PC: Popcorn

- What would be an appropriate function unit of a structural column?



# goal and scope

## Reference flows

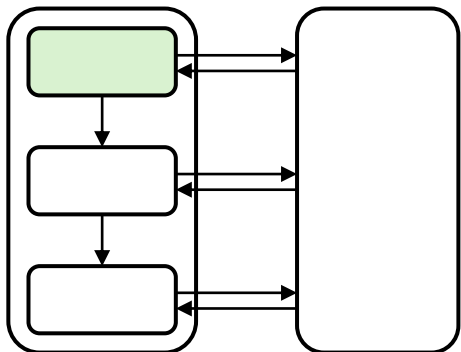
- Quantified amount of product(s) necessary for a specific system to deliver the performance required by the functional unit

- Expressed in:

*Quantity of a product*

*Functional unit*

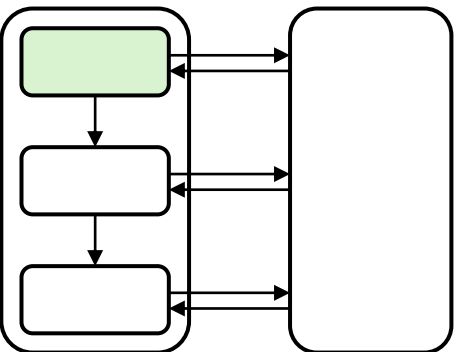
- Can have multiple reference flows for a given FU
- When comparing two things, products and their reference flows can be different, but the FU needs to be the same



# goal and scope

## Reference flows: Example

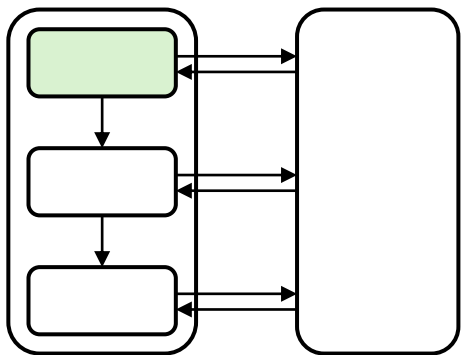
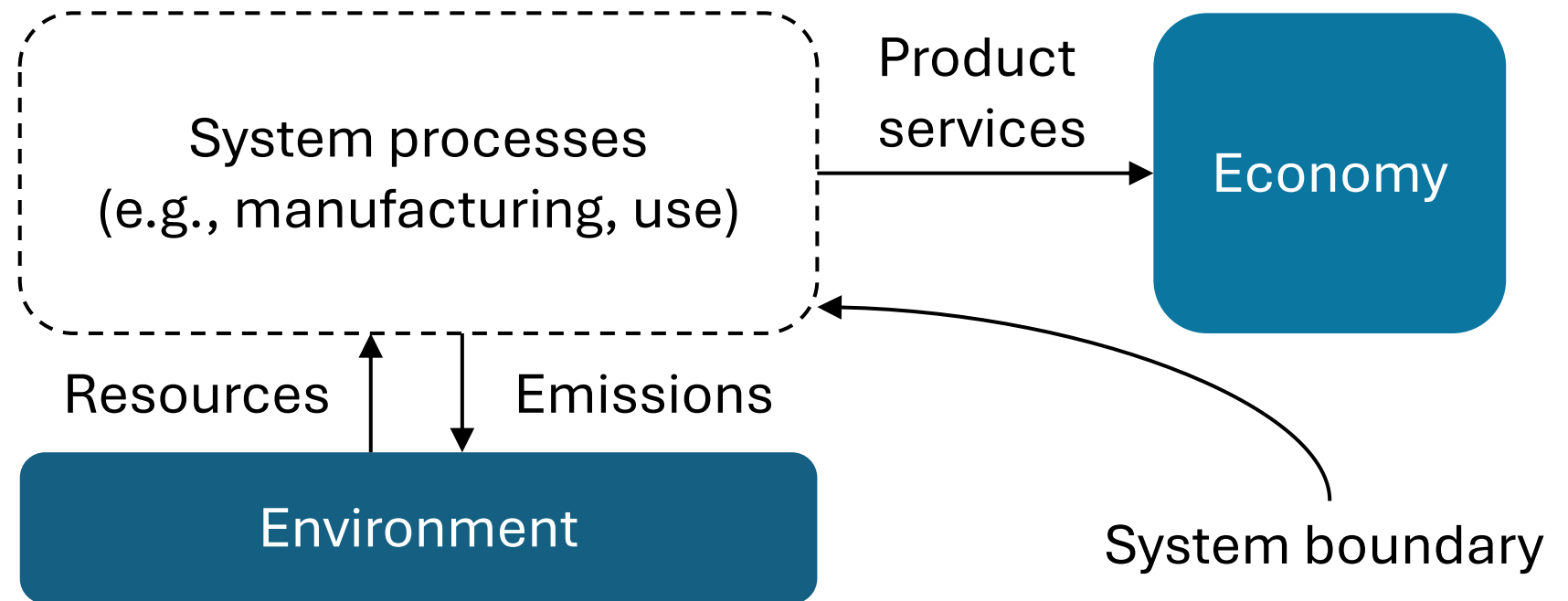
- Functional unit: Serve 3dl of coffee once per day for one year
  - Option A: Disposable cups
  - Option B: Reusable cup
- Key parameters:
  - A: 1 serving per cup
  - B: 1,000 servings per cup, 1 wash per cup
- Reference flows:
  - A:  $RF_{\text{cup}} = 365$  cups (cardboard);  $RF_{\text{disposal}} = 365$  disposals (cardboard)
  - B:  $RF_{\text{cup}} = 0.365$  cups (ceramic);  $RF_{\text{disposal}} = 0.365$  disposals (ceramic);  $RF_{\text{wash}} = 365$  washes



