UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

unite! MSCA Energy

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Life cycle assessment (LCA)

Sustainability course Unite!Energy

2025/2026 Academic Course

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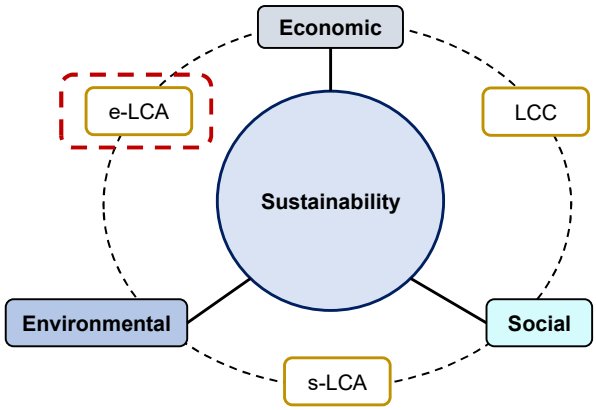
Contents

1. General context

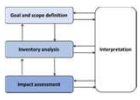


- **Environmental life cycle assessment** (LCA) is a methodology to assess the environmental performance of a product throughout its entire life cycle
- This methodology is based on the ISO 14040 and 14044

1. General context

Framework

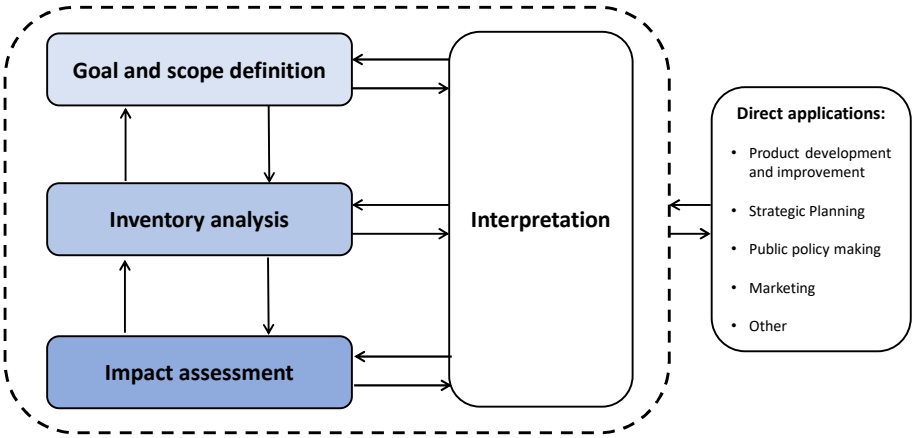
ISO 14040:2006. LCA. Priniciples and framework
ISO 14044:2006. LCA. Requirements and guidelines



ISO 14046:2014. Water footprint
ISO 14067:2018. Carbon footprint of products

2. LCA methodology: stages

LCA stages



Source: ISO 14040

2. LCA methodology: goal and scope definition

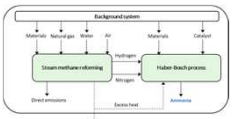
Goal and scope

Goal

Intended application
Expected recipient
Final use of the results

Scope

Functions of the product system
Functional unit
Product system
System boundaries
Methodology description
Hypothesis
Limitations



2. LCA methodology: goal and scope definition

Functional unit

- The **functional unit** is the *quantified performance of a product system* used as a reference for all calculations
- All inputs and outputs in the system are normalized to this unit

Function of a system: Importance to compare based on functionality and not on a product unit

1. Function: "Deliver electricity to a community"

2. Functional unit: "Delivery of 100,000 kWh of electricity to a community under specified conditions"

3. Reference flows
- Option A: PV modules surface area of 330 m^2
- Option B: PV modules surface area or 270 m^2

For the same functional unit, higher efficiency reduces the reference flow (required panel area)

