Techno-economic assessment tools

Sustainability course Unite!Energy

2025/2026 Academic Course

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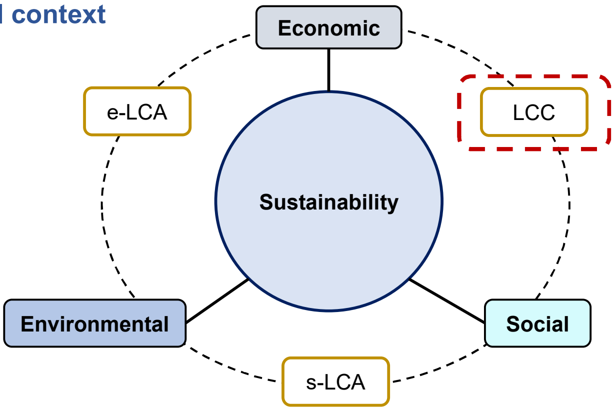
Contents

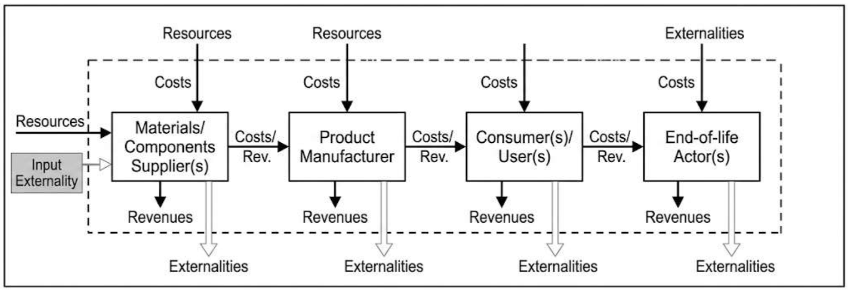
1. General context



- **Life cycle costing (LCC)** is a methodology to assess all the costs that will be incurred during the lifetime of a product, work or service
- Cost-benefit analyses can be performed including the LCC and economic incomes/revenues
- The ISO 15686-5 provides requirements and guidelines for performing LCC analyses of buildings and constructed assets and their parts
- Decision-makers are interested in sustainability specially from and economic perspective

2. LCC concepts

LCC flows



- Covers all cost flows over the product's life cycle: acquisition of materials, manufacturing, operation/use (energy, maintenance), and end-of-life (disposal and/or recycling).
- Expressed in monetary terms by translating physical flows (materials, energy, labor) into financial costs relevant to the product/system evaluated.
- Future costs are typically discounted to present value to reflect investment decisions and financial feasibility.

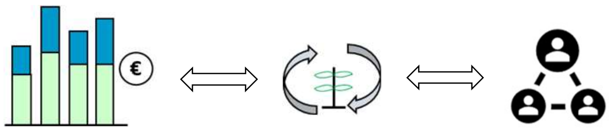
2. LCC concepts

LCC types

Cost Approach

Differentiates LCC based on the costs included in the analysis:

- **Conventional LCC:** Considers only direct monetary costs borne by the owner/operator (e.g., purchase price, maintenance, energy).
- **Environmental LCC:** Incorporates internalized environmental costs (e.g., pollution permits, waste disposal fees, carbon taxes) and potentially monetized external environmental costs.
- **Societal LCC:** The broadest scope, including socio-economic costs and benefits (e.g., health impacts, employment, infrastructure costs) to society as a whole.



2. LCC concepts

Time Value of money in LCC

LCCs are often used to **compare alternatives** in order to identify the cheapest alternative. However, each alternative have costs **incurred at different times**.

To ensure a fair comparison, all future costs must be discounted to their present value (PV).

1. The core concept

- The time value of money: 100€ today is worth more than 100€ in 10 years because today's money can be invested to grow, while the future value of that same 100€ will be reduced by inflation.
  1. Opportunity Cost: Choosing one investment means missing out on the benefits of another (e.g., the benefits you could have earned elsewhere).
  2. Inflation: The general increase in prices over time, which reduces the "purchasing power" of your money.

2. LCC concepts

Time Value of money in LCC

2. Practical example

- Option A: Costs 500€ at year 0 and lasts 10 years with no replacement needed.
- Option B: Costs 200€ at year 0 and lasts only 2.5 years.

