IEooc_Methods4_Exercise 8: LCA with openLCA: Waste treatment, recycling, and allocation

Sample solution

Goal: *Learn how waste treatment, recycling, and allocation are handled in ecoinvent.*

Note: *For this exercise an ecoinvent licence for openLCA is needed. If no license is at hand the exercise can be modified, using the freely available life cycle databases on the openLCA Nexus.*

1) Waste treatment

To start with, remember that in most economic transaction, money and good flow in opposite directions. In LCA, we follow the physical goods from the producer via the markets to the consumer. A flow in that direction has a positive sign in the database and the product system model. For waste treatment, however, businesses who want to get rid of waste often have to pay for its treatment. For waste, money and good often flow in the same direction, which breaks the symmetry of the economic cycle, where money and goods always flow in opposite direction. To restore symmetry, waste treatment is commonly modelled as a service, the service of getting your waste treated. A service is an input and not an output of product, and when modelling waste treatment as service, it has to be moved from the output to the input side. When doing so, the sign of the waste flow has to change to keep the process mass balanced (Fig E6.1).

→ In ecoinvent, waste that is sent for treatment is modelled as input of a waste treatment service with negative sign (Fig. E6.1)

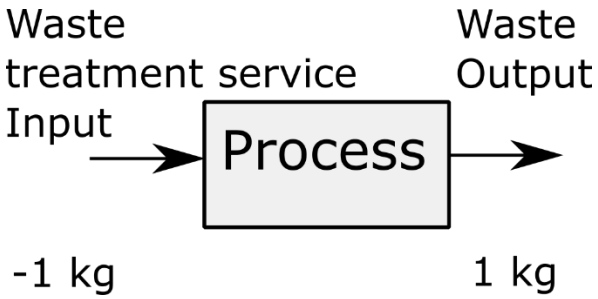

Figure E6.1: Two equivalent ways of representing waste treatment in LCA: left: as service input with negative sign to keep the process mass balanced, right: as output flow.

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Task: Determine the carbon footprint of treating 1 kg of polystyrene waste with ecoinvent 3.2. Use the process from group 3821: "**market for waste polystyrene | waste polystyrene | cut-off, U – GLO**" to reflect a mix of treatment options. Use the ReCiPe Midpoint Hierarchist impact assessment method without long-term effects.

Solution: We create a flow "PlasticWasteTreated" (or so) and a corresponding unit process "TreatMyPlasticWaste". This process has exactly one input: -1 kg of the above-mentioned process from the 3821 group. The newly created process delivers the functional unit of treating 1 kg of polystyrene waste (Fig E6.2), measured in kg.

