

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	Guest lecture: Embodied carbon emissions and materials	The phases of infrastructure life cycles	

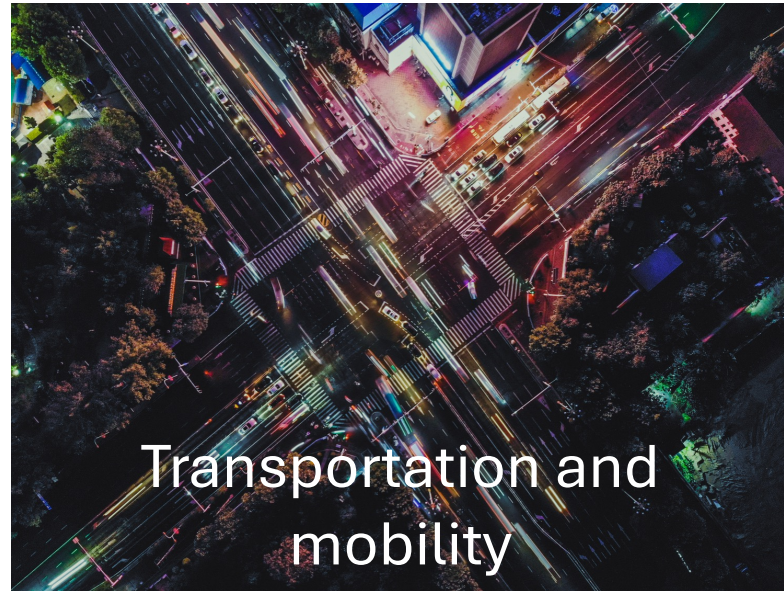
Civil engineering and natural systems

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	Guest lecture: 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	Guest lecture: 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?



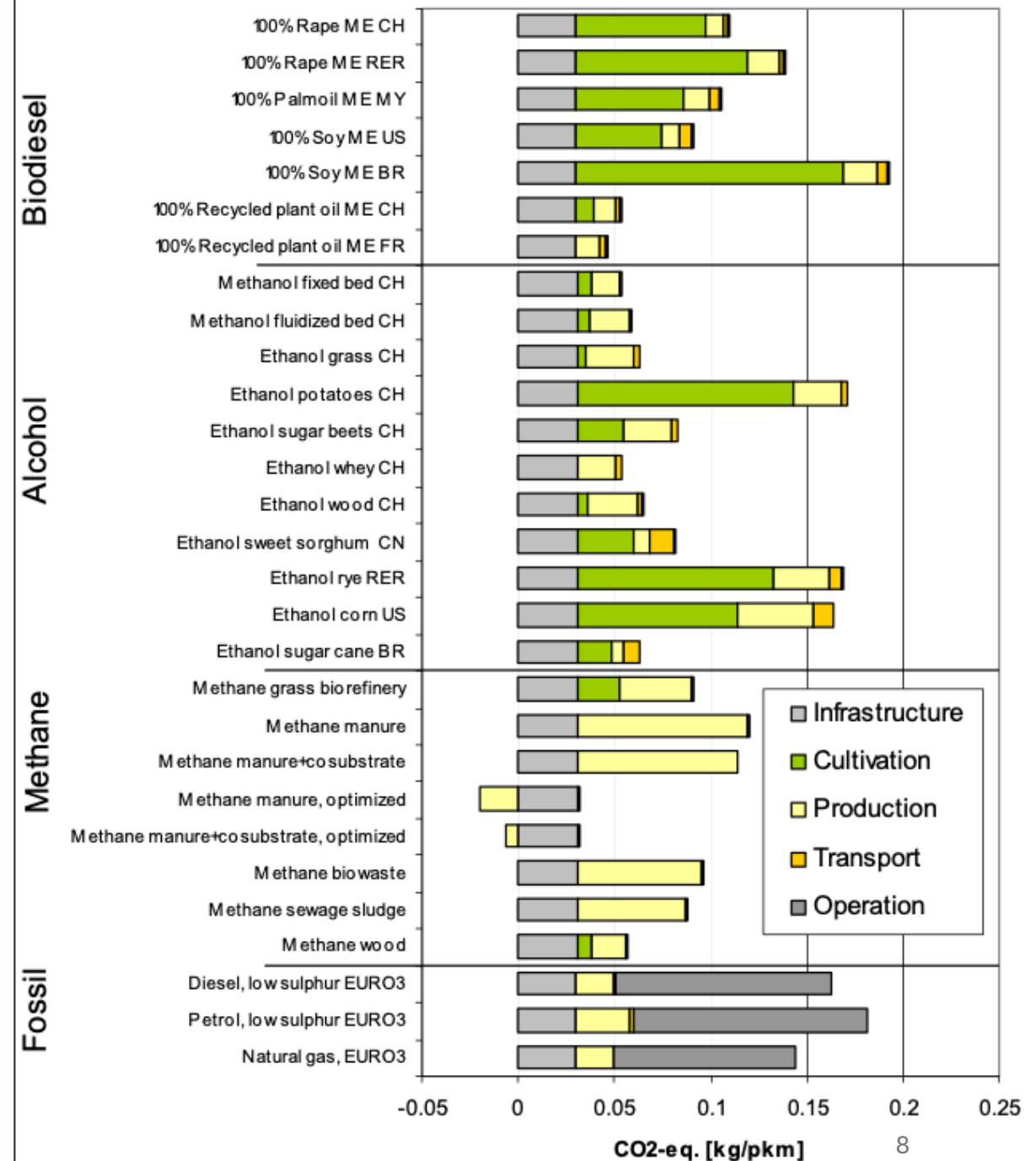
Biogas



Petroleum

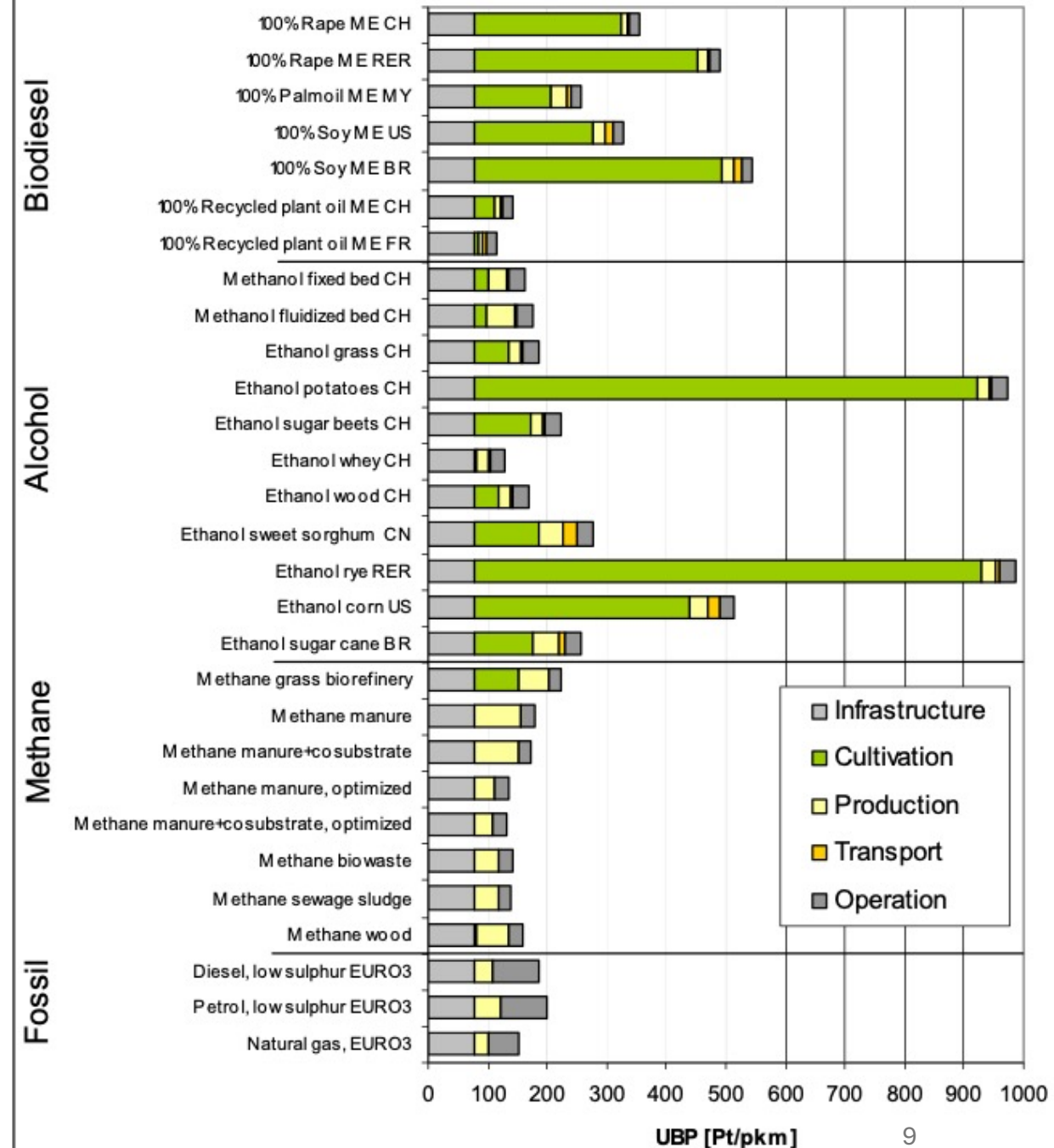
LCA of biofuels vs. fossil fuels

- 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 CO₂ was absorbed during plant growth)