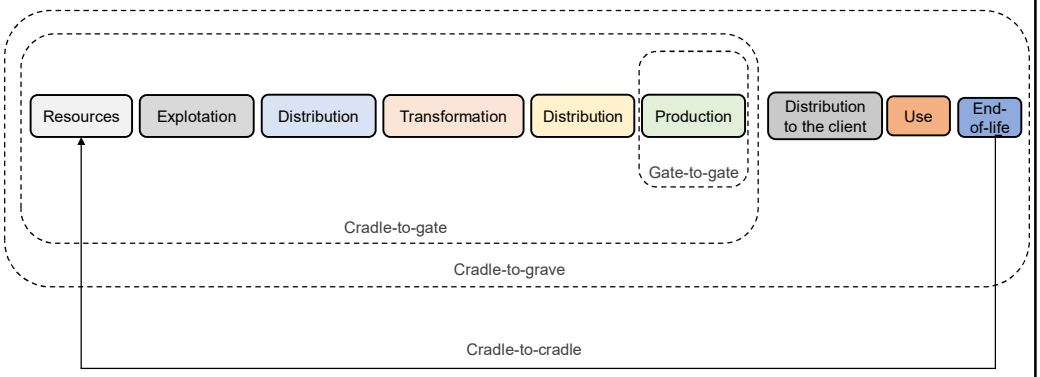
Panel A
η = 20%
A= 330 m^2

Panel B
η = 25%
A= 270 m^2

100,000 kWh of electricity

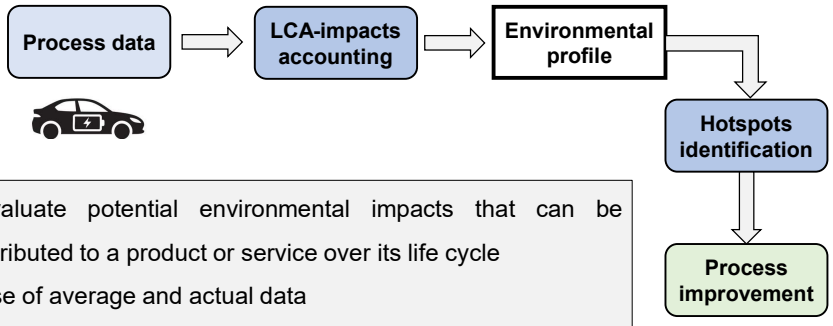
2. LCA methodology: goal and scope definition

System boundaries



2. LCA methodology: goal and scope definition

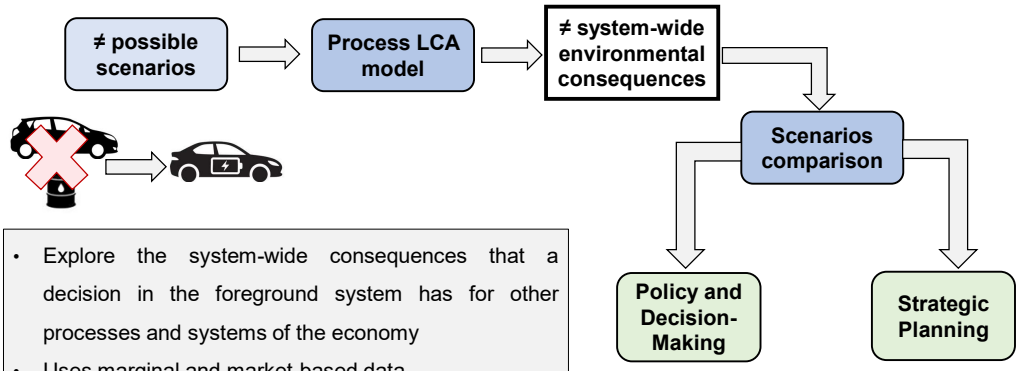
Attributional LCA



- Evaluate potential environmental impacts that can be attributed to a product or service over its life cycle
- Use of average and actual data
- Answer the question “what is?”
- Example: what are the GHG emissions associated with constructing one electric car?

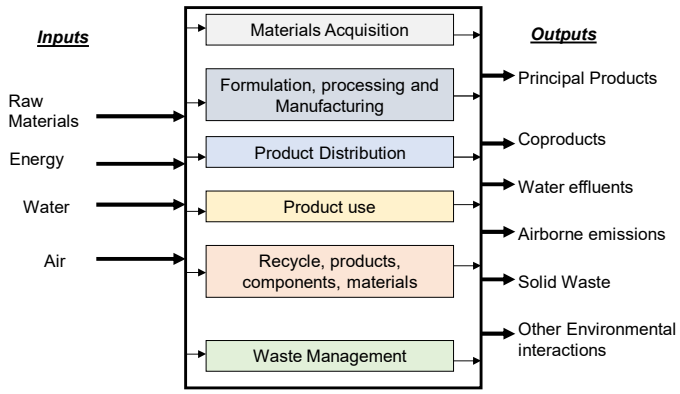
2. LCA methodology: goal and scope definition

Consequential LCA



- Explore the system-wide consequences that a decision in the foreground system has for other processes and systems of the economy
- Uses marginal and market-based data
- Answer the question “what if?”
- Example: what happens to global GHG emissions if the demand for electric cars increases?

