Emilia Nuppumäki, Matti Peltomäki, Markus Reuter, Susanna Horn
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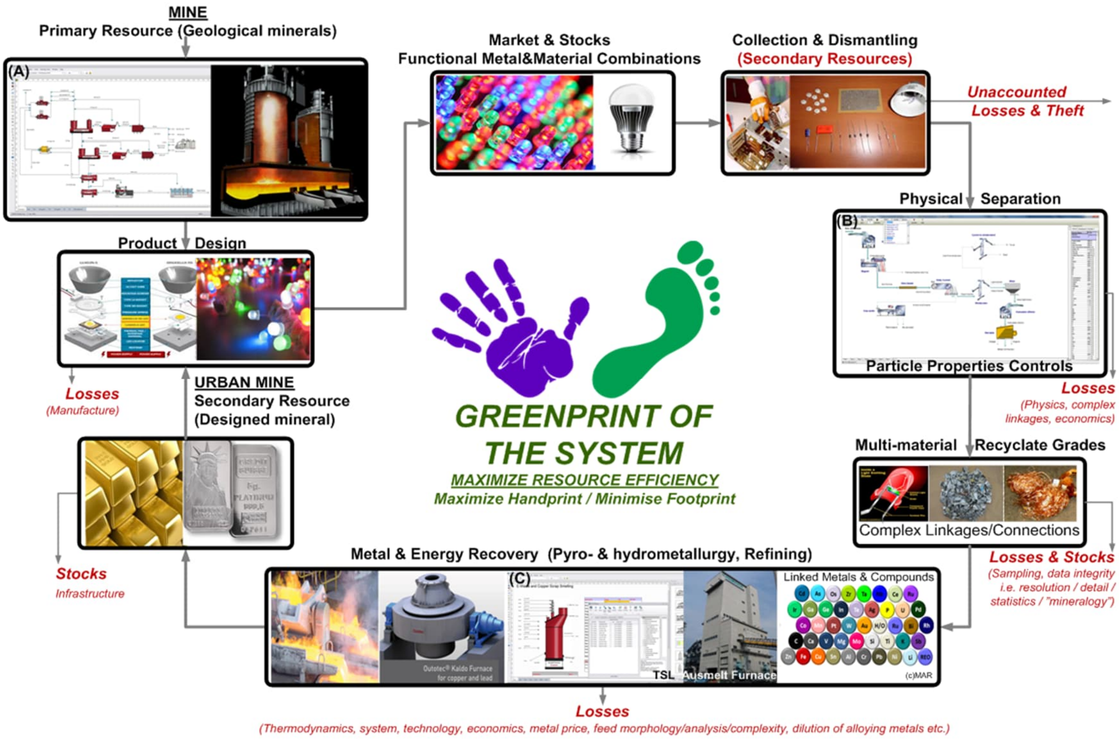
49. Environmental Impacts

HSC Sim includes an option for assessing the environmental impacts of the underlying process using openLCA and GaBi life cycle assessment (LCA) softwares[1]. HSC provides a mass and energy balance for LCA software and thus allows a technology-based environmental assessment of a system.

The aim of an LCA is to study a given system and understand its resource efficiency, as shown in the following figure.



Emilia Nuppumäki, Matti Peltomäki, Markus Reuter, Susanna Horn

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49.1. Introduction to Life Cycle Assessment (LCA)

The concept of LCA is portrayed as the compilation and evaluation of the **inputs, outputs, and potential environmental impacts** of a product system (product/service) throughout its life cycle (ISO 14040).

This means that each life cycle stage, including resource extraction, production, transportation, use/consumption, end-of-life activities (collection, sorting, recycling, waste disposal) should be acknowledged and included in an LCA. The product system is followed from its cradle, where raw materials are extracted from natural resources, through production and use to its grave, i.e., the end-of-life processes. Alternatively, products can be followed from cradle-to-gate (raw materials, production), from gate-to-gate (only production), or from cradle-to-cradle (entire life cycle including recycling).

The aim is to quantify the environmental impacts of a product from each process. Some more common usages of LCA methodology include the carbon footprint (ISO 14044), which is an LCA for only one environmental impact category (global warming potential). The comprehensive scope of LCA is useful in order to avoid problem shifting between life cycle phases, regions, or environmental problems.

An LCA consists of four main phases, presented in **Fig. 1**.

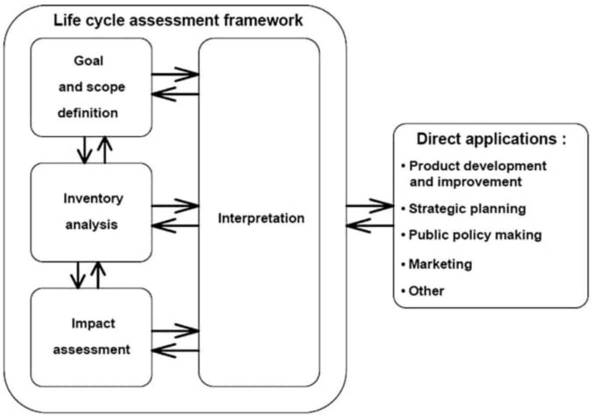

Fig. 1. Steps of Life Cycle Assessment[1-4].

1. Goal and scope definition

a) Definition of what we want to accomplish with the study. For instance, finding hotspots within the life cycle for further product development, informing the customer about the equipment's/process's environmental impacts, strategic planning, marketing, comparing two alternatives.

b) Definition of functional unit (proportioned to the unit for which we wish to estimate the results, for example, one tonne of copper, one piece of equipment, one consumer product). It is very common to use either the produced tonne of concentrate/metal as the functional unit OR one piece of production equipment. This will define which life cycle we are interested in.

c) Definition of system boundaries. Which unit processes will be included in the LCA?

- Cradle-to-Grave (Full Life Cycle Assessment)
- Cradle-to-Gate (Raw materials extraction and production, excluding transportation to customer)

- Gate-to-Gate (One process in the production chain)

2. Life cycle inventory (LCI)

   This phase is usually the most time-consuming phase, where the input and output data of the system are studied and collected. The LCI answers the question: How much of everything flows where?

Usually input and output can be classified into the following main fields:

- energy inputs, raw material inputs, ancillary inputs, other physical inputs
- products, co-products, and waste
- emissions into air, water, and soil
- other environmental aspects

All calculating procedures should be explicitly documented and all assumptions should be explained carefully. It is good to check the data validity during the LCA process. A production flow definition should be made using the real production distribution. For example, in the case of electricity, details such as fuel combustion, mix, conversion, etc. should be included.

When using LCA software, the LCI can be speeded up dramatically, since there are ready-made assumption datasets, e.g., for intermediary products, energy mixes, modes of transport.

However, the ready-made datasets rely heavily on the assumptions of the dataset provider. A trade-off between the accuracy and speed of the analysis may occur. If using datasets from a dataset provider, the process documentation attached to the process is important. **For example, you can find steel in the database, but there are certain assumptions about locations, energy mixes, production technologies used, etc., which the user has to be aware of.** A full-scale analysis requires that the supplier of the steel plate is known and the environmental profile of that particular supplier's steel is collected and used.

3. Life cycle impact assessment (LCIA)

   LCIA identifies and evaluates the amounts and significance of the potential environmental impacts of the product system. LCIA answers the question: What are the resulting impacts? Calculating is usually done using four steps, where the first two are mandatory. **Fig. 2** describes the steps with example values.

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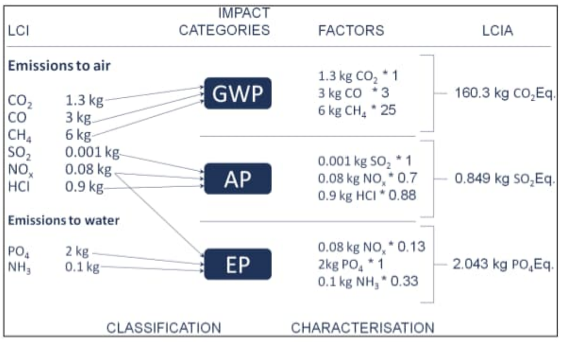


Industrial designation or common name	Chemical formula	GWP for 100-year time horizon	
		Second assessment report (SAR)	4th assessment report (AR4)
Carbon dioxide	CO_2	1	1
Methane	CH_4	21	25
Nitrous oxide	N_2O	310	298
Substances controlled by the Montreal Protocol			
CFC-11	CCl_3F	3,800	4,750
CFC-12	CCl_2F_2	8,100	10,900
CFC-13	$CClF_3$		14,400
CFC-113	CCl_2FCClF_2	4,800	6,130
CFC-114	$CClF_2CClF_2$		10,000
CFC-115	$CClF_2CF_3$		7,370
Halon-1301	$CBrF_3$	5,400	7,140
Halon-1211	$CBrClF_2$		1,890
Halon-2402	$CBrF_2CBrF_2$		1,640
Carbon tetrachloride	CCl_4	1,400	1,400
Methyl bromide	CH_3Br		5
Methyl chloroform	CH_3CCl_3	100	146

Fig. 2. Life Cycle Impact Analysis and a few impact factors for CO_2 Eq.

- Classification: All emissions are linked to one or more impact category, for example CH_4 belongs to the Global Warming Potential (GWP) category. Mandatory.

- Characterization: Converts the reference substance of the category by multiplying the quantities by the characterization factor, which means that the result unit is changed to the reference unit of the category where the quantity belongs. For example, CH_4 has a factor of 25, which means that CH_4 contributes 25 times more than CO_2 to the global warming potential. The most common factor developers are the Institute of Environmental Science (CML) in Europe and TRAICI in the United States[3-4]. Mandatory.

- Normalization: Converts and possibly aggregates the indicator results across impact categories using numerical factors based on value choices. The aim is to understand the relative magnitude for each indicator result. Not mandatory.

- Grouping: Sorting/ranking the characterization results, e.g. global/regional/local impacts, high/medium/low priority impacts, emissions to air/water. Not mandatory.

- Weighting: Different value choices are given to impact categories to generate a single score. The relative importance of an environmental impact is weighted against all the others. Predominantly based on social sciences. Not mandatory or even recommended.

4. Interpretation phase. The results of the LCI or LCA or both, are summarized. The main aim here is to identify significant issues based on the LCI and LCIA phases of an LCA.

Not all these phases are always mandatory. Sometimes sufficient information is already assimilated by carrying out only the LCI and LCIA phases. This is usually referred to as an LCI study.

49.2. LCA in HSC Sim

The HSC Sim LCA tool covers the LCI phase. The subsequent LCIA can be performed by 3rd party LCA software, e.g., GaBi or OpenLCA. When the LCI has been completed with HSC Sim, the process is exported to a separate file. The file can be imported into GaBi (EcoSpold v1.0 file format) or OpenLCA (JSON-LD file format) LCA software. In these 3rd party LCA software programs, other relevant processes (e.g., auxiliaries, transportation) are added. Please consult www.thinkstep.com for more information, and details about GaBi at http://www.gabi-software.com/ and for OpenLCA https://www.openlca.org/.

