Lecture 08
Life-cycle assessment

CIVIL-239: Engineering a sustainable built environment

Andrew Sonta

Scan to add to class Spotify paylist

Housekeeping

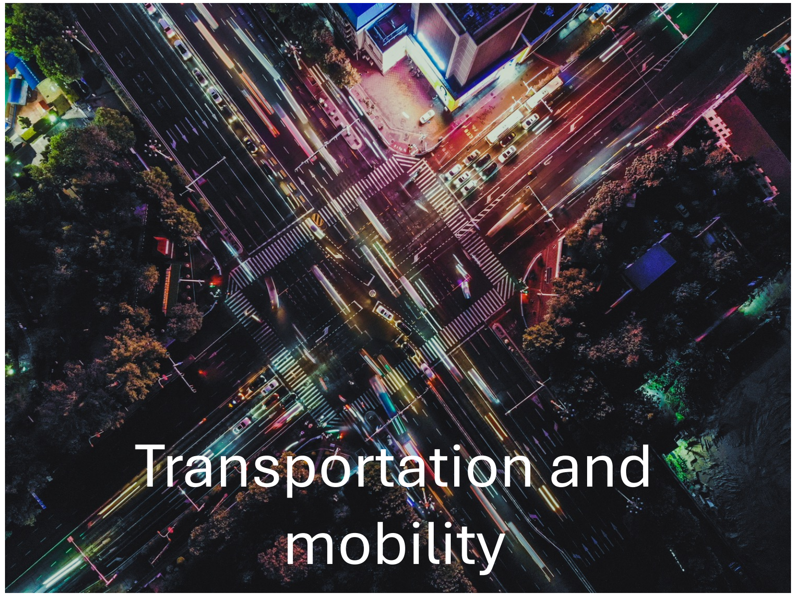
- Assignment 4 out today; due in 2 weeks
- Exam status update

Outline

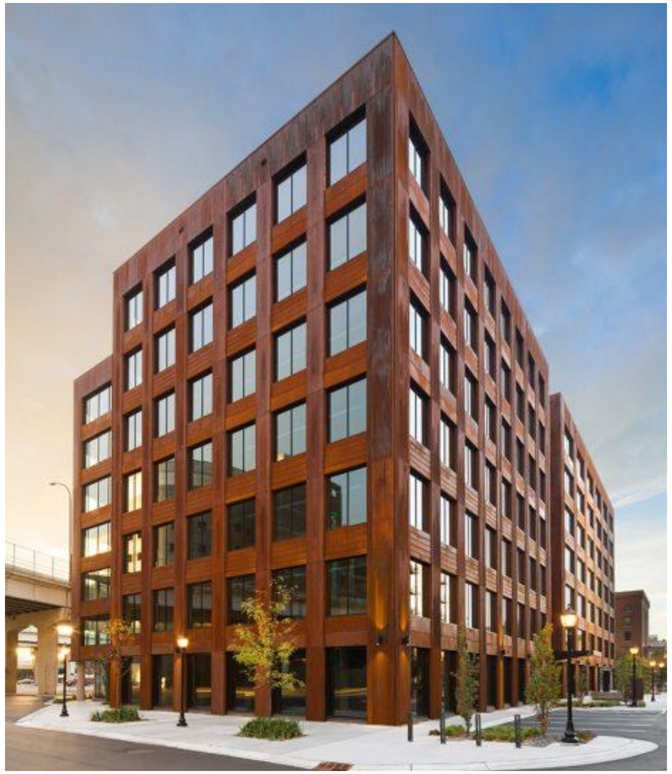
- Introduction to environmental LCA
  - Standards and definitions
- Understand key steps of LCA
  - Defining purpose
  - Functional units
  - System boundaries
  - Interpretation
  - Dealing with uncertainty
- Process-based LCA vs EIO-LCA
- Attributional vs consequential LCA
- Understand how LCAs can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

	Materials, structures, and life-cycle assessment			
9	5-Nov	**Guest lecture**: Embodied carbon emissions and materials	The phases of infrastructure life cycles	
10	12-Nov	Life-cycle assessment	Environmental LCA; Safety factors	
	Natural systems and sustainability economics			
11	19-Nov	**Guest lecture**: Assigning value to natural systems	Sustainability in natural systems; Engineering and sustainability economics	
12	26-Nov	Geo-mechanics, carbon storage, and geo-engineering	Risks of geo-engineering	Assignment 4
	Sustainability in the civil engineering profession			
13	3-Dec	Decision-making in the civil engineering profession	Complexity in civil engineering systems; engineering decision-making	
14	10-Dec	**Guest lecture**: Sustainable engineering in the industry	Practical issues	Assignment 5
15	17-Dec	Course wrap up Thinking in systems Tentative: class debate		
16	27-Jan	***Final Written exam***		

Subdisciplines of civil engineering



Which building material is greener?



Timber

Adobe

Concrete

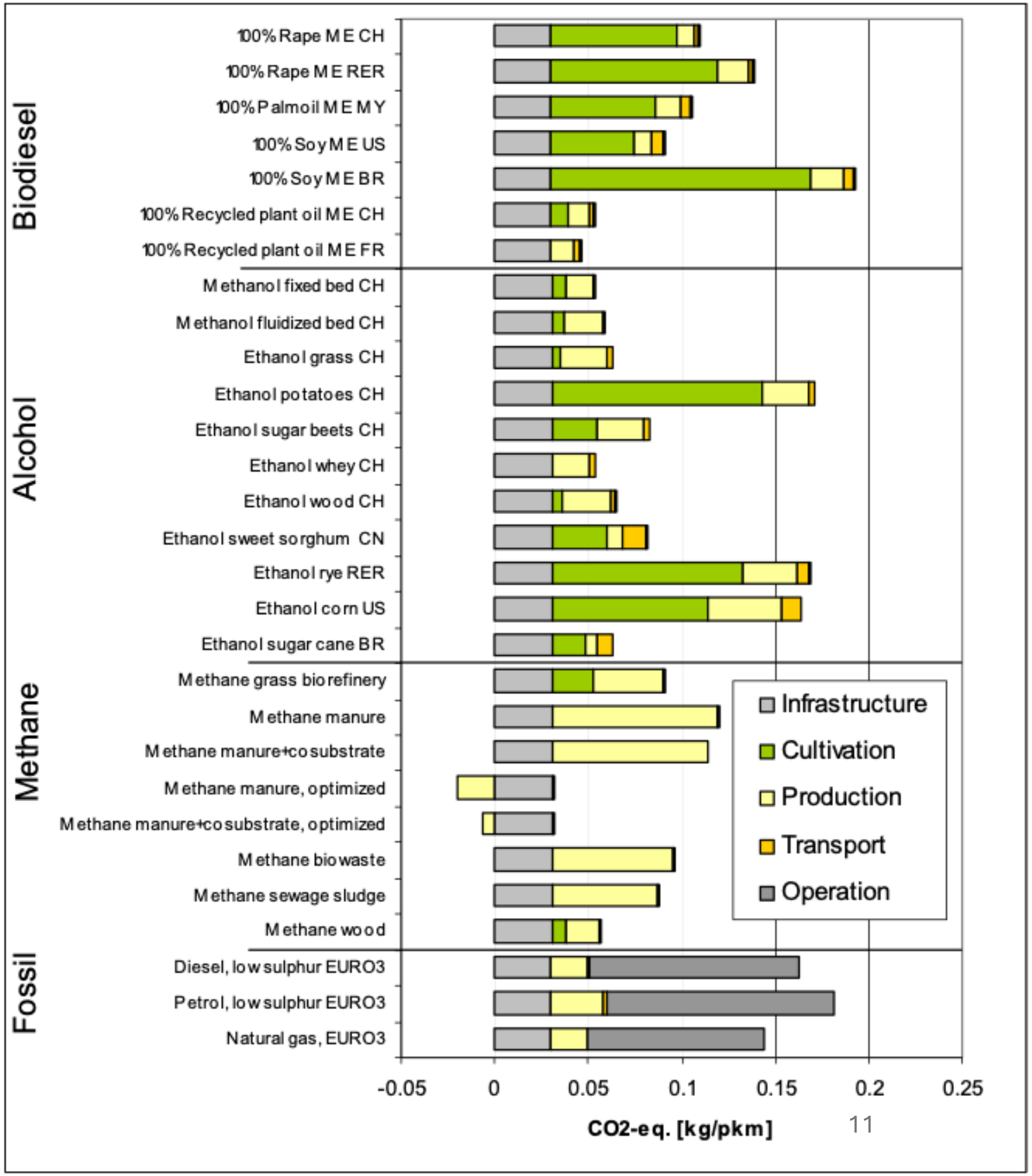
How sustainable is biogas?

Biogas

Petroleum

LCA of biofuels vs. fossil fuels

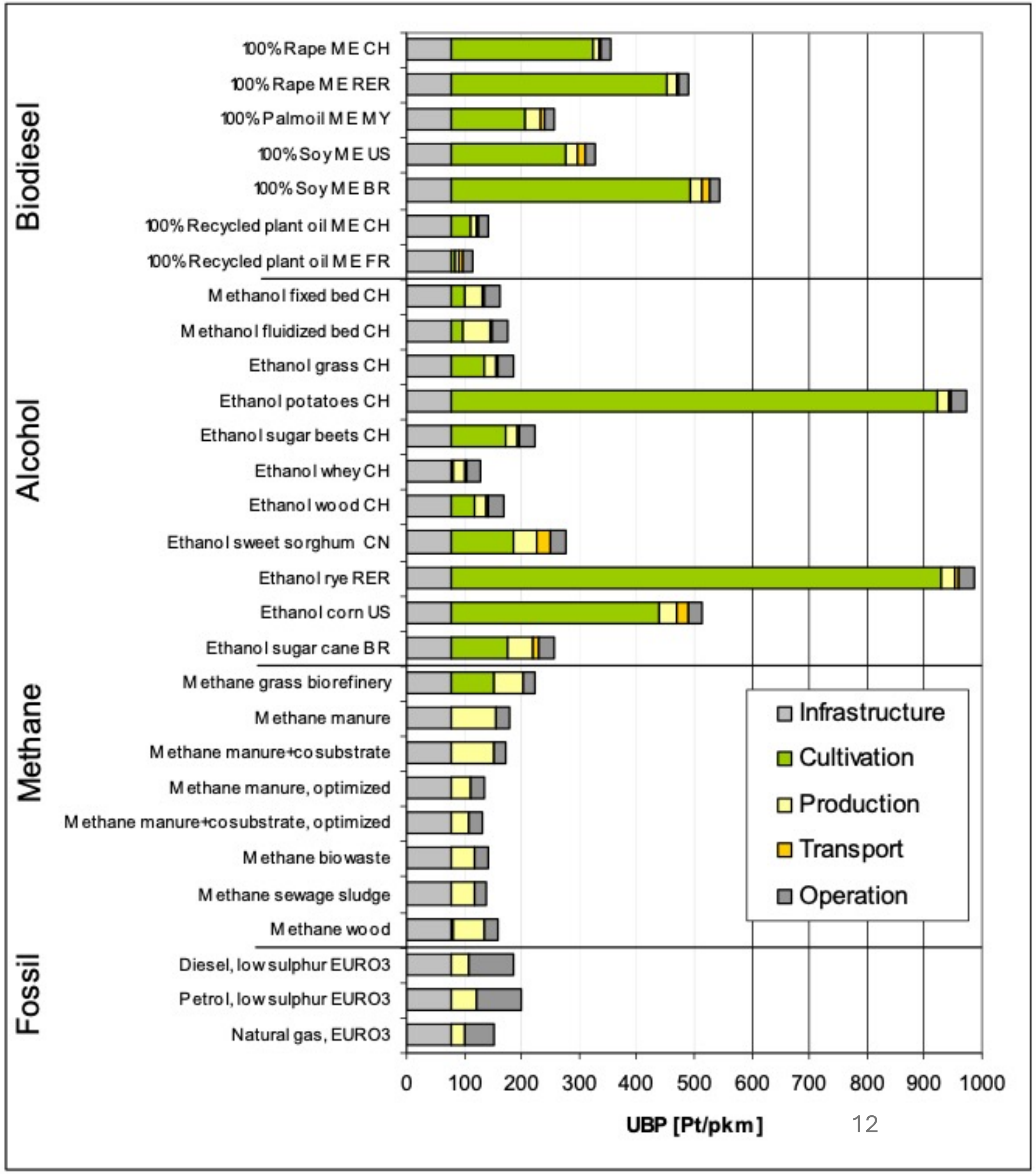
- Greenhouse gas emissions
  - Up to 80% savings are possible
  - Large variation
  - Significant GHG emissions from cultivation
    - Machines
    - Fertilizer and pesticides
    - Direct emissions (e.g. nitrous oxides)
  - No emissions during operation stage (all released CO2 was absorbed during plant growth)