goal  
and  
**scope**

# System boundaries

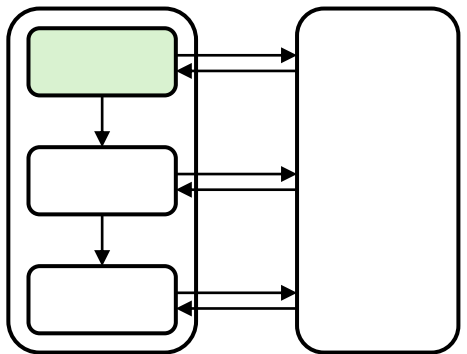
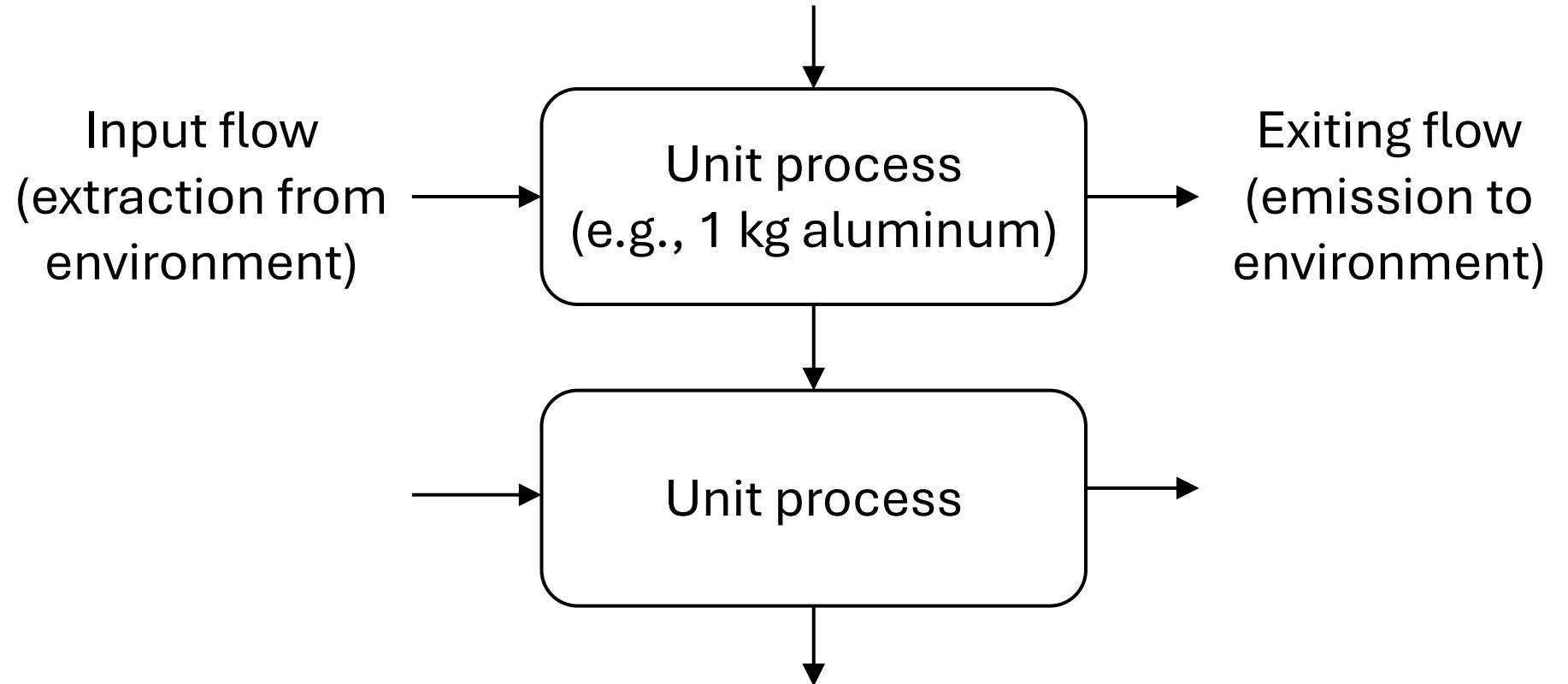
A “complete” LCA



# System boundaries

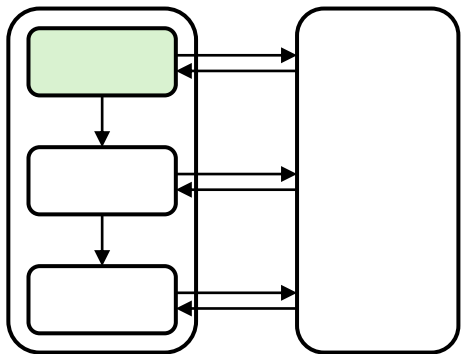
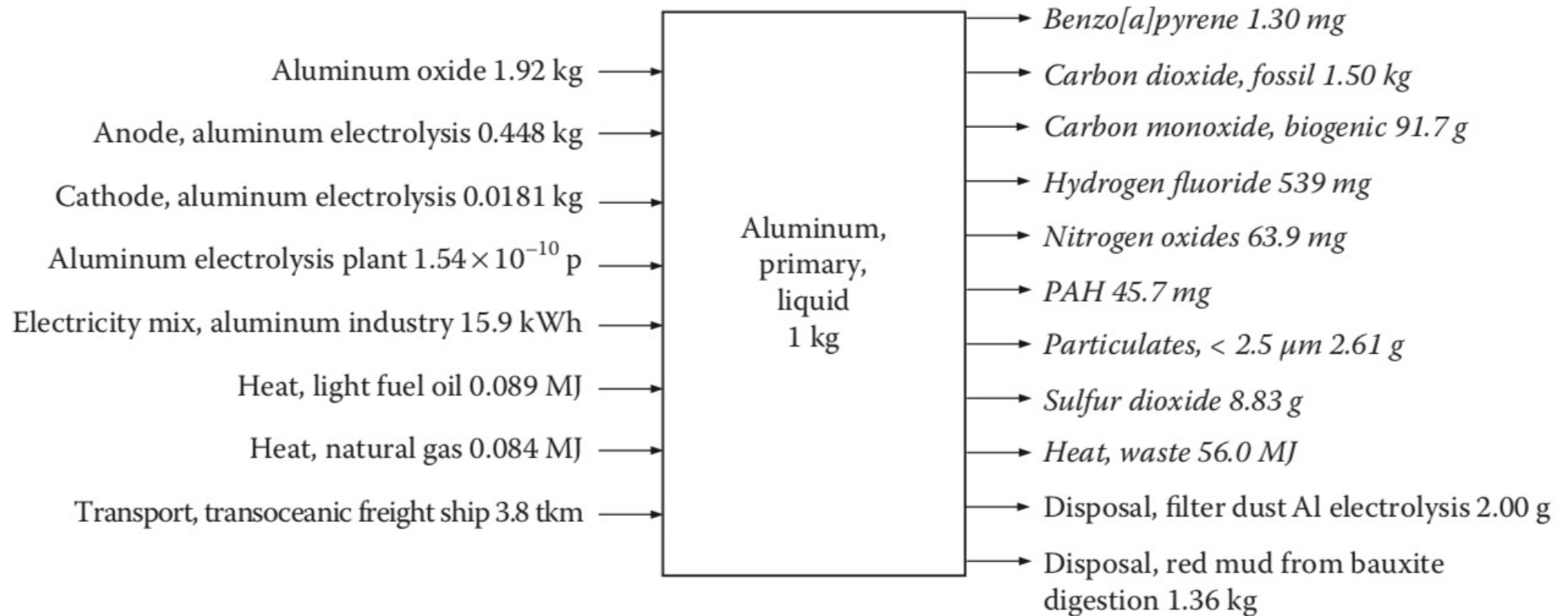
goal  
and  
**scope**