The HSC Sim LCA tool can also be used to capture, in a black box summary of the process, how much of a compound is released into the environment, without the use of LCA software. However, LCA software provides mid- and end-point analyses of the impacts of these flows, materials, compounds etc., providing a detailed impact analysis of the flows.

HSC Sim LCA analysis is always based on a complete HSC Sim process model, where the input and output streams represent the data for the LCI phase. In LCA, the substances of interest are only the input and output streams to the environment (see blue and red streams in **Fig. 1**). Internal streams (black) are not taken into account because they are not relevant when analyzing the process as one black box. As LCA does not generally base its analysis of complete systems on closed mass and energy balances, it is always advisable to create a detailed process model to make the LCA results more accurate[6-7].

49.3. Using LCA Evaluation in HSC Sim

In this example we use a TSL smelter as an example process model (see **Fig. 1**).

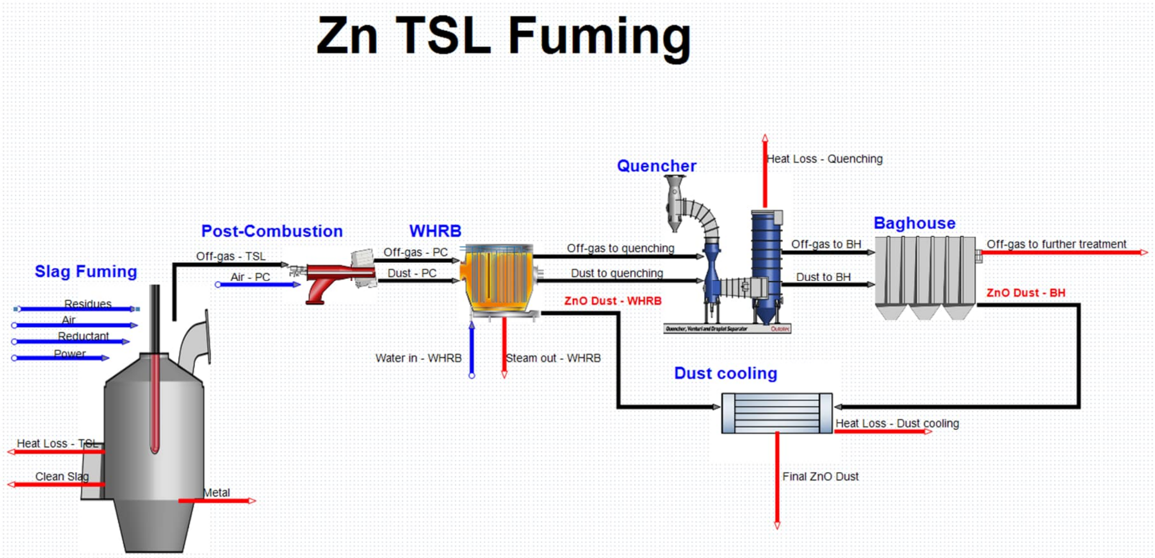


Fig. 3. TSL Furnace process model.

When the process simulation model is ready, the LCA tool is started by selecting Tools → LCA Evaluation from the main menu, as shown in **Fig. 4**.

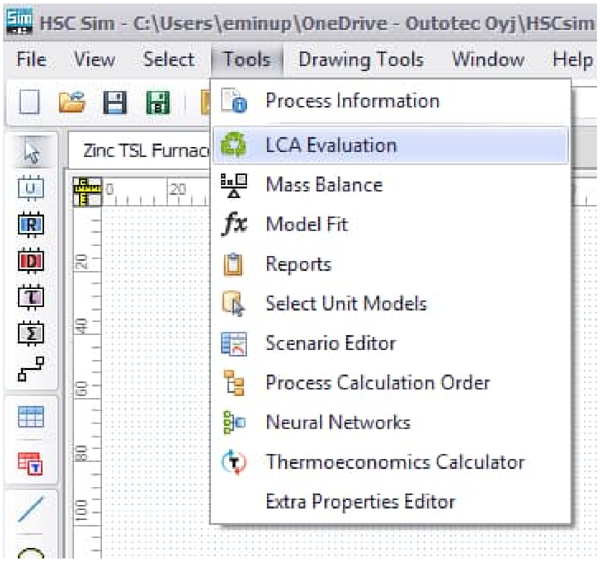


Fig. 4. Starting the LCA tool from the main menu.

49.3.1. Choosing the active database

HSC Sim LCA tool supports two dataset providers: GaBi and OpenLCA. The active database (dataset) can be chosen from the database section in the top menu, see **Fig. 5**.

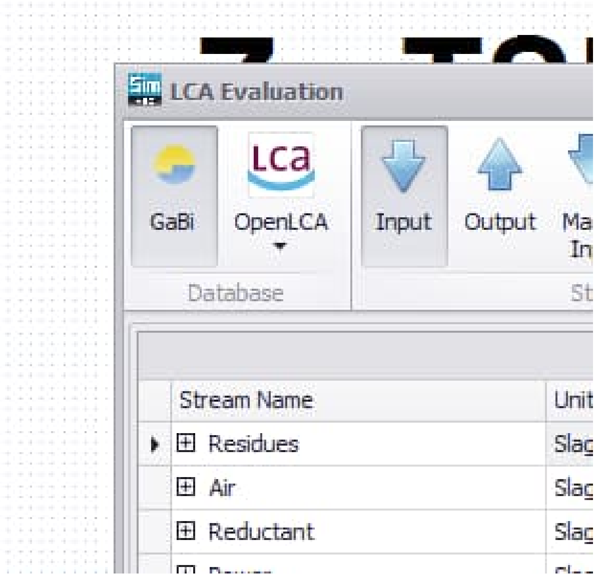


Fig. 5. Choosing the active LCA mode.

By default, the Gabi database is selected. The Gabi database is built into HSC and does not need any additional steps to be downloaded. OpenLCA, however, supports multiple different databases. These databases can be downloaded from https://nexus.openlca.org/ to OpenLCA. Please refer to the OpenLCA manual (http://www.openlca.org/learning/) for more detailed guidelines on how to import the downloaded database to the OpenLCA tool.

OpenLCA supports database export to JSON-LD (.zip) file format, which can be imported to the HSC Sim LCA tool. Start the export by activating the desired database. When the correct database is active, the database name is bolded, then right-click and select “Export…”, see **Fig. 6**.

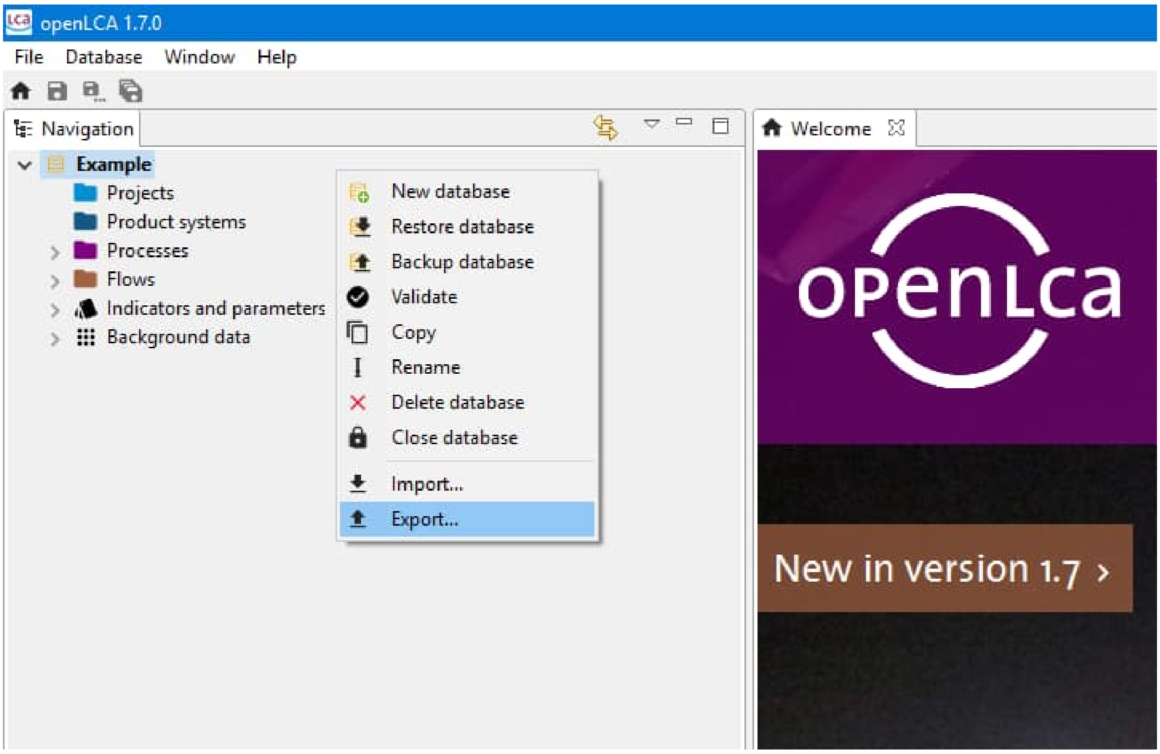


Fig. 6. Right-click when the correct database is active (bolded) and choose "Export…"

This opens a window from where JSON-LD should be selected, see **Fig. 7**. After selection, exported datasets should be defined. For HSC Sim purposes, only the flows are needed.

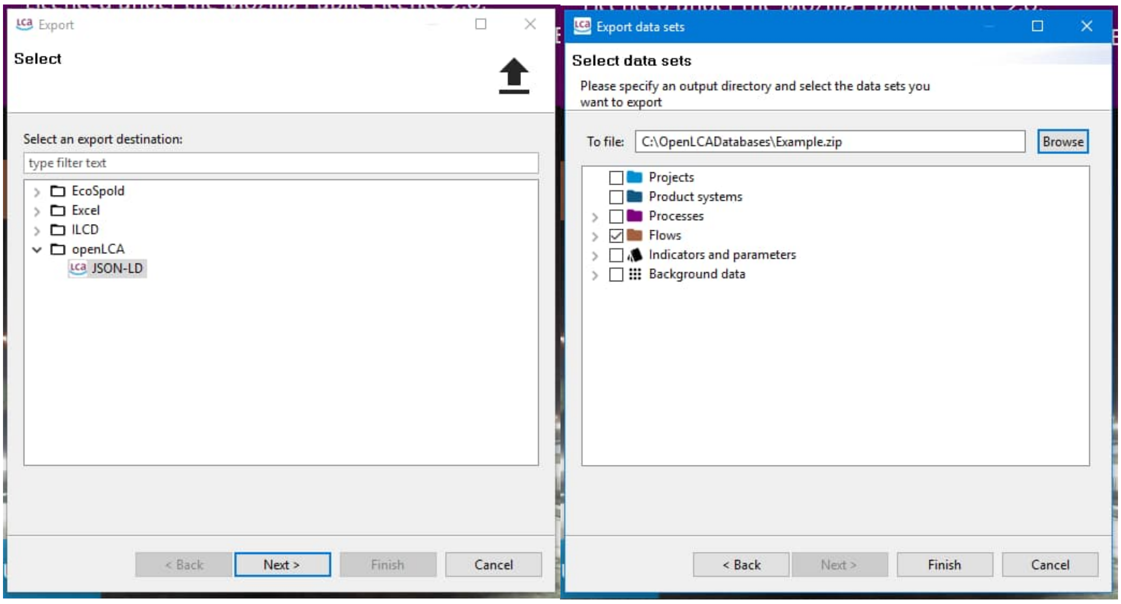


Fig. 7. Select JSON-LD and then click "Next >". Select "Flows".