https://www.osti.gov/etdeweb/servlets/purl/21208801

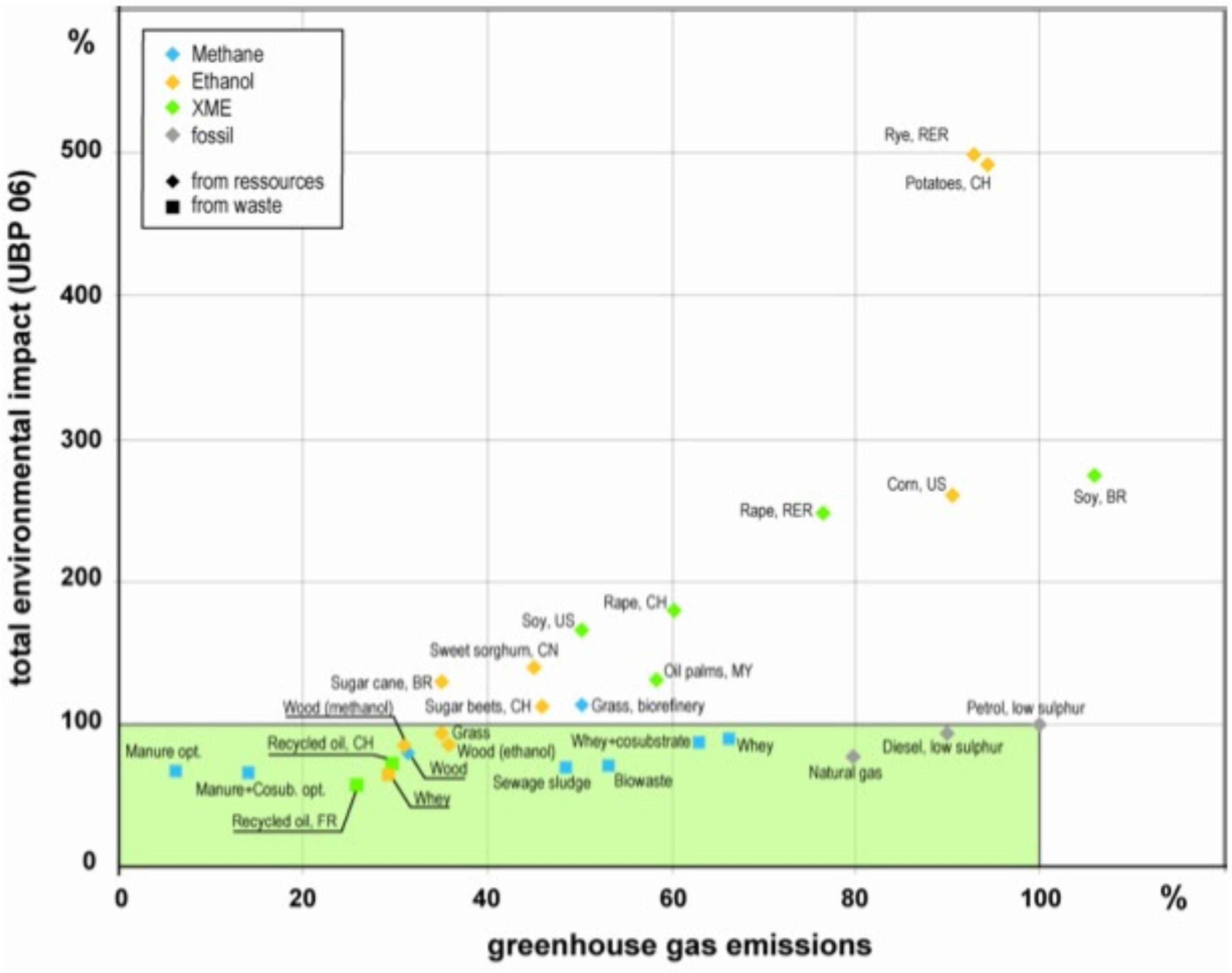
LCA of biofuels vs. fossil fuels

- 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



https://www.osti.gov/etdeweb/servlets/purl/21208801

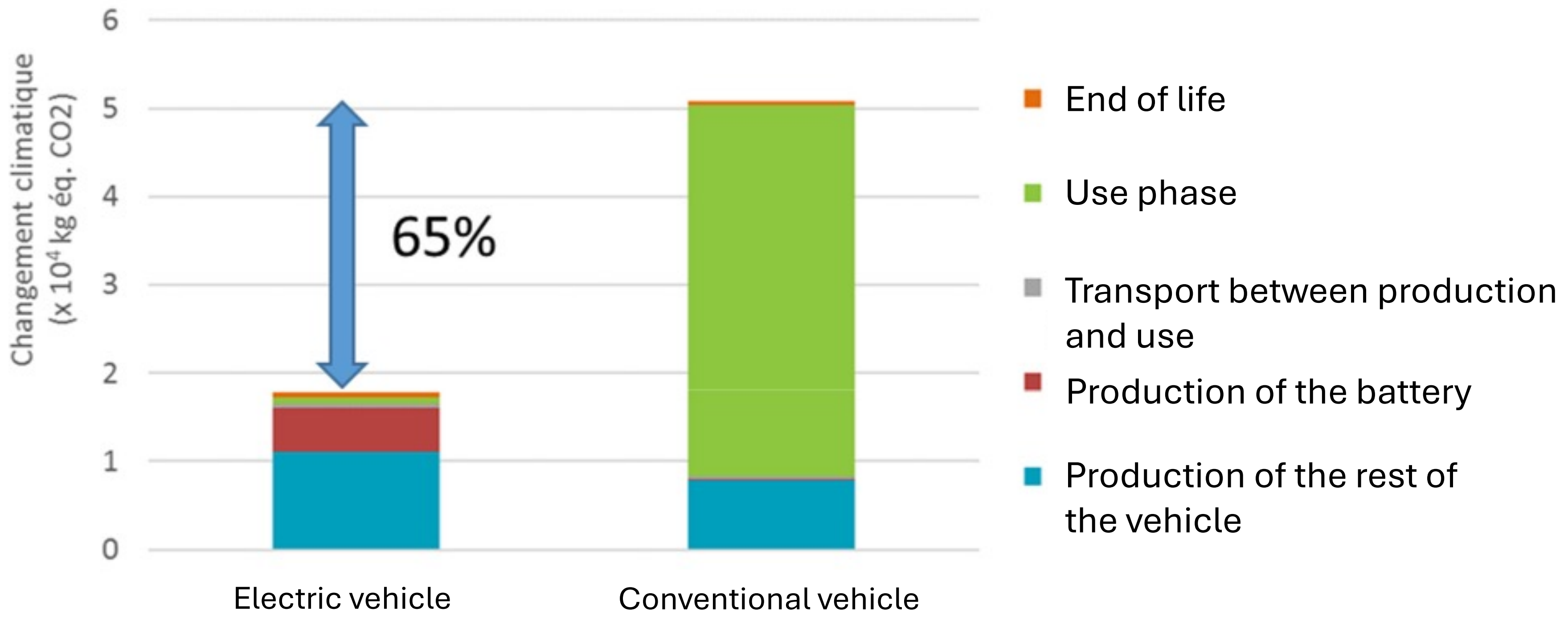
LCA of biofuels vs. fossil fuels



https://www.osti.gov/etdeweb/servlets/purl/21208801

Electric vehicles vs. internal combustion engine vehicles (ICE)

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



vs.