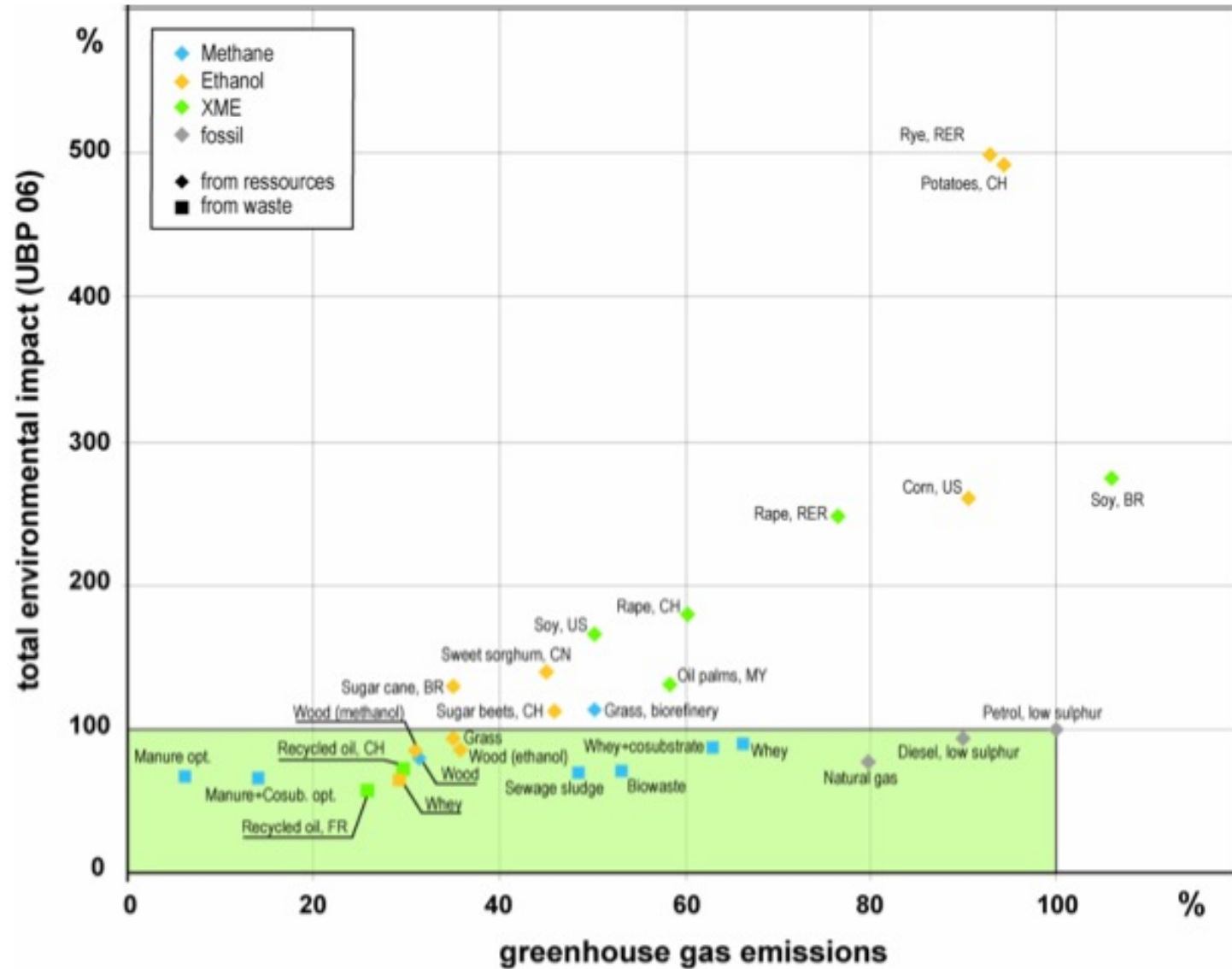


LCA of biofuels vs. fossil fuels

- 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



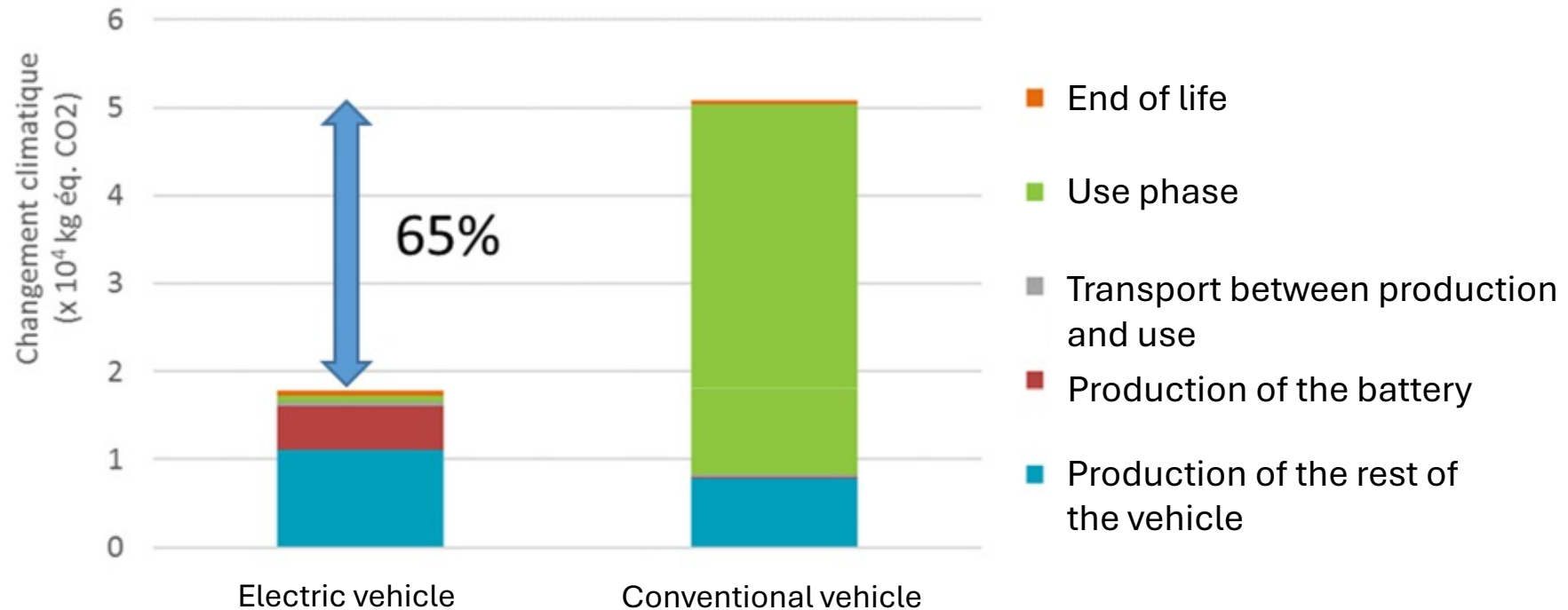
LCA of biofuels vs. fossil fuels



Electric vehicles vs. internal combustion engine vehicles (ICE)



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





VS.



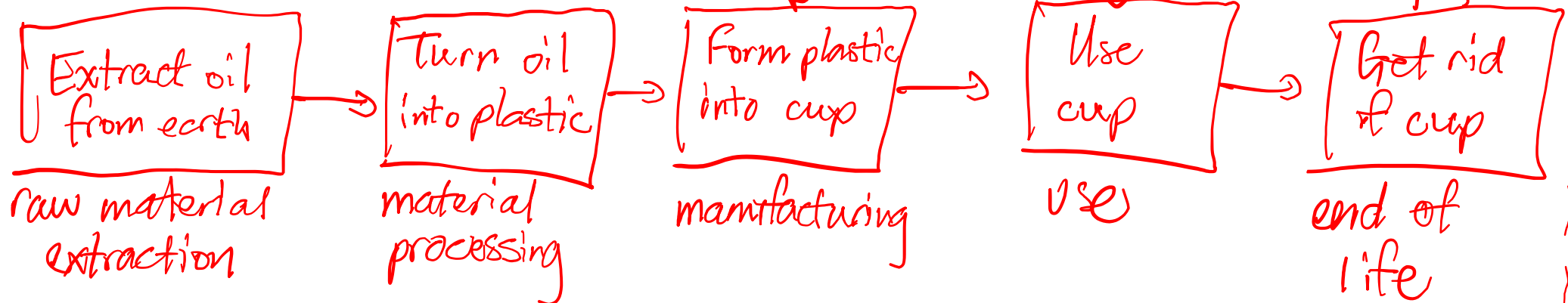
Which cup is greener? Need a framework

STEPS:

- Extract oil from earth
- Turn oil into plastic
- Form plastic into cup
- Use of the cup
- Get rid of the cup
- Re-use the cup
- Recycle the cup

↳ LCA is framework considering all stages of product's life cycle

SYSTEM BOUNDARY



↑ energy
↑ resources
↑ transportation

↓ emissions
↓ solid waste

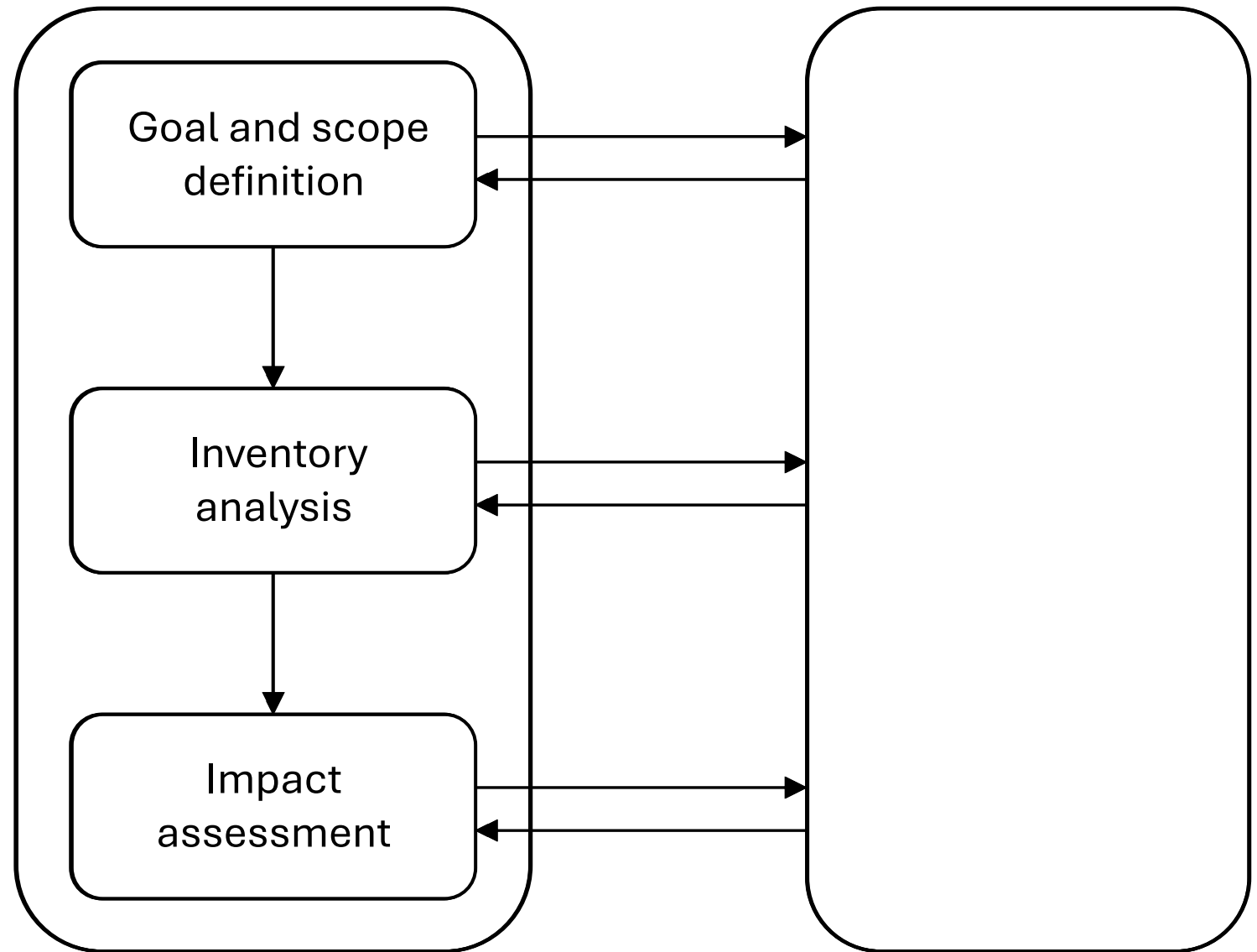
LCA Definition

- 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**

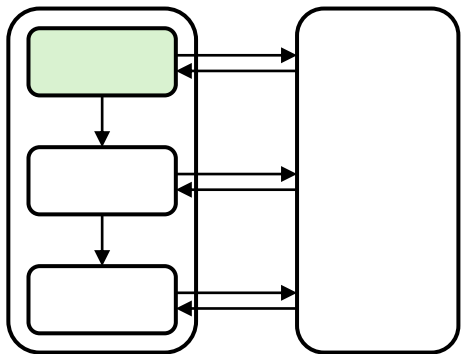


Intended application

Purpose

Intended audience

Whether the results will be used for
comparative assertions



VS.