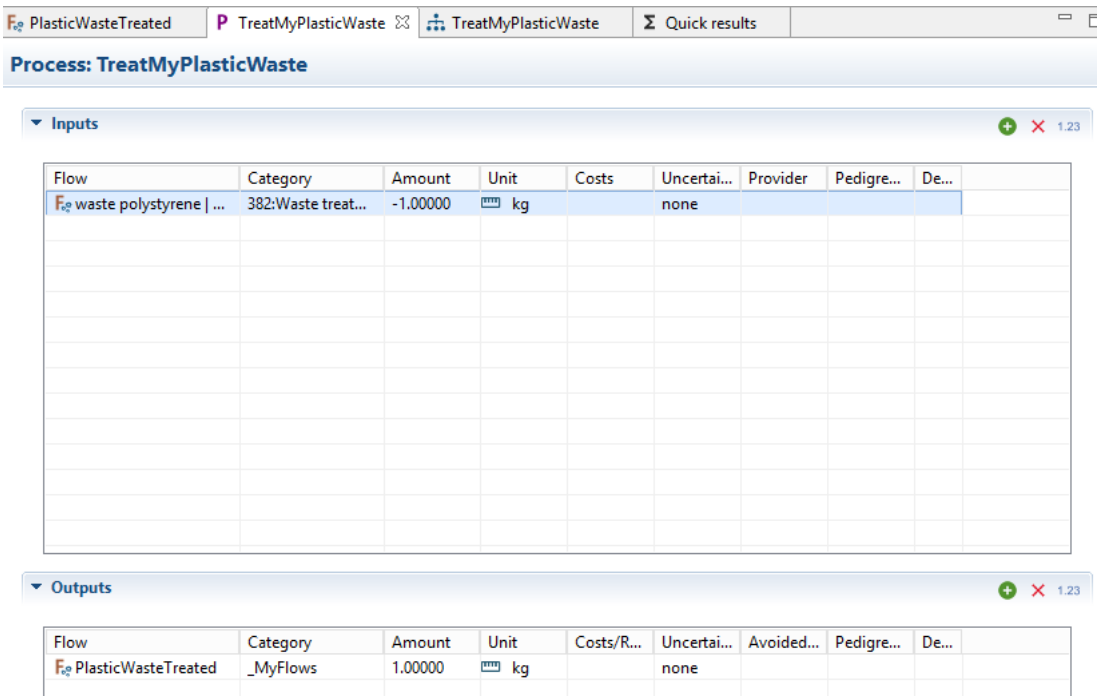

Figure E6.2: Input-output lists of the plastics treatment process.

Fig. E6.3 below shows the LCIA result: 0.43 kg CO_2-eq.

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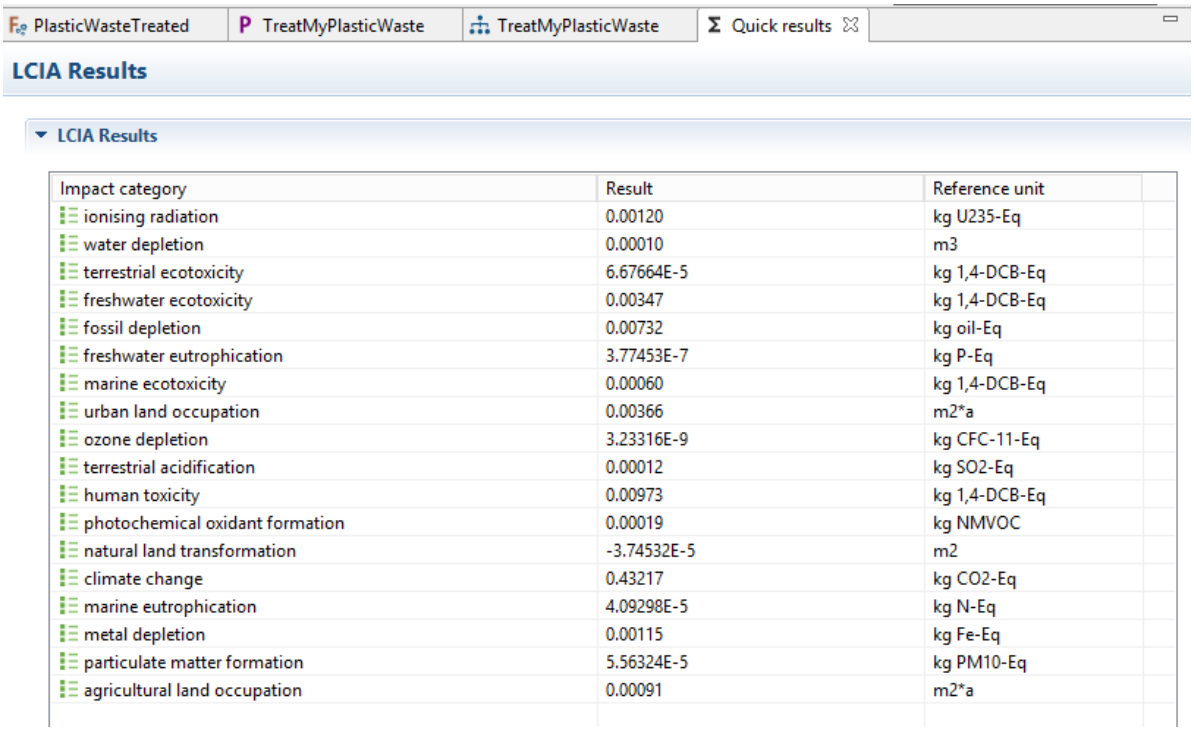