Unit processes (within boundary)



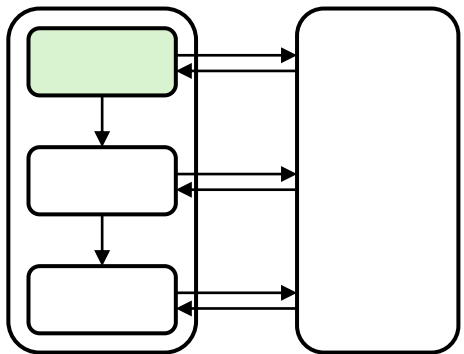
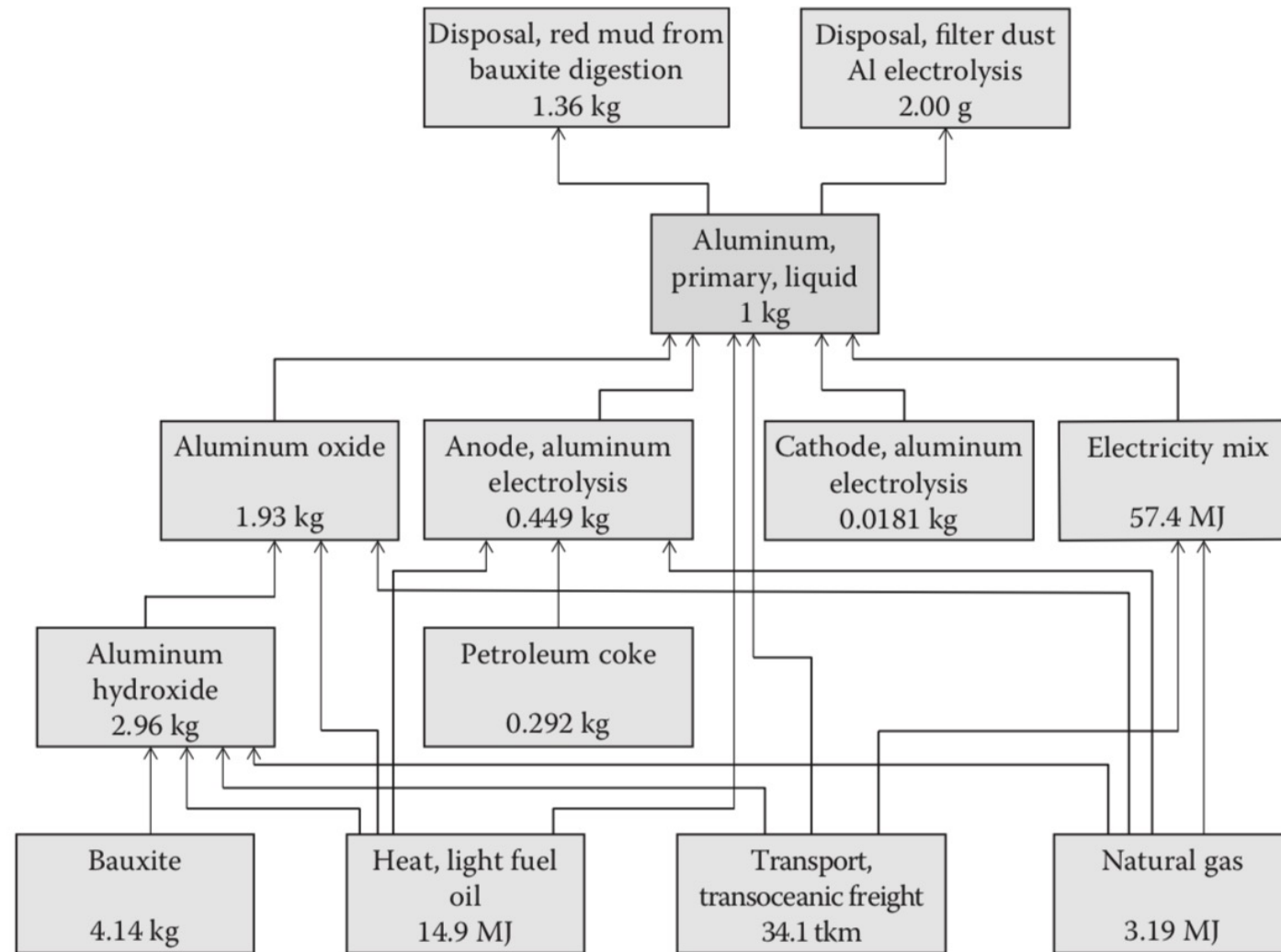
# goal and scope