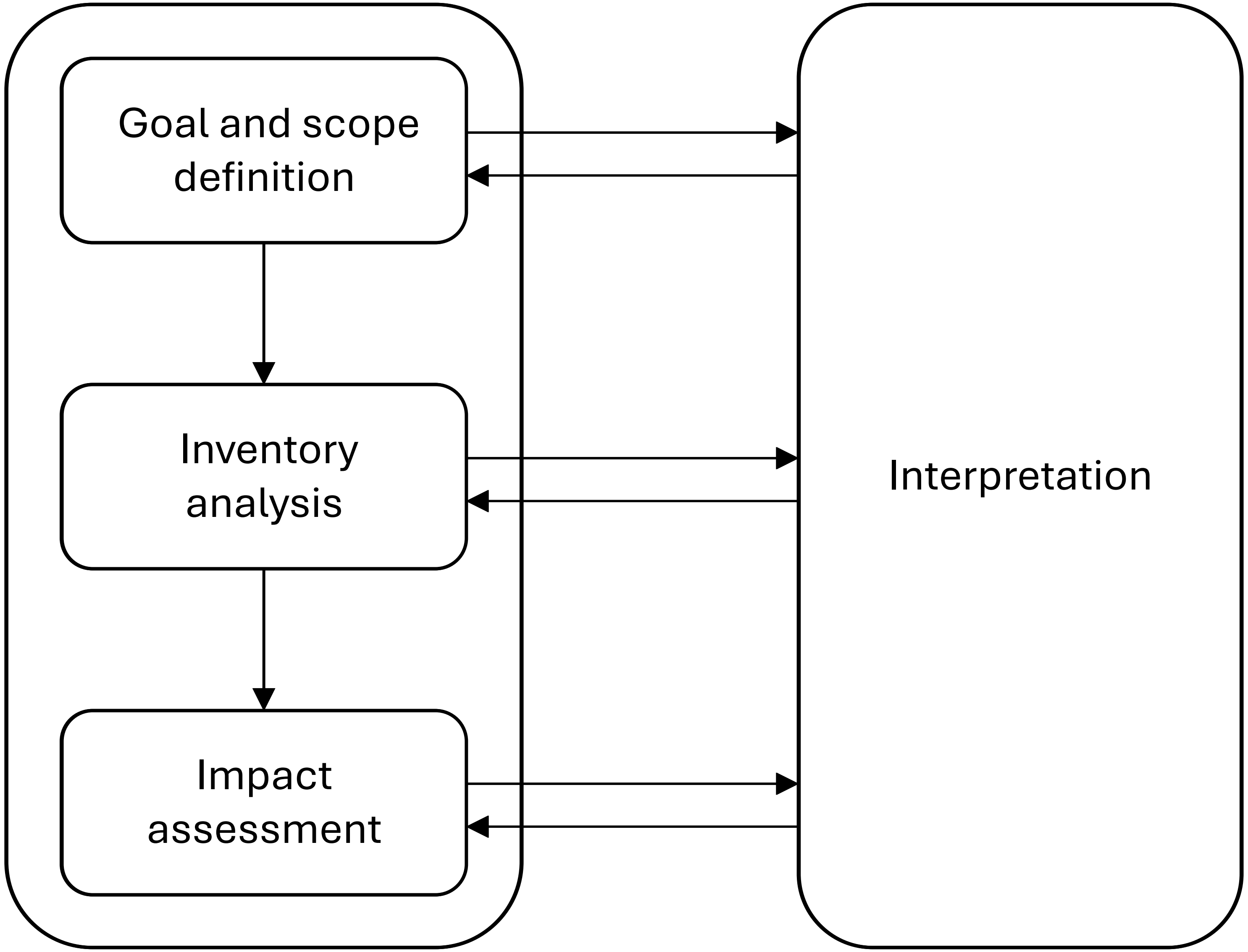
LCA Definition

- 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]

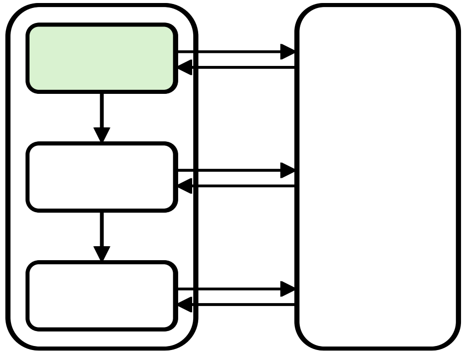
Common LCA Applications

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

LCA Framework



goal and scope



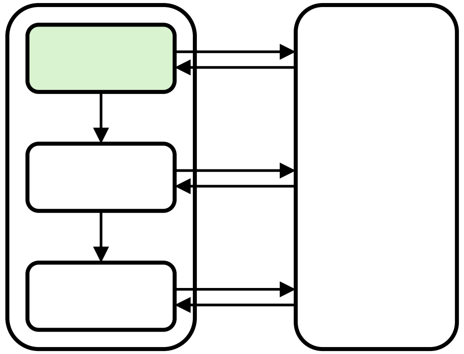
goal and scope

Intended application

Purpose

Intended audience

Whether the results will be used for comparative assertions



vs.

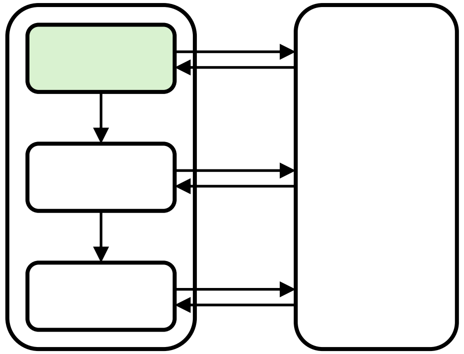
goal
and
scope

Product or service

Function and functional unit

System boundaries

Data requirements / assumptions / limitations

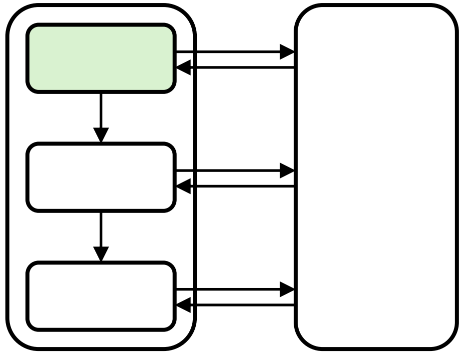


goal and **scope**

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

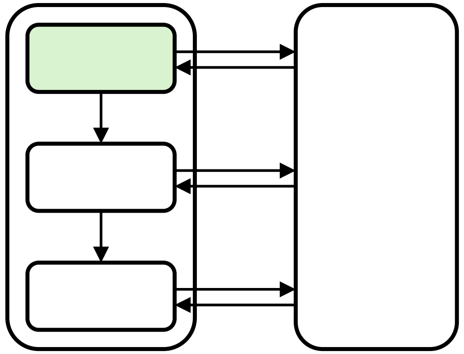


goal
and
scope

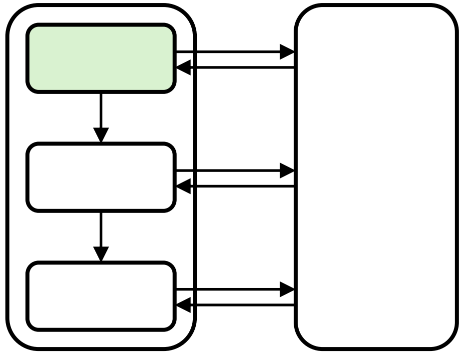
Function and functional unit

vs.

Function	Drying hands
Functional unit	One pair of hands dried through each system



goal
and
scope

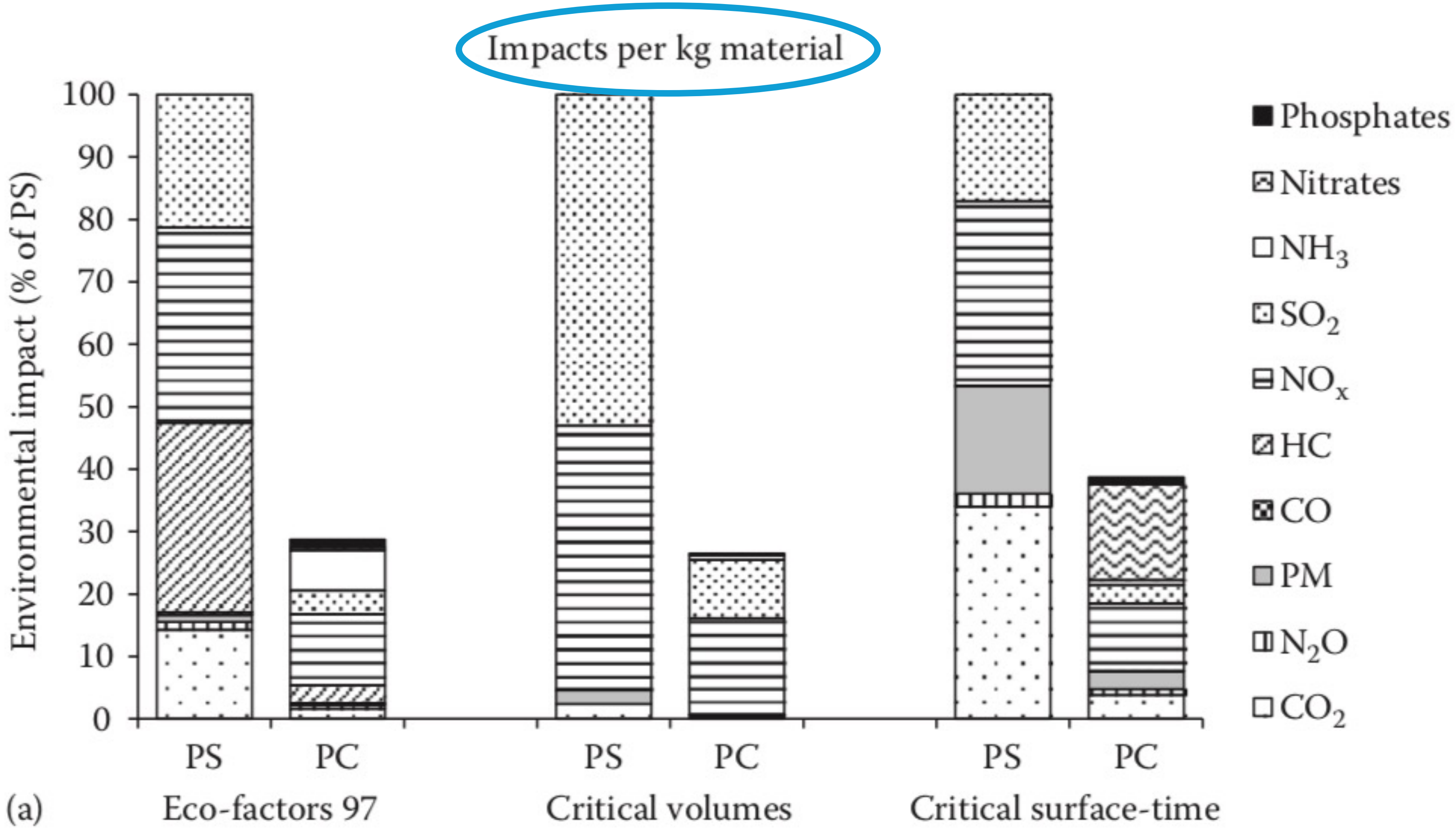


Function and functional unit

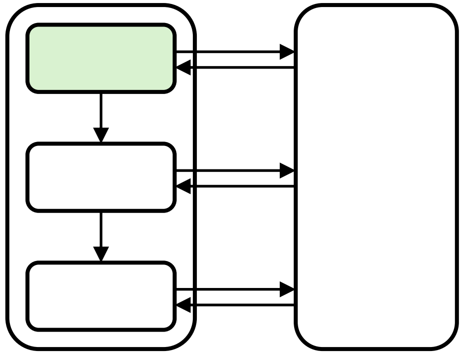
- The functional unit should answer the following questions:
  - What?
  - How much?
  - For how long / how many times?
  - Where?
  - When?
  - With what quality?
- Example: Commute transportation for one person in Lausanne over 5km for one year in 2024

