Energy Systems Analysis: An Introduction and Overview with Applications

My First LCA

Environmental Life Cycle Assessment

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0 Introduction

In this exercise, you will undertake a fundamental, simplified Life Cycle Assessment (LCA). The main aim of this exercise is to enhance your understanding of the LCA methodology, familiarizing you with its procedures and underlying principles, and apply theoretical knowledge from the lecture. While LCAs are typically executed using specialized software like Brightway, openLCA, SimaPro, and GaBi, for this beginner's session, we will be doing a hands-on, manual LCA. This approach will introduce you to foundational LCA concepts such as the functional unit (FU), unit processes and inventory data, allocation, and characterisation factors, along with the associated elementary calculations. Feel free to collaborate and discuss your findings with your peers.

Your assignment revolves around the use of a battery electric vehicle (EV) and an internal combustion engine vehicle (ICEV). Instead of a comprehensive LCA, you'll be examining select processes and specific emissions: carbon dioxide (CO2), methane (CH4), and dinitrogen monoxide (N2O, commonly referred to as nitrous oxide or "laughing gas'). Consequently, your primary focus will be on the "Global Warming" impact category (the methodology for other categories would be the same). Below are the process flow diagrams of the two systems you will be analyzing.

The EV system comprises five main processes:

1. Natural gas supply.
2. Manufacturing the electric vehicle.
3. Power generation through Cogeneration (also known as Combined Heat & Power).
4. Battery manufacturing
5. Operating the electric vehicle over its lifetime (estimated at 160,000km).

The ICEV system also comprises five main processes:

1. Natural gas supply.
2. Manufacturing the diesel vehicle.
3. Power generation through Cogeneration (also known as Combined Heat & Power).
4. Diesel supply.
5. Operating the diesel vehicle over its lifetime (estimated at 160,000km).

Please note that certain processes like "vehicle components" and "waste processing" are excluded from this exercise and are marked in grey on the diagram.

The description and the questions to be answered below will guide you through the calculations step-by-step.

1 Goal and Scope

a) What would constitute a suitable function and functional unit for comparing different passenger vehicle options?