Now the created file can be imported to HSC Sim. This is done in the HSC Sim LCA Evaluation tool. If there is no previously defined OpenLCA database, the program will request it when the OpenLCA is first activated. The active database is visible in the dropdown menu under the OpenLCA button. From there, the active database can also be changed, see **Fig. 8**.

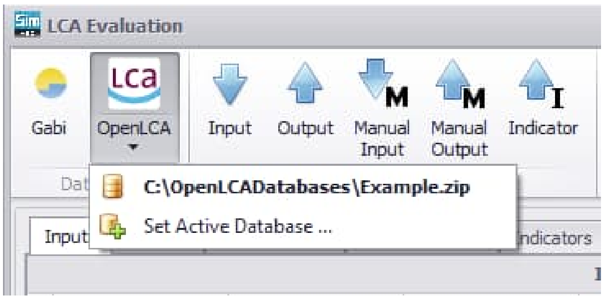


Fig. 8. Active Database is shown in the dropdown menu. Active database can be changed with "Set Active Database…"

49.3.2. Automatic Import of All Input and Output Streams

The LCA tool creates up to five sheets, named Input, Output, Manual Input, Manual Output, and Indicator, as shown in **Fig. 9**. The Input and Output Streams info sheets contain all the process input and output streams in HSC Sim format for the process or complete flowsheet. In these sheets, stream detail content is available and imported directly from the simulation model.

NOTE! No internal streams are captured through this, as only streams that can interact with the environment and flow out from the system into the environment are used in the assessment.

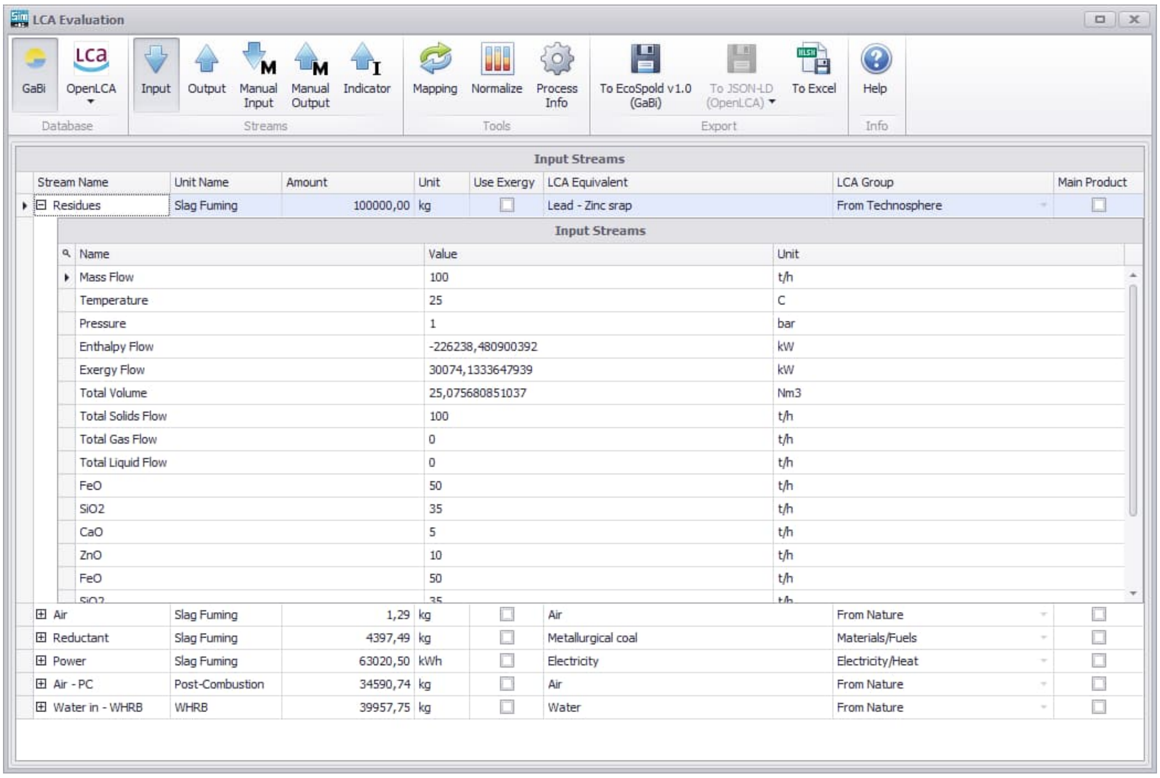
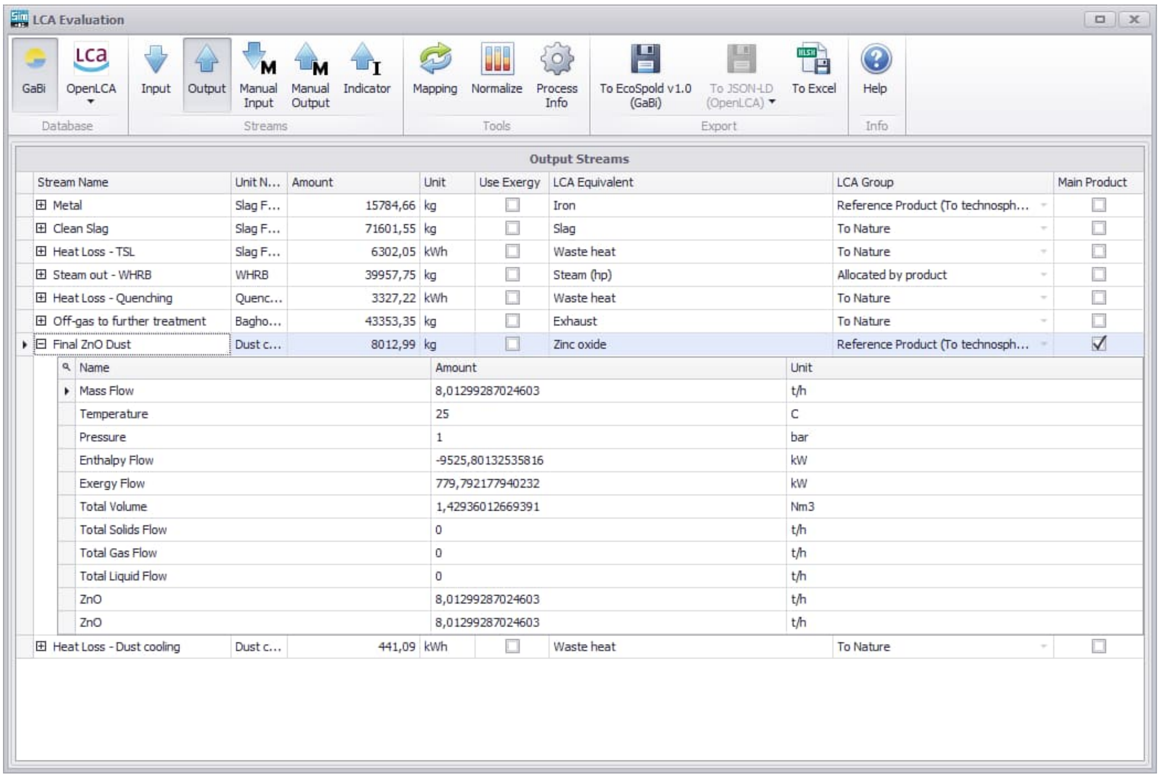


Fig. 9. "Input" streams info sheet extracted from flowsheet showing details of "Residues".

The LCA streams sheets contain the HSC Sim stream names (as defined by the design engineer) and amounts, which must be mapped to the LCA software equivalents on the active database. The default is "No Mapping" which, unless changed, will exclude that stream from the evaluation. **Fig. 9** shows the details of the Residues input stream while **Fig. 10** shows the output and more specifically the final ZnO dust stream. Please note that the exergy value is also given, which is very useful additional information for analyzing technology, reactors, plants, and systems. The exergy value can also be used as the amount for the stream and this is done by checking the "Use Exergy" box.



Stream Name	Unit N...	Amount	Unit	Use Exergy	LCA Equivalent	LCA Group	Main Product
Metal	Slag F...	15784,66	kg	☐	Iron	Reference Product (To technosph...	☐
Clean Slag	Slag F...	71601,55	kg	☐	Slag	To Nature	☐
Heat Loss - TSL	Slag F...	6302,05	kWh	☐	Waste heat	To Nature	☐
Steam out - WHRB	WHRB	39957,75	kg	☐	Steam (hp)	Allocated by product	☐
Heat Loss - Quenching	Quenc...	3327,22	kWh	☐	Waste heat	To Nature	☐
Off-gas to further treatment	Bagho...	43353,35	kg	☐	Exhaust	To Nature	☐
Final ZnO Dust	Dust c...	8012,99	kg	☐	Zinc oxide	Reference Product (To technosph...	☑
Heat Loss - Dust cooling	Dust c...	441,09	kWh	☐	Waste heat	To Nature	☐

Name	Amount	Unit
Mass Flow	8,01299287024603	t/h
Temperature	25	C
Pressure	1	bar
Enthalpy Flow	-9525,80132535816	kW
Exergy Flow	779,792177940232	kW
Total Volume	1,42936012669391	Nm3
Total Solids Flow	0	t/h
Total Gas Flow	0	t/h
Total Liquid Flow	0	t/h
ZnO	8,01299287024603	t/h
ZnO	8,01299287024603	t/h

Fig. 10. LCA Streams sheet for “Output,” also marking the main product relative to which every flow is normalized.

49.3.3. Adding Manual Streams not Defined in the Process Simulation Model

Sometimes, during LCI compilation in HSC Sim, some missing streams may be identified. The best and recommended way is to add missing streams directly to the process simulation model. This typically would include all fugitive emissions, additional power, leakages from the system, etc. In some cases, it is also appropriate to add streams for LCA purposes only. Adding these is done via the “Manual Streams” sheet, as depicted in **Fig. 11**.

For example, if general ancillary process electricity usage is not defined with its own stream in the process simulation model, then it can be defined via the Manual Streams dialog sheet. This can also be done for the output side. As shown in **Fig. 11**, the stream can be added (click on “Add new input stream” button at the bottom of the window), adding a name as well as the units and the amount for the flow that matches the data in the flowsheet as it is being simulated.