goal and **scope**

Packing "peanuts" vs. real popcorn



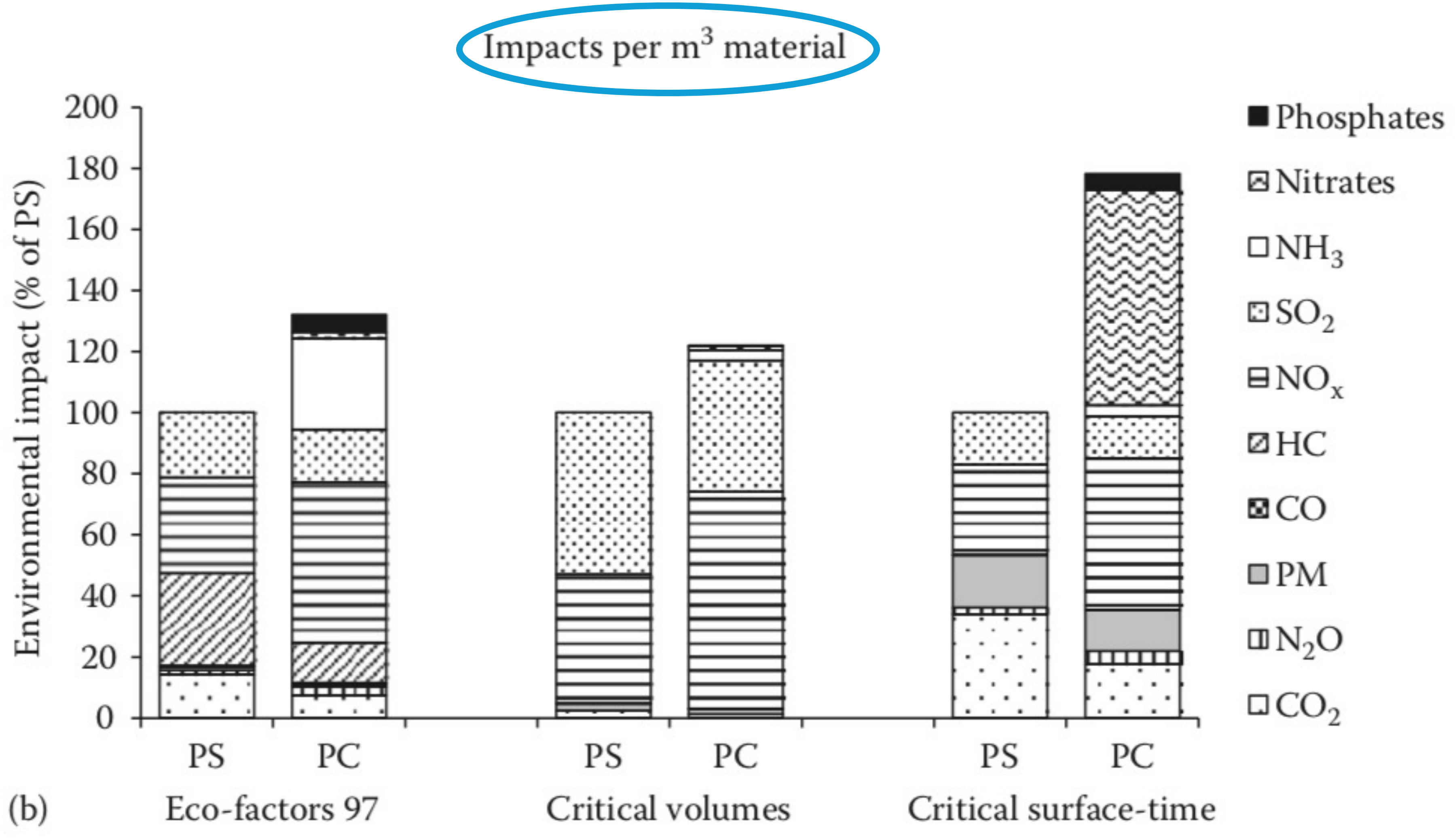
PS: Polystyrene
PC: Popcorn



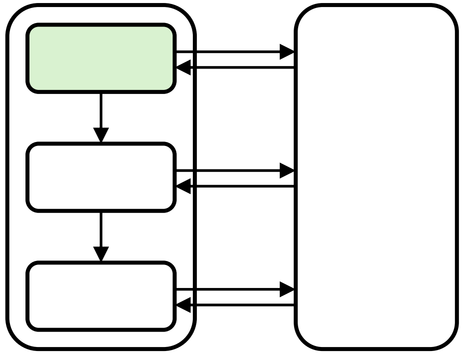
Adapted from Jolliet, O., et al., Agriculture, Ecosystems and Environment, 49, 253–266, 1994.

goal and **scope**

Packing "peanuts" vs. real popcorn

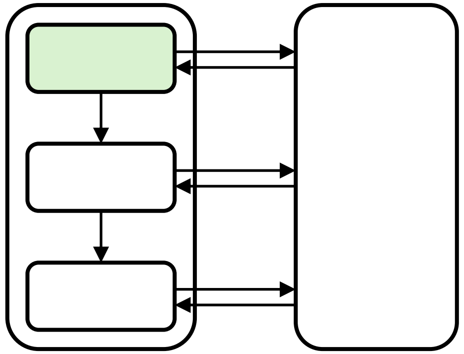


PS: Polystyrene
PC: Popcorn



Adapted from Jolliet, O., et al., Agriculture, Ecosystems and Environment, 49, 253–266, 1994.

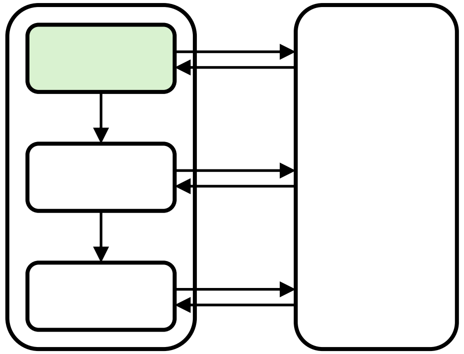
goal
and
scope



Reference flows

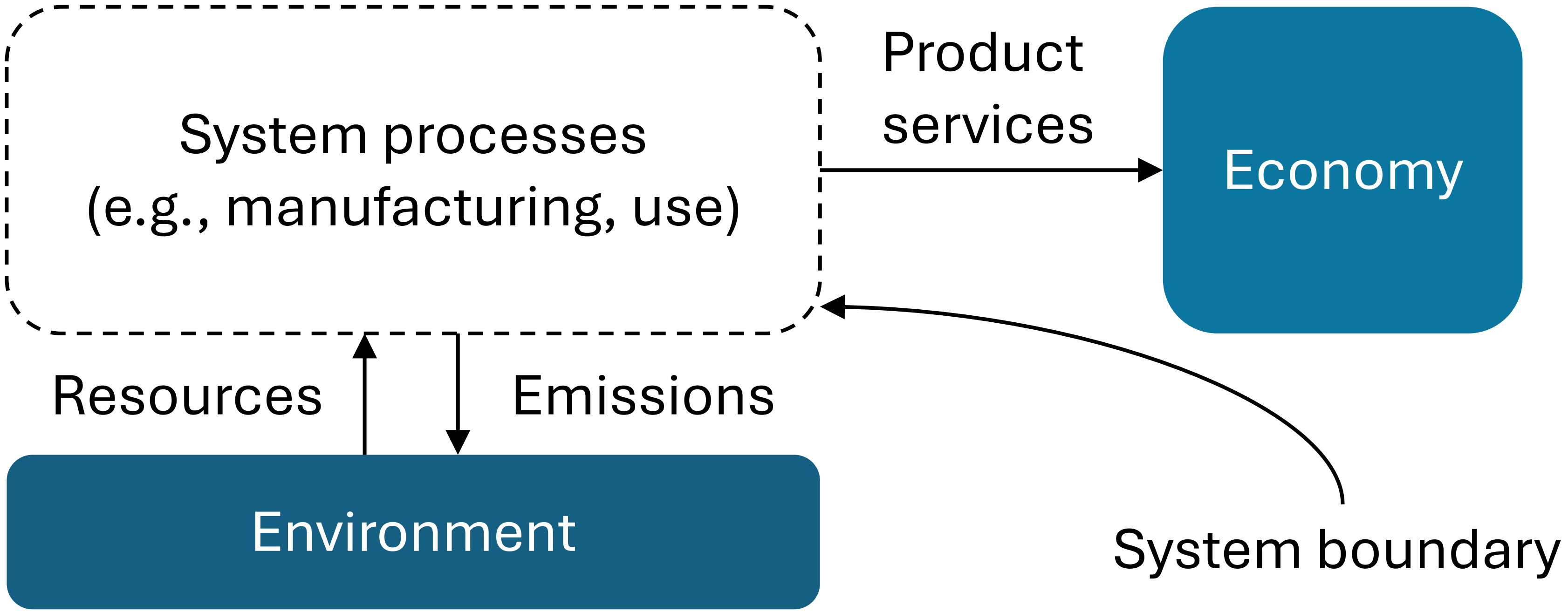
- Quantified amount of product(s) necessary for a specific system to deliver the performance required by the functional unit
- Example:
  - Functional unit: One cup used to consume one cup of coffee once per day for one year
  - Reference flows:
    - Option A: 365 disposable cups
    - Option B: 1 reusable cup; 0.5L of soap; 1kWh energy used to heat water