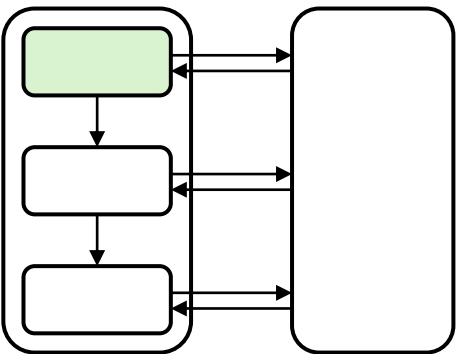
goal
and
scope

Product or service

Function and functional unit

System boundaries

Data requirements / assumptions /
limitations



goal and scope

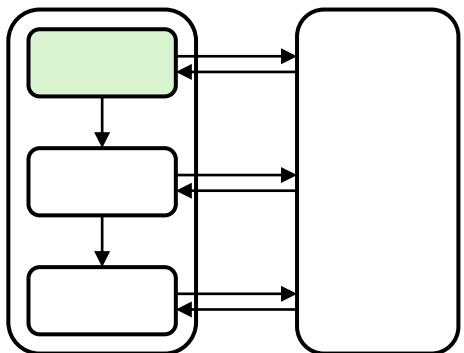
Function and functional unit

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.

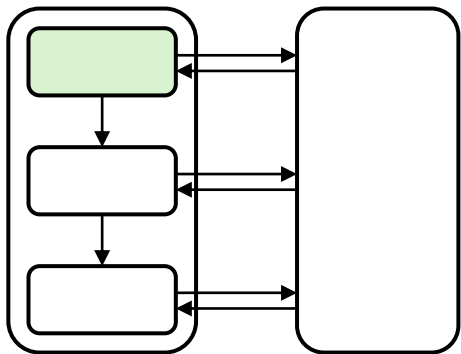


Function

Drying hands

Functional
unit

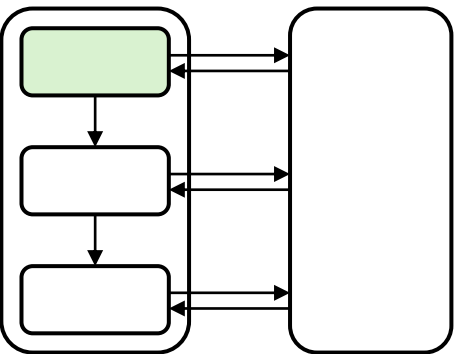
One pair of hands dried
through each system