2. LCA methodology: inventory analysis



2. LCA methodology: inventory analysis

Data collection for unit process

- Input and output *product flows* →
- *Elementary flows* from or to the environment →

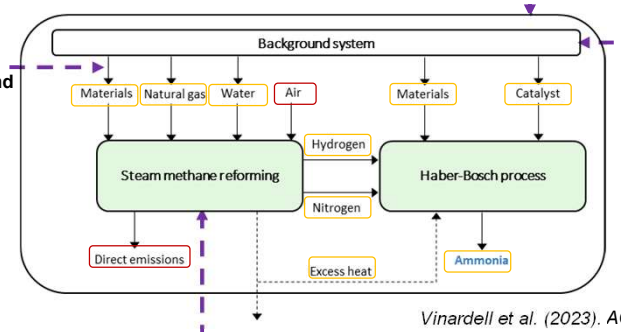
Product system

System boundaries

ecoinvent

Background data

Foreground data



Foreground system: The core processes under the direct control or influence of the decision-maker, modelled using primary data

Background system: The upstream and downstream processes that support the foreground system, modelled using secondary data from generic databases.

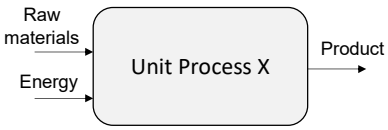
Vinardell et al. (2023). ACS Sustainable Chemistry & Engineering, 11, 44, 15975–15983
https://doi.org/10.1021/acssuschemeng.3c04694

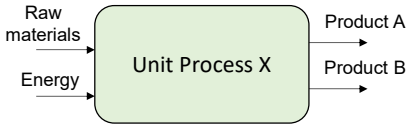
Unit process

Smallest element considered in the life cycle inventory analysis for which input and output data are quantified.

2. LCA methodology: inventory analysis

Inventory Analysis: The multifunctionality problem



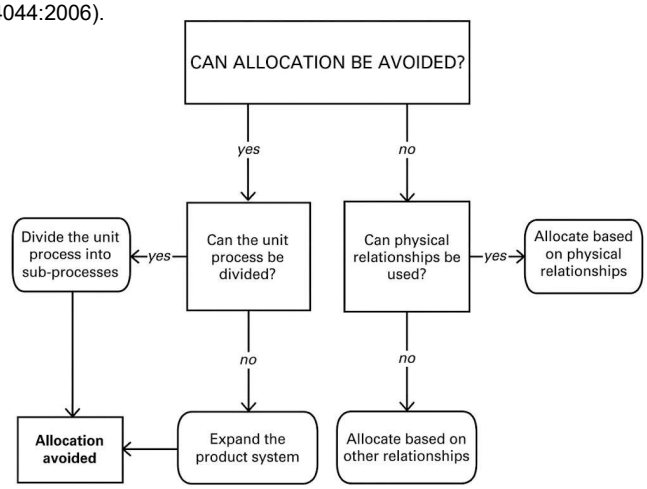


Multi-output process

2. LCA methodology: inventory analysis

Multifunctionality: Allocation or system expansion?

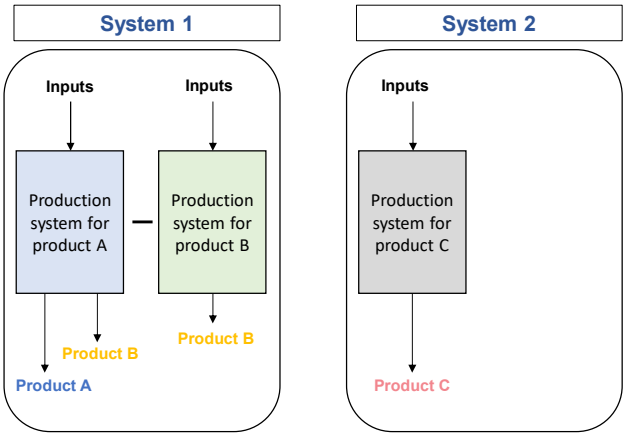
ISO 14044 states: Wherever possible, allocation should be avoided by dividing the unit process into subprocesses or by expanding the product system to include the additional functions related to the co-products (ISO 14044:2006).



2. LCA methodology: inventory analysis

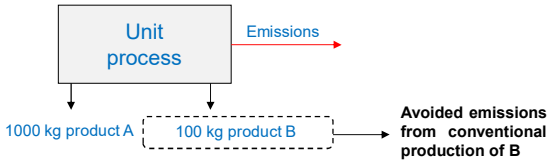
Multifunctionality: System Expansion

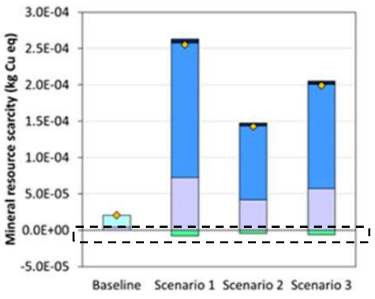
ISO 14040/14044



2. LCA methodology: inventory analysis

Multifunctionality: System expansion



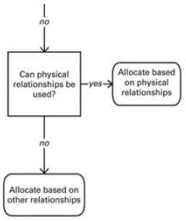


Vinardell et al. (2023). ACS Sustainable Chemistry & Engineering, 11, 44, 15975–15983
https://doi.org/10.1021/acssuschemeng.3c04694

2. LCA methodology: inventory analysis

Multifunctionality: Allocation Co-products

ISO 14044 states: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects relevant underlying physical relationships between them (ISO 14044:2006).