goal
and
scope



System boundaries

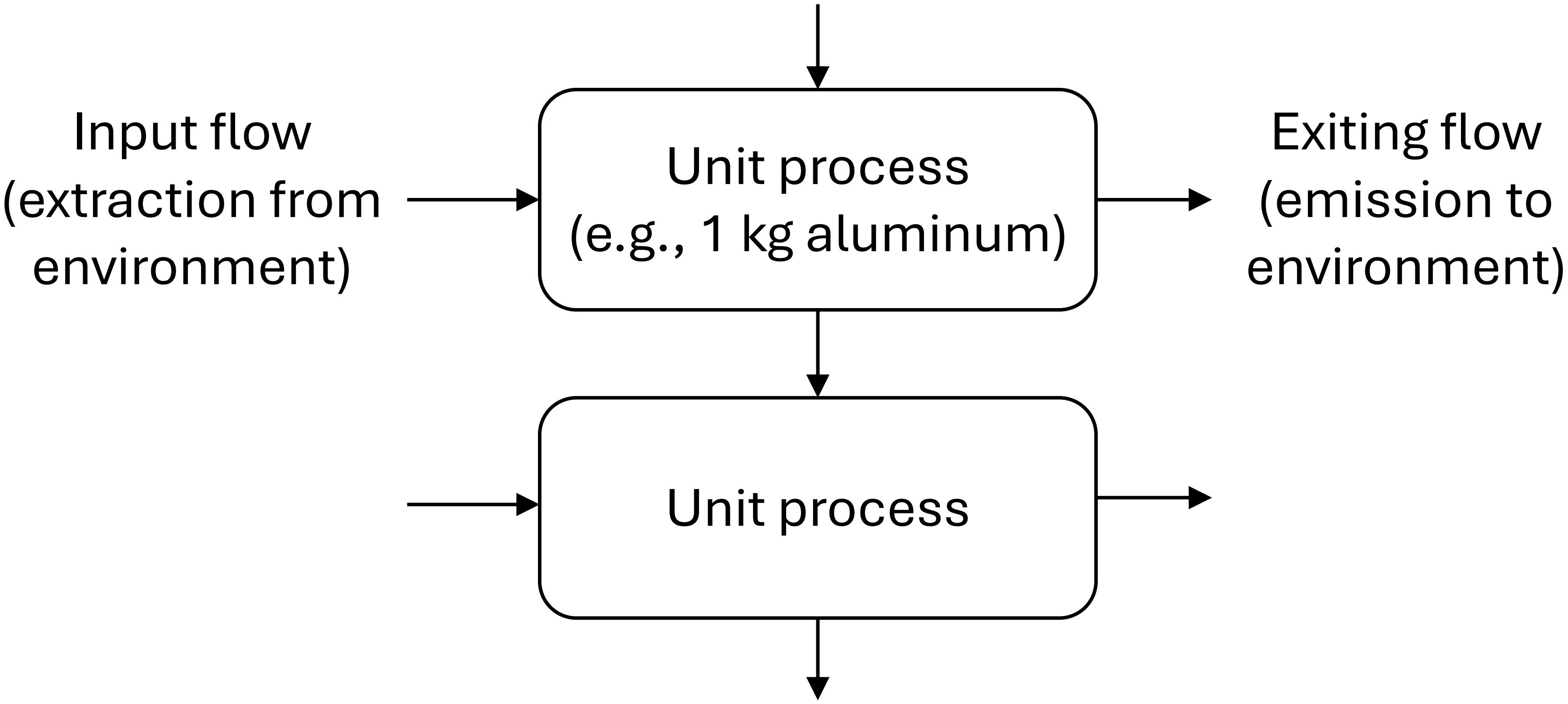
A “complete” LCA

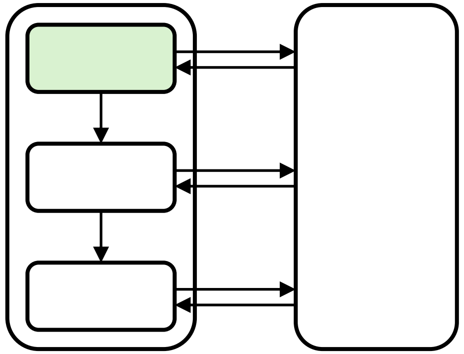


goal
and
scope

System boundaries

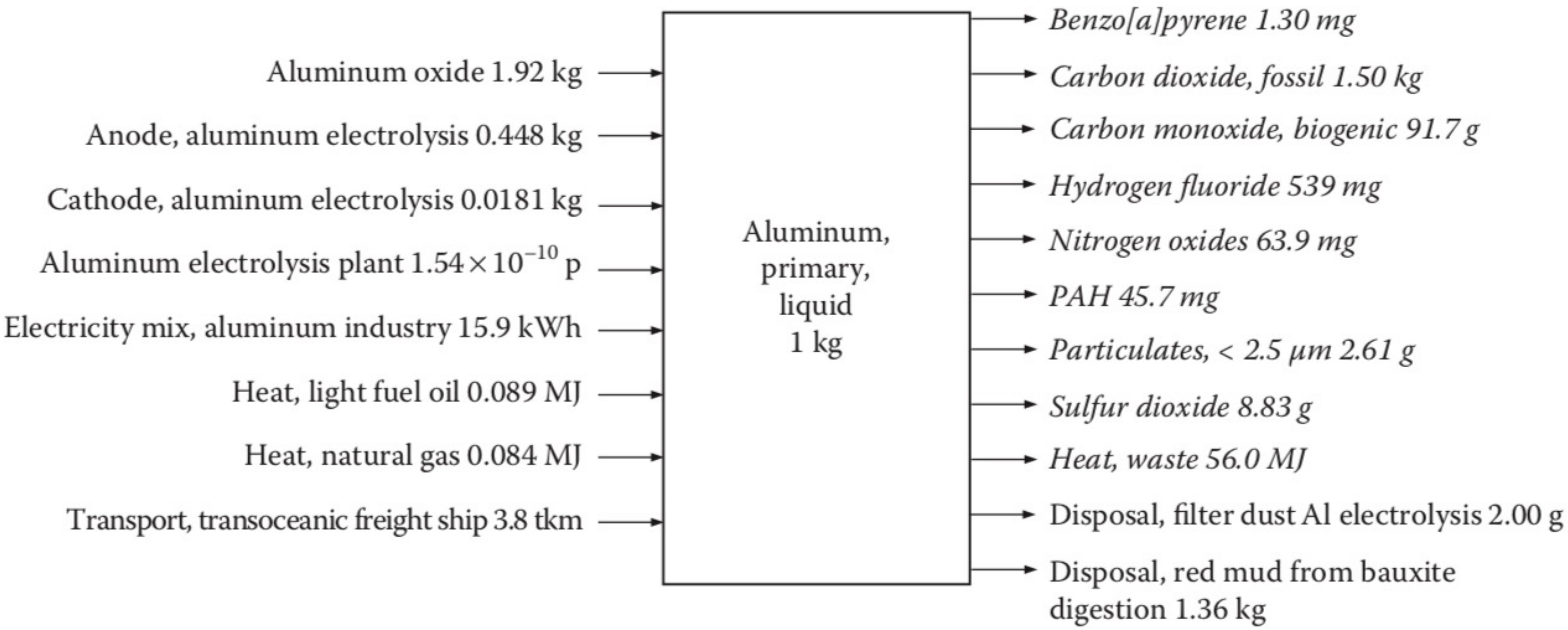
Unit processes (within boundary)