goal and scope

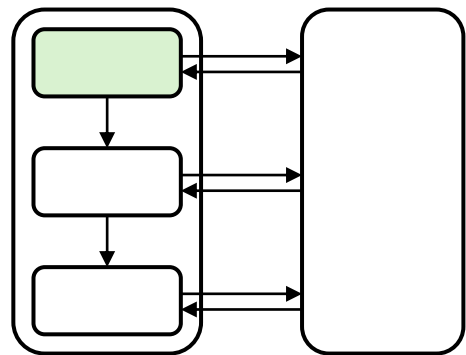
Function and functional unit

- 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

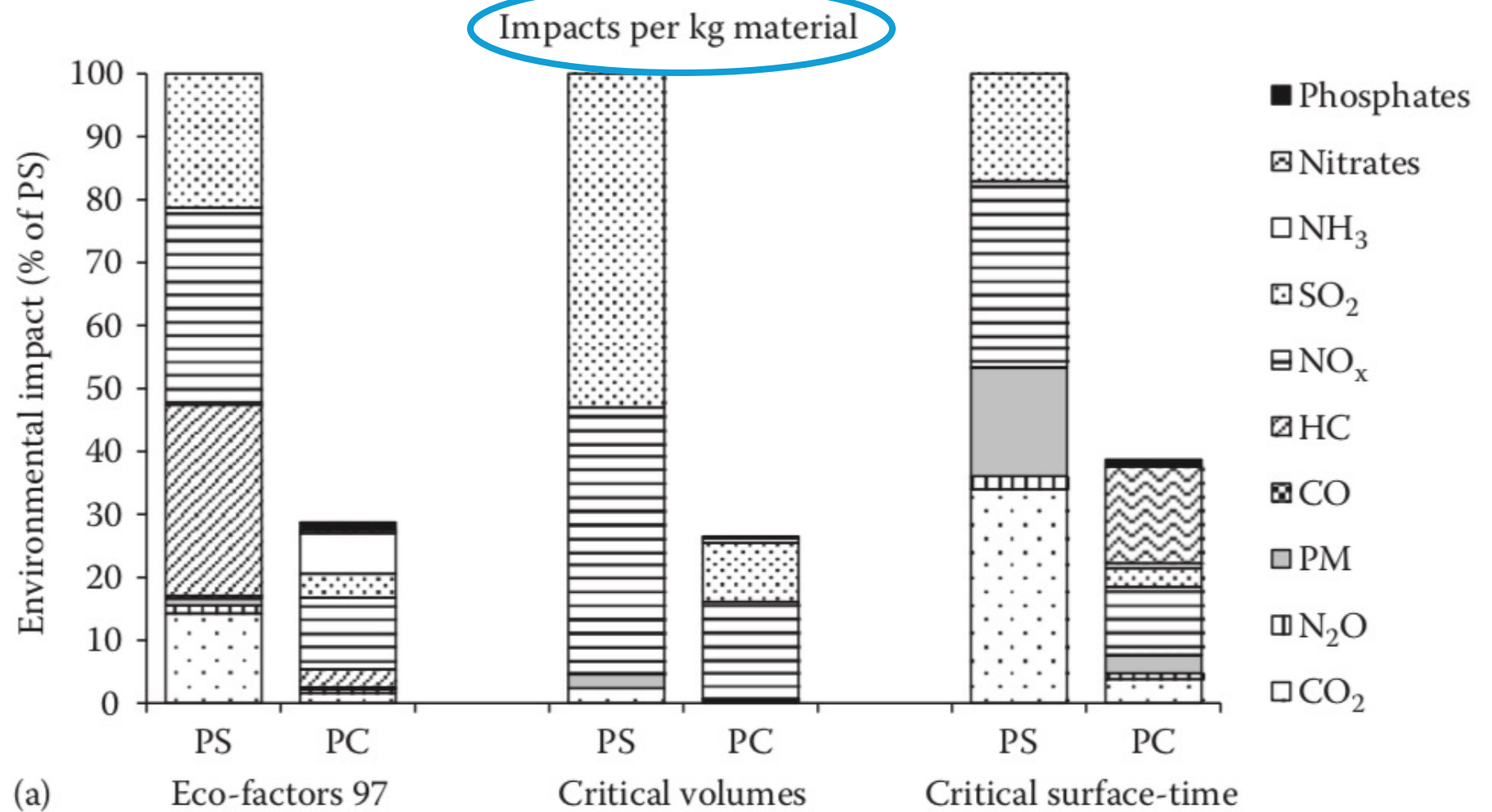


goal and scope

PS: Polystyrene
PC: Popcorn

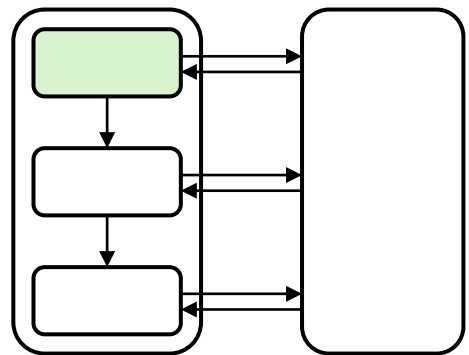


Polystyrene (PS) vs. Popcorn (PC) for packaging



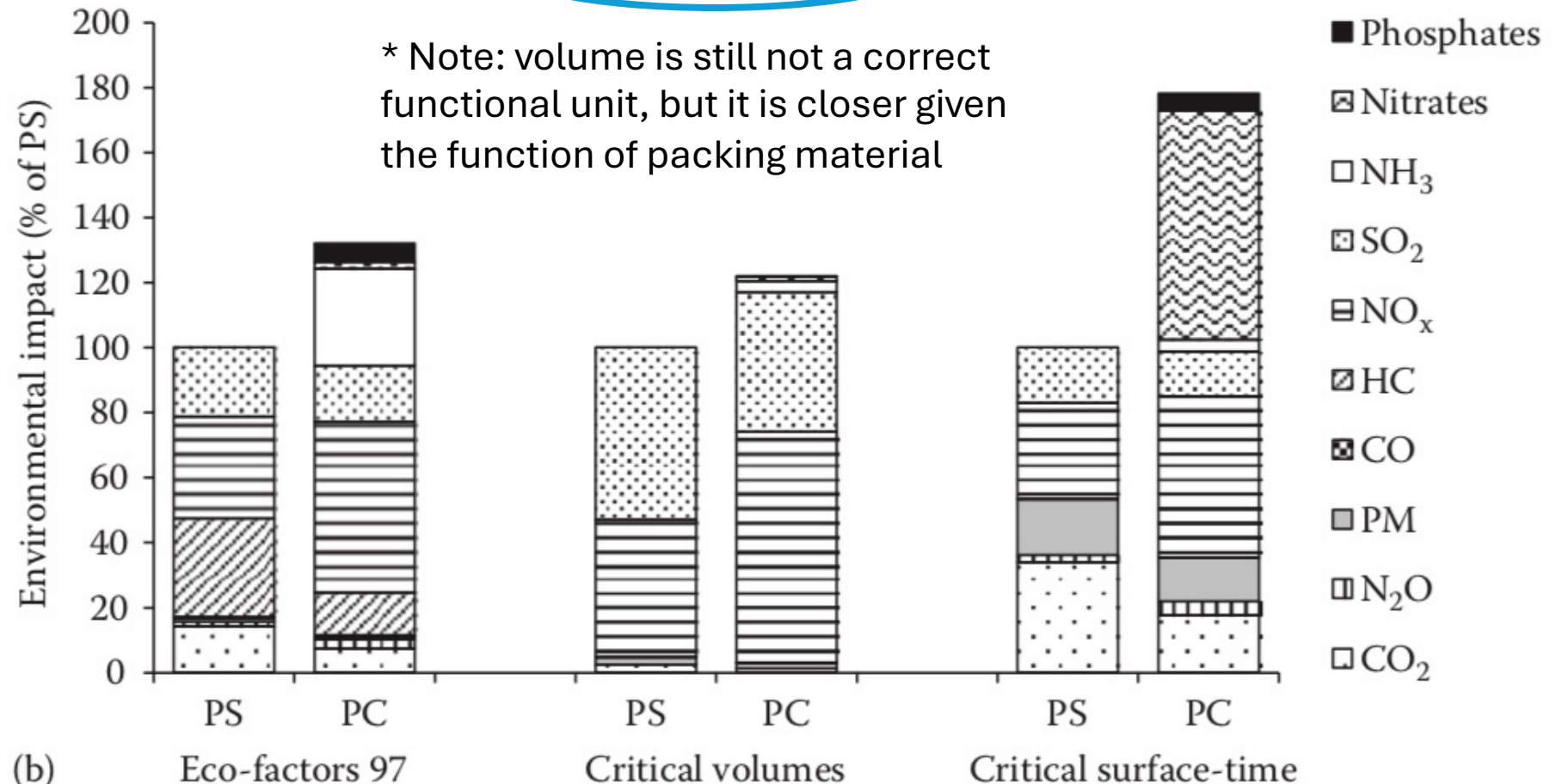
goal and scope

PS: Polystyrene
PC: Popcorn



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

Impacts per m³ material



(b)

Eco-factors 97

Critical volumes

Critical surface-time

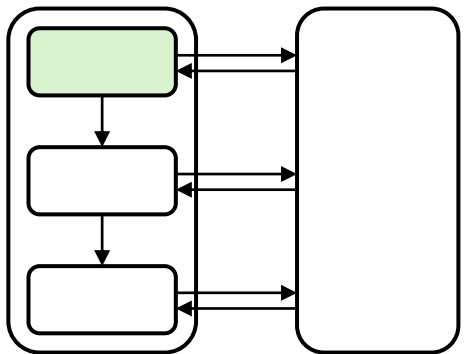
Functional unit exercise

goal
and
scope

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

PS: Polystyrene
PC: Popcorn

A 3-m tall structural column that supports a given action effect for the building's lifetime.



goal and scope

Reference flows

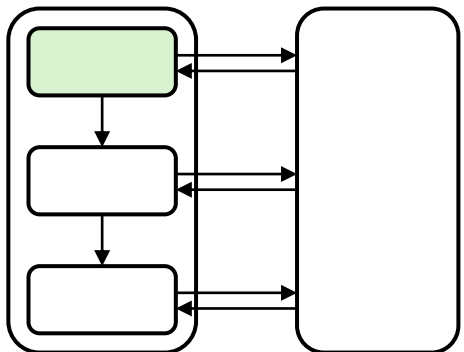
- Quantified amount of product(s) necessary for a specific system to deliver the performance required by the functional unit

- Expressed in:

Quantity of a product

Functional unit

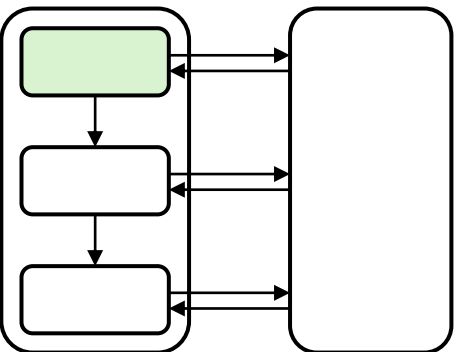
- Can have multiple reference flows for a given FU
- When comparing two things, products and their reference flows can be different, but the FU needs to be the same



goal and scope

Reference flows: Example

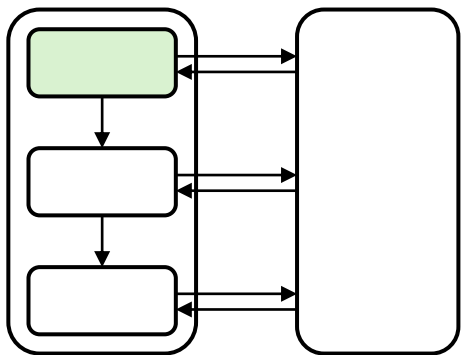
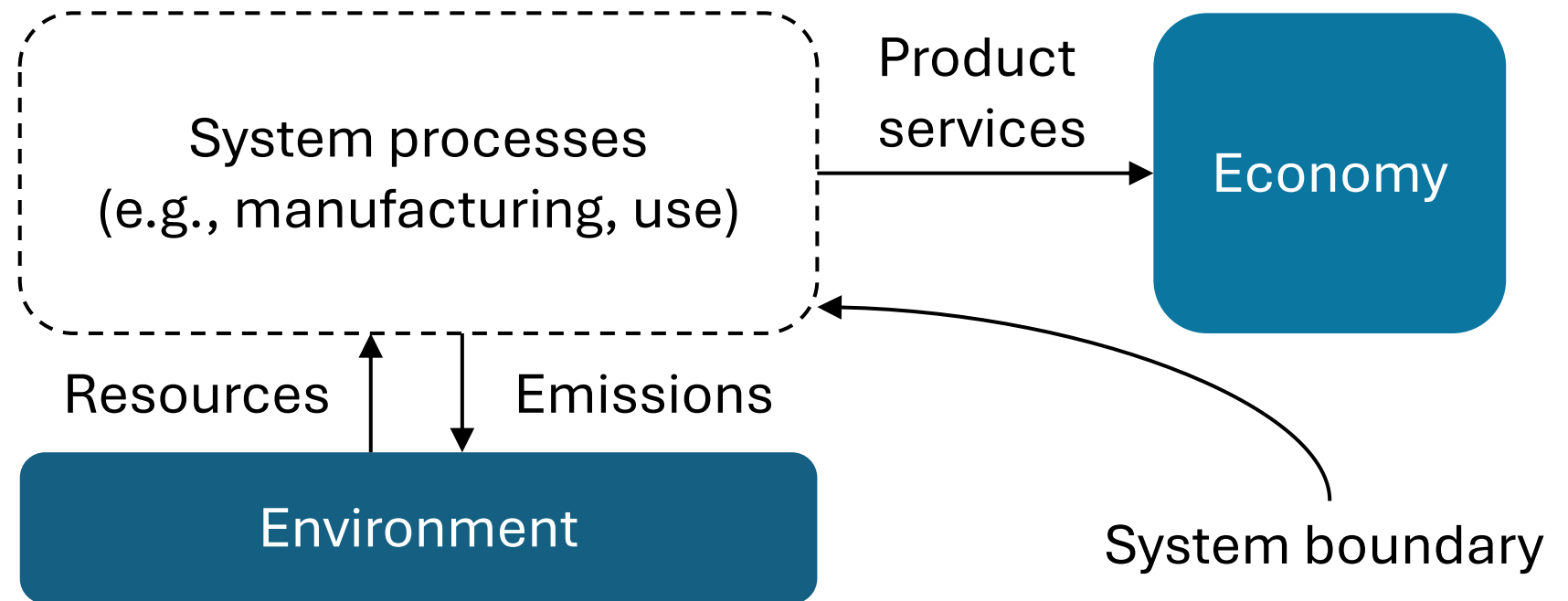
- Functional unit: Serve 3dl of coffee once per day for one year
 - Option A: Disposable cups
 - Option B: Reusable cup
- Key parameters:
 - A: 1 serving per cup
 - B: 1,000 servings per cup, 1 wash per cup
- Reference flows:
 - A: $RF_{\text{cup}} = 365$ cups (cardboard); $RF_{\text{disposal}} = 365$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

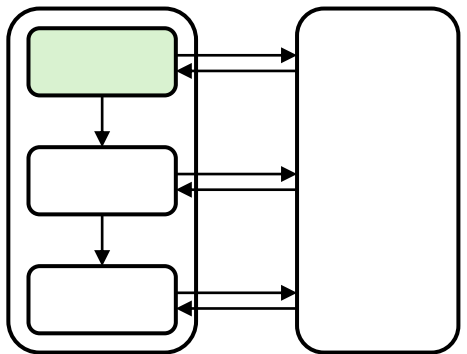
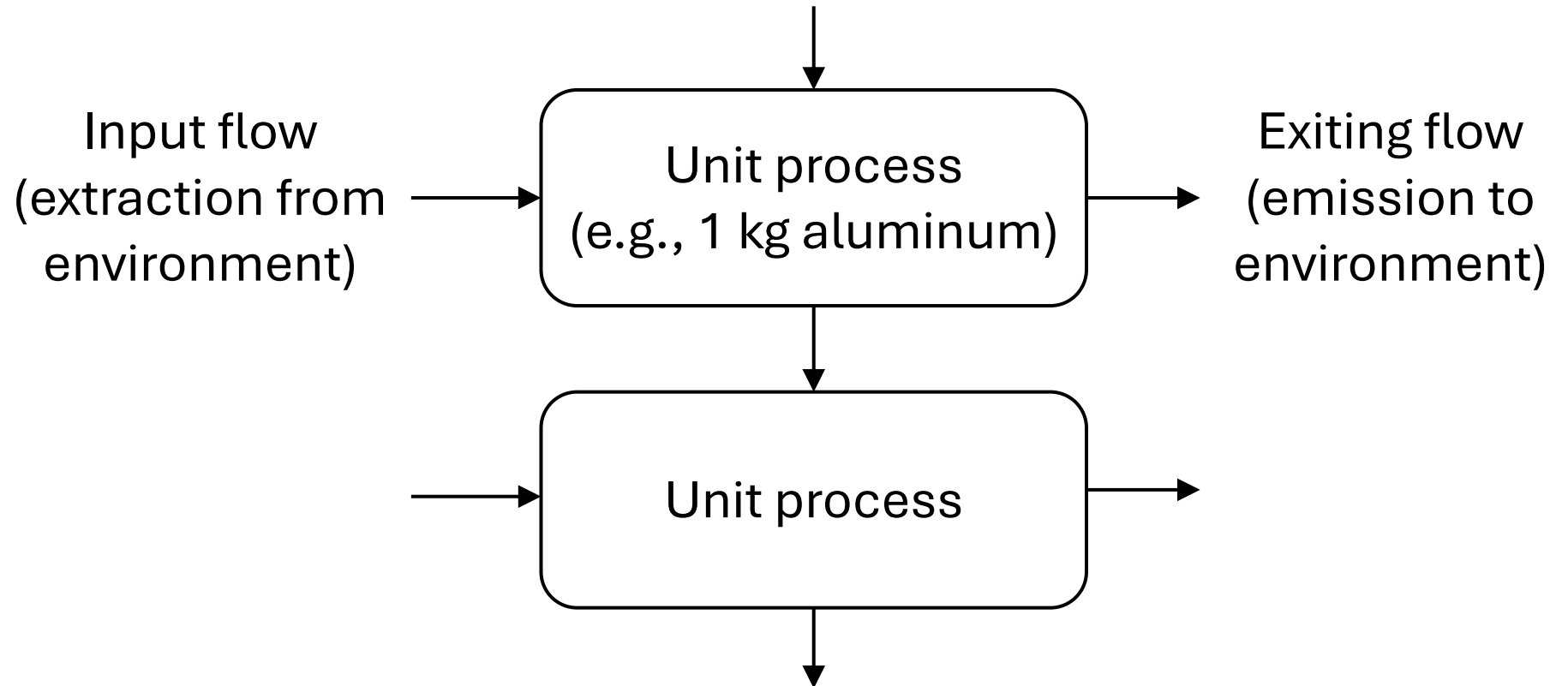
A “complete” LCA