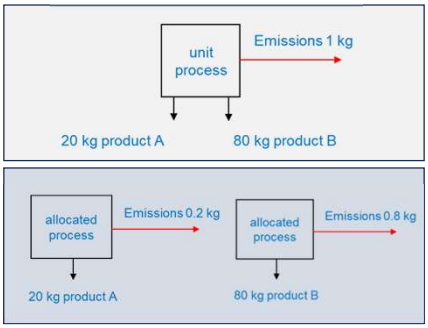


Allocation based on physical relationships:

- Mass, volume or energy are common ways to decide based on physical relationships

When no physical relationships exists between outputs:

- Allocation based on economic value is a common choice



2. LCA methodology: inventory analysis

Multifunctionality: Reuse and recycling

Recycling and reuse processes in LCA deals with two important aspects

- The recycling/reuse process features environmental impacts
- The use of recycled material avoids the use of primary material (similar to system expansion)

Which product takes on these impacts/avoided impacts?

- The one being disposed of?
- The one being produced?

Cut-off approach

- The first product system only bears burdens until the waste leaves the system
- Recycling burdens are fully assigned to the next product system.
- Recycled material enters the new system "burden-free."

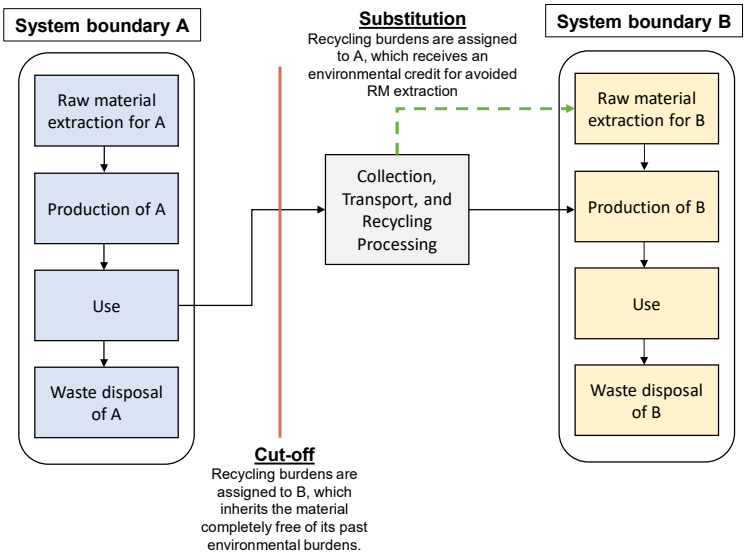
Substitution/avoided burden (system expansion)

- The first product system bears the recycling burdens but also gets a credit for avoiding production of virgin material in the next system

2. LCA methodology: inventory analysis

Multifunctionality: Reuse and recycling

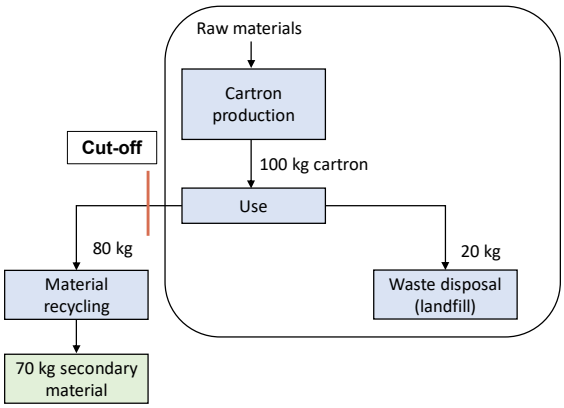
ISO 14040/14044



2. LCA methodology: inventory analysis

Modelling of recycling and waste disposal of a product

ISO 14040/14044



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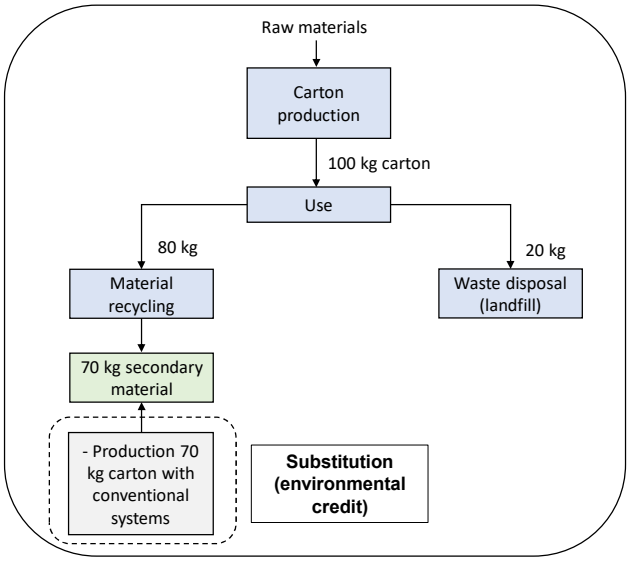