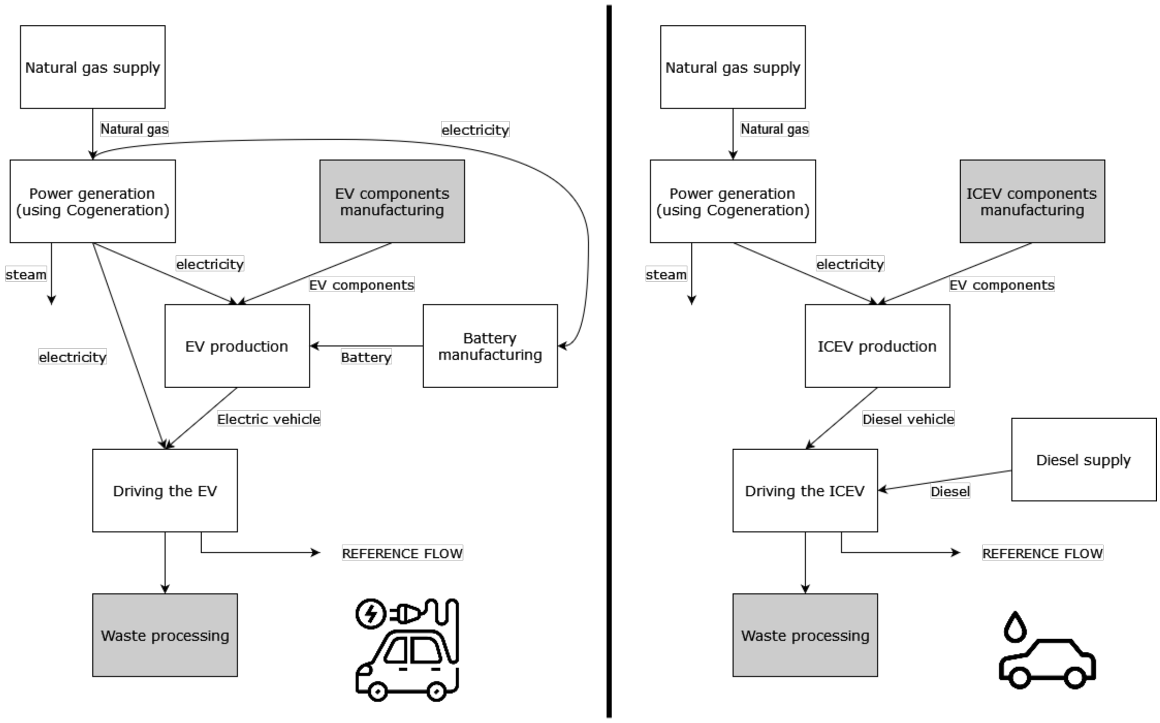


Figure 1: Simplified process Flow Diagrams of the Electric Vehicle (EV) and Internal Combustion Engine Vehicle (ICEV) Systems for the Life Cycle Assessment Exercise.

2 Life Cycle Inventory Analysis (LCI)

b) Illustrate the different processes using rectangles. Designate inflows and outflows for each process with arrows: vertical for economic flows and horizontal for environmental flows. Refer to the provided table for specifications, but remember not to link to other processes. Place the numerical data from the aforementioned table adjacent to each flow. Remember to exclude waste processing and components manufacturing. Below you can find an example.

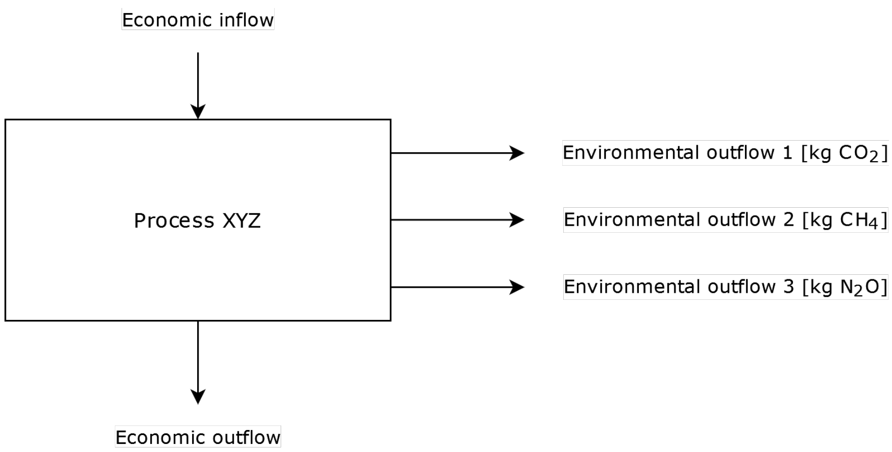


Table 1: Process data. Environmental inflows (e.g., consumption of natural resources) are excluded for the sake of simplification.

Process	**Economic inflows**	**Economic outflows**	**Environmental inflows**	**Environmental outflows**
Natural gas supply	• None	• 1000 m^3 natural gas	• None	• 0.05 kg CO2
Power generation	• 100 m^3 natural gas	• 500kWh electricity • 1000kg steam	• None	• 400 kg CO2 • 6 kg CH4 • 5e-3 kg N2O
EV production	• 4000 kWh electricity • 1 battery	• 1 electric vehicle	• None	• None
Battery manufacturing	• 600 kWh electricity	• 1 battery	• None	• None
Driving the EV	• 1 electric vehicle • 31500 kWh	• 160,000km	• None	• None
ICEV production	• 3000 kWh electricity	• 1 diesel vehicle	• None	• None
Diesel supply	• 0.015 kWh electricity	• 1 liter diesel	• None	• 2e-5 kg CH4 • 1.5e-6 kg N2O
Driving the ICEV	• 1 diesel vehicle • 12200 liter diesel	• 160,000 km	• None	• 3.8e+4 kg CO2 • 4e-3 kg CH4 • 8e-3 N2O