goal
and
scope

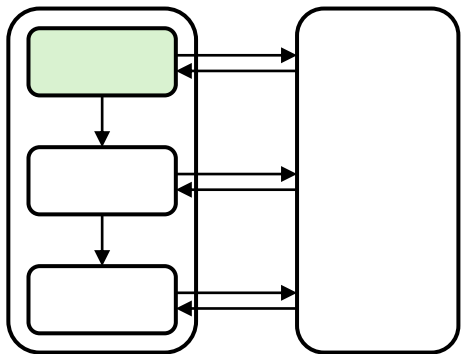
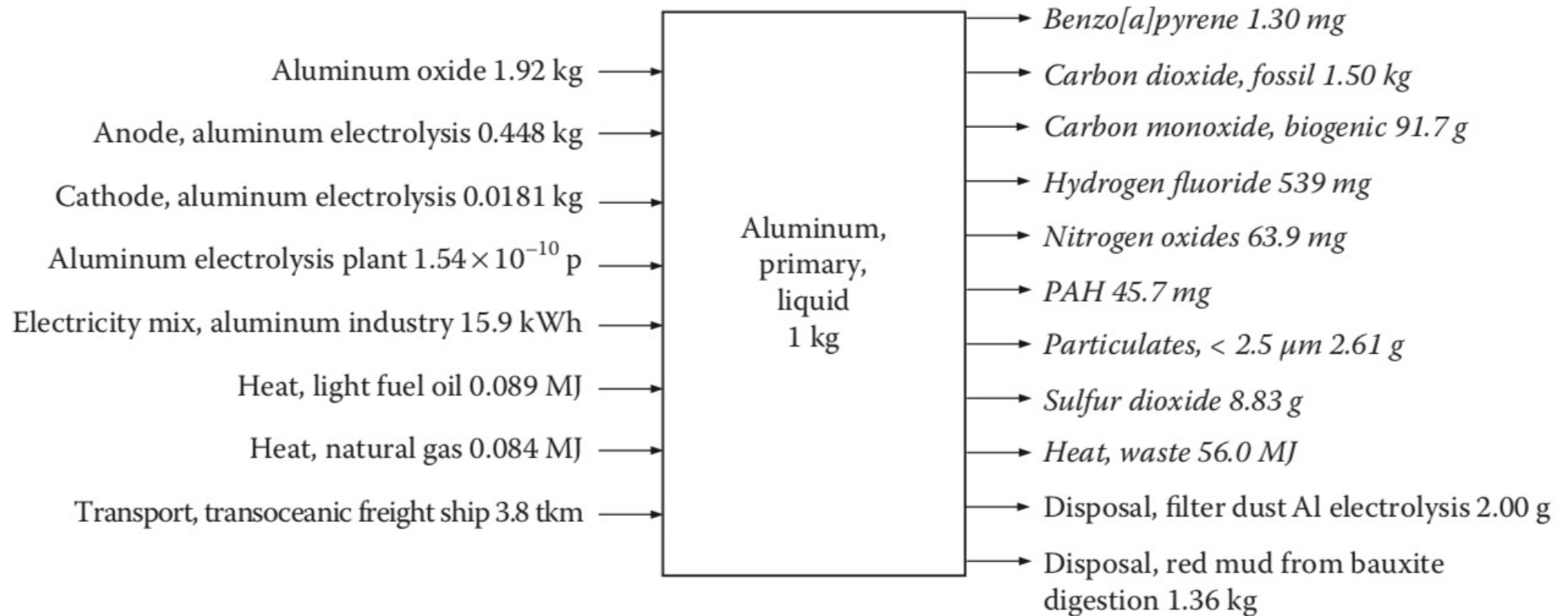
System boundaries

Unit processes (within boundary)



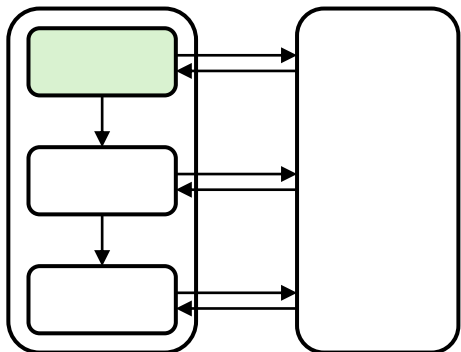
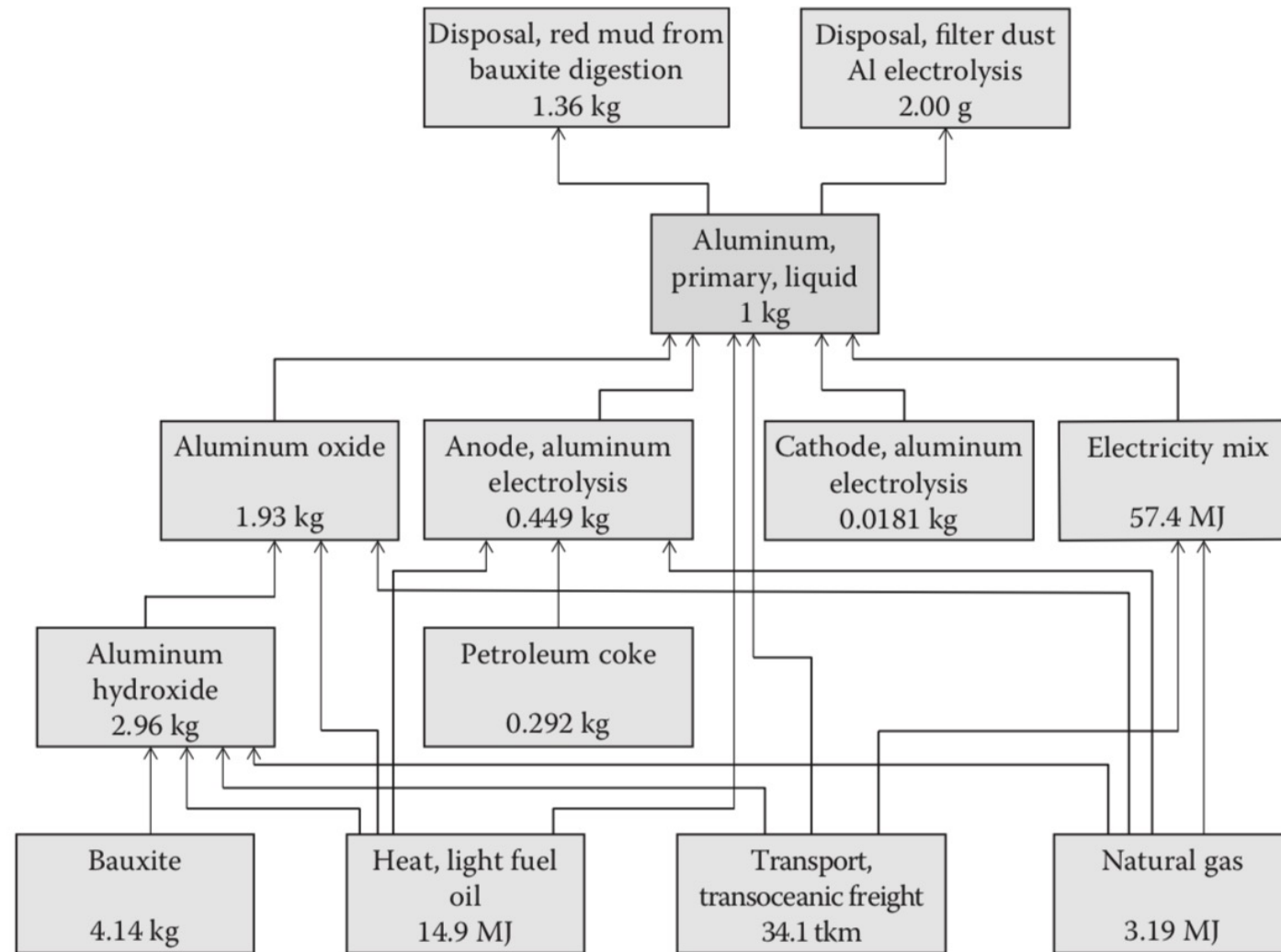
goal and scope