PlasticWasteTreated | TreatMyPlasticWaste | TreatMyPlasticWaste | Quick results

LCIA Results

LCIA Results

Impact category	Result	Reference unit
ionising radiation	0.00120	kg U235-Eq
water depletion	0.00010	m3
terrestrial ecotoxicity	6.67664E-5	kg 1,4-DCB-Eq
freshwater ecotoxicity	0.00347	kg 1,4-DCB-Eq
fossil depletion	0.00732	kg oil-Eq
freshwater eutrophication	3.77453E-7	kg P-Eq
marine ecotoxicity	0.00060	kg 1,4-DCB-Eq
urban land occupation	0.00366	m2*a
ozone depletion	3.23316E-9	kg CFC-11-Eq
terrestrial acidification	0.00012	kg SO2-Eq
human toxicity	0.00973	kg 1,4-DCB-Eq
photochemical oxidant formation	0.00019	kg NMVOC
natural land transformation	-3.74532E-5	m2
climate change	0.43217	kg CO2-Eq
marine eutrophication	4.09298E-5	kg N-Eq
metal depletion	0.00115	kg Fe-Eq
particulate matter formation	5.56324E-5	kg PM10-Eq
agricultural land occupation	0.00091	m2*a

Figure E6.3: LCIA results for treating 1 kg of polystyrene waste.

→ Confirmation: waste treatment services with negative input quantities yield positive impacts.

2) Recycling

In life cycle databases recycling can be modelled in two different ways: a) as unit process whose main output is a service of recycling waste or scrap, in which case the secondary material would be a by-product. Or b) as unit process whose main output is the secondary material, and waste or scrap is an input flow (Fig. E6.4).

In **ecoinvent version 2**, waste treatments are recorded as service inputs to the activities supplying the waste.

In **ecoinvent version 3**, changes relative to ecoinvent version 2 were introduced: While in ecoinvent version 2, waste treatments were recorded as service inputs to the activities supplying the waste, all such waste treatment services were re-viewed and are now expressed as negative outputs of wastes.

Reference: https://www.ecoinvent.org/files/dataqualityguideline_ecoinvent_3_20130506.pdf

Section "4.1.3 By-products and wastes"

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→ By default no benefits for substituting primary for secondary material are given by the cut-off version of ecoinvent. These have to be estimated by the practitioner, if meaningful.

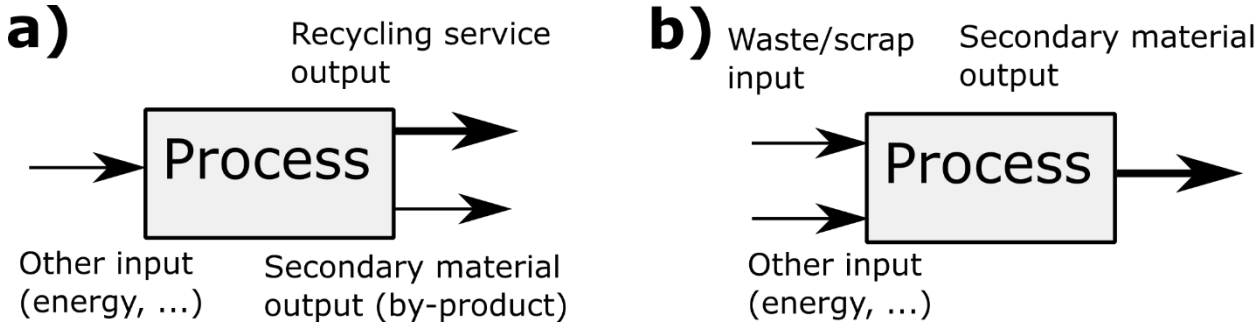

Figure E6.4: LCIA

Task: Determine the net carbon emissions savings of remelting 1 kg of steel scrap! Assume that secondary steel is a perfect substitute for primary steel. Use the processes "steel production, electric, low-alloyed | steel, low-alloyed | cut-off, U - RoW" for recycling and "steel production, converter, low-alloyed | steel, low-alloyed | cut-off, U - RoW" from the 2410 process group for primary steel production, and ignore that there is already some scrap input to the converter steel process (cf. Exercise 5).