## System boundaries



goal  
and  
**scope**

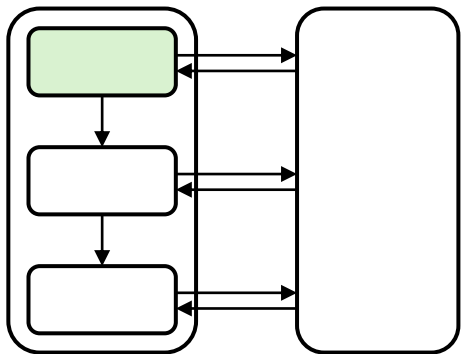
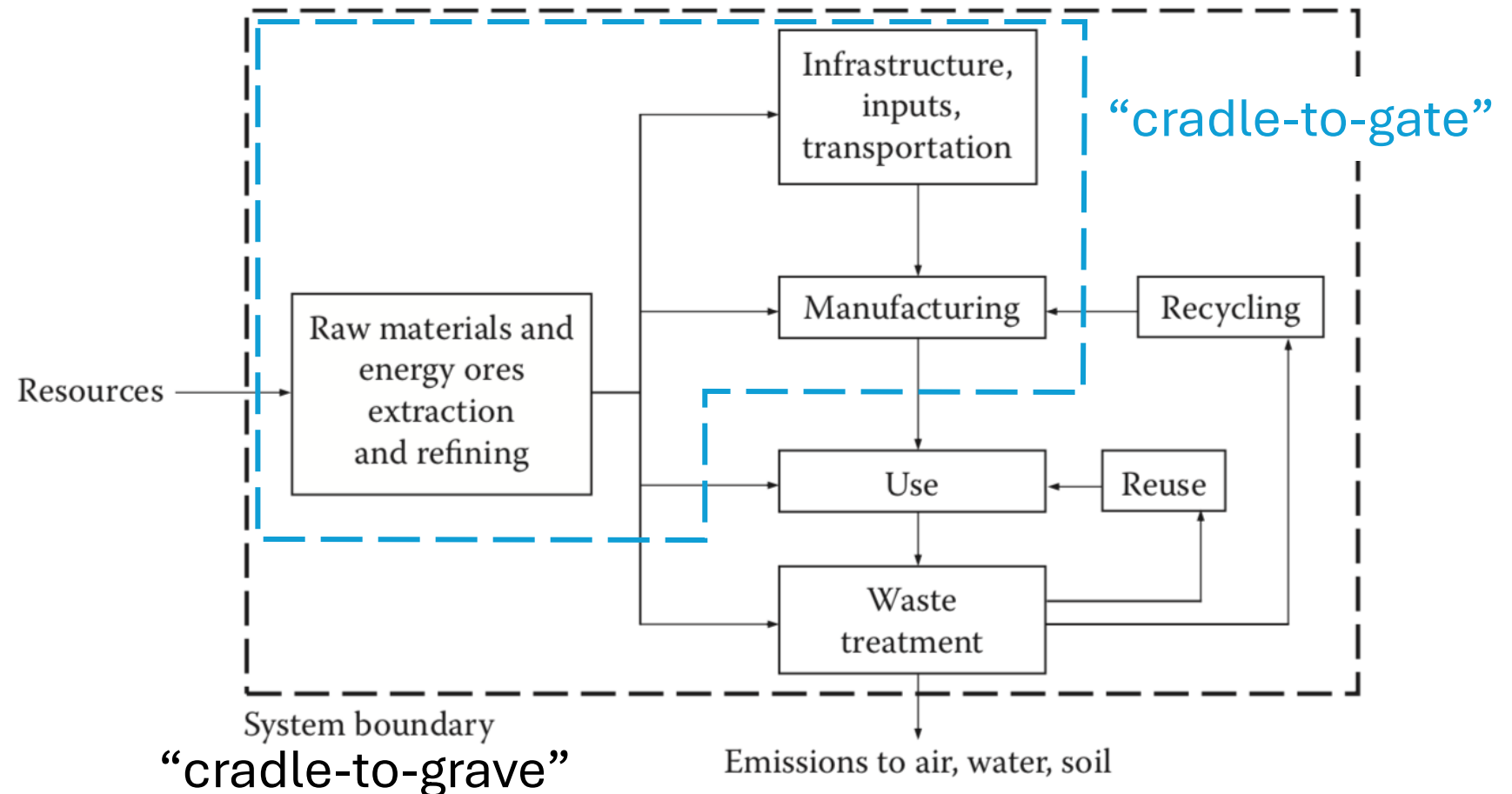
# System boundaries



goal  
and  
**scope**

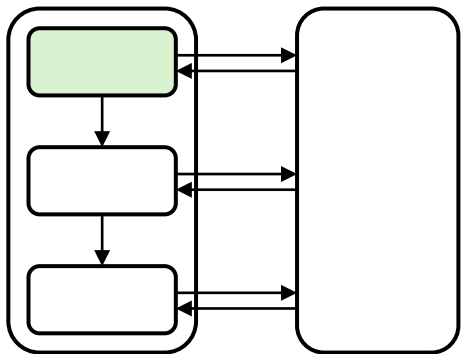
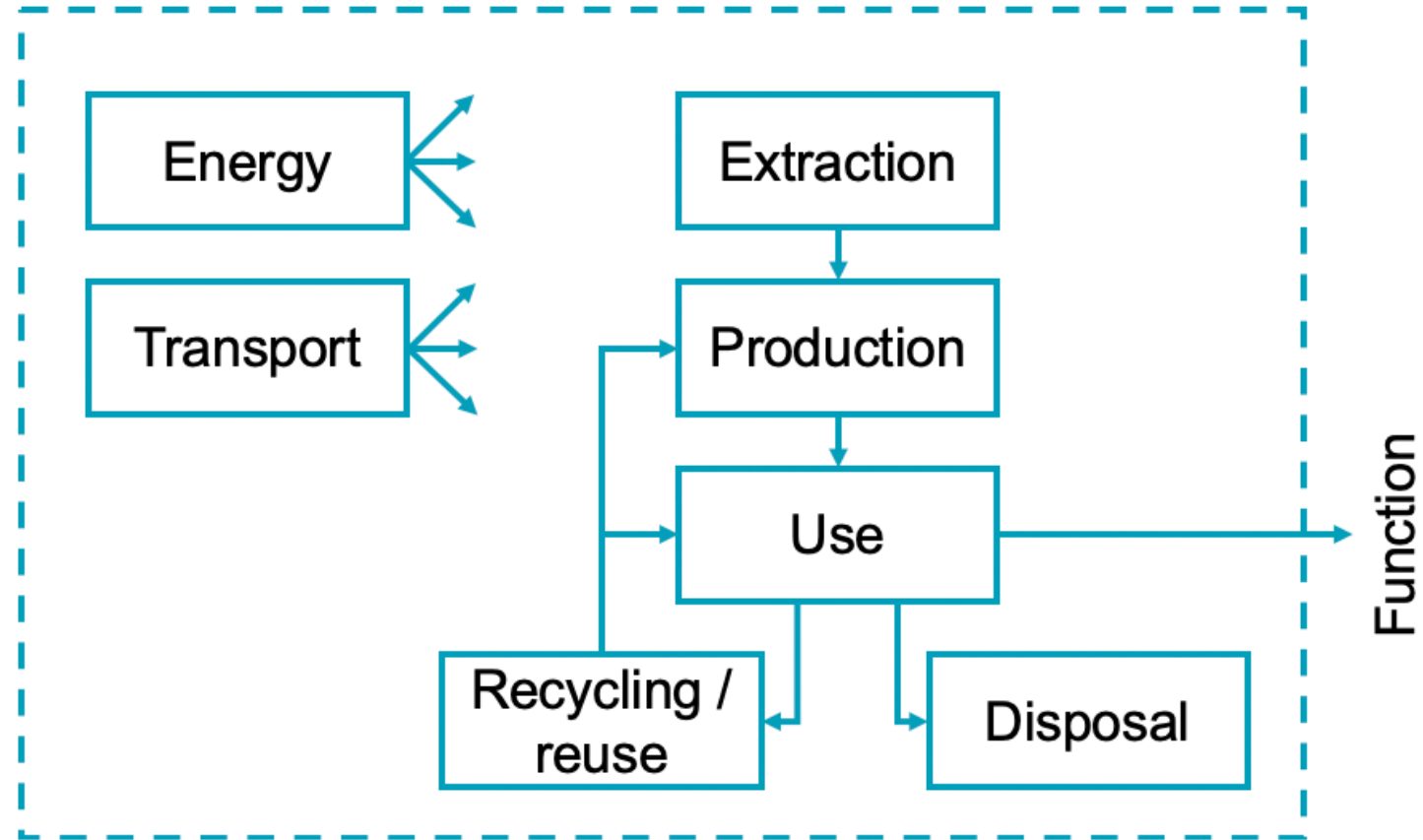
# System boundaries