Allocation

The cogeneration process for generating electric power also produces a secondary useful product: steam. However, vehicle production, battery manufacturing and the EV use exclusively utilize the electric power generated. Therefore, it becomes necessary to distribute the total emissions from the cogeneration process between the two outputs: electricity and steam. There are several allocation methods, and in this case we will allocate on the basis of the energy content of the economic outflows, using the following data:

- 4 MJ/kWh electricity
- 3 MJ/kg steam

c) Determine the "allocation factors" by assessing the energy contribution of each product to the total energy content. Complete the following table to derive these ratios.

Table 2: Allocation data.

Product	**Outflow**	**Energy content (GJ)**	**Allocation factor F_i**
1. Electricity	500 kWh		.....
2. Steam	1000 kg		.....
Total			**1.00**

d) Determine the environmental emissions for the (mono-functional) processes of generating electricity (for every 500 kWh) and producing steam (for each 1000 kg of steam):

Table 3: Solving the multi-functionality.

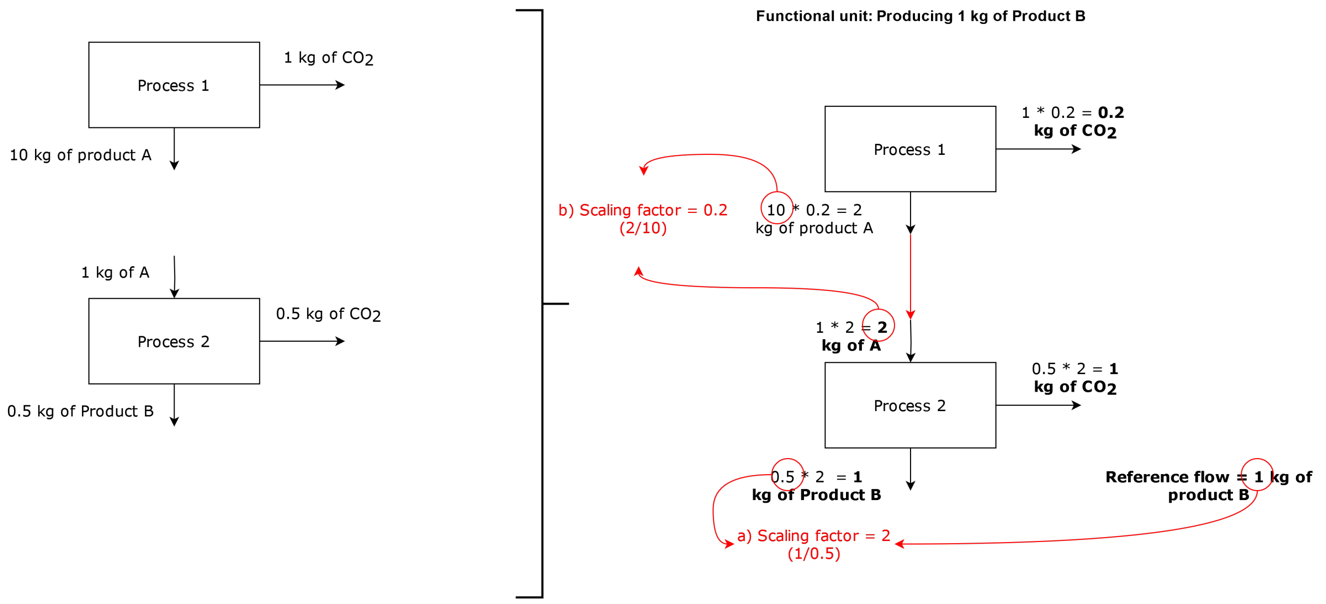
Environmental outflow	**unit**	**Quantity allocated to 500 kWh electricity**	**Quantity allocated to 1000 kg steam**
CO_2	kg	F_{elect} x 400 = ...	F_{steam} x 400 = ...
CH_4	kg	F_{elect} x 6 = ...	F_{steam} x 6 = ...
N_2O	kg	F_{elect} x 0.005 = ...	F_{steam} x 0.005 = ...

e) Now, revise the process flow diagram from Assignment B, updating the quantitative process data for 'Power generation (using Cogeneration)' with the values you determined for 500 kWh electricity in Assignment d (Do not forget to also partition the economic inflow of natural gas).