Solution: We first need to determine how much secondary metal we get out of 1 kg steel scrap with that process. Therefore, open the input-output tab of the "electric" steelmaking process, where you find that 1.105 kg of scrap are needed for 1 kg or secondary steel. Hence, once gets 1/1.105 or 0.905 kg of secondary steel out of 1 kg scrap.

With that info a new flow/process pair "SteelScrapTreatmentSubstitution" or so can be created with an input list as shown in Fig. E6.5. The first input, 0.905 kg of "steel, low-alloyed | steel production, electric, low-alloyed" will cause, among other inputs, a scrap demand of exactly 1 kg, which is what is available. The second input, -0.905 kg of "steel, low-alloyed | steel production, converter, low-alloyed" represents the avoided production (emissions savings) from substituting an equal amount of primary steel.

The result is a net emissions saving of 1.46 kg CO_2-eq, which is ca. 63% of the total primary production emissions (compared to the result of Exercise 5) (Fig. E6.6).

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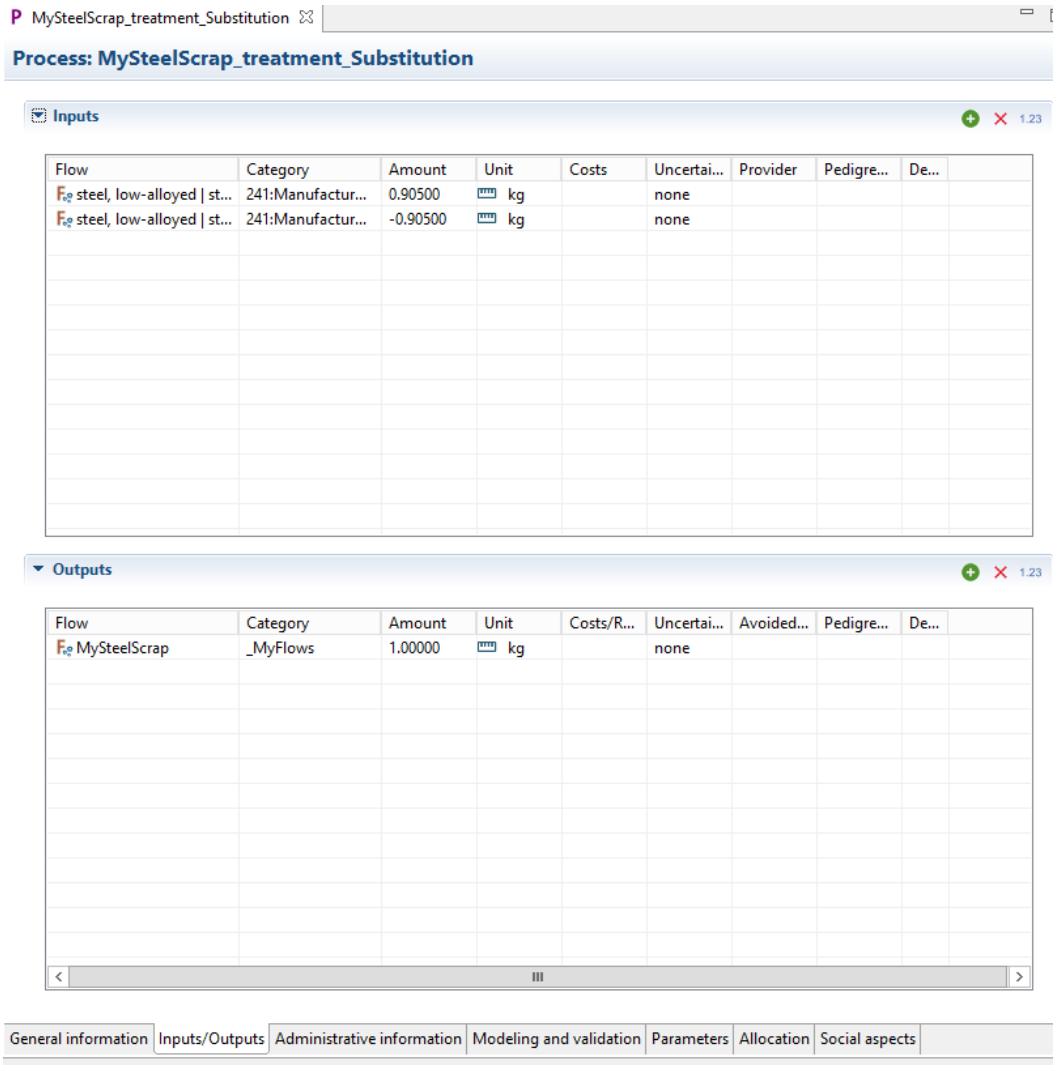

