Assignment week 5: Life Cycle Assessment

Teachers: Julien Michellod, Polina Boiko, Martin K. Patel

Subjects and objectives of this assignment: In this assignment you will analyse the environmental life cycle impacts of 1) a photovoltaic (PV) system, and 2) an electric car. You will:

- Learn how to implement and calculate a Life Cycle Assessment (LCA)
- Learn how to critically analyse the results of an LCA
- Learn the basics of OpenLCA, a well-known software tool for LCA

Final product: A report including graphs and tables

Group size: 2 persons per group

Literature concerning the assignment (on Moodle)

- Gerbinet et al.; Life Cycle Analysis (LCA) of photovoltaic panels: A review; Renewable and Sustainable Energy Reviews (2014)
- Vuarnoz et al.; Temporal variations in the primary energy use and greenhouse gas emissions of electricity provided by the Swiss grid; Energy (2018)
- Basic modelling of a Plastic bottle (Example to better understand the use of the software)

Software

- To download the software (use the installer option): http://www.openlca.org/download/
- For your convenience, we provide a Virtual Machine that has OpenLCA installed. To access it, please go to eduvdi.unige.ch, install the VMware Horizon Client, click on adding a server (enter your credentials, server name "eduvdi.unige.ch") and select the Virtual Machine named 'ISE-ETU'.
- To download the database: https://drive.switch.ch/index.php/s/1jFgf2K1rxZ2k3u
- YouTube Tutorial on OpenLCA: https://youtu.be/kEosW6PceVg

Submission date

The report has to be handed in on Wednesday 27 March 2024 at the latest. Please upload it on Moodle. Only a single (MS-Word or pdf) file will be accepted. Any other (e.g., Excel) attachments will be ignored. When writing down your answers, please explain very briefly the main intermediate steps in the calculations. This will allow the teachers to follow the reasoning and thus award you points for the various steps. Please pay attention to the correct use of units and terminology.

Debriefing: The debriefing of the assignment will take place in the morning of Friday 12th of April 2024.

Part 1: PV System (40 pt)

In this assignment you will analyse the life cycle environmental impacts of a photovoltaic installation on a roof in Geneva and compare it with other sources of electricity.

1.1 General concepts (10 pt)

Questions

1a) What are the four main phases of LCA? Could you please briefly describe the content of each phase? (8 pt)

1b) What would be an appropriate functional unit for an LCA on PV panels? (2 pt)

1.2 Life cycle of PV system (10 pt)

The manufacturing processes of multi-Si PV panels involves several stages. Firstly, silica sand is mined and then processed in a furnace to obtain metallurgical grade silicon with a purity of approximately 99%. The metallurgical grade silicon then needs to be further purified into electronics grade silicon and solar grade silicon. These forms of silicon are casted using moulds. Multi-Si wafers can be produced by sawing casted silicon. The next stage is cell production, which involves the creation of solar cells from the multi-Si wafers. Finally, the solar cells are assembled with glass and aluminium frames to create solar panels.

Questions

1c) Which stages of the life cycle of multi-Si PV panels are addressed in the above text? (2 pt)

1d) Please draw a flowchart of the manufacturing process described in the above text. (6 pt)

1e) Please expand the flow chart to include all cradle-to-grave stages. (2 pt)

1.3 Environmental impact of photovoltaic electricity (12 pt)

Now we are going to evaluate the environmental impact of electricity produced from PV systems. We include in our system boundary PV system production, transportation, installation and operation. We consider a 3 kW_p PV system installed on a flat roof in Geneva. This system requires 1) PV panels, 2) a mounting system, 3) Transportation, 4) Inverters, and 5) Electric installation.

The ecoinvent life cycle inventory database will be used for this exercise. For simplicity, we will not search for data about the stages of raw material extraction and manufacturing of PV panels, inverters, and related components. Instead, we will use the readily available data provided by ecoinvent.

The following detailed information is provided:

- The key characteristics of the PV panels are:
  - Each panel has a size of 1 m^2
  - Peak power: 125 W_p/m^2 ("W_p" stands for $Watt_{peak}$; it represents the *peak power* or the *nominal power*; in French: "W_c" which stands for $Watt_{crête}$)
  - Weight: 15 kg/m^2
- The installation has a nominal power (*peak* power) of 3kW_p, so you need to calculate how many panels you will need for the entire installation.
- The key characteristics of the mounting system are:
  - The area of the mounting system should be the same as the total area of PV panels.
  - Weight: 20 kg/m^2
- The transportation distances for both the PV and the mounting systems are assumed to be 900 km by train.
- An inverter of 2.5kW is required.
- The electricity produced by the PV system is 4109 kWh/y.
- The lifetime of the system is 25 years.
- We assume that there is no environmental impact to be expected from the use phase.