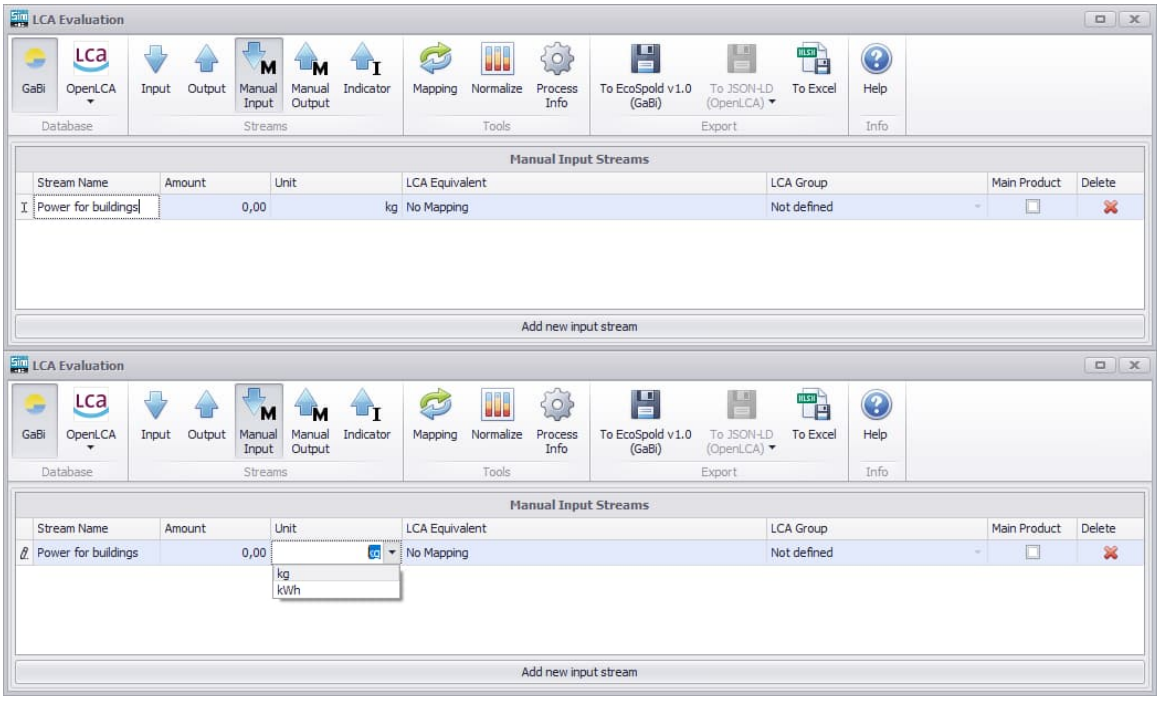


Fig. 11. LCA Manual Input Streams sheet for defining additional flows that do not appear in the simulation.

49.3.4. Adding key indicators in the Process Simulation Model

The Key Indicator sheet offers the possibility to examine how much of the compounds are released into the environment (Nature). The output streams that “LCA Group” in the mapping has selected “To Nature” are those that are counted to indicators. Indicators are a valuable part of the evaluation as a transparent analysis can be made of all the compounds that flow into the environment. **Fig. 12** shows all the indicator values and adds them together once they have been mapped as entering the environment. You can use the “*”' wildcard (**Table 1**) to capture more than a single compound, e.g. CO* will collect all CO and CO_2 etc. species, as defined in the model.

Table 1. Possible wildcard for compound definition

Wildcard	Description
*	Zero or more characters
?	Any single character
#	Any single digit (0-9)

You can type any compound in the sheet after having clicked on the Add new indicator stream bar at the bottom of the window. Some defaults are given. The compound definition may contain wildcards, as presented in **Table 1**. The LCA tool will automatically check if there are double counts of elements/compounds/species. A message box will inform the user of double counting and will not add the compound to the list.

All the indicators that contain some amount will be automatically added to the Manual Output streams list. If these emissions are to be excluded from the LCA, the streams can be deleted manually by clicking the red cross.

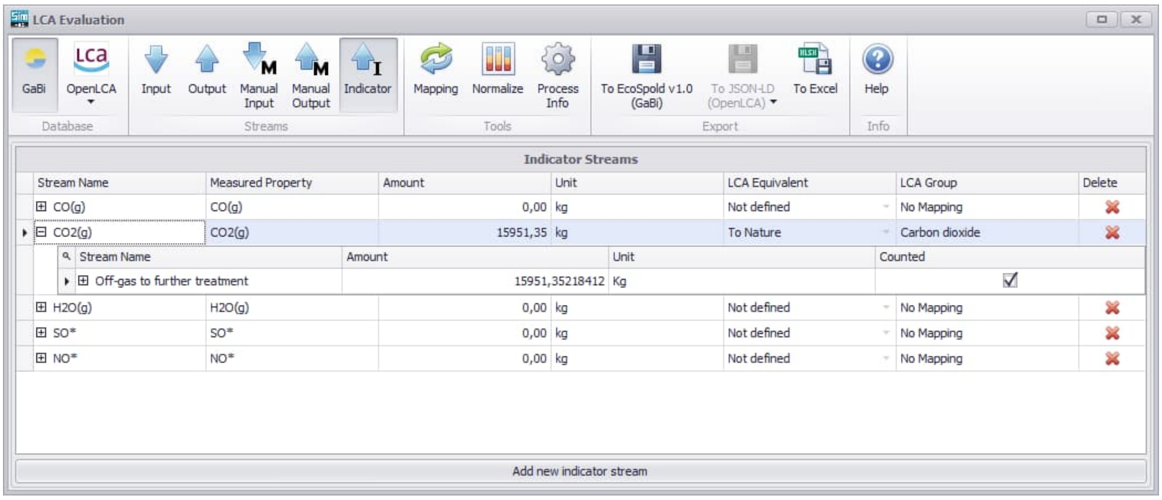


Fig. 12. Key Indicator sheet.

49.3.5. Mapping of Process Simulation Flows with LCA software Flow Definitions

In order to perform LCA calculations, all HSC streams have to be mapped to LCA software equivalents. It is recommended to map all streams, but those which are left without mapping will be discarded and reported to the user in the normalization and export phases.

The mapping dialog is started by clicking the mapping button on the button menu. On the left side of the dialog window, all the HSC Sim process streams are shown and the search tool for the active database is on the right side. Stream mapping and selection are done by drag-and-drop from the database side to the HSC stream side (see **Fig. 13** and **Fig. 14**).

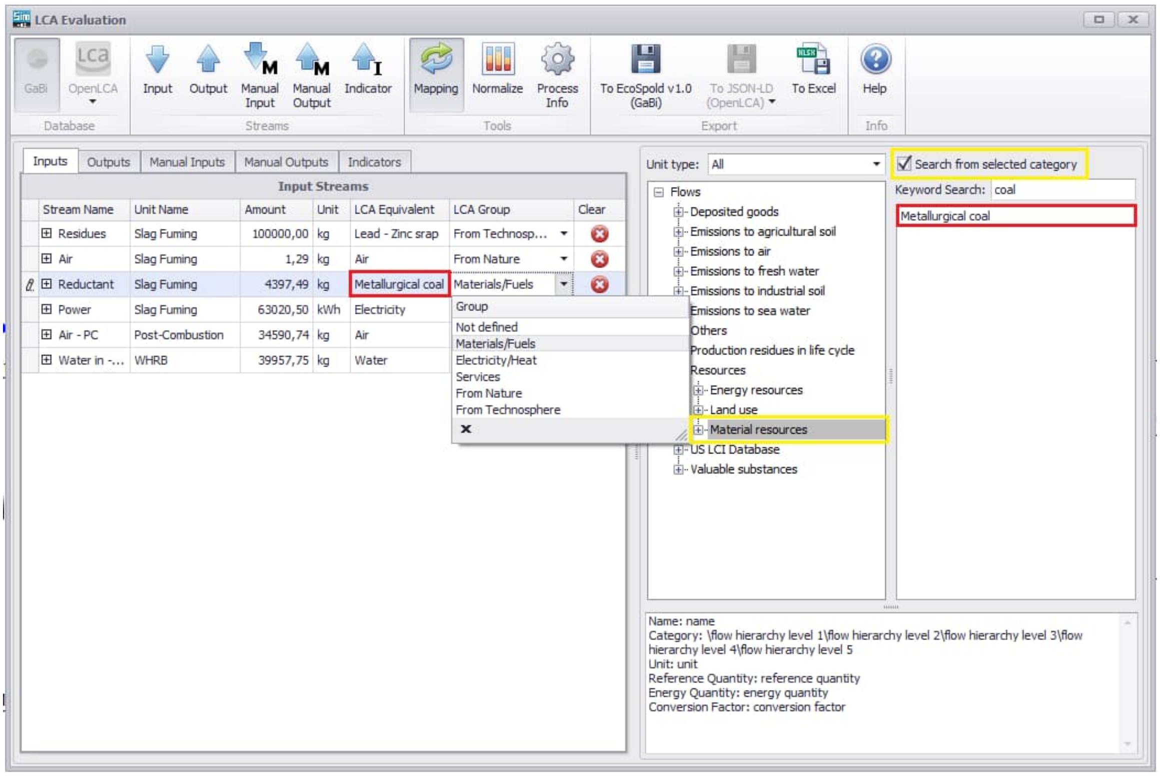


Fig. 13. Selecting a stream for mapping by drag-and-drop from the right into the LCA Equivalent box as shown in red. Please note that here you also need to select where this stream comes from, using the dropdown menu.

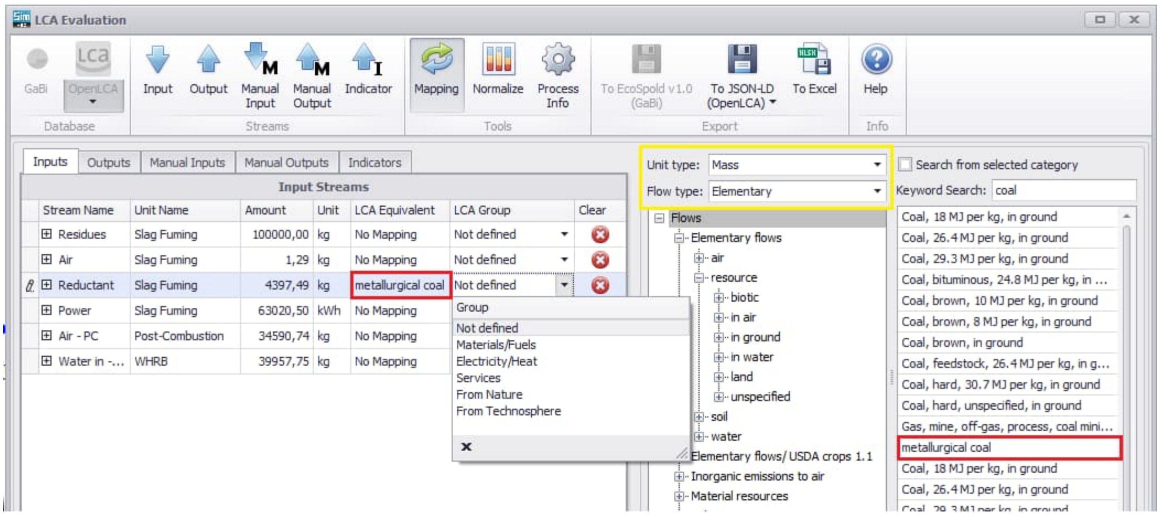


Fig. 14. In OpenLCA mode, flows can be filtered according to their unit and/or type as shown in yellow. Keyword search and drag-and-drop works the same as with the GaBi mode as shown in red.