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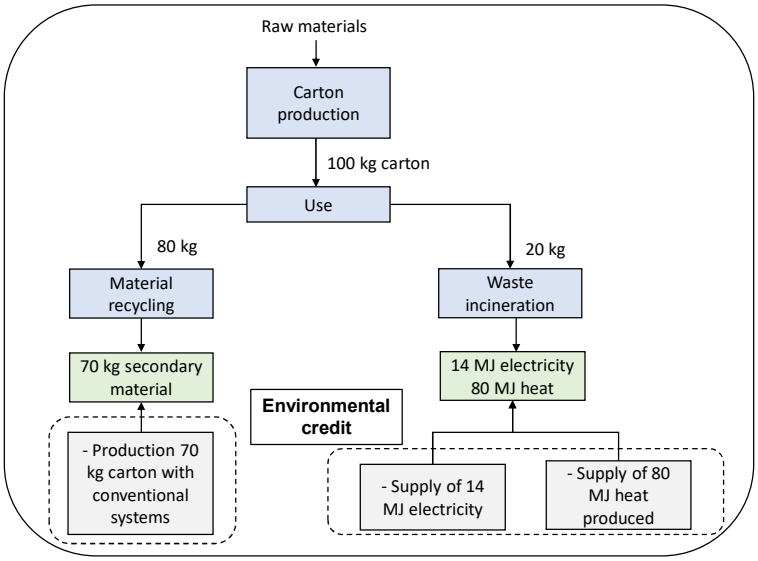
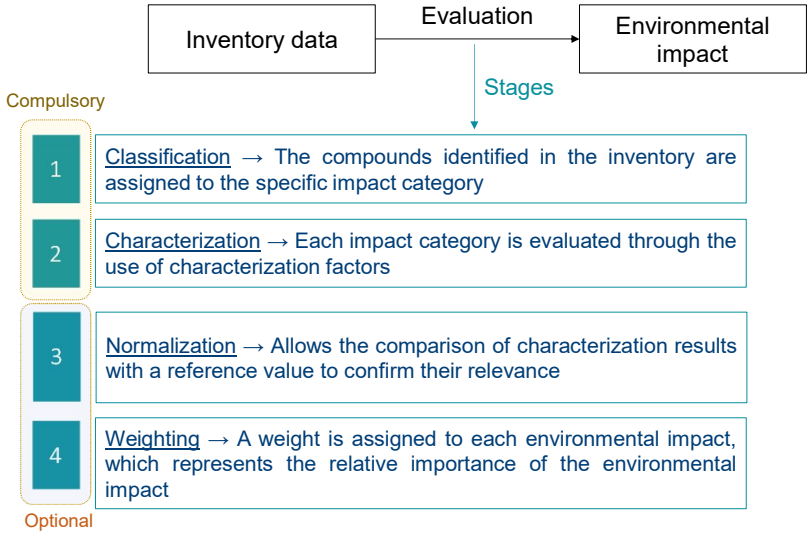
Modelling of recycling and waste disposal of a product

ISO 14040/14044



2. LCA methodology: impact assessment



2. LCA methodology: impact assessment

Impact Assessment Methods

Endpoint methodology

Damage-oriented methods

Evaluation method most used: *Eco-indicator or ReCiPe*

→ This method allows analysing the last effect of the environmental impact (*endpoints*)

Midpoint methodology

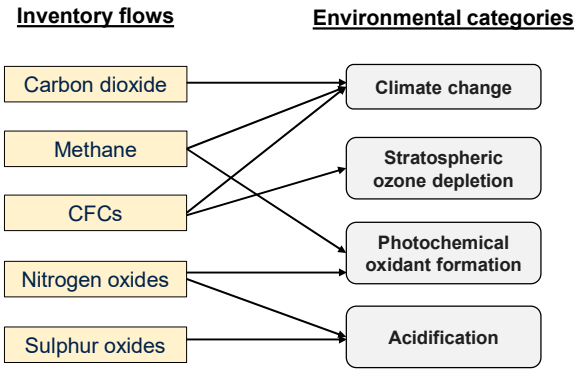
Quantitative modeling before the end of the impact