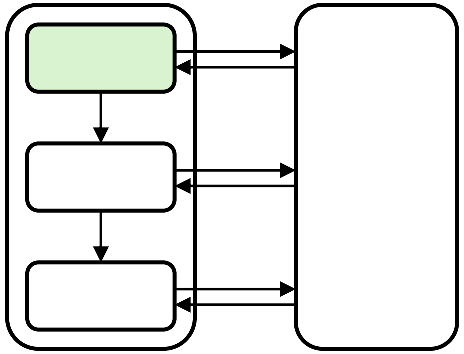




goal and **scope**

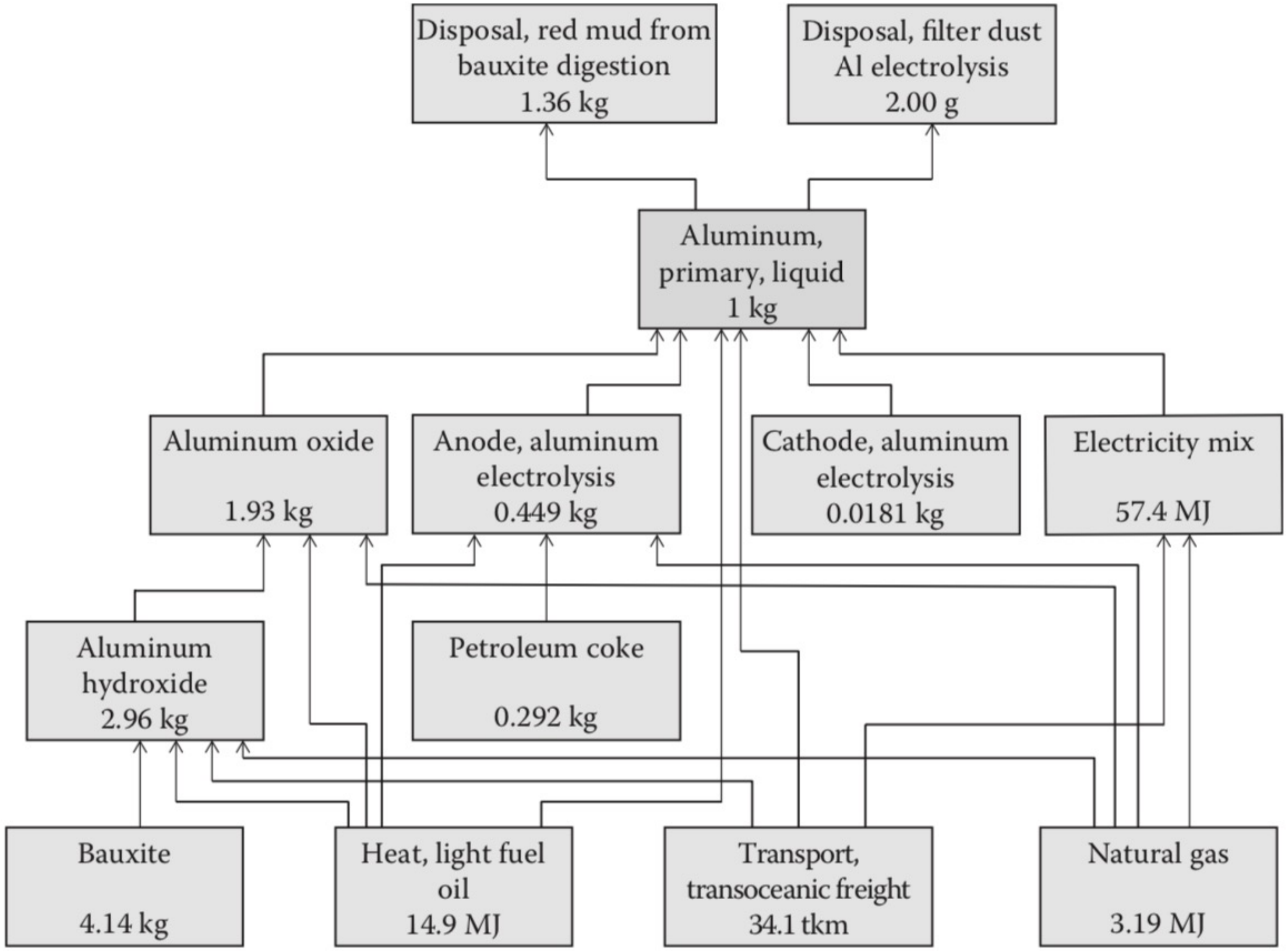
System boundaries

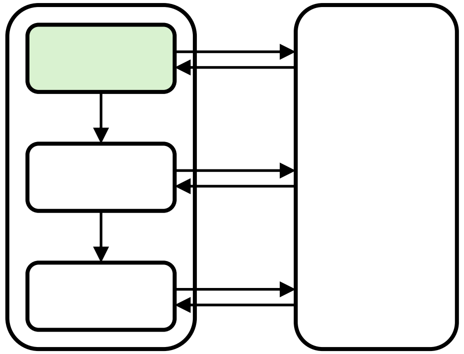




goal
and
scope

System boundaries

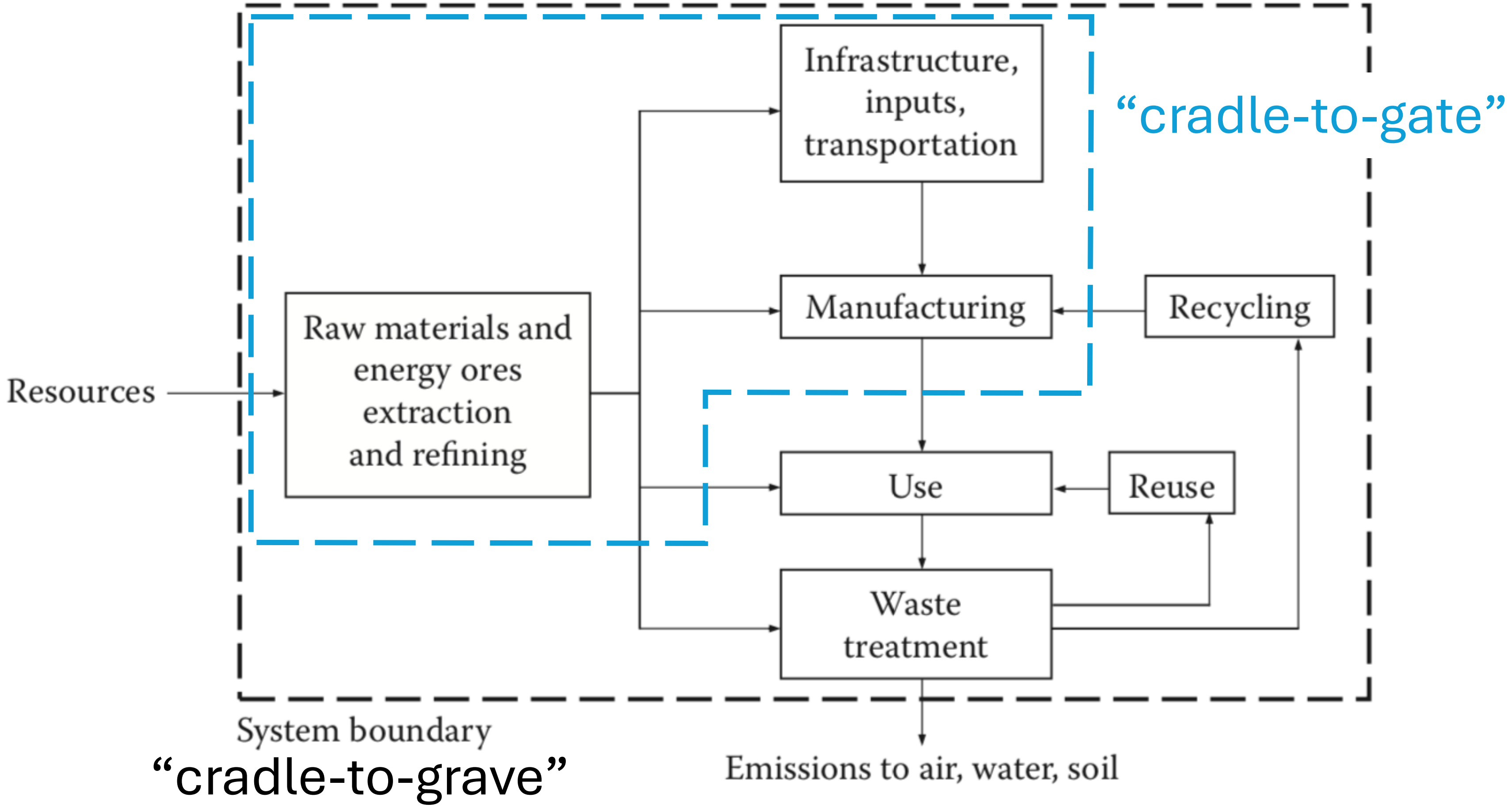


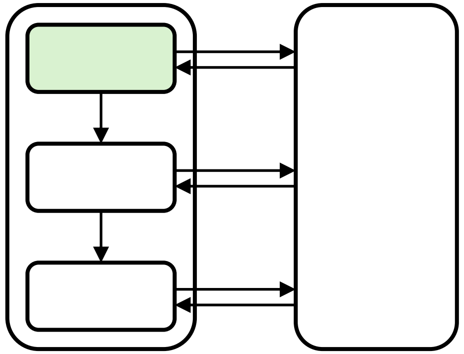


goal
and
scope

System boundaries

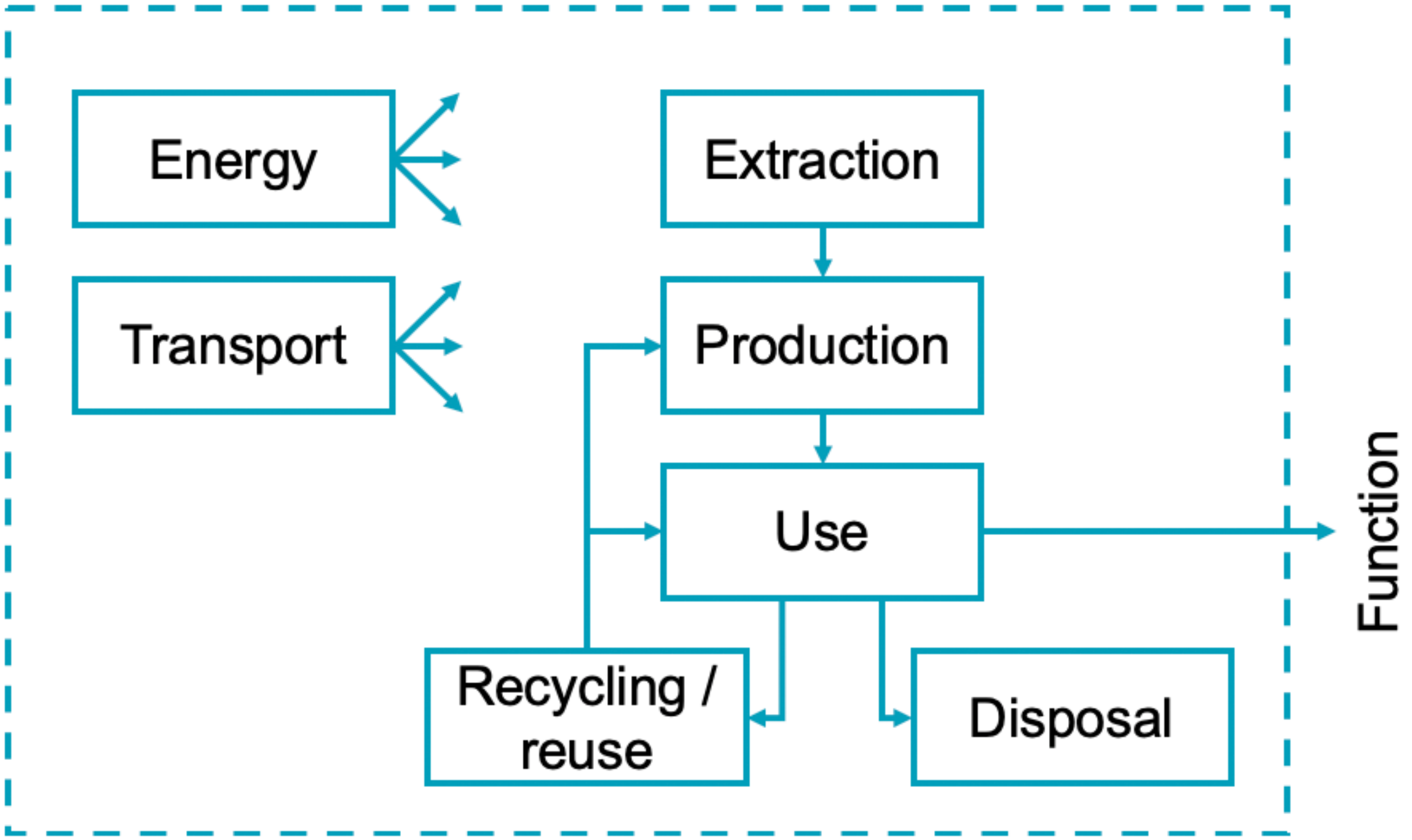
Main processes to consider

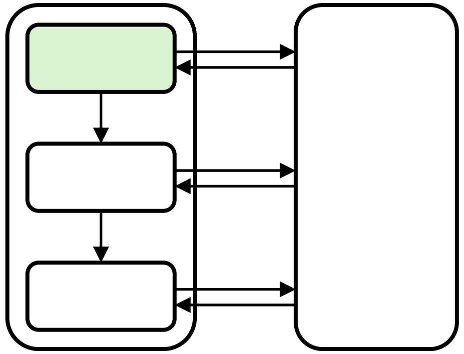




goal and **scope**

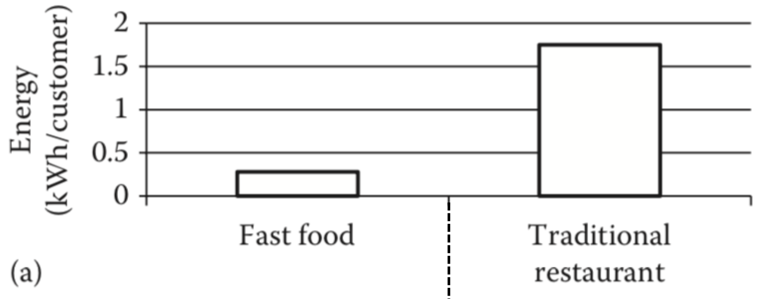
Another perspective





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)

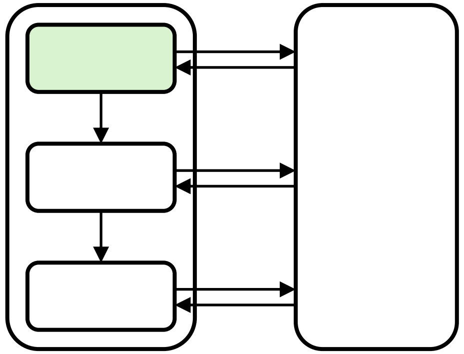
Production chain for reusable dishes

Preparation of food and cooking

Cleaning, heating, and lighting of restaurant (same)

Clean reusable dishes

Management of food and packaging waste

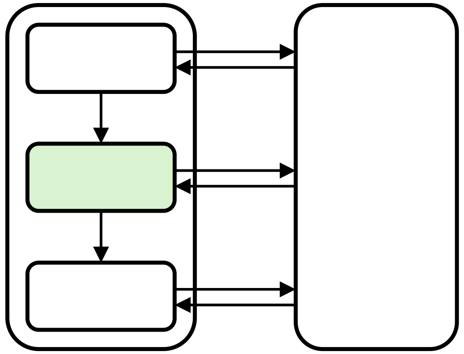


inventory analysis

The goal

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

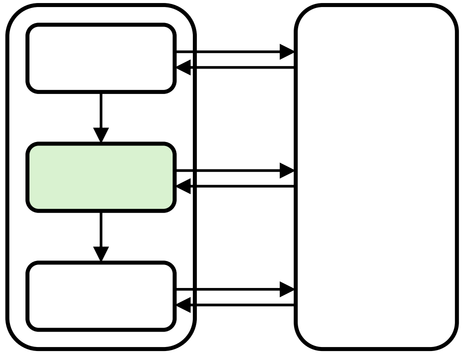
In other words, quantify the total inputs and outputs



inventory analysis

An example

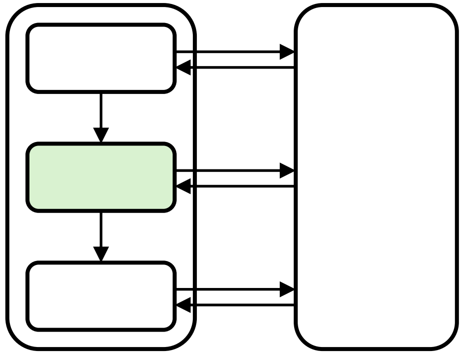
Light bulbs!