- While **Option A** requires a higher initial investment for a maintenance-free 10-year lifespan, **Option B** offers a lower initial investment but incurs higher long-term expenses through mid-cycle replacement

- The problem: We cannot compare them directly because their lifespans and payment schedules differ. We must “bring" future costs to year 0.

2. LCC concepts

Time Value of money in LCC

3. The calculation

We discount the future value based on a specific weight (the discount rate) to find the Present Value (PV):

$$PV = \frac{F_n}{(1 + \text{discount rate})^n}$$

PV: Present value (the value in today's €).
F: Future value (the cost incurred in year n).
n: number of years of the project.
Discount rate: The "weight" or interest rate used.

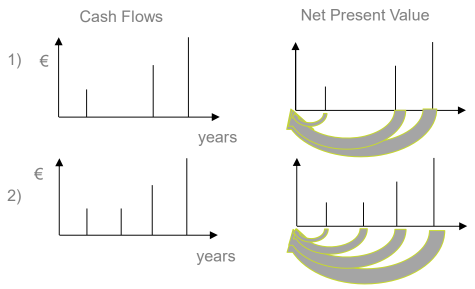
The “discount rate" is not just a random number and it typically incorporates three layers:

- **Opportunity cost (earning power):** The "lost" interest or profit you could have made if you invested that money elsewhere today.
- **Inflation (purchasing power):** Accounts for the fact that 100 € today buys more things than 100 € will in 10 years.
- **Risk :** A "buffer" added to account for the uncertainty and risks of the project.

2. LCC concepts

Time Value of money in LCC

To compare alternatives all the cash flows of all the options have to converted in the time unit.



Convert cash flows to present value (year 0):

$$NPV = \sum_{t=0}^{T} \frac{R_t - Costs_t}{(1+i)^t}$$

When the initial investment takes place at year 0:

$$NPV = \sum_{t=1}^{T} \frac{R_t - OPEX_t}{(1+i)^t} - CAPEX$$

CAPEX (Capital expenditure) represents the total investment required to design, purchase, and install the physical assets of a system

OPEX (Operating Expenditure) refers to the ongoing costs required for the day-to-day functioning of a system, including chemical consumption, energy usage, and labour

R (revenue) refers to the total income generated by the system from the sale of its products

2. LCC concepts

Cost-benefit analysis

Cash-flow

$$NPV = \sum_{t=1}^{T} \frac{R_t - OPEX_t}{(1+i)^t} - CAPEX$$

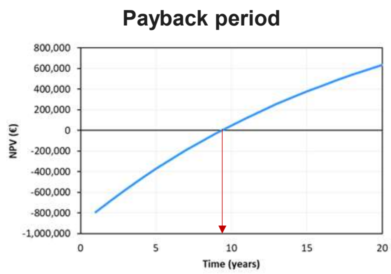
NPV > 0 ⇨ **Economically feasible**

NPV < 0 ⇨ **Not economically feasible**

NPV is the net present value (€)
CAPEX is the initial capital expenditure (€)
$OPEX_t$ is the operating expenditure at year t (€)
R_t is the revenue at year t (€)
T is the project lifetime (years)
i is the discount rate (-)

Internal rate of return (IRR)

$$0 = NPV = \sum_{t=1}^{T} \frac{R_t - OPEX_t}{(1+IRR)^t} - CAPEX$$



2. LCC concepts

Cost-benefit analysis

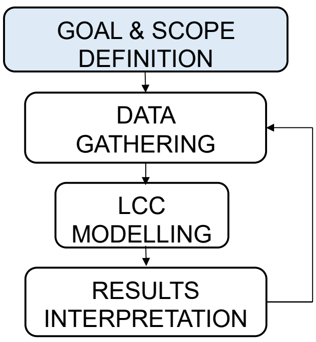
$$PV_{COST} = CAPEX + \sum_{t=1}^{T} \frac{OPEX_t}{(1+i)^t}$$

PV_{COST} is the present value of the cost (€)
CAPEX is the initial capital expenditure (€)
$OPEX_t$ is the operating expenditure at year t (€)
T is the project lifetime (years)
i is the discount rate (-)

$$PV_{NC} = CAPEX + \sum_{t=1}^{T} \frac{OPEX_t - R_t}{(1+i)^t}$$

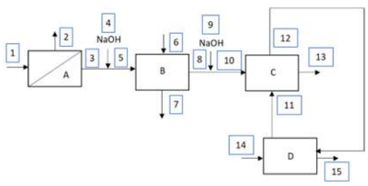
R_t is the by-product revenue at year t (€)
PV_{NC} is the present value of the net cost (€)