Selection of the flow "LCA Group" is always a very important step. The flow group defines the nature of the stream, i.e., where it comes and where it flows to. There are specific group types for input flows and output flows. The flow group is selected from the dropdown menu as shown in **Fig. 13** and **Fig. 14.** NB! The "To Nature" selection only has meaning in the case of OpenLCA because indicators will be calculated based on this selection.

There are two ways of searching for the LCA equivalent of each stream in GaBi mode. A keyword search is one option, during which the hits are listed below the search word (**Fig. 13** and **Fig. 14**) and the second option is a tree view for manual searching. In both cases, double click on the stream name to select. With the keyword search, it is possible to limit the search by selecting some tree view node before the search, so that the search is performed under the selected node. All hits below this node will be presented. In OpenLCA mode, possible streams can also be filtered by unit and type, see **Fig. 14.** Filtering applies to visible nodes and hence filters the keyword search as well. Also shown is the pulldown menu for the LCA Group (**Fig. 13** and **Fig. 14**) and the possible places it can flow to, as selected.

The stream description field is shown when clicking a stream. In OpenLCA mode, the description can show the stream name, category, reference quantity, flow type, CAS number, and formula. With Gabi the properties are the stream name, category, unit, reference quantity, energy quantity, and conversion factor, see **Fig. 15**.

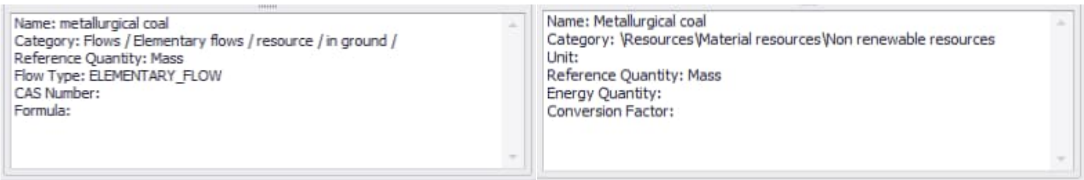


Fig. 15. On the left is the stream description with OpenLCA, and on the right with GaBi.

If changes are required, simply drag and drop a new LCA software equivalent or if something is to be omitted select <u>Not defined</u> from the pulldown menu or click on the cross at the end of the row. When navigating away from the page you will be prompted to apply the changes, as shown in **Fig. 16**. All changes must always be saved to be effective.

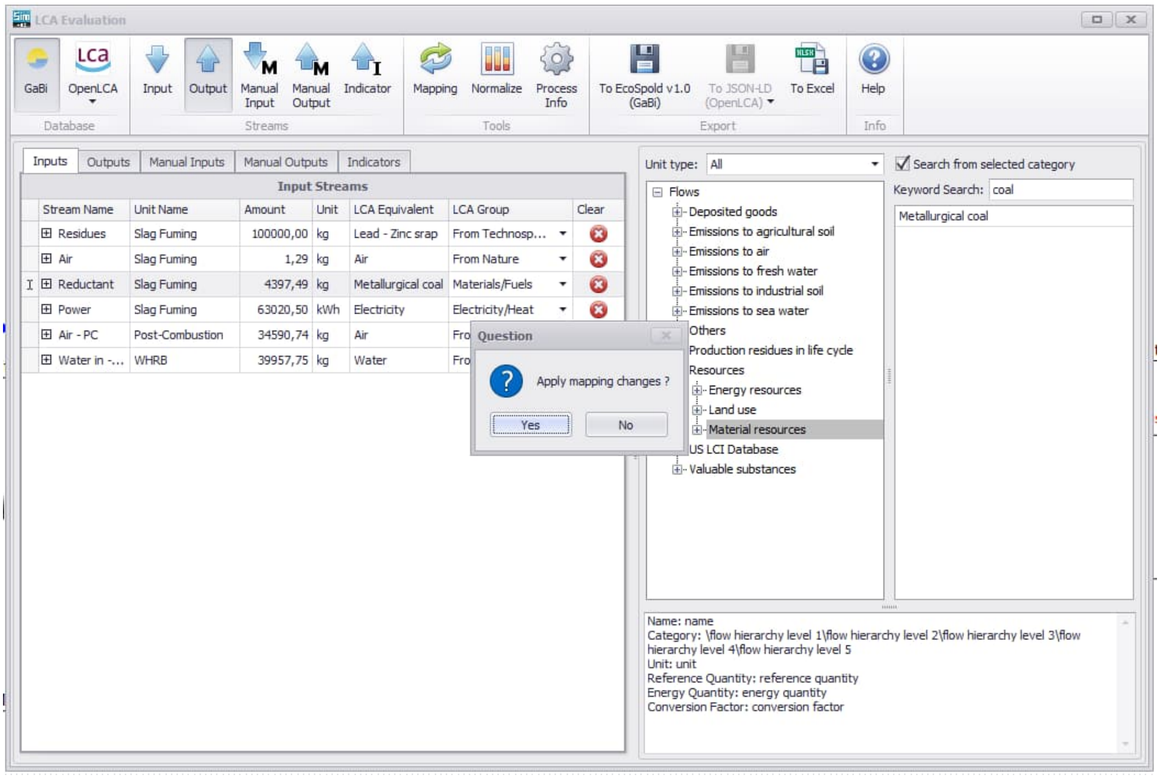


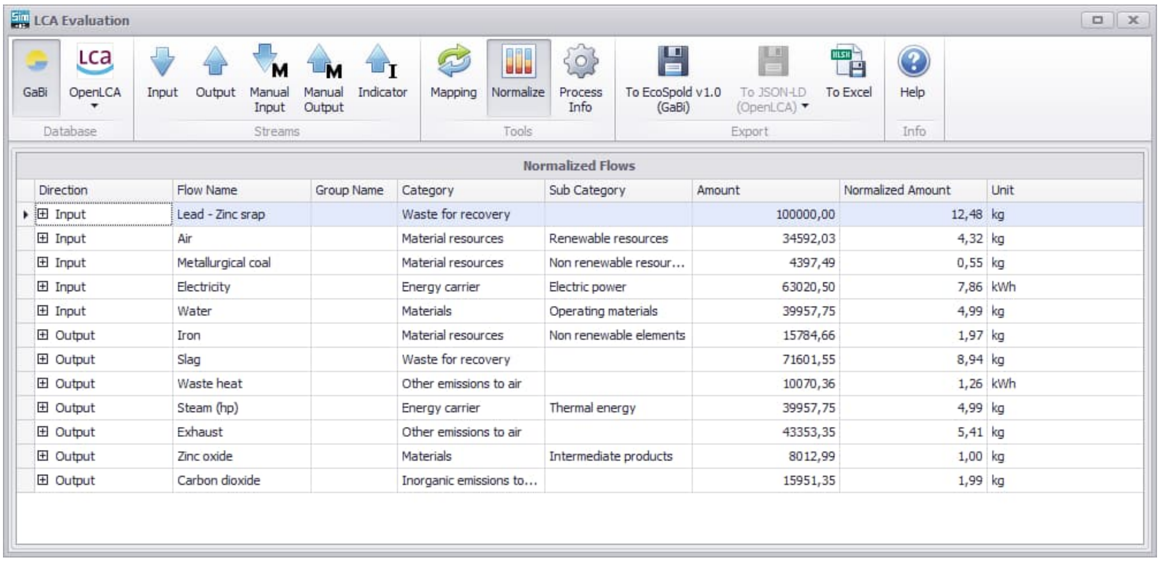
Fig. 16. When navigating away from the "Mappings" sheet, you will be asked to apply mapping changes.

49.3.6. Main Product Selection and Normalization of Data

Selection of the Main Product is needed in order for normalization of the data to be performed. There can only be one main product. The main product is selected by checking the box as shown in **Fig. 12**. The main product can be from either the Input or Output side.

Normalize calculates how much of each flow is needed to obtain 1 kg of the main product. The Normalize button in the button menu executes normalization and the results are written in a new LCA normalized data sheet, which appears after the calculation, as shown in **Fig. 17**. The normalization sheet summarizes all the process LCA data and in addition provides a good opportunity to check the data validity. All the same mappings are combined in one stream and unmapped streams are not included in the summary. If, for example, more than one stream is mapped with the same LCA software data “Air”, all Air LCA Equivalents will be added to create one stream.

This normalization sheet (**Fig. 17**) also provides a complete overview of all the flows, which thus provides an excellent black box summary of the complete simulation, producing a complete and consistent mass and energy balance. As only mapped inputs and outputs are considered and there are no internal flows, the black box does not reveal any proprietary process detail, making it ideal for benchmarking processes, inclusion in environmental databases, etc.



Direction	Flow Name	Group Name	Category	Sub Category	Amount	Normalized Amount	Unit
Input	Lead - Zinc srap		Waste for recovery		100000,00	12,48	kg
Input	Air		Material resources	Renewable resources	34592,03	4,32	kg
Input	Metallurgical coal		Material resources	Non renewable resour...	4397,49	0,55	kg
Input	Electricity		Energy carrier	Electric power	63020,50	7,86	kWh
Input	Water		Materials	Operating materials	39957,75	4,99	kg
Output	Iron		Material resources	Non renewable elements	15784,66	1,97	kg
Output	Slag		Waste for recovery		71601,55	8,94	kg
Output	Waste heat		Other emissions to air		10070,36	1,26	kWh
Output	Steam (hp)		Energy carrier	Thermal energy	39957,75	4,99	kg
Output	Exhaust		Other emissions to air		43353,35	5,41	kg
Output	Zinc oxide		Materials	Intermediate products	8012,99	1,00	kg
Output	Carbon dioxide		Inorganic emissions to...		15951,35	1,99	kg

Fig. 17. A complete normalized data set defining the complete process, flowsheet, or system as a black box.

49.3.7. Exporting LCI Data

To Gabi

The To EcoSpold v1.0 (GaBi) exporting menu button writes an EcoSpold version 1.0 XML file. The exported file contains metadata, which provides general process information as required by the LCA methodology. Metadata information is entered in the Process Information window and needs to be completed before exporting (**Fig. 18**). The process information window can be opened from the menu with the Process Information button. Stream details are taken from the normalization sheet.