inventory analysis

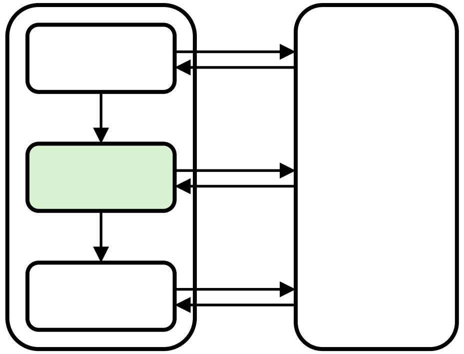
Two approaches

Conventional process-based LCA	**Economic Input-Output LCA (EIO-LCA)**
More common approach, quantifies every step in the identified process	Maps money spent in an entire economic sector (e.g., "iron ores") to environmental impact
Combination of primary data (from manufacturer) and third-party software (Ecoinvent, SimaPro, GaBi)	Carnegie Mellon EIO-LCA tool

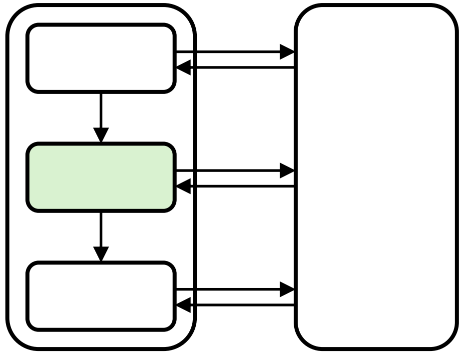


Two approaches

Conventional process-based LCA	Economic Input-Output LCA (EIO-LCA)
The good: compare products within sector	**The good:** fast, complete
The bad: data completeness, process completeness	**The bad:** cannot distinguish within-sector



inventory analysis



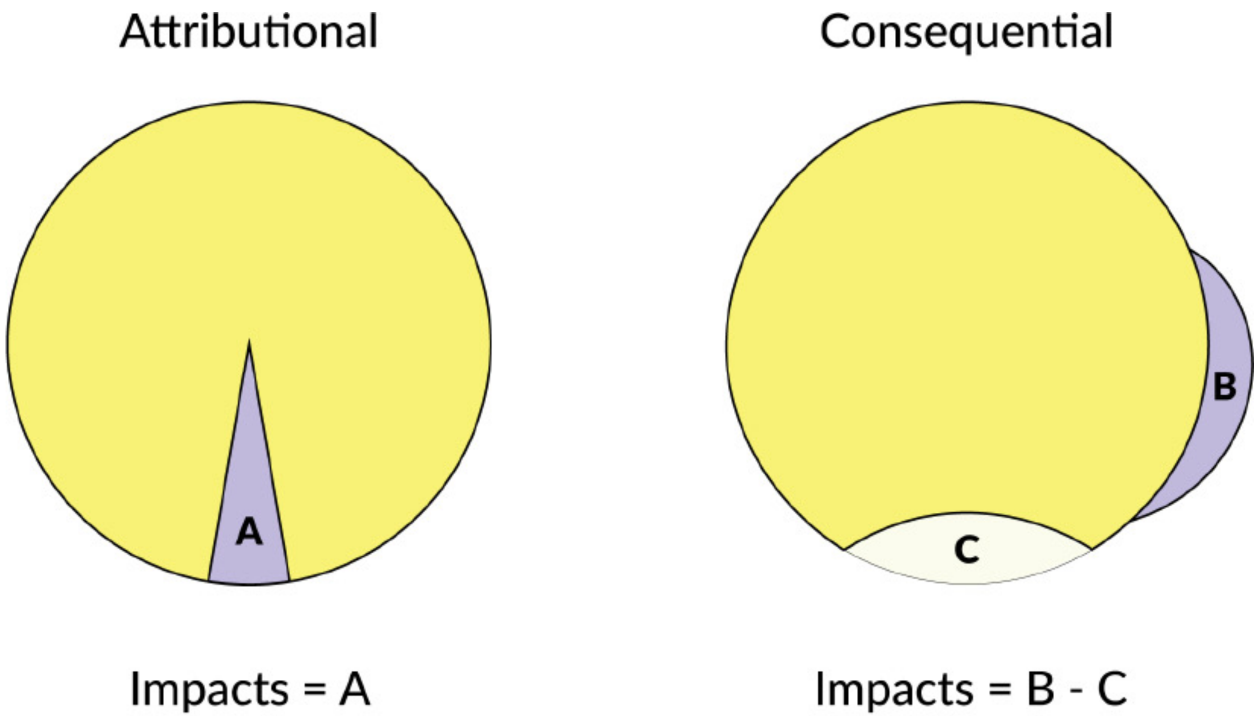
Two approaches

Conventional process-based LCA

Economic Input-Output LCA (EIO-LCA)

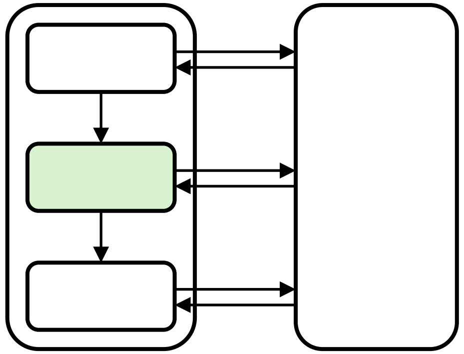
inventory analysis

Attributional vs. Consequential LCA



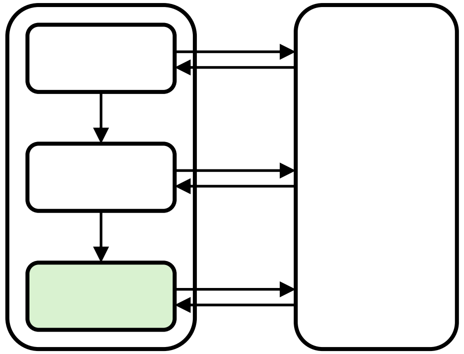
What part of the global environmental burdens should be assigned to the product?

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



National Academies of Sciences, Engineering, and Medicine. 2022. *Current Methods for Life-Cycle Analyses of Low-Carbon Transportation Fuels in the United States*.

impact
assess
-ment



What can we measure?

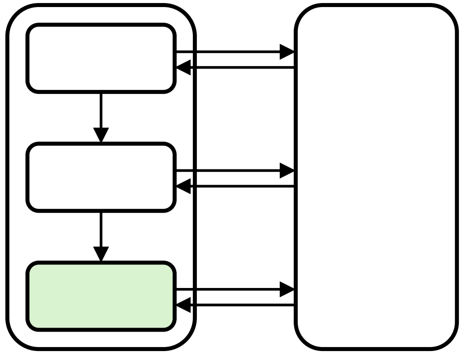
- Greenhouse gas emissions (CO_2 equivalent)
- Others?

impact assess-ment

EPA TRACI

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

- Global warming (CO_2 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

System processes for each scenario

$5kg_{CO2} + 2kg_{methane}$

Resources (e.g. water)

Emissions (e.g. CO_2, methane)

Environment

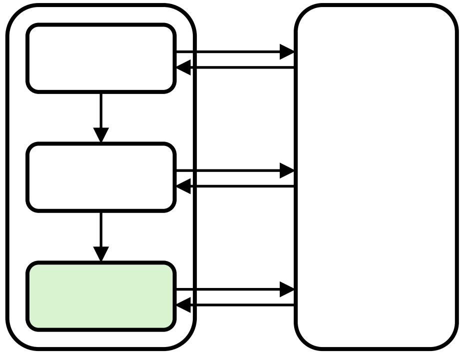
Both contribute to global warming

$1kg_{CO2} = 1kg_{CO2\text{-}eq}$

$1kg_{methane} = 25kg_{CO2\text{-}eq}$

Characterization factors

Example: $5kg_{CO2} + 2kg_{methane} \rightarrow 55kg_{CO2\text{-}eq}$ (Midpoint score)



impact assess -ment

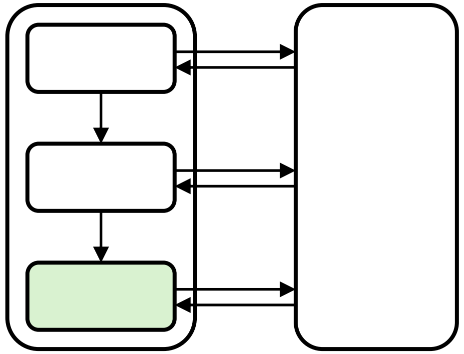
Methodology

Example: $5kg_{CO2} + 2kg_{methane} \rightarrow 55kg_{CO2\text{-}eq}$ (Midpoint score)

What does global warming cause?

