IEooc_Methods4_Exercise4: LCA with Excel, matrix operations in Excel

Goal: *Understand the computational structure of LCA, understand and implement basic matrix operations in Excel*

Electric vehicles per se are not 'more sustainable' than conventional vehicles, as the electricity source has a major impact on the overall environmental performance. In this exercise we consider a truncated product system with real data for the functional unit '*1000 km driving with a passenger vehicle*', and compare its environmental performance with a gasoline vehicle.

The overarching question for this exercise is: "**How big a share of renewable energy do we need in the electricity grid for the carbon footprint of electric vehicles to become smaller than the footprint of gasoline-driven vehicles?**"

Data: Previous LCA research has shown that for gasoline-driven vehicles the emissions from the vehicle manufacturing phase are much smaller than tailpipe emissions (Hawkins et al., 2013), and we therefore neglect those emissions from this exercise. A typical gasoline-driven vehicle has an energy consumption of 2.2 MJ per km (Modaresi et al., 2014). The CO_2 intensity of gasoline is 14 MJ/kg CO_2 (derived from the energy and carbon content of gasoline), and the CO_2 intensity of gasoline supply 10g CO_2/MJ of gasoline (Modaresi et al., 2014). The electric vehicle has an energy consumption of 0.75 MJ/km, that is 0.2 kWh/km (Modaresi et al., 2014).

For the electric vehicle and electricity generation a dataset is provided on the sheet 'Process inventory full' in the accompanying excel file 'IEooc_Methods4_Exercise4_LCA_Excel'. Data on the sheet 'Process inventory basic' are meant to be used for the preparatory exercise. The total service life of the electric vehicle, measured in driving distance, is 200000 km.

Exercise part I, determining a product system in Excel:

On the sheet 'Process inventory basic' in the accompanying excel file 'IEooc_Methods4_Exercise4_LCA_Excel' you find the resource matrix R, the emissions table B, and the matrix of technological coefficients A for six processed related to the electric vehicle life cycle and the respective main products. Use these data to answer the following tasks:

1) **Functional unit and reference flow:** For the functional unit of '*1000 km driving with an electric vehicle*', determine the reference flow y of industrial output to deliver the functional unit!
2) **Build the product system by iteration:** Assume that no further industries and products as contained in the 6x6 matrix are needed, and determine the different iteration steps to produce the reference flow! ($x_0 = y$, $x_1 = A \cdot y$, $x_2 = A^2 \cdot y$, …until x_6). Does the series for the total output x converge?
3) **Build the product system by the Leontief inverse:** Determine the total output x by applying the Leontief inverse L to the reference flow. How much does it differ from $x_0+x_1+…x_6$?

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4) **Determine total resource needs and emissions:** How much iron ore and coal was used for the production of the reference flow? How high are CO_2 and N_20 emissions for the delivery of the functional unit?

Link: Help on matrix multiplication in Excel: https://www.youtube.com/watch?v=G8w-d9U3PJM

Exercise part II, comparative LCA for passenger transportation in Excel:

With the basic skills obtained in the first part the actual problem of the comparative LCA can now be addressed using the data provided on the sheet 'Process inventory full'. The solution can be broken down into the following steps:

1) **What is the reference flow in both the electric vehicle and the gasoline vehicle case?**
2) **What are the life cycle CO_2 emissions for the gasoline vehicle given the simplifications above?**
3) **What are the life cycle CO_2 emissions for the electric vehicle for a 50:50 ratio of coal-based and wind-based electricity in the grid?**
4) **How does the result change with the share of wind-based electricity in the grid, and what share corresponds to the break even with the gasoline case?**

Is your result realistic and correct?

Tip: The A matrix on the sheet 'Process inventory full' is not valid yet as the total electricity demand (row 25) needs to be split up into coal-based electricity (row 10) and wind-based electricity (row 11). This can be done by defining a parameter 'market share wind' and multiplying the total el. Demand by this parameter and by (100% - market share wind) and assigning the resulting numbers to the rows 11 and 10, respectively. As an alternative, you can introduce a new process 'electricity market' and a corresponding product 'electricity, grid mix' to the A matrix by inserting a row and a column at a convenient place (which place does not matter, but the order of products and associated processes needs to be preserved).

References:

Hawkins, T.R., Singh, B., Majeau-Bettez, G., Strømman, A.H., 2013. Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles. J. Ind. Ecol. 17, 53–64.

Modaresi, R., Pauliuk, S., Løvik, A.N., Müller, D.B., 2014. Global carbon benefits of material substitution in passenger cars until 2050 and the impact on the steel and aluminum industries. Environ. Sci. Technol. 48, 10776–10784.

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