Evaluation method most used: *CML or ReCiPe*

→ This method allows evaluating the the intermediate effects (*midpoints*) of an impact category

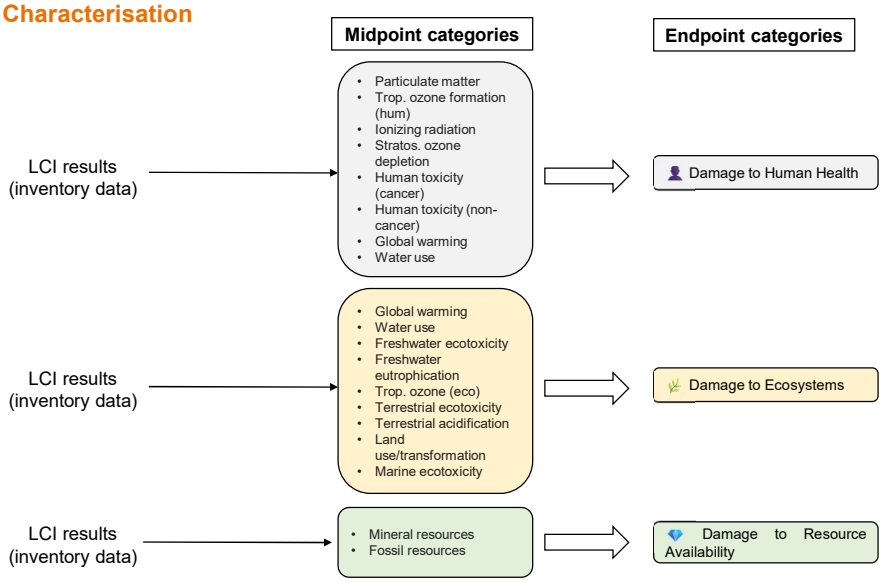
2. LCA methodology: impact assessment

Classification



2. LCA methodology: impact assessment

Characterisation



2. LCA methodology: inventory analysis

Quantification of environmental burdens

Environmental burdens are quantified for each subsystem of the supply chain according to the formula

$$B_j = \sum_{i=1}^{i} bc_{j,i} x_i$$

Where $bc_{j,i}$ is burden j from activity i and x_i is a mass or energy flow associated with that activity

Example of calculation for global warming:

Global Warming Potential (GWP): measure for Global Warming in terms of radiative forcing of a mass-unit

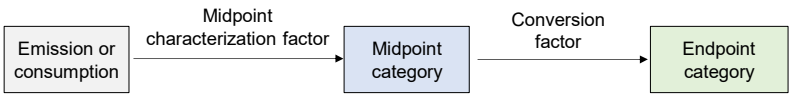
1 kg CO_2 (GWP = 1) + 0,6 kg CH_4 (GWP = 28)

= 1 x 1 + 0,6 x 28 kg CO_2-equivalents = 17,8 kg CO_2-eq

2. LCA methodology: impact assessment

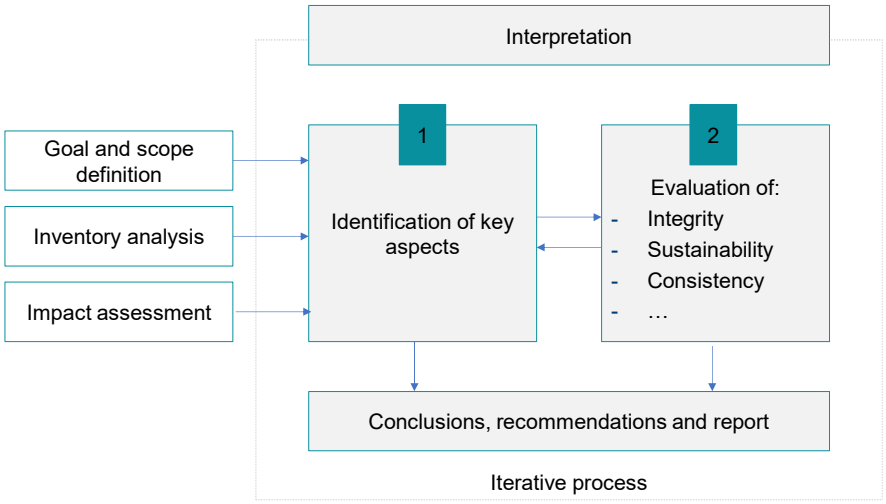
Recipe LCIA method

18 Midpoint indicators
3 Endpoint indicators



Cultural perspective	Time Horizon	Philosophy	Required Evidence
Individualist	Short-term	Technology can prevent many problems	Only proven effects
Egalitarian	Very long-term	Problems can lead to catastrophe	Minimal scientific evidence is sufficient
Hierarchical	Balanced between short and long-term	Proper policy can prevent many problems	Consensus among scientists