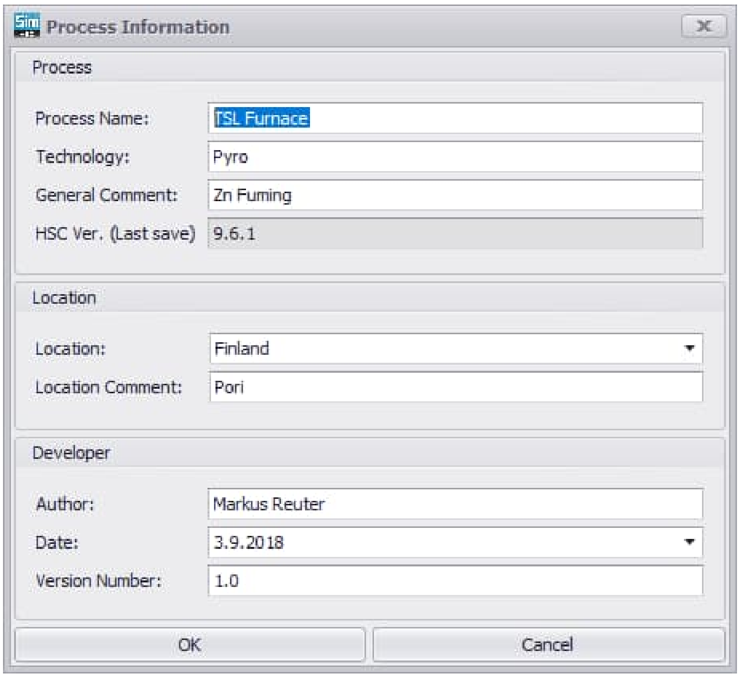


Fig. 18. Process Info dialog for entering process detail.

It is not mandatory to complete all the process information fields, but it is worth filling them well. After completion of the process information, save it by clicking. Process info can also be used without the LCA tool to describe the process well, hence providing a good summary for use in process design.

Exporting buttons are found on the right of the button menu. If normalization has not been done, the LCA tool will automatically ask you to perform normalization first. Exporting opens a file search dialog where the location and name of the exported file is defined/entered. A popup window will inform the user if the export was successful and in what format, as shown in **Fig. 19**.

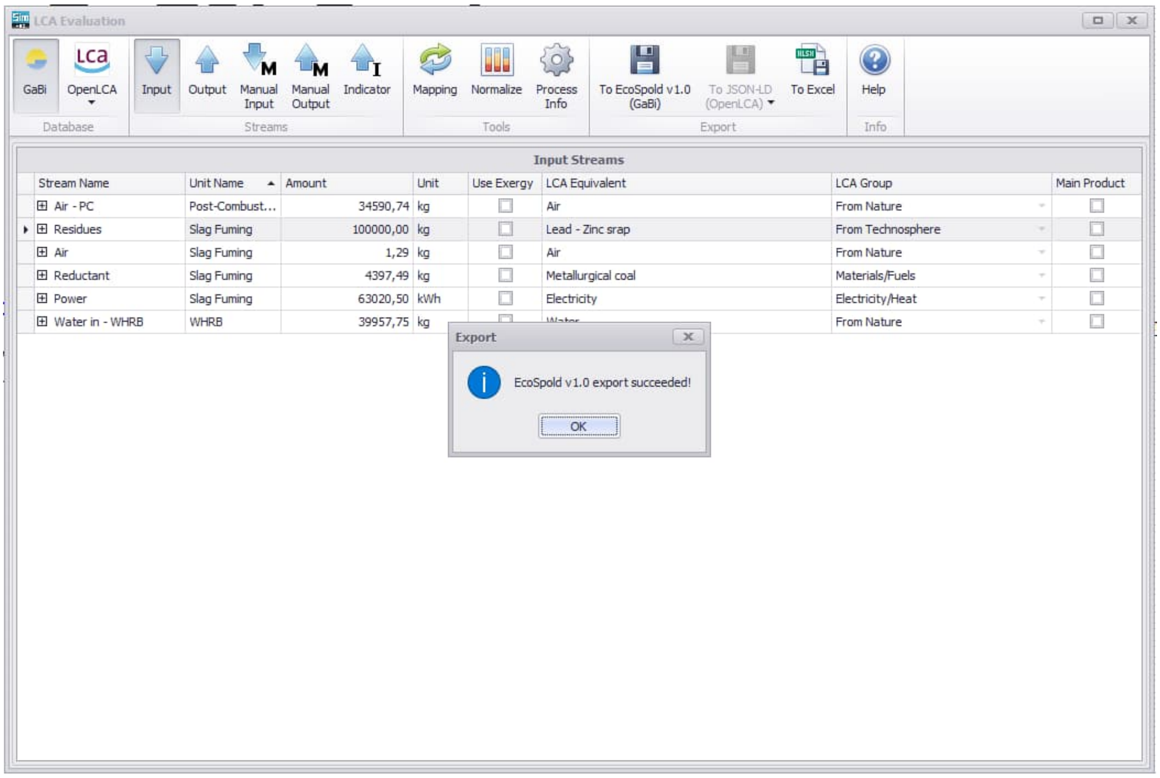


Fig. 19. Popup to inform the user of successful export.

To OpenLCA

The To JSON-LD (OpenLCA) exporting menu button writes a JSON-LD compressed file. The exported file contains metadata, which provides general process information as required by the LCA methodology. Metadata information is entered in the Process Information window and needs to be completed before exporting (**Fig. 19**). The process information window can be opened from the menu with the Process Information button. Stream details are taken from the normalization sheet.

It is not mandatory to complete all the process information fields, but it is worth filling them well in order to export the process in a form that is the most usable in OpenLCA. After completion of the process information, save it by clicking. Process info can also be used without the LCA tool to describe the process well, hence providing a good summary for use in process design.

Exporting buttons are found on the right of the button menu. With OpenLCA, there are two export options, as shown in **Fig. 20.** To Active Database exports the process to the active database (database which is active in HSC Sim LCA Tool). To Empty File opens a file window where the user can specify the file where the process is exported. To ensure compatibility in the OpenLCA software, it is recommended to export to the same database as that used in the HSC Sim tool.

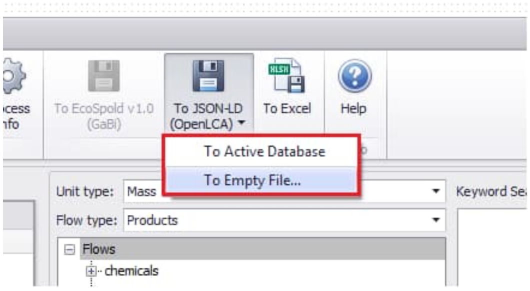


Fig. 20. OpenLCA export options.

If normalization has not been done, the LCA tool will automatically ask you to perform normalization first. A popup window will inform the user if the export was successful and in what format, as shown in **Fig. 21**.

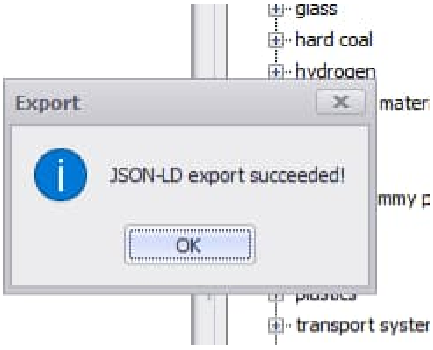
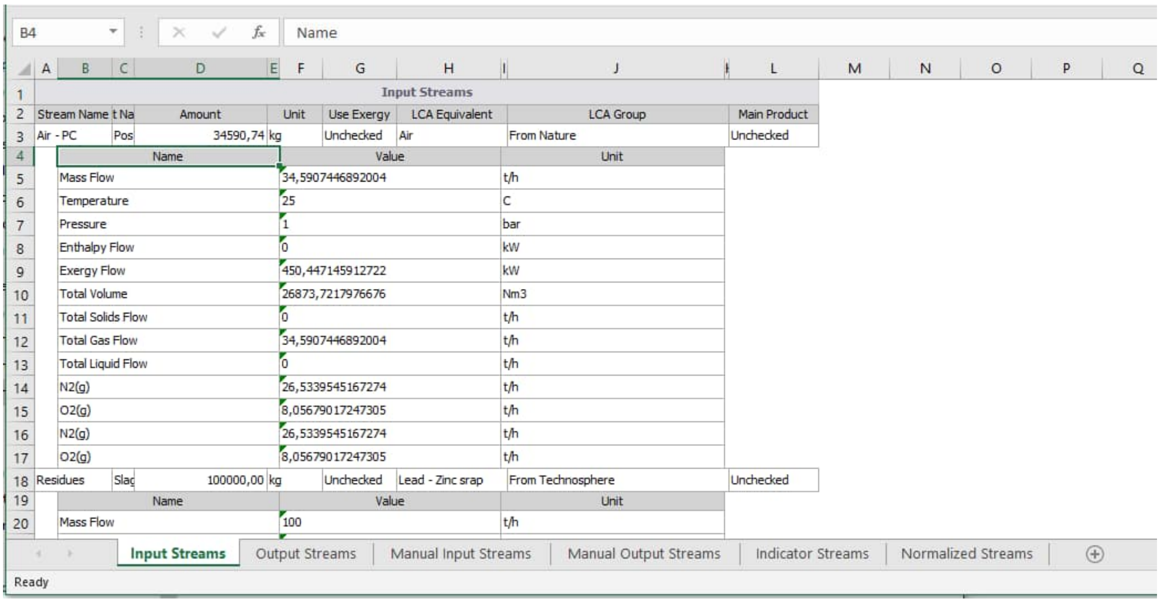


Fig. 21. Popup to inform the user of successful export.

To Excel

There is also an option to export the information to Excel, which can be used as an input for other applications, reports, publications etc., as shown in **Fig. 22**.



Row	Stream Name	t Na	Amount	Unit	Use Exergy	LCA Equivalent	LCA Group	Main Product
1	Input Streams							
3	Air - PC	Pos	34590,74	kg	Unchecked	Air	From Nature	Unchecked
18	Residues	Slag	100000,00	kg	Unchecked	Lead - Zinc srap	From Technosphere	Unchecked

Row	Name	Value	Unit
5	Mass Flow	34,5907446892004	t/h
6	Temperature	25	C
7	Pressure	1	bar
8	Enthalpy Flow	0	kW
9	Exergy Flow	450,447145912722	kW
10	Total Volume	26873,7217976676	Nm3
11	Total Solids Flow	0	t/h
12	Total Gas Flow	34,5907446892004	t/h
13	Total Liquid Flow	0	t/h
14	N2(g)	26,5339545167274	t/h
15	O2(g)	8,05679017247305	t/h
16	N2(g)	26,5339545167274	t/h
17	O2(g)	8,05679017247305	t/h
20	Mass Flow	100	t/h

Fig. 22. Excel export of all information for further use by other software.