Figure E6.5: Input-output lists of the steel scrap recycling and substitution process.

In case you are wondering why we model steel scrap as an output in this task: Because the question is "Determine the net carbon emissions savings of remelting 1 kg of steel scrap!", we chose the function of the newly created process to be "remelt 1 ton of steel scrap AND avoid a corresponding amount of primary steel" and the corresponding reference flow is then the service of getting one 1kg of steel scrap treated (labelled as 'MySteelScrap' in Fig. 6.5 above).

There are of course other ways to model this problem. We could simple perform an LCA of X kg primary and secondary steel separately, determine the difference and the scrap input needed, and scale the result to 1 kg of scrap input to the secondary steel making process. The result would be the same as above.

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MySteelScrap | MySteelScrap_treatment_Substitution | MySteelScrap_treatment_Substitution | Quick results

LCIA Results

LCIA Results

Impact category	Result	Reference unit
ionising radiation	-0.00179	kg U235-Eq
water depletion	-0.00324	m3
terrestrial ecotoxicity	0.00020	kg 1,4-DCB-Eq
freshwater ecotoxicity	4.84217E-5	kg 1,4-DCB-Eq
fossil depletion	-0.30418	kg oil-Eq
freshwater eutrophication	-0.00059	kg P-Eq
marine ecotoxicity	-0.00127	kg 1,4-DCB-Eq
urban land occupation	-0.02292	m2*a
ozone depletion	-6.26647E-8	kg CFC-11-Eq
terrestrial acidification	-0.00620	kg SO2-Eq
human toxicity	0.89415	kg 1,4-DCB-Eq
photochemical oxidant formation	-0.00825	kg NMVOC
natural land transformation	-0.00012	m2
climate change	-1.45770	kg CO2-Eq
marine eutrophication	-0.00020	kg N-Eq
metal depletion	-4.58293	kg Fe-Eq
particulate matter formation	-0.00776	kg PM10-Eq
agricultural land occupation	-0.03488	m2*a

Figure E6.6: LCIA of the scrap remelting and substitution process.

3) Allocation

The different allocation mechanisms are explained in the LCA textbook. Here, a simple model for the two major partitioning allocations *economic* and *physical* shall be created and evaluated. For this exercise consider a process with electricity as its main output and heat as a by-product (1.5 kWh heat per kWh electricity). CO_2 emissions (1.0 kg CO_2 per kWh electricity) and coal input (0.27 kg lignite per kWh electricity) are the only other flows. The total revenues are 0.2 EUR for electricity and 0.1 EUR for heat.

Task: 1) Create a process description in openLCA as shown in Fig. E6.7 below, using the information supplied in the text. **2)** Determine the carbon footprint of the electricity generated for both physical and economic allocation, *both by hand and with openLCA* (The carbon footprint of 1 kg of lignite group 051: "lignite | market for lignite" is 0.01955 kg CO_2/eq per kg (pre-calculated)). **3)** Interpret your results! Use the ReCiPe Midpoint Hierarchist impact assessment method without long-term effects.

Hint: To enter prices the currency "Euro" must be created by adding it to the currency group in the main menu (bottom left in Fig. E6.7).