System boundaries



goal
and
scope

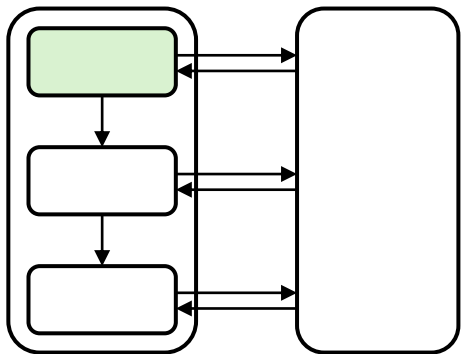
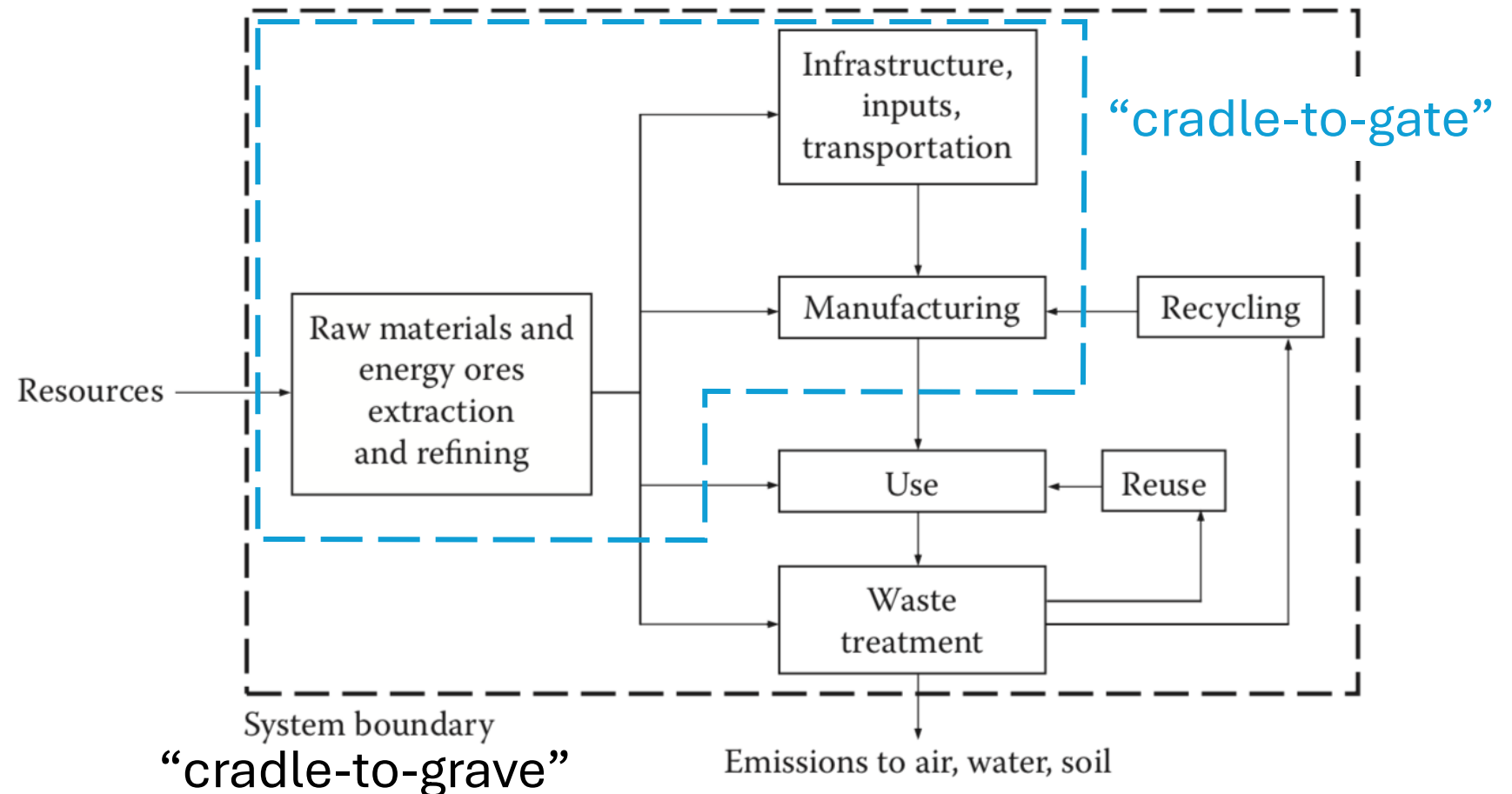
System boundaries



goal
and
scope

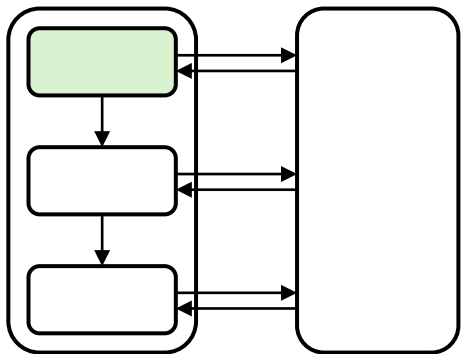
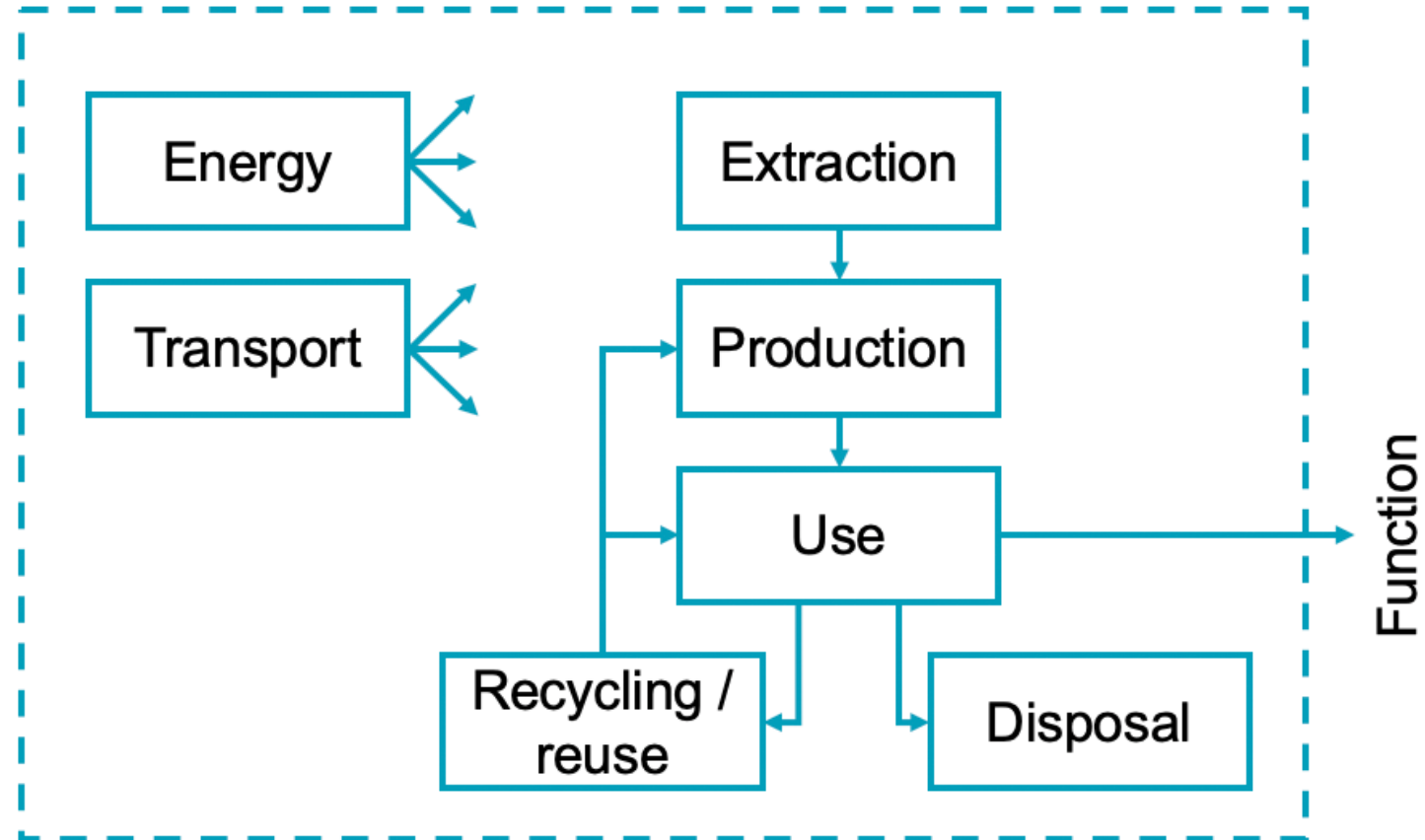
System boundaries

Main processes to consider



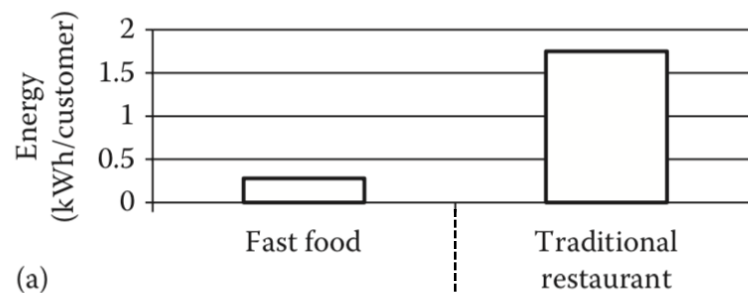
goal
and
scope

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)

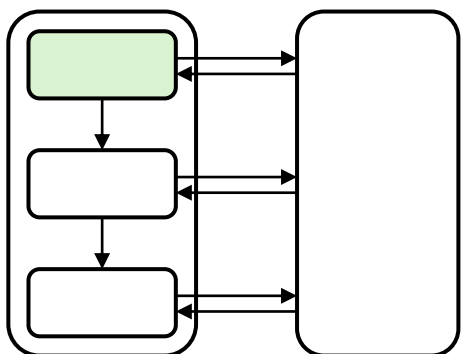
Production chain for reusable dishes

Preparation of food and cooking

Cleaning, heating, and lighting of restaurant (same)

Clean reusable dishes

Management of food and packaging waste

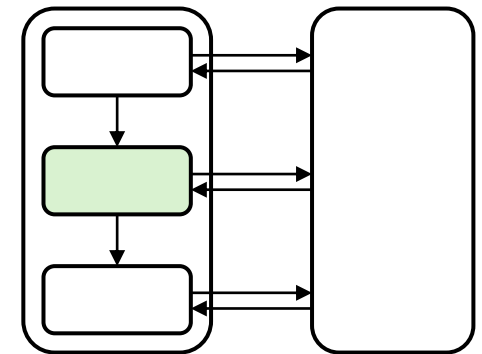


inventory analysis

The goal

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

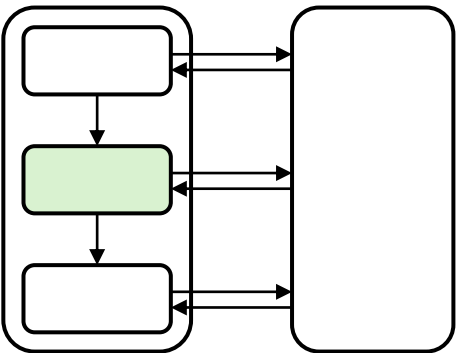
In other words, quantify the total inputs and outputs



inventory
analysis

An example

Light bulbs!