49.3.8. Importing a Process to GaBi and Further Analysis

GaBi software is 3rd party LCA software and not part of HSC Chemistry software (http://tutorials.gabi-software.com/). Extending the GaBi process database is possible by selecting Edit→Import→Ecospold V1 (see **Fig. 23**), which produces functional GaBi processes.

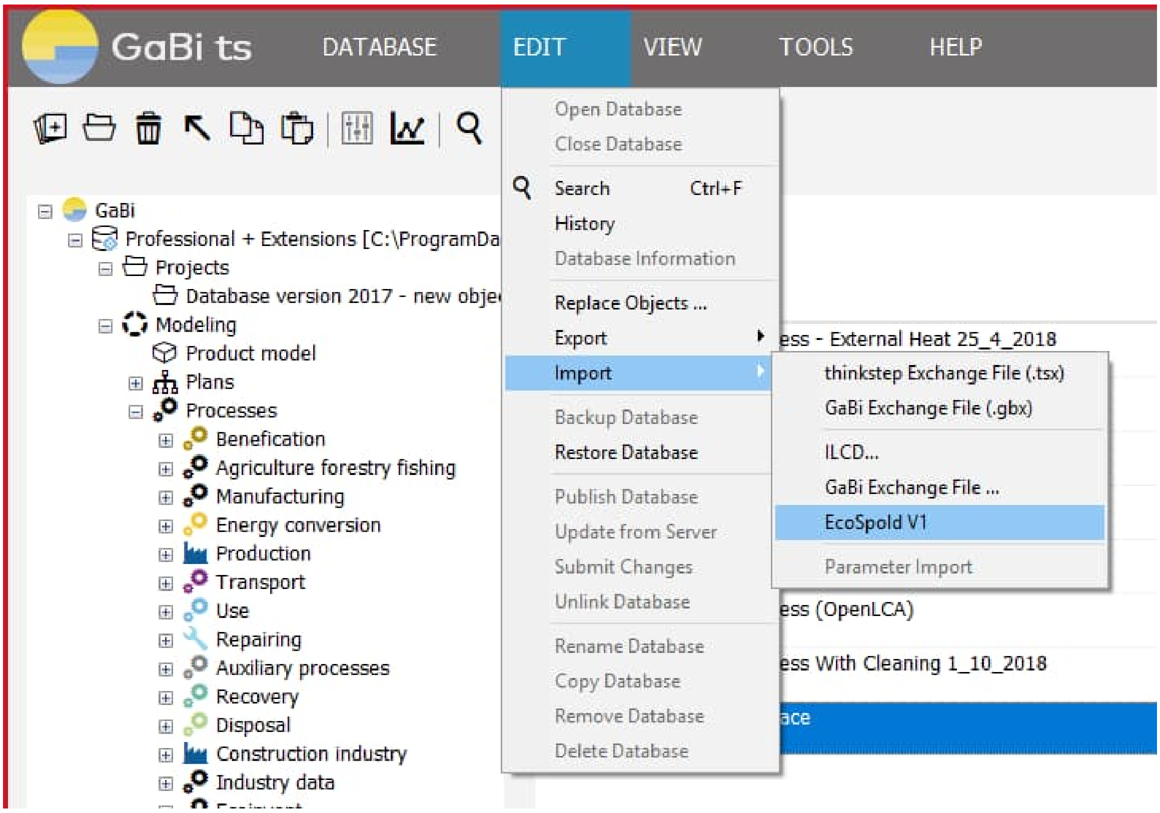


Fig. 23. Importing a new process to the GaBi database from the directory into which the XML file was exported.

A file search window opens for the exported HSC Sim file search. The file selection function first opens the process summary, where the user is also informed of the process export path in the GaBi process tree. **Fig. 24** lists all the flows and amounts and if this summary is OK, the final import can be started by clicking the green play button. At the end of this import, a log file popup appears in GaBi that informs the user whether the import was successful or not. The log file can be closed without saving in GaBi.

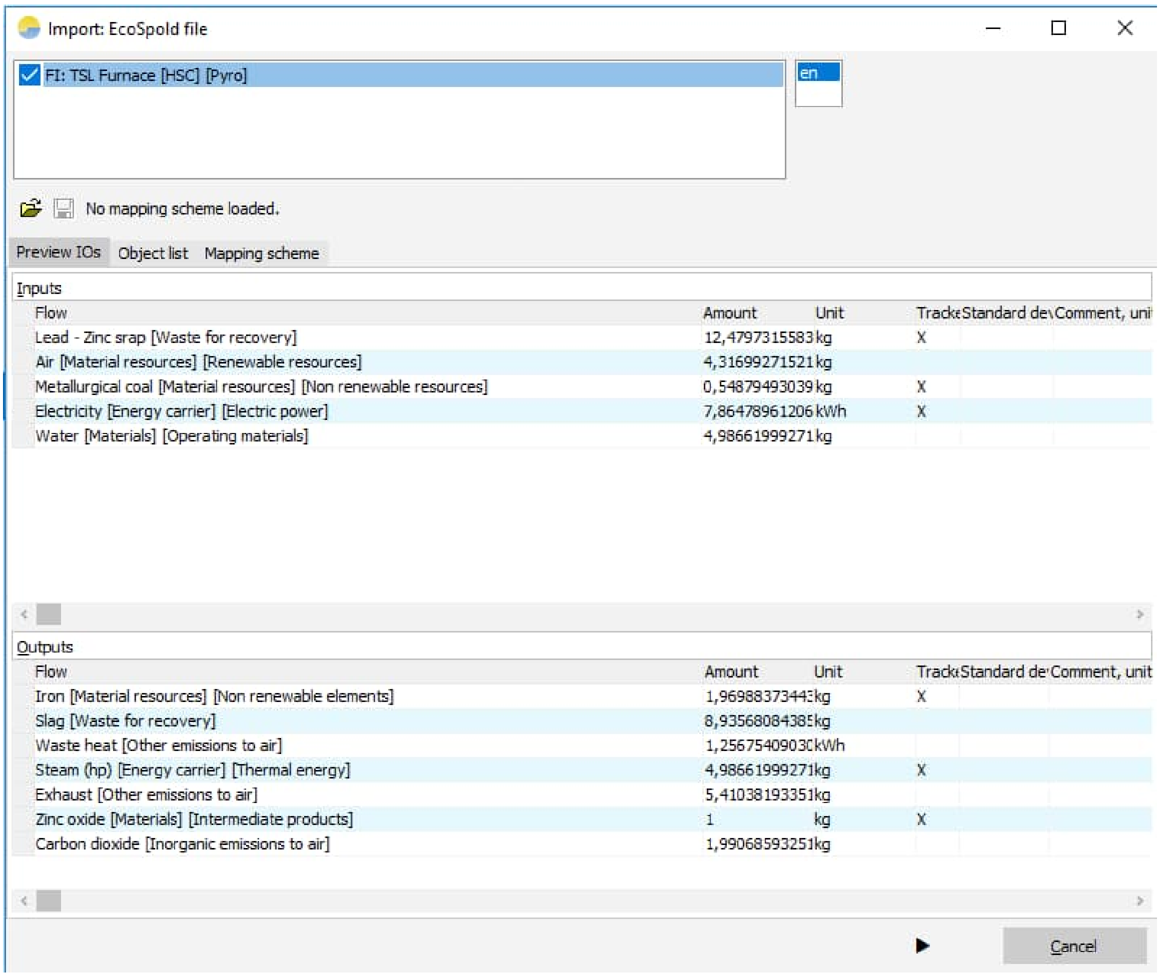


Fig. 24. Process summary presented during import as a check before clicking on the play button to complete the import.

The new process is available in GaBi processes under the HSC folder. This HSC Sim generated process can now be used in the new LCA plans together with all the other GaBi processes. By double clicking the process you can see the process details (see **Fig. 25**).

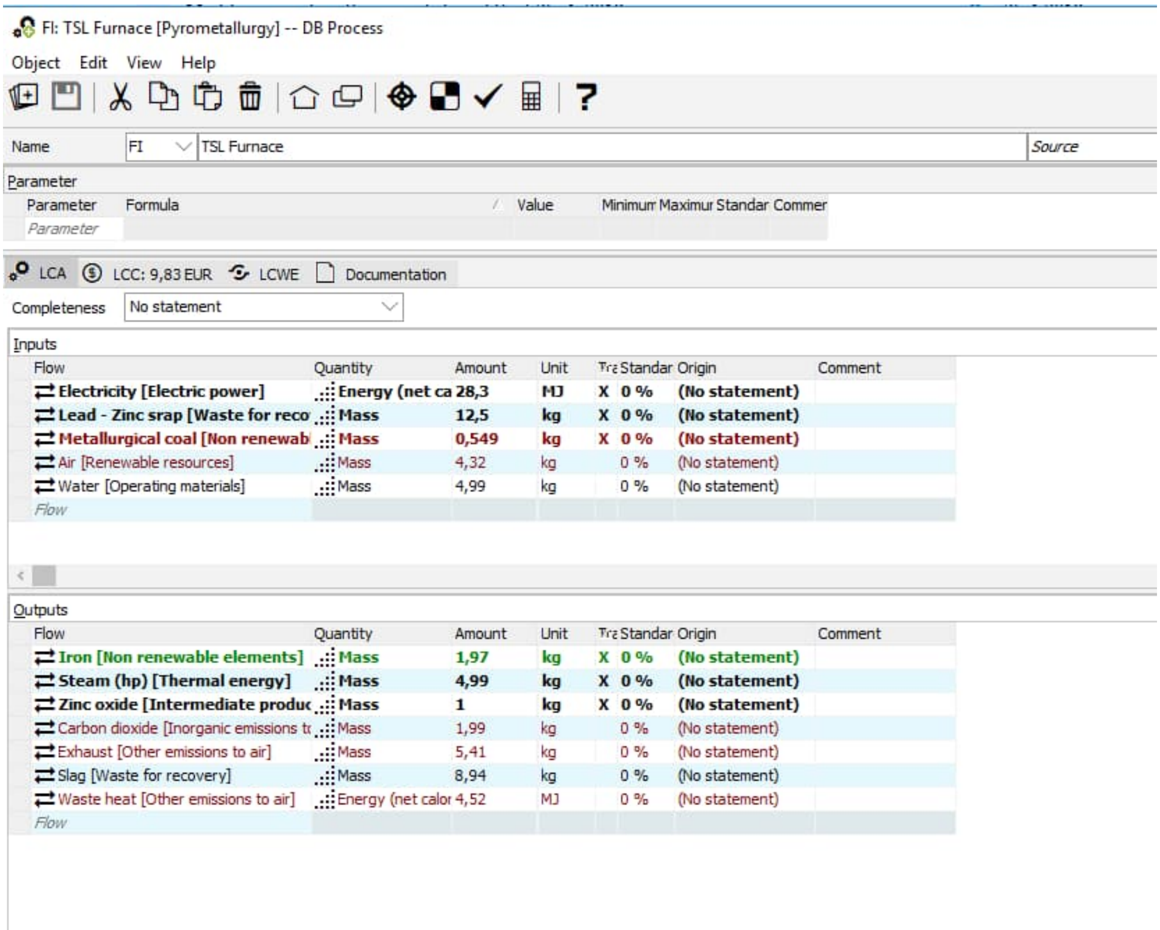


Fig. 25. New process information after import.