Main processes to consider



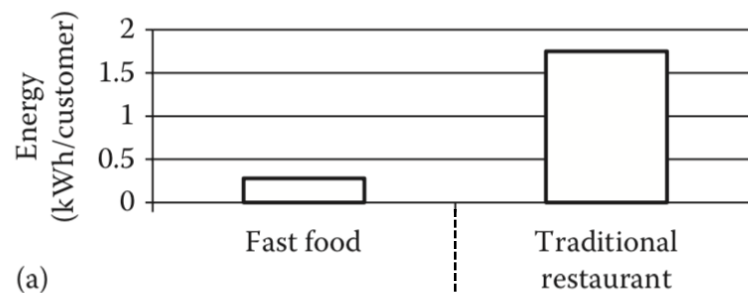
goal  
and  
**scope**

# Another perspective



# goal and scope

## System boundaries



\*items in italics  
**not** included

### Fast-Food Restaurant

*Agricultural production chain*

*Transport*

*Production chain for plastic tableware  
(knives, forks, cups, etc.)*

*Initial preparation and packaging of food  
(preparation of burgers, salads, etc.)*

Final cooking

Cleaning, heating, and lighting of restaurant

*Management of packaging and food waste*

### Traditional Restaurant

*Agricultural production chain (same as fast-food)*

*Transport (same)*

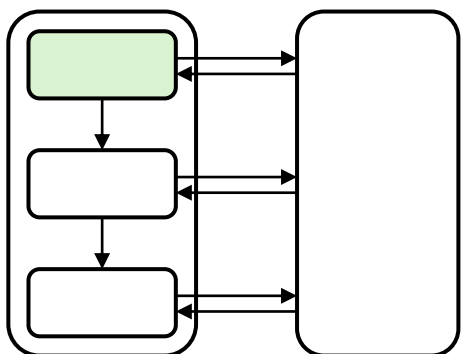
*Production chain for reusable dishes*

Preparation of food and cooking

Cleaning, heating, and lighting of restaurant (same)

Clean reusable dishes

*Management of food and packaging waste*

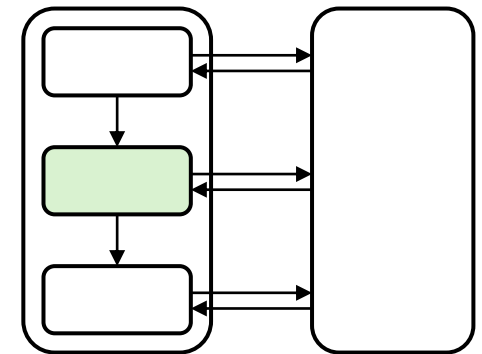


# inventory analysis

## The goal

Quantify the various **flows** (raw materials, energy, products) and **emissions** (air, water, waste) across the system boundary

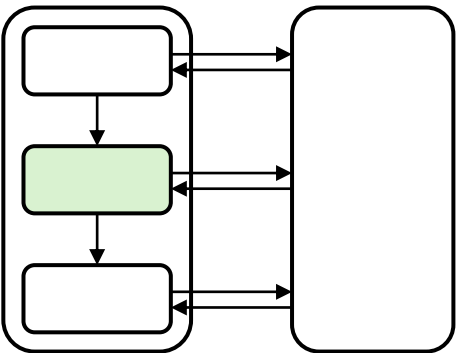
In other words, quantify the total inputs and outputs



inventory  
analysis

# An example

Light bulbs!







# inventory analysis

## Two approaches

### Conventional process- based LCA

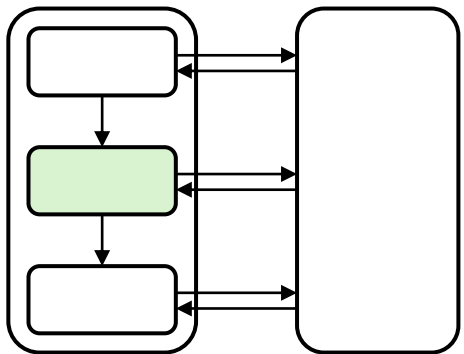
More common approach,  
quantifies every step in the  
identified process

Combination of primary data  
(from manufacturer) and third-  
party software (Ecoinvent,  
SimaPro, GaBi)

### Economic Input-Output LCA (EIO-LCA)

Maps money spent in an entire  
economic sector (e.g., “iron  
ores”) to environmental impact

Carnegie Mellon EIO-LCA tool



# inventory analysis

## Two approaches

### Conventional process- based LCA

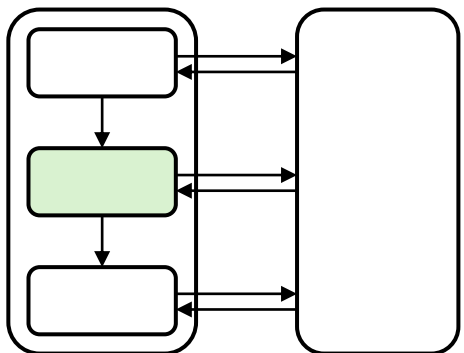
**The good:** compare  
products within sector

**The bad:** data  
completeness, process  
completeness

### Economic Input-Output LCA (EIO-LCA)

**The good:** fast, complete

**The bad:** cannot distinguish  
within-sector



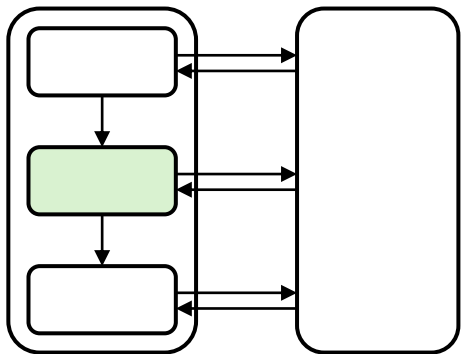
inventory  
analysis

# Two approaches

**Conventional process-  
based LCA**



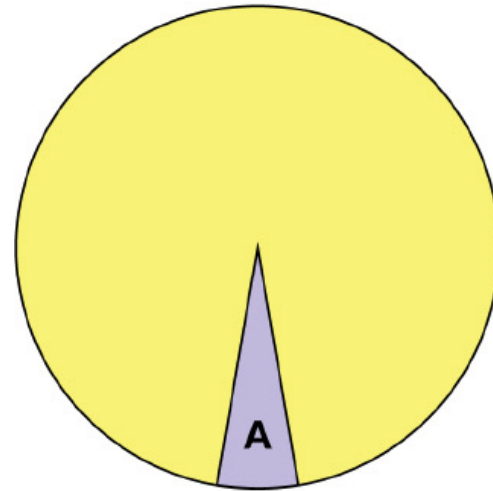
**Economic Input-Output  
LCA (EIO-LCA)**