Scenario	① INCANDESCENT	② FLUORESCENT
F.U.	800 lm	over 5000h
Key param	lifespan 1000h 60W	5000h 13W
References		
① Energy	$60W \cdot 5000h = 300kWh$	$13W \cdot 5000h = 65kWh$
② Materials - glass	$\underline{0.02kg} \cdot 5 = 0.1kg$	$\underline{0.1kg} \cdot 1 = 0.1kg$
- lighting material	$\underline{0.015kg Cu} \cdot 5 = 0.075kg Cu$	$\underline{0.06kg}$ electronics

Primary
nonrenewable
energy
demand

Electricity: 12.1 MJ/kWh

Glass: 11.5 MJ/kg

Cu: 31.2 MJ/kg

Electronics: 896 MJ/kg

Primary
energy

$$300 \text{ kWh} \cdot \frac{12.1 \text{ MJ}}{\text{kWh}} = 3633 \text{ MJ}$$

$$0.10 \text{ kg glass} \cdot \frac{11.5 \text{ MJ}}{\text{kg}} = 1.15 \text{ MJ}$$

$$\text{Cu: } 2.34 \text{ MJ}$$

$$3637 \text{ MJ}$$

$$65 \text{ kWh} \cdot \frac{12.1 \text{ MJ}}{\text{kWh}} = 787 \text{ MJ}$$

$$1.15 \text{ MJ}$$

$$\text{Electronics: } 53.7 \text{ MJ}$$

$$841.9 \text{ MJ}$$

inventory analysis

Two approaches

Conventional process- based LCA

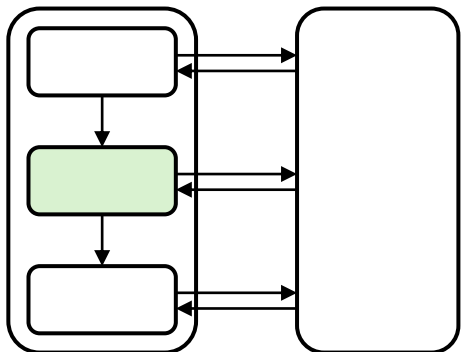
More common approach,
quantifies every step in the
identified process

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

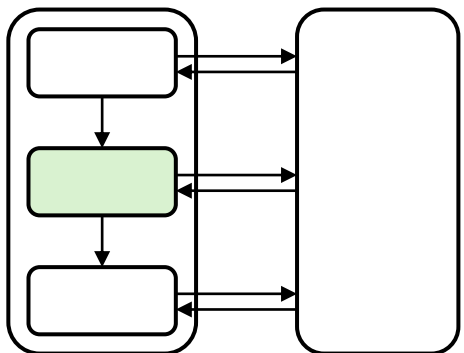
The good: compare
products within sector

The bad: data
completeness, process
completeness

Economic Input-Output LCA (EIO-LCA)

The good: fast, complete

The bad: cannot distinguish
within-sector



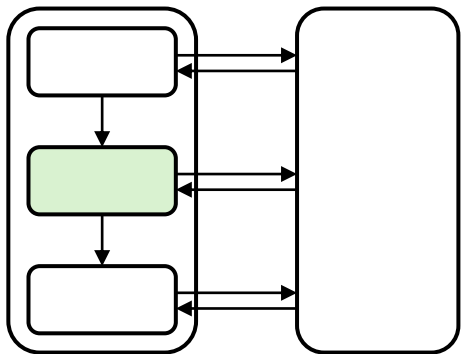
inventory
analysis

Two approaches

**Conventional process-
based LCA**



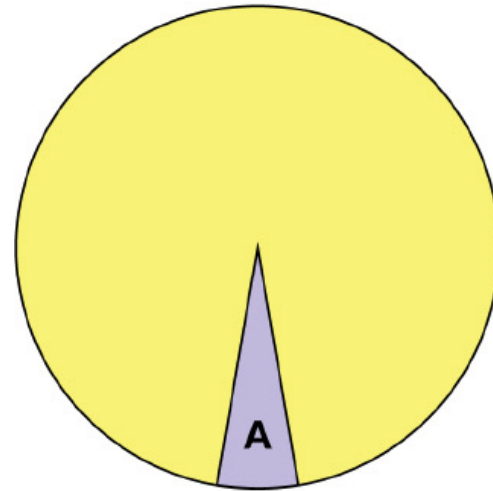
**Economic Input-Output
LCA (EIO-LCA)**



inventory analysis

Attributional vs. Consequential LCA

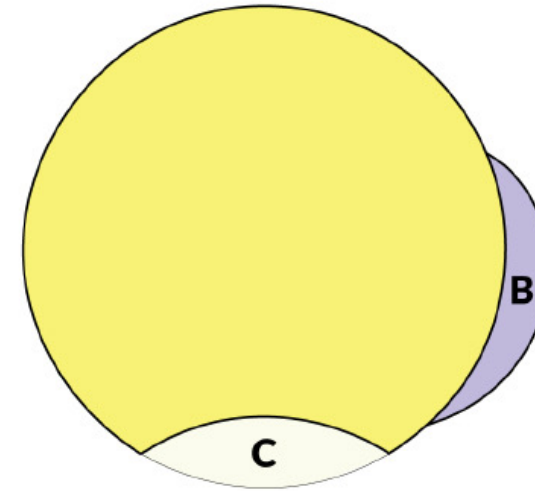
Attributional



Impacts = A

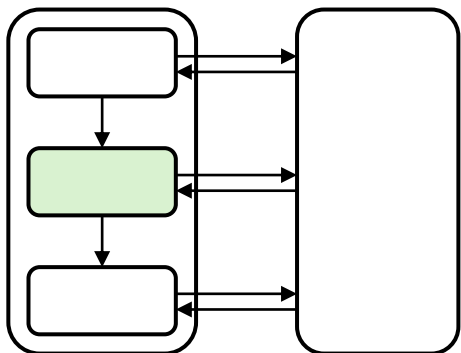
What part of the global environmental burdens should be assigned to the product?

Consequential



Impacts = B - C

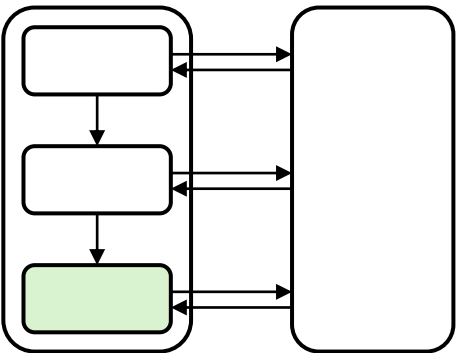
What is the change in global environmental burdens resulting from a change in the use or production of a product?



impact assess -ment

What can we measure?

- Greenhouse gas emissions (CO₂ equivalent)
- Others?

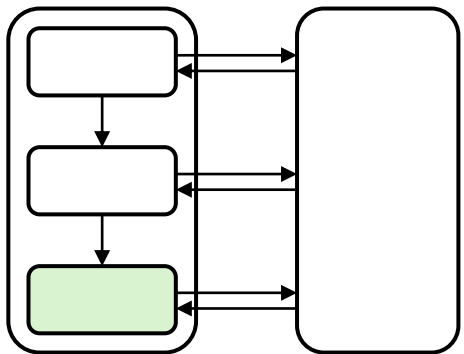


impact assess -ment

EPA TRACI

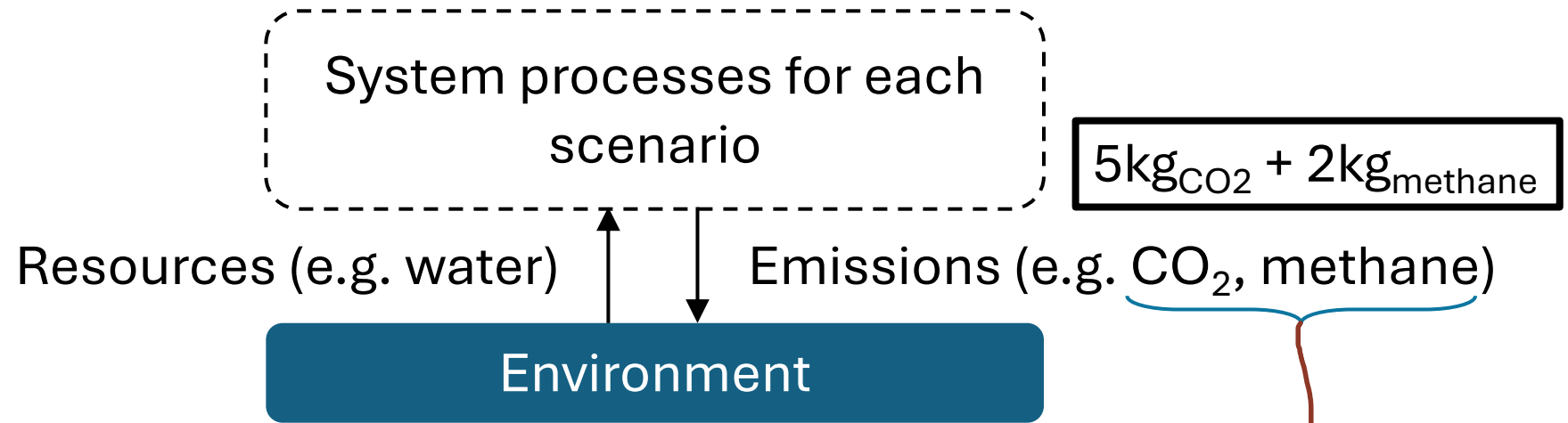
(Tool for the **R**eduction and **A**ssessment of **C**hemical and other environmental **I**mpacts)

- Global warming (CO₂ equivalent)
- Ozone depletion
- Smog formation
- Acidification
- Eutrophication
- Human health (carcinogens)
- Human health (criteria pollutants (SO_x, NO_x, etc.))
- Eco-toxicity
- Fossil fuel depletion
- Land use
- Water use



impact assess -ment

Methodology

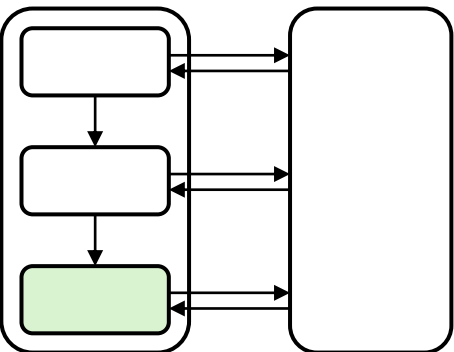


Both contribute to global warming

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

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

(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)

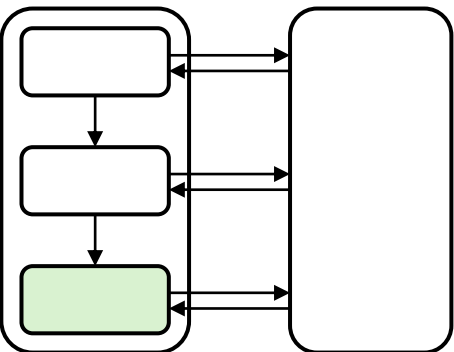
What does global warming cause?