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Solution:

a) by hand: First, we calculate the total emissions of the inventory as 1.0 kg CO_2-eq + 0.01955 kg CO_2 = 1.01955 kg CO_2 (the sum of direct and indirect emissions from lignite mining). We then derive the following allocation table (Table E6.1) by calculating

$$allocation\ coeff_1 = \frac{output\ flow_1}{output\ flow_1 + output\ flow_2} \quad (1)$$

For the monetary allocation coefficients the revenue streams are used and for the physical allocation coefficients the energy output flows are used.

Table E6.1: Allocation coefficients for the process inventory

Allocation coefficients	**Monetary**	**Physical**
Electricity	0.667 (2/3)	0.4
Heat	0.333 (1/3)	0.6

Applying these allocation coefficients to the total GHG emission then yields the following results (Table E6.2):

Table E6.2: Allocated emissions for process inventory.

kg CO_2-eq per kWh of output	**Monetary**	**Physical**
Electricity, per kWh	0.67(0185667)	0.40(21114)
Heat, for 1.5 kWh	0.33(5092833) (0.34)	0.60(31671)
Heat, per 1 kWh	0.22(3395222)	0.40(21114)

b) with openLCA: On the 'Allocation' tab of the cogeneration process created under task 1, click the 'Calculate default values' button and the result as in Figure E6.8 will show up, which is identical to the coefficients shown in Table E6.1 (barring rounding).

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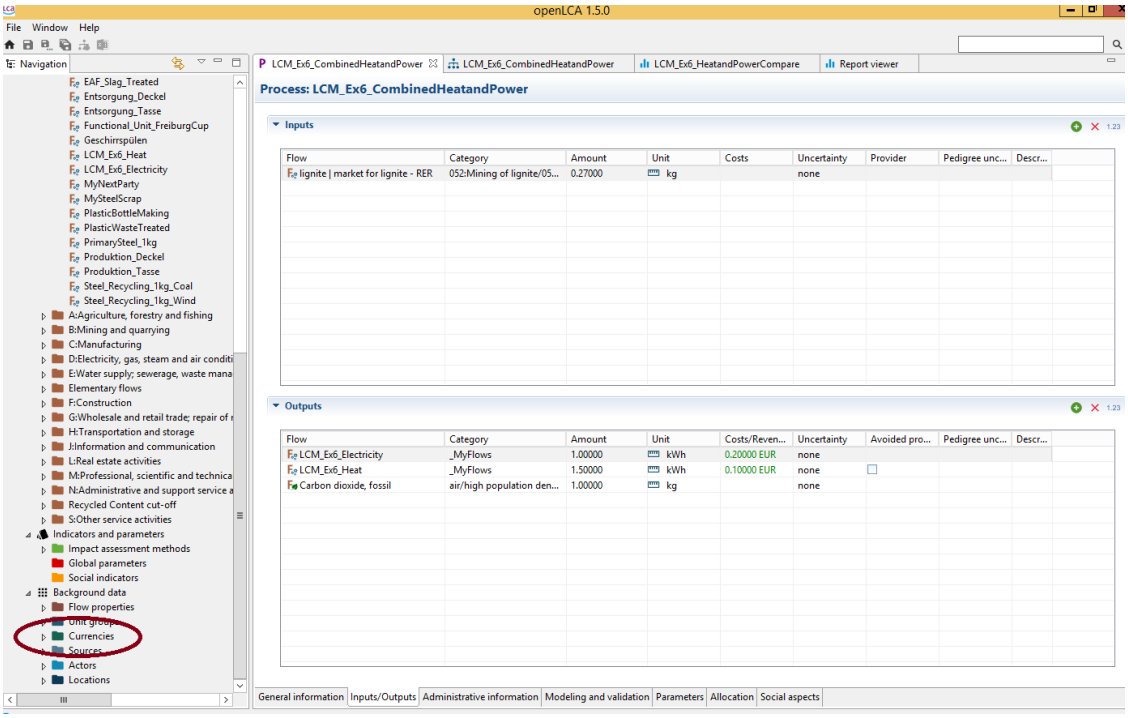

Figure E6.7: Input-output panel of the exemplary multi-output process.