# inventory analysis

# Attributional vs. Consequential LCA

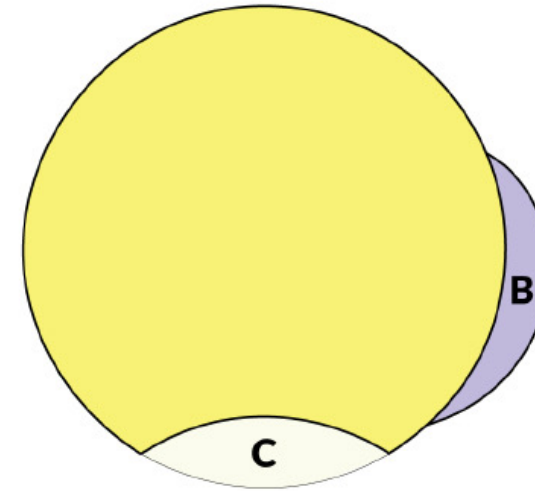
Attributional



Impacts = A

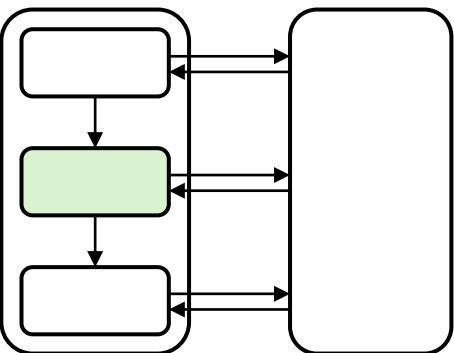
What part of the global environmental burdens should be assigned to the product?

Consequential



Impacts = B - C

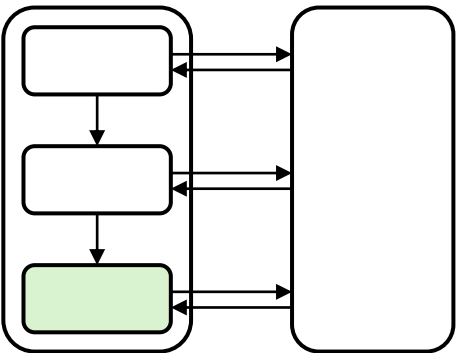
What is the change in global environmental burdens resulting from a change in the use or production of a product?



# impact assessment -ment

## What can we measure?

- Greenhouse gas emissions (CO<sub>2</sub> equivalent)
- Others?

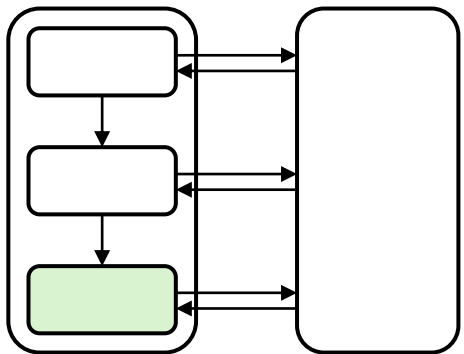


# impact assess -ment

## EPA TRACI

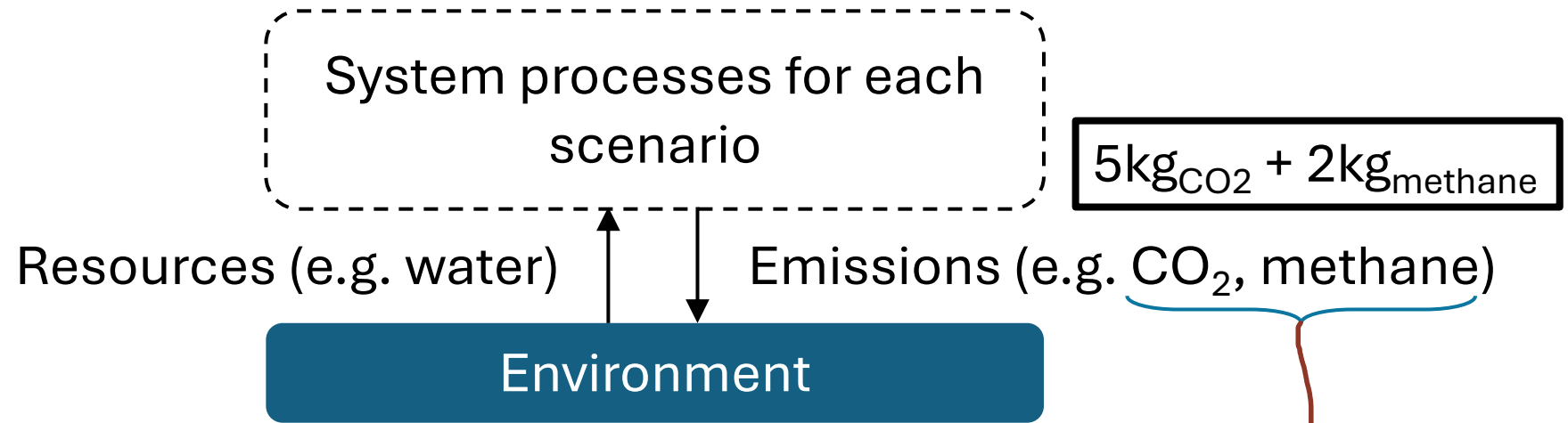
(Tool for the **R**eduction and **A**ssessment of **C**hemical and other environmental **I**mpacts)

- Global warming (CO<sub>2</sub> equivalent)
- Ozone depletion
- Smog formation
- Acidification
- Eutrophication
- Human health (carcinogens)
- Human health (criteria pollutants (SO<sub>x</sub>, NO<sub>x</sub>, etc.))
- Eco-toxicity
- Fossil fuel depletion
- Land use
- Water use



# impact assess -ment

## Methodology



Both contribute to global warming

$$\left. \begin{array}{l} 1\text{kg}_{\text{CO}_2} = 1\text{kg}_{\text{CO}_2\text{-eq}} \\ 1\text{kg}_{\text{methane}} = 25\text{kg}_{\text{CO}_2\text{-eq}} \end{array} \right\} \text{Characterization factors}$$

$$\text{Example: } 5\text{kg}_{\text{CO}_2} + 2\text{kg}_{\text{methane}} \rightarrow 55\text{kg}_{\text{CO}_2\text{-eq}}$$

(Midpoint score)

# impact assess -ment

## Methodology

Example:  $5\text{kg}_{\text{CO}_2} + 2\text{kg}_{\text{methane}} \rightarrow 55\text{kg}_{\text{CO}_2\text{-eq}}$  (Midpoint score)

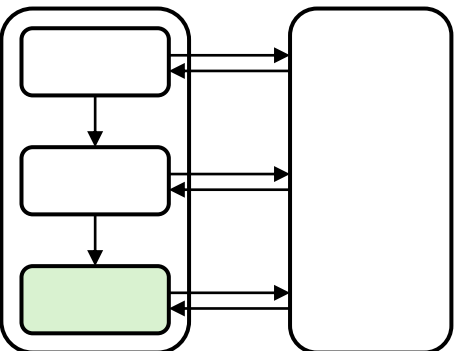
What does global warming cause?