3. Methodology



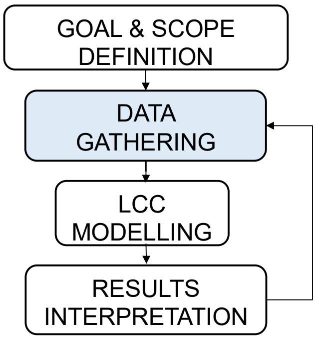
Key steps:

- Define the main goal of your work.
- Conceptualise a comprehensive flow diagram illustrating all stages of your system, clearly identifying each process step and all associated material and energy input and output flows.



- Define a time horizon of the project (e.g. 30 years plant lifetime), the discount rate, and the plant capacity.
- Decide the capital and operating costs to be included in the analysis.

3. Methodology



Key steps:

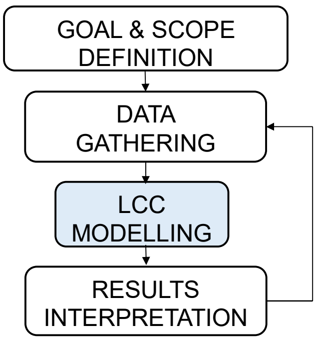
Stage 1: Inventory data calculation

- Data collection: Gather technical specifications (e.g., chemical, water and and energy consumption) from literature, technical reports, and industry websites.
- Mass and energy balances: Perform balances to determine the system's quantitative inputs and outputs.
- Equipment sizing: Determine the dimensions and capacities of equipment (e.g., reactor volumen in m^3, membrane surface area in m^2).

Stage 2: Unit cost data collection

- Cost data collection: Gather unit costs and scale-dependent cost functions from literature, technical reports, and industrial websites to calculate CAPEX, OPEX, and projected revenue.
- The unit cost data will be needed for the next LCC modelling step.

3. Methodology



CAPEX calculation

First approach

$$C_2 = C_1 \left(\frac{S_2}{S_1}\right)^n$$

⟹ Typically not applicable for systems with limited industrial data

C_2: capital cost of the plant with capacity S_2
C_1: capital cost of the plant with capacity S_1
n: exponent parameter dependent on the type of plant

Second approach

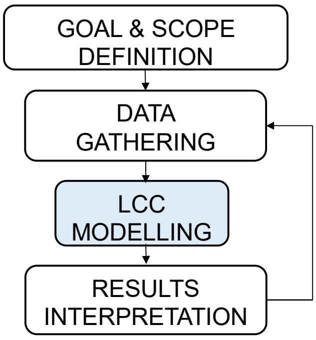
$$C_e = a + bS^n$$

⟹ Calculate the equipment costs based on the specific equipment size (*S*) and equipment-dependent parameters *a*, *b*, and *n*

- If parameters *a*, *b*, and *n* are unavailable for specific process units, utilize cost data (e.g., €/m^3, €/m^2) or scale-dependent cost functions sourced from literature, technical reports, and industrial websites.
- Besides equipment, other direct capital costs (e.g., piping, valves, instrumentation.) and indirect costs (e.g., engineering, contingency) can be included.

Towler and Sinnott (2008). Chemical Engineering Design. Pages 297-392

3. Methodology



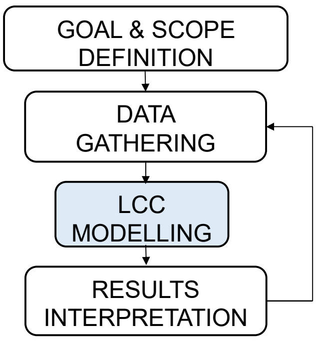
OPEX and revenues calculation:

- Utilize cost data sourced from literature, technical reports, and industrial websites during the data gathering step:

Electricity (€/kWh)
Chemicals (€/t, €/m^3)
Natural gas (€/MWh)
Labour and maintenance (% of CAPEX, others)
Other operating costs
Final recovered materials market price (€/t)

- The **operating costs** are calculated based on the quantitative mass and energy balances established during the inventory stage.
- The **revenues** from products and by-products are calculated by multiplying the quantity produced (as determined by the mass balances) by the unit market price.