We have to create a PROCESSES called "Providing and operating a 3 kW_p PV System" for which we will be combining PV panels, mounting system, transportation, inverters, electric installation, with the output being the electricity produced over the system's lifetime (create a new flow with the reference flow property of "energy"). For this we can use the datasets listed below. The folders containing them are indicated in the brackets (but we recommend searching for them directly in the search bar at the top right corner of the software):

- photovoltaic panel production, multi-Si wafer RER (Manufacturing processes folder 2610)
- photovoltaic mounting system production, for flat-roof installation RER (Construction processes folder 4390)
- market for transport, freight train CH (Transportation and storage processes folder 4912)
- inverter production, 2.5kW RER (Manufacturing processes folder 2790)
- photovoltaics, electric installation for 3kW_p module, at building CH (Construction processes folder 4390)

It is important to correctly define <u>Amounts</u> and <u>Units</u> of inputs and outputs based on the data given.

Questions

1f) Create in OpenLCA the PROCESS "Providing and operating 3 kW_p PV System". Provide a screenshot of the tab 'Inputs/Outputs' of this process (6pt).

1g) Create a PRODUCT SYSTEM in OpenLCA called "3 kW_p PV System" and obtain the contribution tree for Climate Change for **1 kWh** produced from it using the ReCiPe Midpoint (H) impact assessment method. Which PV system's inputs have the highest global warming potential? Provide a screenshot of the contribution tree (we also recommend taking a look into the "Sankey diagram" tab). (6pt).

1.4 Compare with other renewable energy sources (8pt)

Now we compare the environmental impact of electricity generated from various renewable sources. Currently, the electricity consumed in Switzerland is mainly produced from hydropower (approximately 60%) followed by nuclear power (approximately 30%), while the remainder is imported from neighbouring countries. However, with the implementation of the Swiss Energy Strategy 2050, the Swiss electricity mix is expected drastically change until 2050. In particular, nuclear energy is planned to be replaced by alternative sources.

Apart from photovoltaic electricity, there are other options available to replace nuclear electricity production, such as hydropower, wind power, increased imports, etc. In this exercise, please compare the environmental impact of electricity generated from nuclear power, photovoltaic electricity, and at least one other source of your choice.

To analyse photovoltaic electricity, we can use the existing PRODUCT SYSTEM '3 kW_p PV System'. For other sources, we will need to create new PRODUCT SYSTEMS from data provided in the Electricity folder 3510 (or by typing "electricity production [choose source] CH" in the search bar). Then we generate a new PROJECT to compare the impact of 1 kWh from the selected sources.

Questions

1h) Launch the PROJECT calculations using the ReCiPe Midpoint (H) indicators. Tips: The impact assessment method can be selected in the "Calculation setup" field, you also have to click on the "create report" button, and the different electricity sources have to be entered into the "Compared product systems" field. Prepare a screenshot of the "Relative Results" from the "Report" tab. Which electricity source looks most attractive based on a visual comparison? (4pt.)

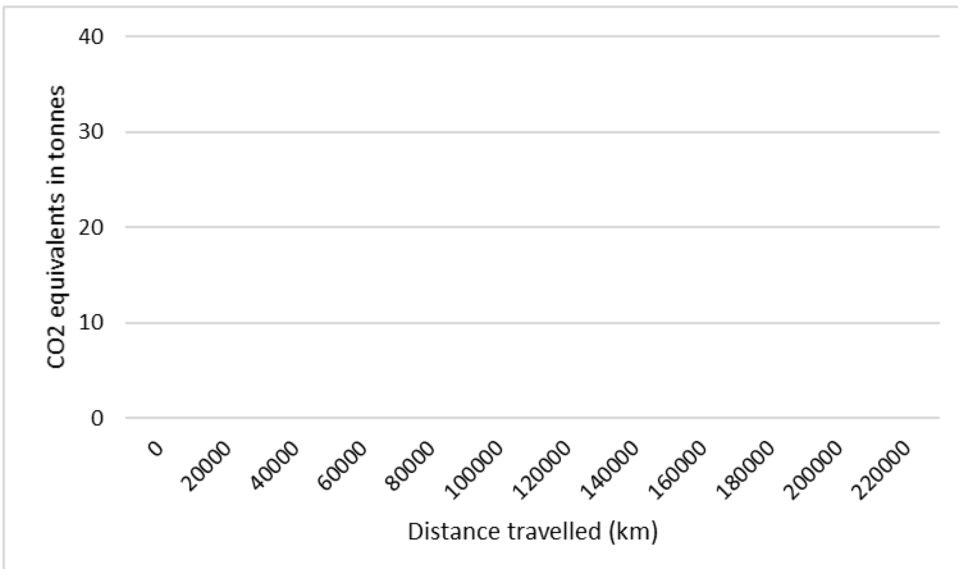
1i) Launch the PROJECT calculations using the ReCiPe Endpoint (H) indicators. Based on the impact assessment results for three summarizing indicators (total: ecosystem quality, total: human health, and total: natural resources), which source looks most attractive? (4pt.)