Example: **human health**

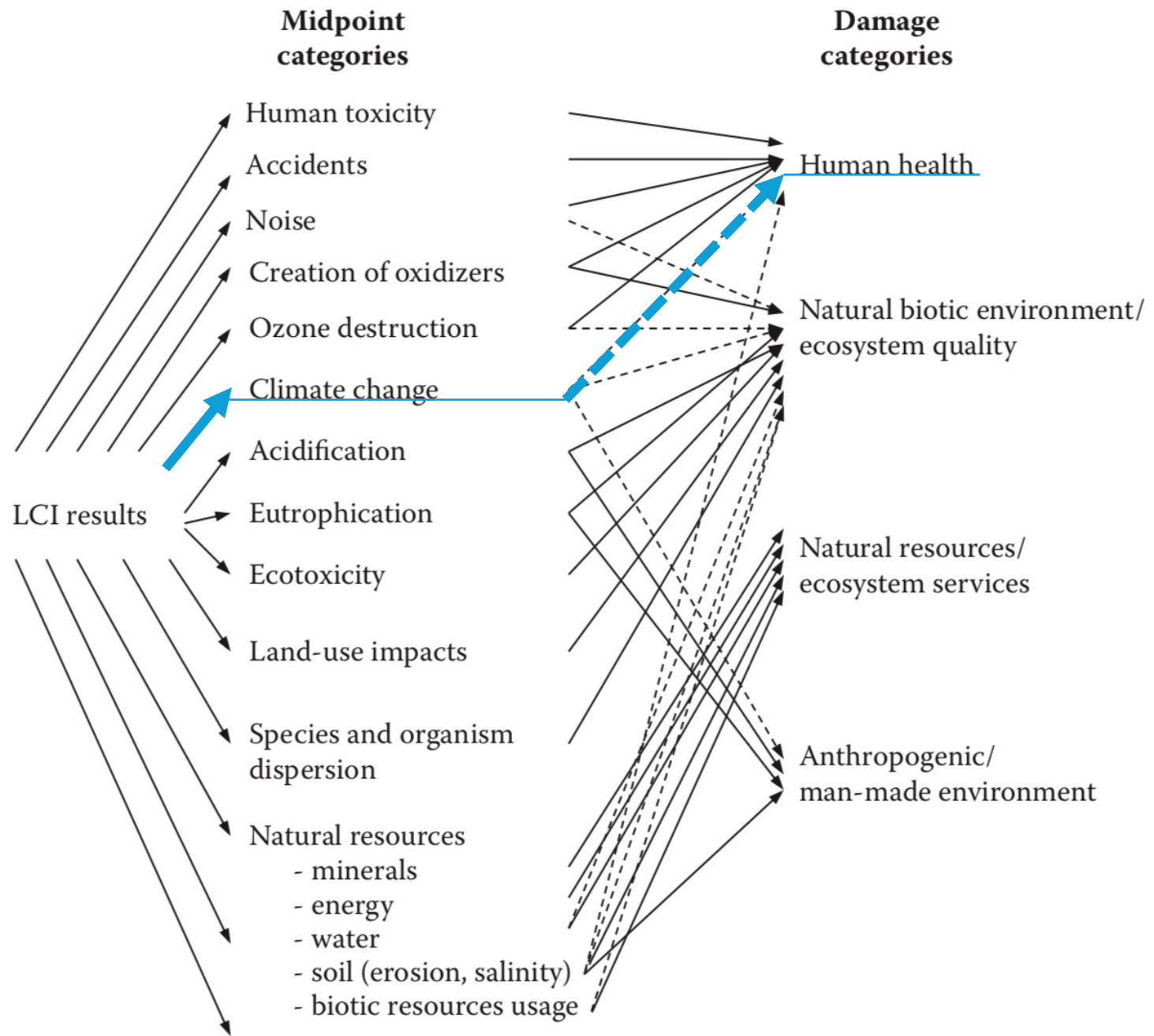
Measured through disability-adjusted life years (DALY)

$8.3 * 10^{-7} \text{ DALY/kg}_{\text{CO}_2\text{-eq}}$  (*midpoint-to-damage characterization*)

Example:  $55\text{kg}_{\text{CO}_2\text{-eq}} * 8.3 * 10^{-7} \text{ DALY/kg}_{\text{CO}_2\text{-eq}} = 0.00005 \text{ DALY}$



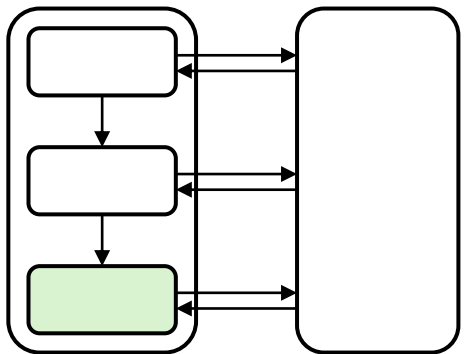
# impact assessment -ment



Example:

**UNEP-SETAC**  
United Nations  
Environment  
Program – Society  
of Environmental  
Toxicology and  
Chemistry

impact  
assessment  
framework



interpret  
-ation

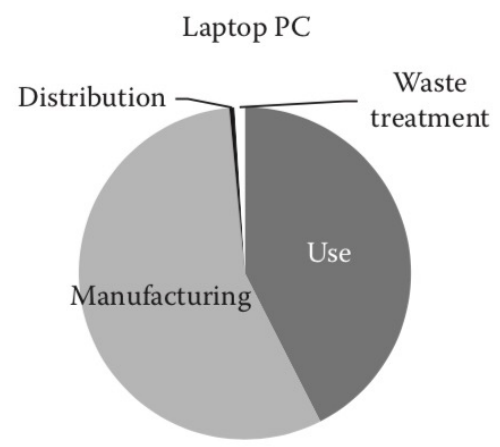
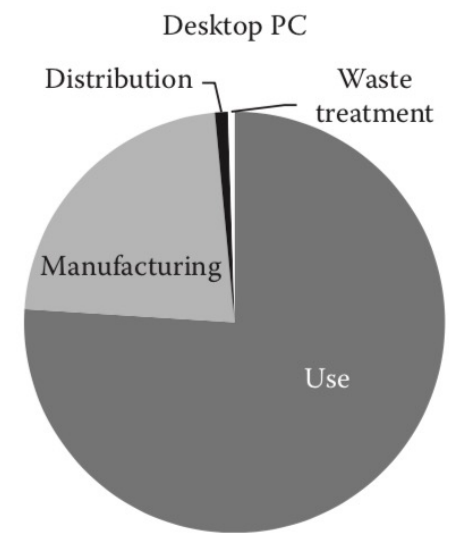
# Goals