3. Methodology



Cost Escalation

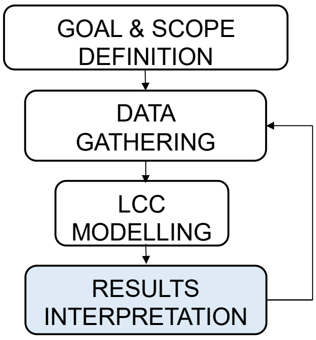
- The costs are subject to inflation. Methods have to be used to update old cost data.

$$\text{Cost in year A} = \text{Cost in year B} \times \frac{\text{Cost index in year A}}{\text{Cost index in year B}}$$

Chemical Engineering Plant Cost Index (CEPCI)

- Once CAPEX, OPEX, and revenues have been calculated and updated, apply economic evaluation metrics, such as NPV, to determine the project's viability.

3. Methodology



Key aspects

- Utilize calculated economic metrics to determine if the project meets economic benchmarks.
- Identify the process hotspots within your recovery scheme to determine which stages require targeted efforts for overall cost reduction.
- Interpretation is not a final destination; results should be looped back to the data gathering phase if inconsistencies or gaps are identified.

3. Methodology

Sensitivity analysis

What is a sensitivity analysis?

- A technique to determine how the output of an LCC model (e.g., NPV, PV_{cost}) changes when the inputs (parameters) are changed over a defined range.
- Sensitivity analysis allows testing the robustness and reliability of LCC conclusions, and to identify the most influential cost drivers.

Why is a sensitivity analysis important?

- Addresses uncertainty concerns as LCC calculations often rely on uncertain future estimates and economic input parameters
- Highlights which variables have the greatest financial risk if their estimated values are not correct
- Prevents relying a major investment in a result that is highly sensitive to a small change.

3. Methodology

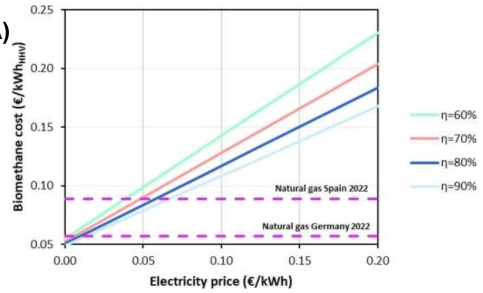
Sensitivity analysis

Key steps

- Select critical input parameters that are highly uncertain or expected to vary over time (e.g., fuel price, discount rate, or efficiency).
- Establish a low and high range for each critical variable.

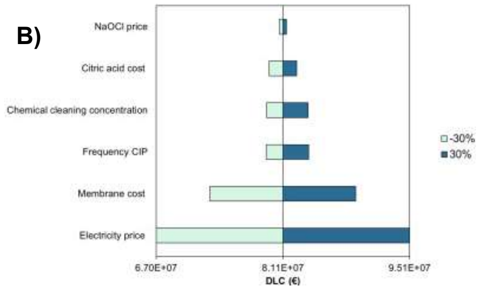
Examples of sensitivity analysis:

A)



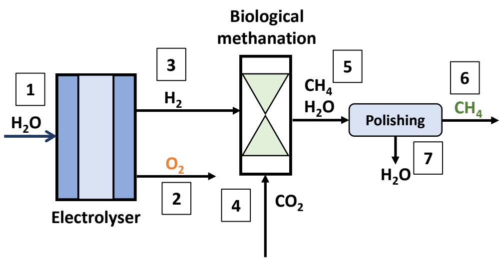
Vinardell et al. (2024). ECM. 307, 118339
https://doi.org/10.1016/j.enconman.2024.118339

B)



Vinardell et al. (2022). STOTEN. 825, 153907
https://doi.org/10.1016/j.scitotenv.2022.153907

4. Case study - TEA



Adapted from Vinardell et al. (2024). ECM. 307, 118339
https://doi.org/10.1016/j.enconman.2024.118339

Water electrolysis

$$2H_2O \rightarrow 2H_2 + O_2 \quad \Delta H^\circ = 285.8\ kJ/mol$$

Biomethanation reaction

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad \Delta H^\circ = -165\ kJ/mol$$

Production target (calculation basis): 10 t CH_4/day

1- Calculate the input and output mass flows (kg/y)
2- Calculate the electricity consumption (kWh/y) and the electrolyser capacity (MW)
3- Calculate the size of the biomethanation reactor (m^3) and electricity consumption (kWh/y)
4- Calculate capital (€) and operating costs (€/y)
5- Calculate economic metrics and perform the economic analysis

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