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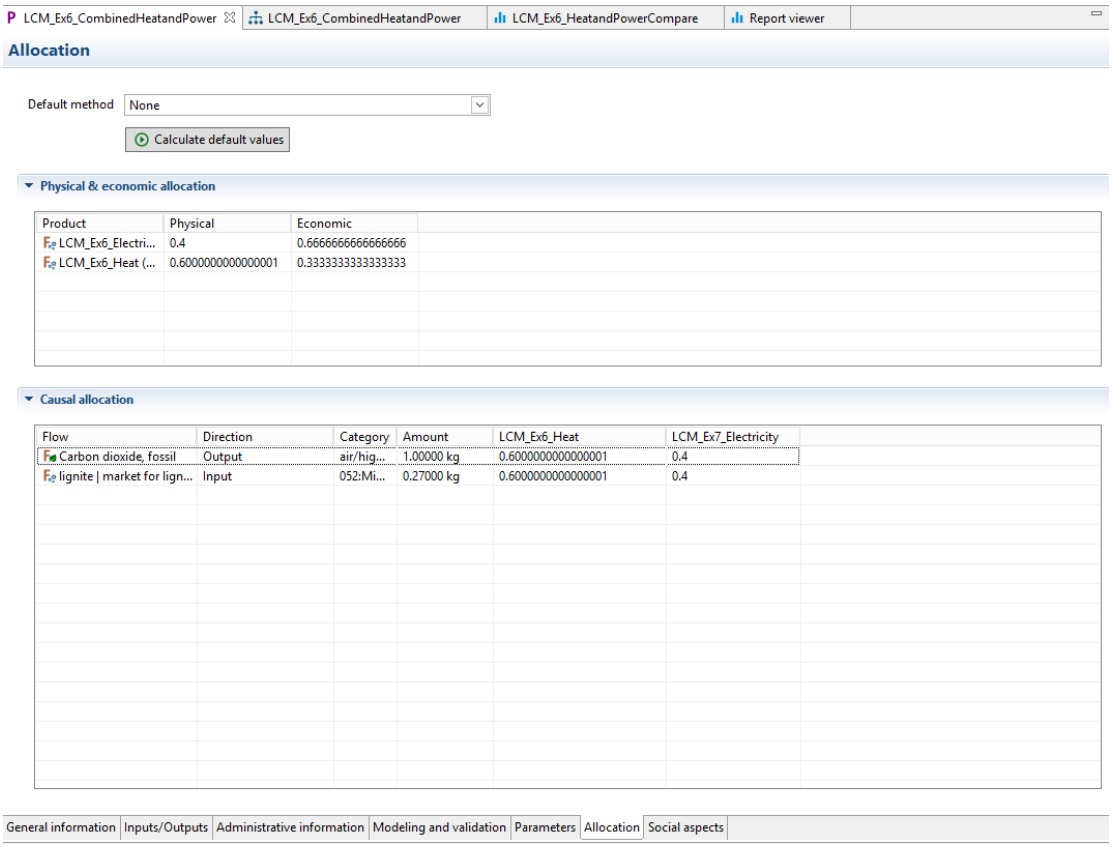

Figure E6.8: Allocation tab of the cogeneration process.

With the allocation factors in place, one can now create a project and select the product system created from the cogeneration process twice. In the column 'Allocation method' we select both: economic and physical allocation (Fig. E6.9).