Done at each step

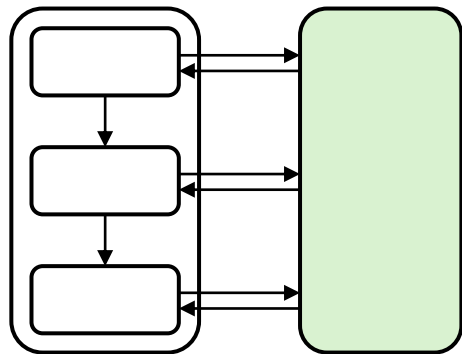
Identify areas of  
intervention

Quality control

**Quantify sensitivity/uncertainty**



embodied energy



interpret  
-ation

# Sensitivity analysis

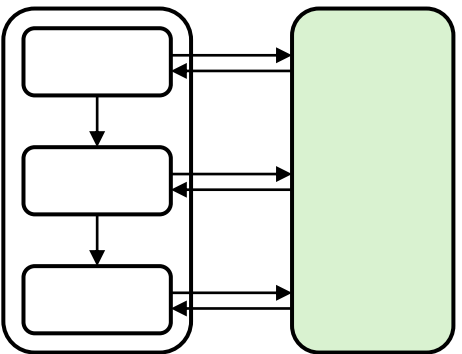
Look at key variables that could differ between scenarios and pick a reasonable range to test different values

## **Light bulb example:**

transportation distance between manufacturing plant and store

(100 km +/- 50%)

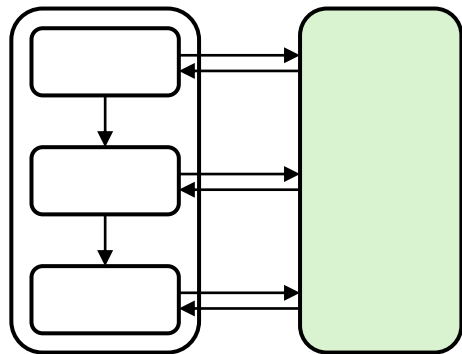
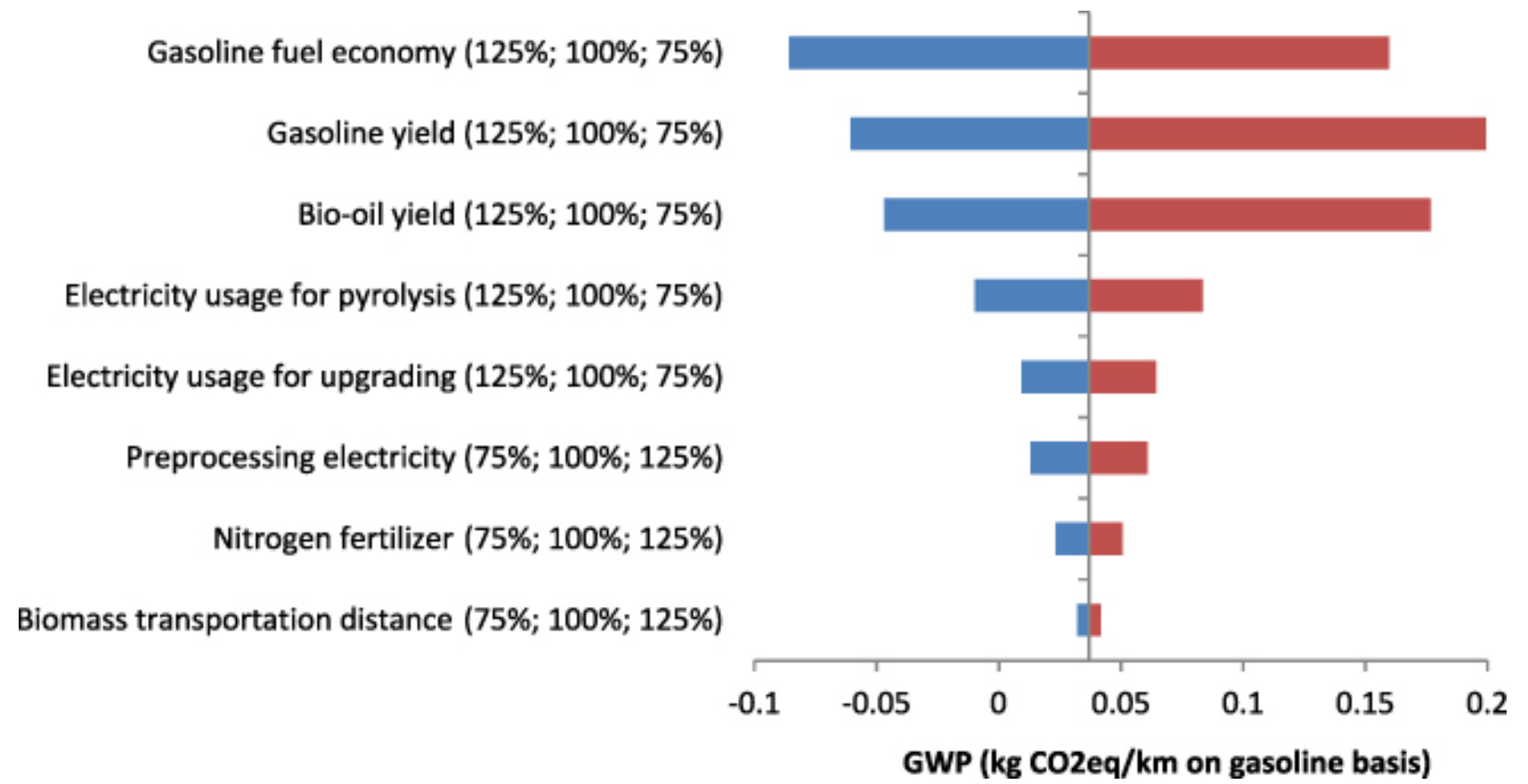
Gather full results for all three scenarios



interpret  
-ation

# Sensitivity analysis

## hydrogen and transportation fuels from corn LCA



# Topics not covered

- Allocation when a process produces more than one product
- Data quality
- Life-cycle costing
- Complex uncertainty analysis procedures
- And much much more!
  - LCA classes at EPFL: ENV 370, ENV 510, ME 516