Part 2: Electric vehicle (20 pt.)

Please prepare the type of graph below in which you will include a) a petrol car, b) an electric vehicle (EV) operated in Switzerland, c) an electric vehicle operated in Germany.

For this purpose we make the following simplifying assumptions:

- The petrol car and the EV are identical in all respects with the only difference being that the EV contains a battery (this is a rough assumption because in reality, the motor of an EV is much simpler and lighter than an internal combustion engine).
- We disregard the "grey energy" and "grey CO_2", i.e. the impacts related to the production of the cars. As only exception, we consider the impacts of battery production because this is the main differentiating factor between the two types of cars.



The data are provided in the following (some of the following key data are summarized in the table below):

i) Petrol car (Hyundai Kona, **<u>petrol</u>**)

- Petrol consumption (= Direct fuel-related energy) = 5.4 l/100 km * 0.75 kg/l (density) * 42 MJ/kg (calorific value of petrol) = 170.1 MJ/100 km
- CO_2 emissions of combustion only = 74.6 g CO_2 eq./MJ petrol
- CO_2 emissions of supply chain of petrol: see below question 2a)

ii) Electric vehicle (Hyundai Kona, **<u>electric</u>**)

- Electricity required for operating the car = 18 kWh electricity/100 km
- CO_2 intensity of electricity generation in Switzerland: see below question 2b)
- CO_2 intensity of electricity generation in Germany: Assume the value of 655 g CO_2 eq./kWh

- Battery size of Hyundai Kona = 64 kWh (average range = 64/0.18 = 355 km).
- Carbon footprint of battery production = 106 kg CO_2 eq./kWh of energy storage (cradle to factory gate; this is a rather conservative estimate considering the study of IVL which reports a range of 61-106 kg CO_2 eq./kWh batt. capacity for the most reliable data and a range of 61-146 kg CO_2 eq./kWh batt. Capacity when including less transparent data) https://www.ivl.se/english/ivl/topmenu/press/news-and-press-releases/press-releases/2019-12-04-new-report-on-climate-impact-of-electric-car-batteries.html).

Please also assume that no battery replacement is needed during the entire lifetime considered.

Questions

2a) Look up the CO_2 emissions of supply chain of petrol (production of crude oil and refining to produce petrol): calculate this value based on the ecoinvent dataset "market for petrol, low-sulfur | petrol, low-sulfur | Cutoff, U – CH" (Manufacturing processes folder 1920); you can use the same midpoint impact assessment method as before; please assume a heating value of 42 MJ/kg petrol) (3pt)

2b) Look up the CO_2 impact of low-voltage electricity in Switzerland based on the dataset "market for electricity, low voltage | electricity, low voltage | Cutoff, U - CH" (Electricity & Cie processes folder 3510, scroll down!); you can use the same midpoint impact assessment method as before (3pt)

2c) Please graph the CO_2 emissions of per "vehicle-km" travelled (see "empty" sample graph above) for Hyundai Kona. Please insert in the same graph the emissions of the petrol car, the EV car operated in Switzerland and the EV car in Germany (8pt).

2d) What is the breakeven travel distance beyond which the carbon footprint of the EV is clearly lower compared to the petrol car? (2pt)

Note: You may answer this question without exactly interpolating your calculated values, i.e. it is sufficient if you give the interval (km-range) for which the difference between the two types of cars is smallest.

2e) Which policy conclusions (4pt): (i) do you draw for Switzerland? (ii) do you draw for Germany?

Summary table of data provided above:

	Hyundai Kona, electric	Hyundai Kona, petrol
Battery capacity	64 kWh	--
Range	355 km	--
Petrol consumption acc. to manufacturer	--	5.4 litres/100 km
Energy consumption	18 kWh/100 km (electricity)	170 MJ/100 km (petrol)