Scaling the process data

You will now have to scale the (allocated) process data to the functional unit defined.

f) Determine the scaling factors for the various processes. These factors indicate the portion of the process required to meet the defined functional unit. Remember to use the flow diagram you created in Assignment e (which includes the process data from the first table) to understand how the scaling factor for the 'Driving the vehicle' process impacts the other processes. Begin with the functional unit, identify the reference flow from the usage process, and so on. Here's an illustrative example:



Inventory table

g) Now you can fill in the so-called 'inventory table' by adding up the scaled environmental data for each item over the different processes for each system:

Table 4: Inventory table for the electric vehicle system

Item	unit	Quantity
CO_2	kg	....
CH_4	kg	....
N_2O	kg	....

Table 5: Inventory table for the diesel vehicle system

Item	unit	Quantity
CO_2	kg	....
CH_4	kg	....
N_2O	kg	....

3 Life Cycle Impact Assessment (LCIA)

The outcome of the previous task provides a table that details the quantified emissions of greenhouse gases (GHGs). To translate these emissions into their impact on the "Climate Change" (or "Global Warming") category, you can utilize Global Warming Potentials (GWPs). GWPs quantify the potential influence of a specific GHG on "Climate Change". This metric offers a way to compare the greenhouse effect of releasing 1 kg of a specific GHG to the effect of emitting 1 kg of carbon dioxide (CO2). By this measure, the GWP for 1 kg of CO2 is, by definition, equivalent to 1 kg CO2-eq/kg. GWPs are determined over a set time span (denoted by subscript α in the subsequent equation, typically 100 years). It's essential to specify this duration when referencing a GWP (for instance, GWP100). The GWP values for the three GHGs addressed in this activity are:

Table 6: Characterization factors of individiual greenhouse gases

	GWP_{100} **(in kg CO_2 eq./kg)**
CO_2	1
CH_4	28
N_2O	265

h) Calculate the 'climate change indicator' result by multiplying the greenhouse gas emissions by their respective GWPs.

Climate change = $\sum GWP_{\alpha,i} \cdot m_i$

Table 7: 'Climate change indicator' for the electric vehicle system

Impact category	**Quantity**	**Unit**
Climate change	....	kg (CO_2eq)

Table 8: 'Climate change indicator' for the diesel vehicle system

Impact category	**Quantity**	**Unit**
Climate change	....	kg (CO_2eq)

4 Interpretation

i) Which emission from which process contributes most to the result for the climate change indicator?

j) Discuss, qualitatively, the impact of the allocation method in the final results.

k) The data presented in Table 1 has faced significant scrutiny. The independent research group "Octane Optimists Organization" contends that modern diesel cars are anticipated to be more efficient, halving both the CO2 emissions during operation and diesel consumption. On the other hand, an EV manufacturer has indicated that the longevity of electric vehicles surpasses initial expectations, suggesting they can last up to 300,000 km. Evaluate the robustness of our LCA in light of these claims.

In addition, please think about the following issues and questions, which will be discussed in a (semi-)quantitative and qualitative way in a week after providing and discussing the solution of this exercise and answering your questions.

l) What would be the impact of using alternative power generation technologies on the LCA results of both the BEV and the ICEV?

m) Think about expanding the scope of this comparative LCA to include other means of transport, namely bicycles and tramways. In which way would goal and scope as well as the functional unit have to be modified? What would be additional information and data required?

n) If you would have to decide today, whether to buy an EV or an ICEV, would this LCA be useful as decision support? If so, why? If not, why not?