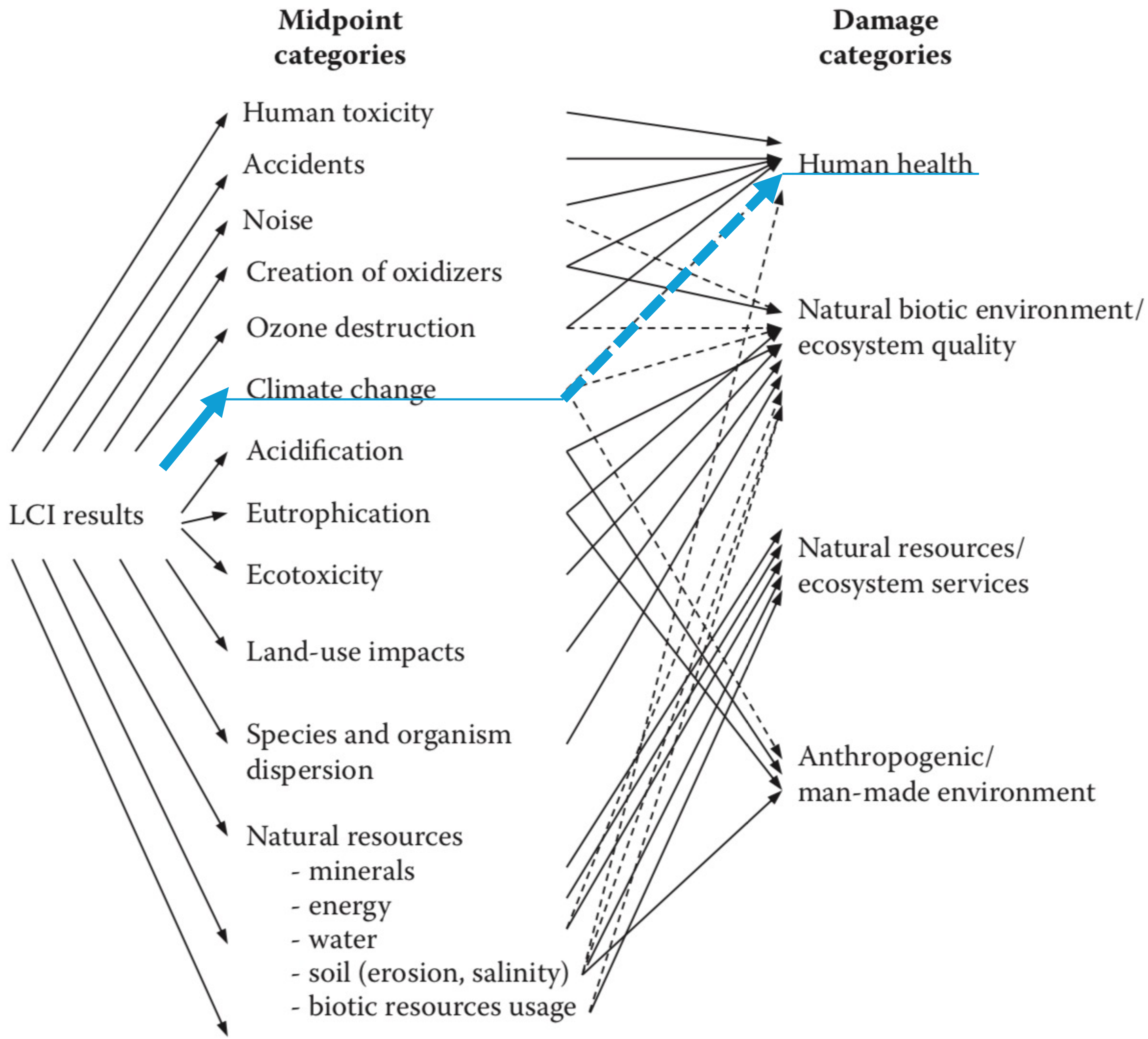
Example: **human health**
Measured through disability-adjusted life years (DALY)

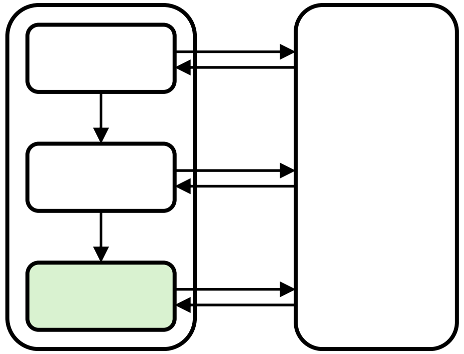
$8.3 * 10^{-7}$ DALY/$kg_{CO2\text{-}eq}$ (*midpoint-to-damage characterization*)



Example: $55kg_{CO2\text{-}eq} * 8.3 * 10^{-7}$ DALY/$kg_{CO2\text{-}eq}$ = 0.00005 DALY

impact assess -ment



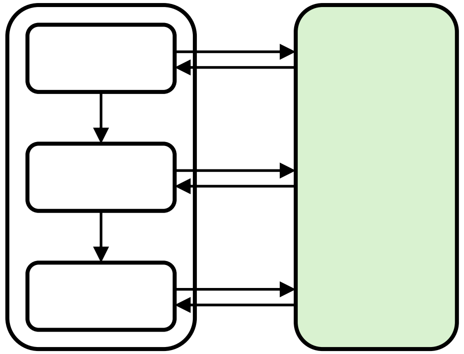


Example:

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

impact assessment framework

interpret
-ation



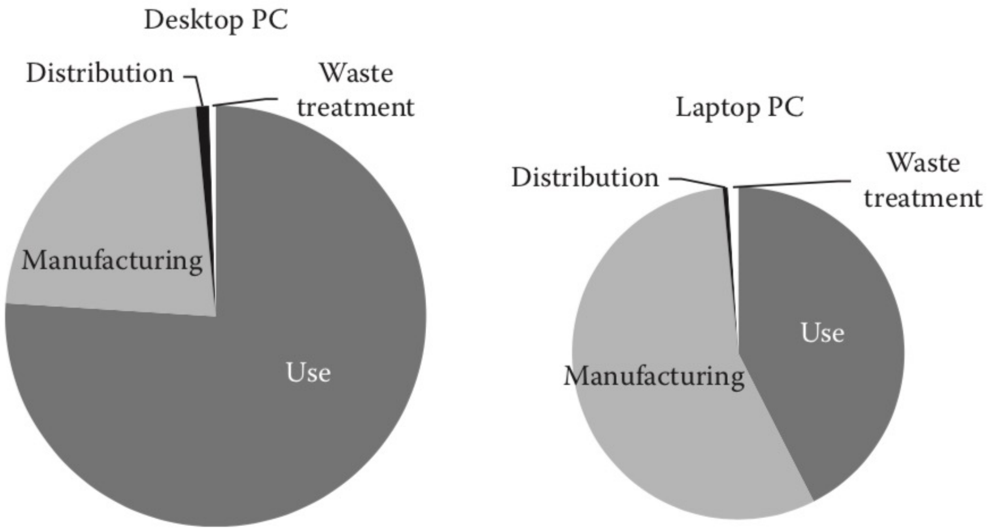
Goals

Done at each step

Identify areas of intervention

Quality control

Quantify sensitivity/uncertainty



embodied energy

interpret
-ation

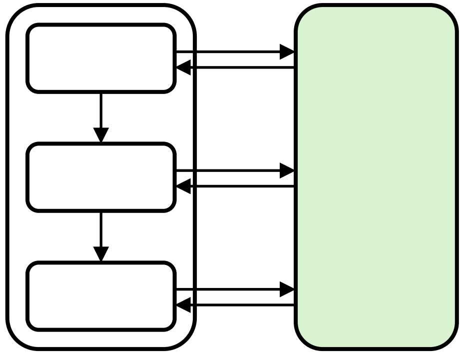
Sensitivity analysis

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

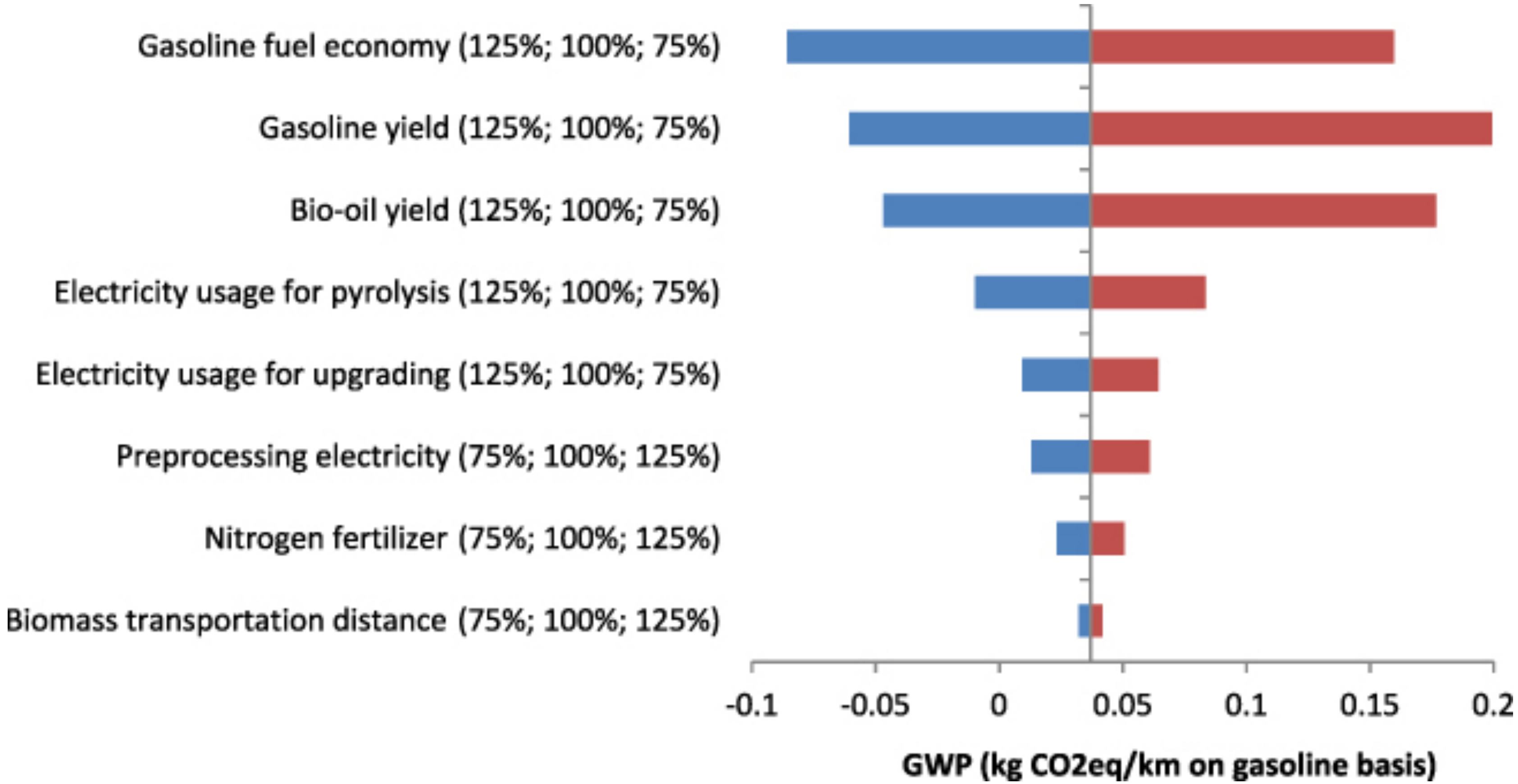


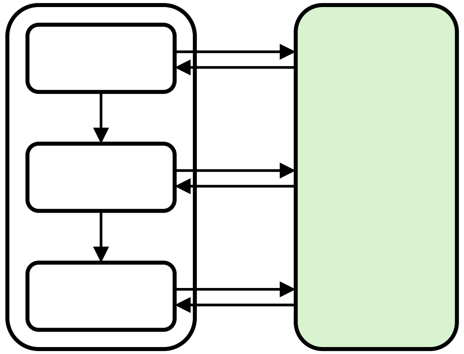
https://iopscience.iop.org/article/10.1088/1748-9326/8/2/025001

interpret
-ation

Sensitivity analysis

hydrogen and transportation fuels from corn LCA





https://iopscience.iop.org/article/10.1088/1748-9326/8/2/025001

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