2. LCA methodology: interpretation of the results



3. Software and database

SimaPro

GaBi Software
PRODUCT SUSTAINABILITY

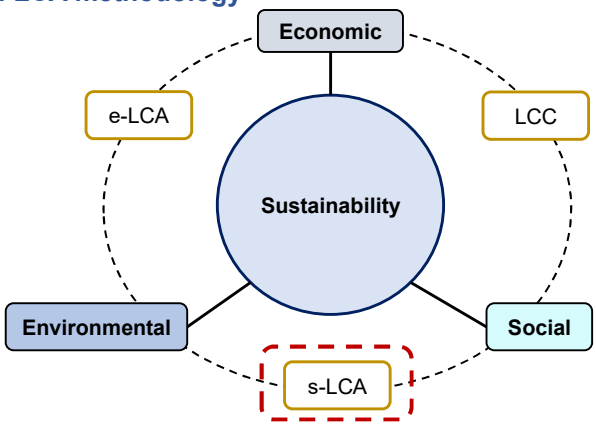
openLCA

umberto®
know the flow.

These software can be equipped with specific databases:

- Ecoinvent
- Industry data 2.0
- EU and Danish Input Output database
- Agri-Footprint
- …

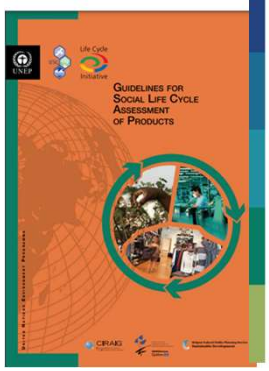
4. Social LCA methodology



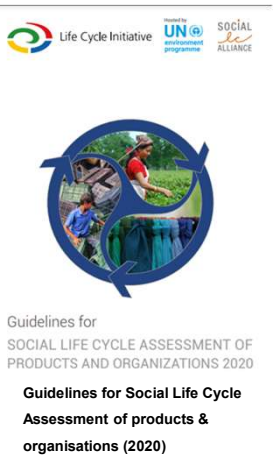
- **Social life cycle** assessment is a methodology to assess the social impacts of products and services across their life cycle
- This methodology is in line with **ISO14040 and ISO14044,** and it can be applied by itself or combined with environmental LCA and LCC

4. Social LCA methodology

S-LCA guidelines



Guidelines for Social Life Cycle Assessment of products (2009)



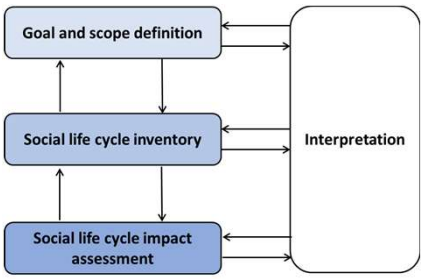
Guidelines for Social Life Cycle Assessment of products & organisations (2020)

"The Guidelines for Social Life Cycle Assessment (S-LCA) of Products provide a roadmap and a body of knowledge to help stakeholders in the assessment of social and socio-economic impacts of products' life cycles and their related value chains"

4. Social LCA methodology

S-LCA Framework

Systematic approach



Aim:

- To evaluate the social impacts of a product across its entire life cycle, integrating diverse stakeholder perspectives

Uses:

- **Identify hotspots:** Finds social risks and positive impacts throughout the entire product life cycle
- **Prevent oversight:** Ensures social impacts are understood and managed, rather than ignored in sustainability efforts
- **Integration with environmental LCA:** The combination with environmental assessments helps to align both social and ecological goals

4. Social LCA methodology

How does S-LCA work?

- A stakeholder is any individual, group, or organization that can affect, be affected by, or has an interest in the social impacts of a product, service, or organization's activities throughout its life cycle.
- **The impact categories** are the types of social impacts that can occur for each stakeholder category. It reflects the type of issue that matters for the stakeholders.
- **The impact subcategories** are specific themes or issues within each impact category that make the impacts more concrete and measurable. It reflects which specific issues compose that impact.
- To make S-LCA results easier to compare, the same stakeholder categories and impact categories are generally used across studies. However, the specific impact subcategories chosen can differ depending on the context and focus of each study.