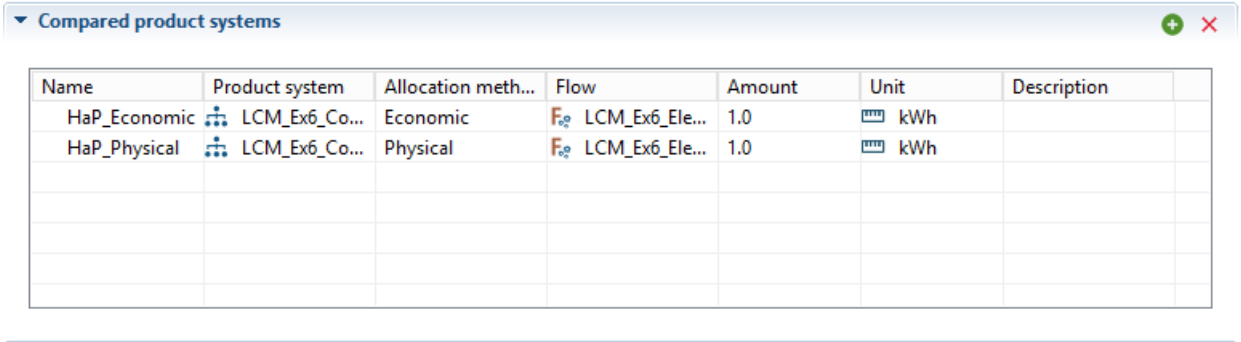

Figure E6.9: Screenshot from the project setup tab.

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With the ReCiPe Midpoint Hierarchist impact assessment method without long-term effects we then arrive at the following result for electricity (Fig. E6.10):

LCIA Results

This table shows the LCIA results of the project variants. Each selected LCIA category is displayed in the rows and the project variants in the columns. The unit is the unit of the LCIA category as defined in the LCIA method.

Indicator	Economic	Physical	Unit
agricultural land occupation	2.26290e-4	1.35774e-4	m2*a
climate change	6.70186e-1	4.02112e-1	kg CO2-Eq
fossil depletion	4.11724e-2	2.47034e-2	kg oil-Eq
freshwater ecotoxicity	1.79244e-5	1.07546e-5	kg 1,4-DCB-Eq

Figure E6.10: Screenshot of the results section for electricity for economic and physical allocation.

For heat the procedure can be repeated: A copy of the process is created and this time, heat is chosen as the reference product. The product system for heat is then created, and in a new project, 1.5 kWh of heat is selected twice, with different allocation methods. With the ReCiPe Midpoint Hierarchist impact assessment method without long-term effects we then arrive at the following result (Fig. E6.11):

LCIA Results

This table shows the LCIA results of the project variants. Each selected LCIA category is displayed in the rows and the project variants in the columns. The unit is the unit of the LCIA category as defined in the LCIA method.

Indicator	Economic	Physical	Unit
agricultural land occupation	1.13145e-4	2.03661e-4	m2*a
climate change	3.35093e-1	6.03167e-1	kg CO2-Eq
fossil depletion	2.05862e-2	3.70552e-2	kg oil-Eq

Figure E6.11: Screenshot of the results section for heat for economic and physical allocation. Note that the impacts shown here are for 1.5 kWh of heat, not for 1 kWh.

The results returned by openLCA are the same as those in Table E6.2 (barring rounding).

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Interpretation: For the physical allocation the carbon footprint of both heat and electricity is the same. This is no coincidence, as the measurement unit of heat and electricity is kWh, which is a physical unit. If we were to calculate the carbon footprint per EURO of electricity or heat using economic allocation, the results would also be the same. Although the physical allocation of emissions to electricity and heat is not even (0.4 vs. 0.6), the heat flow is bigger than the electricity flow, which leads to equal footprints on a per kWh basis.

The economic allocation assigns a higher share of the total emissions to electricity, as it stands for 2/3 of the revenue.

Both allocation methods lead to very different results, both regarding the total footprint levels and the ratio of footprints between heat and electricity. Allocation is a necessary step when creating product systems, but there is not universally preferred allocation method. The ISO standard stipulates to use physical allocation whenever possible, like in this case, and economic allocation if not. One could also argue that the customers who are willing to pay a high price for electricity but not for heat should also be allocated a higher share of the total burden via their purchase of electricity, which is an argument for using economic allocation.

Because of their crucial role in splitting impacts of multi-output processes onto single products allocation choses must always be clearly documented and, ideally, the impact of different allocation choices should be examined.

More tutorials for openLCA:

https://www.youtube.com/channel/UCGiahq1YZWK4pRXDVXuIi6w

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