Example: **human health**

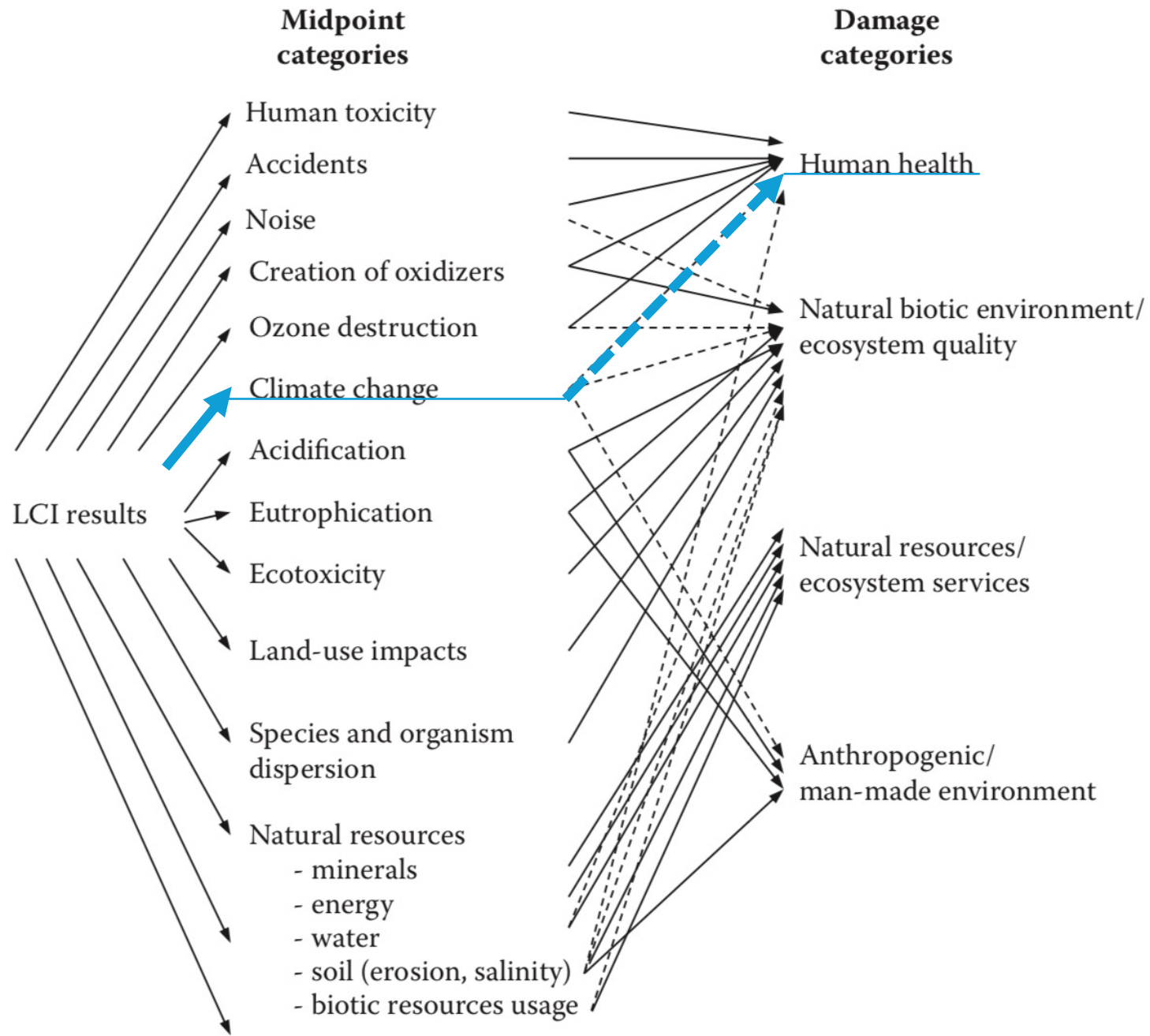
Measured through disability-adjusted life years (DALY)

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

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



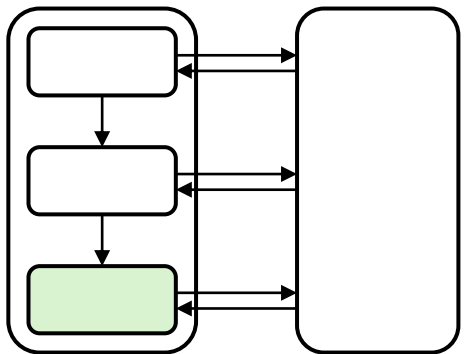
impact assessment -ment



Example:

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

impact
assessment
framework



interpret
-ation

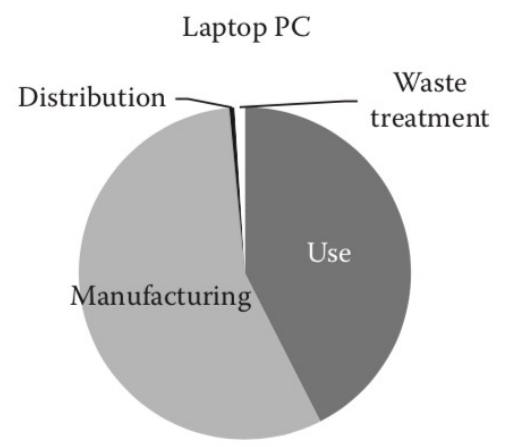
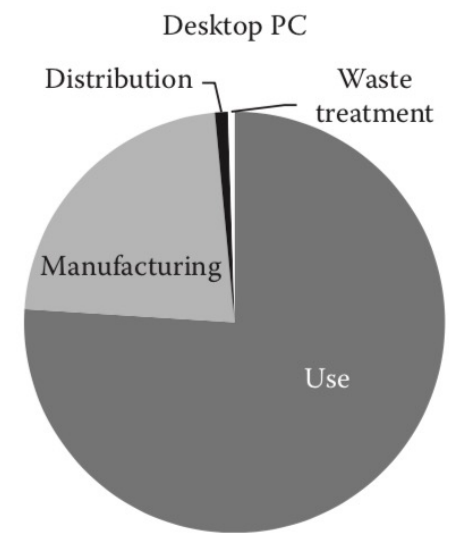
Goals

Done at each step

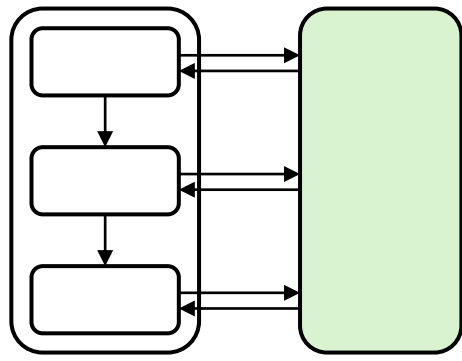
Identify areas of
intervention

Quality control

Quantify sensitivity/uncertainty



embodied energy



interpret
-ation

Sensitivity analysis

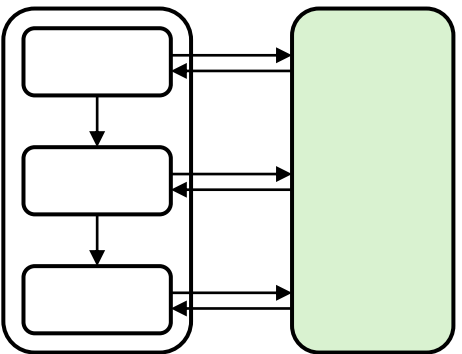
Look at key variables that could differ between scenarios and pick a reasonable range to test different values

Light bulb example:

transportation distance between manufacturing plant and store

(100 km +/- 50%)

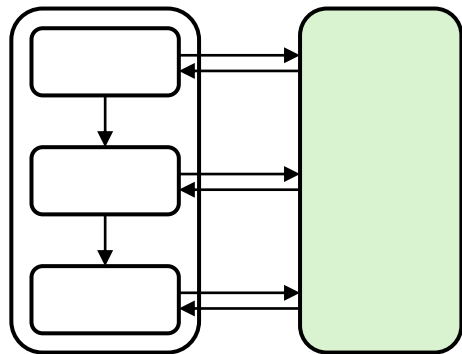
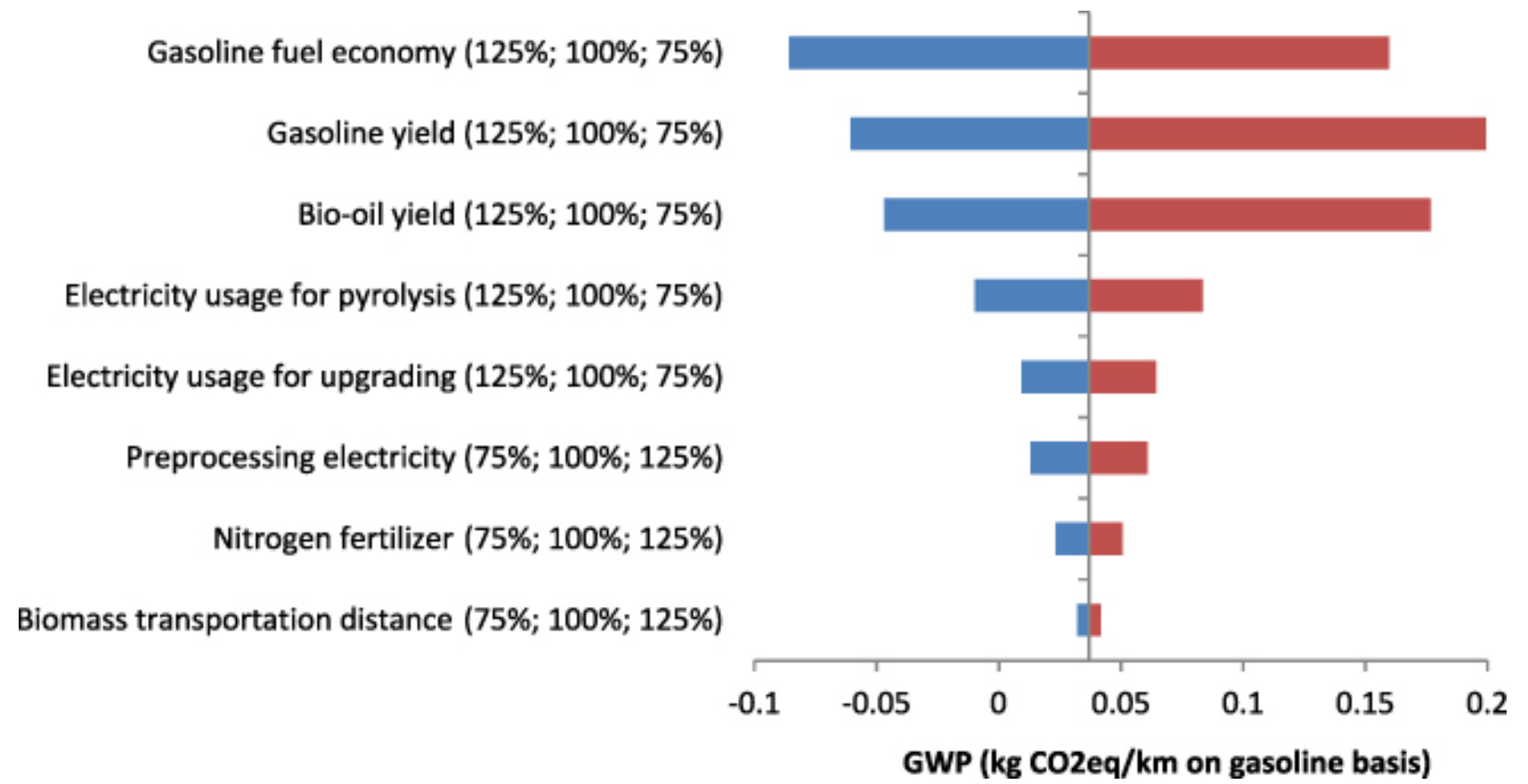
Gather full results for all three scenarios



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