Stakeholder Category	Impact Category	Example of Subcategories
Worker	• Working conditions • Health and safety	• Fair salary and working hours • Workplace safety and accident prevention
Local Community	• Human rights • Health and safety	• Respect of indigenous rights • Safe and healthy living conditions
Value Chain Actors	• Governance • Socio-economic repercussions	• Supplier relationships / Corporate responsibility • Fair competition and wealth distribution
Consumer	• Governance • Health and safety	• Consumer privacy and transparency • Product health and safety standards
Society	• Governance • Socio-economic repercussions	• Prevention of corruption / Sustainability commitments • Contribution to economic development
Children	• Human rights • Socio-economic repercussions	• Elimination of child labor / Protection from predatory marketing • Access to education in local communities

4. Social LCA methodology

Social life cycle inventory

- The **life cycle inventory** aims to collect data on social and socio-economic conditions across all life-cycle stages (from raw materials to disposal)
- **Data types:**
  - Quantitative (e.g., % child labour, injury rates)
  - Qualitative (e.g., freedom of association, discrimination policies)
- **Data can be sourced** from company surveys, audits, national statistics, and databases (e.g., PSILCA)

- The inventory stage is structured **by life-cycle stage and stakeholder categories** (workers, community, society, etc.)
- **Data availability and comparability** across countries and suppliers is an important challenge of the life cycle inventory stage
- The output of this stage is a **set of inventory indicators** that describe social conditions

4. Social LCA methodology

Social indicators:

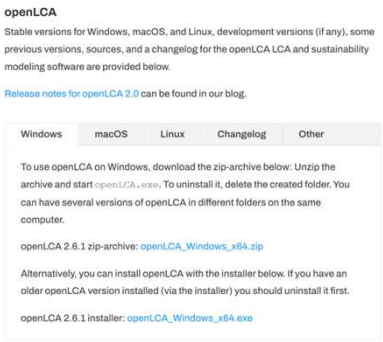
The concrete and measurable metrics used to gather data for a specific impact subcategory concerning a particular Stakeholder group. They turn conceptual social issues into trackable data.

Stakelholder	Impact sub-category	Social indicator
Worker	Working hours	Average weekly working hours per worker
Local community	Acess to resources	Amount of water consumed by the factory relative to local community availability.
Consumer	Health and safety	Number of product safety incidents or recalls reported.

Social Life Cycle Impact Assessment

Rating each indicator based on performance and level of compliance

5. Case Study - LCA



https://www.openlca.org/download/

https://nexus.openlca.org/

5. Case Study - LCA

ecoinvent

https://ecoinvent.org/database/

Flows are the individual materials, energy types, products, emissions, or wastes that enter, circulate through, or exit the boundaries of a process.

Processes are the individual building blocks (unit process) of the database representing technical activities (like manufacturing, transport, or waste treatment) that transform physical inputs into specific outputs.

Product systems are the complete, interconnected supply chains generated by openLCA that link unit processes together to model the entire lifecycle of a specific functional unit.

Results serve as a repository for storing saved calculation sheets generated from your product system evaluations.

Indicators and parameters contains the environmental impact assessment methods and calculation metrics used to quantify your LCA results.

Background data serves as the supporting information of the database, storing the structural, administrative, and geographical metadata that supports all modelling activities.

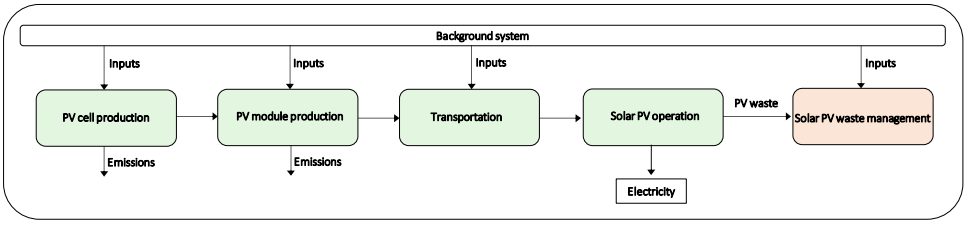
Projects are used to compare multiple product systems side-by-side or analyse different design scenarios.

EPDs (Environmental Product Declarations) allow users to create and manage standardized environmental reports for their products compliant with ISO 14025 standards.

5. Case Study - LCA

Goal and scope definition

- To evaluate the environmental impacts of life-cycle solar photovoltaic (PV) manufacturing within a cradle-to-grave scope
- Supply-chain stages:

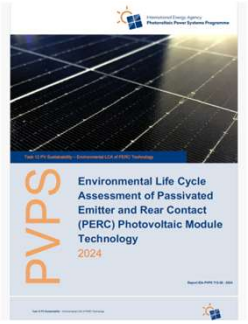


- Installation of 100 m^2 of solar PV panels
- Functional unit: 1 kWh of electricity delivered

5. Case Study - LCA

Life cycle inventory

Foreground data ⇨



Background data ⇨ ecoinvent
https://ecoinvent.org/database/

Life cycle impact assessment ⇨ ReCIPe 2016 Midpoint Hierarchist (H) method

Acknowledgements

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Life cycle assessment (LCA)

Sustainability course Unite!Energy

2025/2026 Academic Course

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