In Gabi, the system where processes can be connected to each other is called “Plan”. **Fig. 26** presents a plan where electricity and the TSL furnace are connected. Right click on the Plan and select “Calculate Results” to calculate the LCIA results.

The results sheet contains multiple tabs; one tab for each impact method. All common impact categories are presented in the bar charts (see **Fig. 27**). Numerical values are available in the results tab.

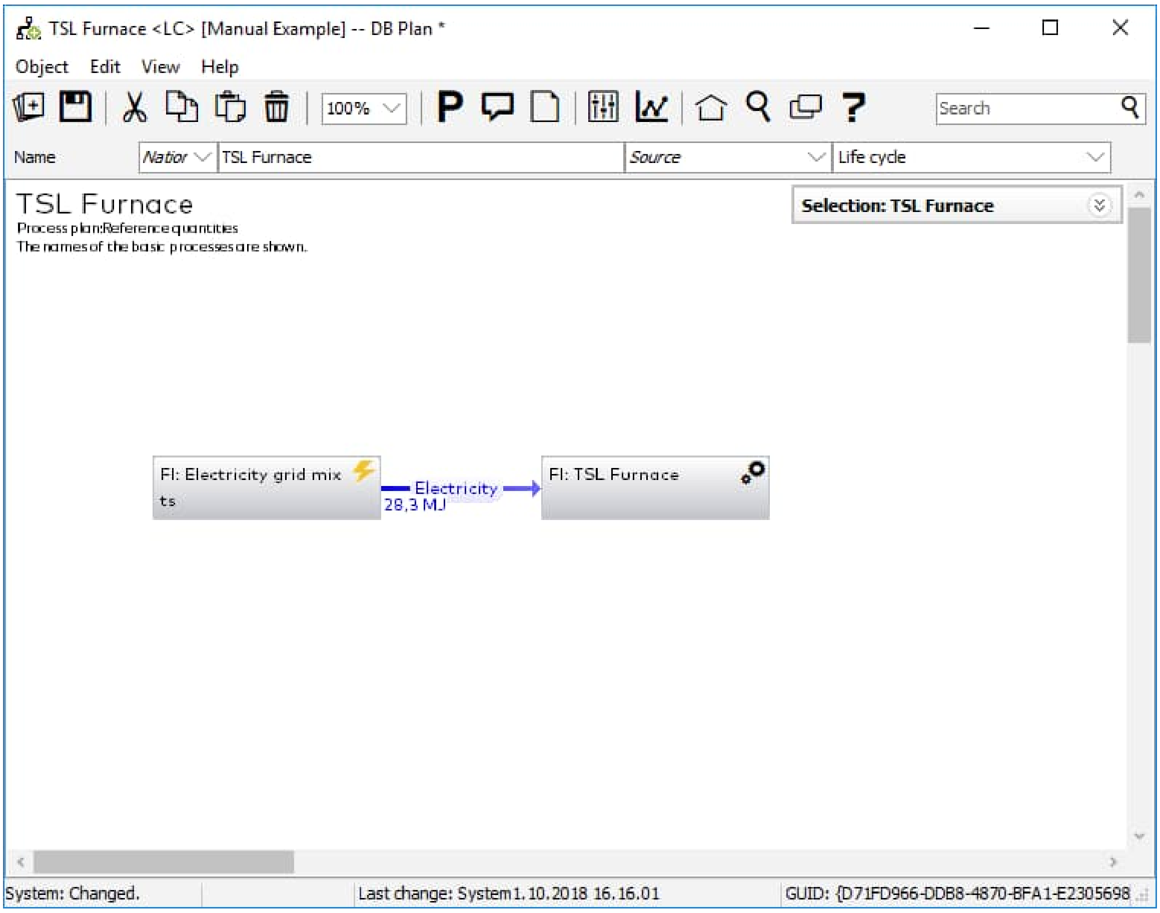


Fig. 26. The imported process can now be linked to other GaBi processes, e.g., energy.

-

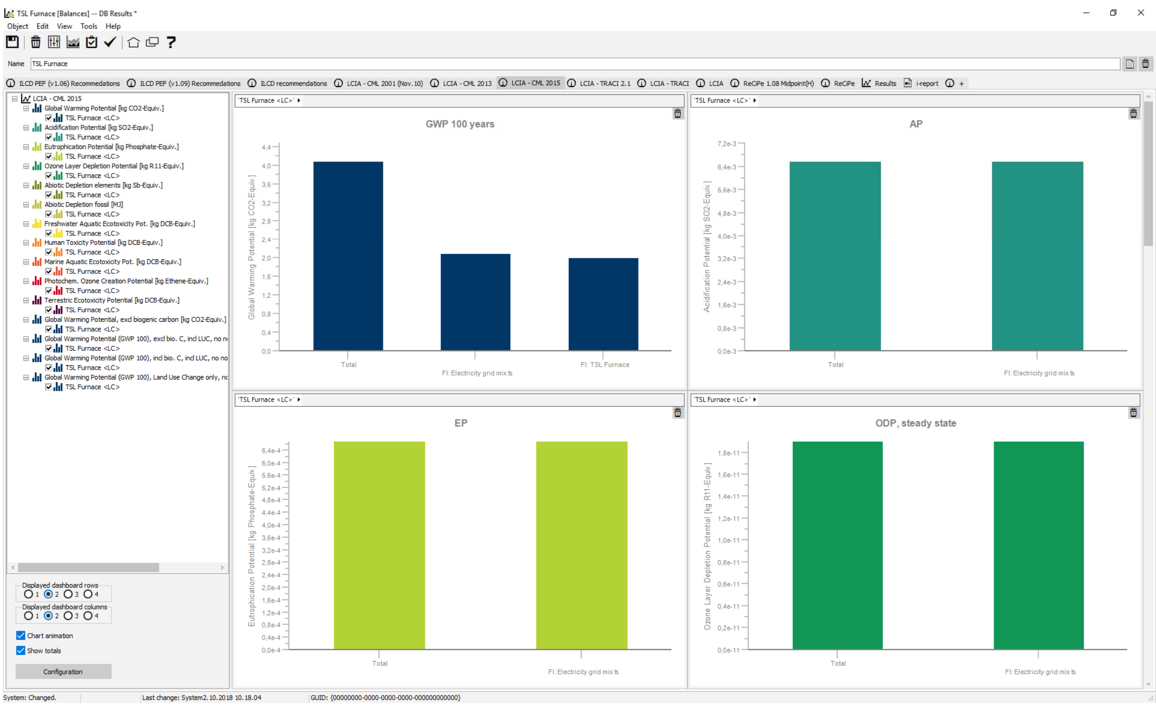


Fig. 27. Example of calculated environmental impacts.

49.3.9. Importing a Process to OpenLCA and Further Analysis

OpenLCA software is 3rd party LCA software and not part of HSC Chemistry software (http://www.openlca.org/learning/). Extending the OpenLCA process database is possible by right clicking on the active database and selecting import (see **Fig. 28**). Make sure that the database contains the flows used in HSC Sim when the export is done. NB! The safest way is to import exactly the same database that is used in HSC Sim.

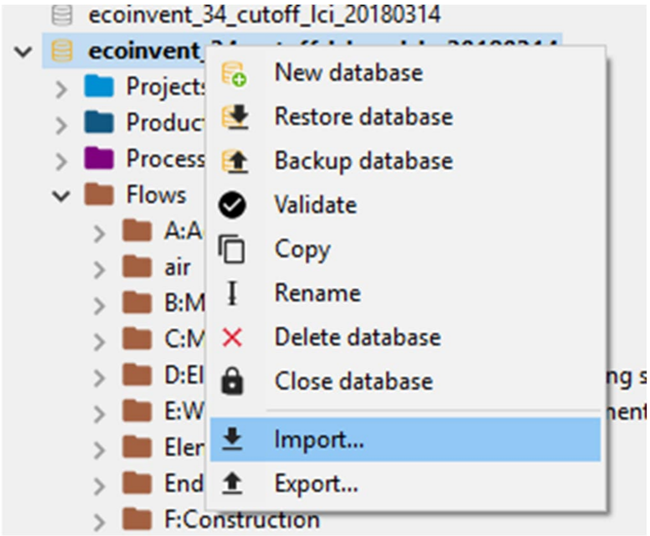


Fig. 28. Importing a new process to the OpenLCA database.

Import opens a file type selection dialog (see **Fig. 29**). After type selection, the actual file search window will open for the exported HSC Sim file (JSON file) search.

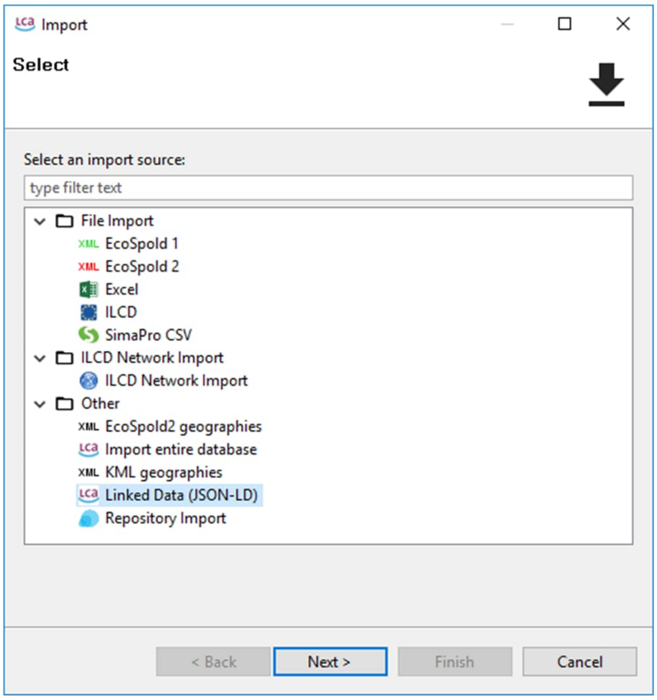


Fig. 29. Import file type selection.

The new process is available in “Processes” under the HSC folder. This HSC Sim generated process can now be used in the new “Product Systems” together with all the other processes. To create a new Product System, double-click the process and select “Create product system” (see **Fig. 30Error! Reference source not found.**). A new p roduct system creation dialog will open where the provider adding method is selected. “Prefer default providers” will automatically add processes which generate a product needed by our processes. In other cases, processes should be added manually.

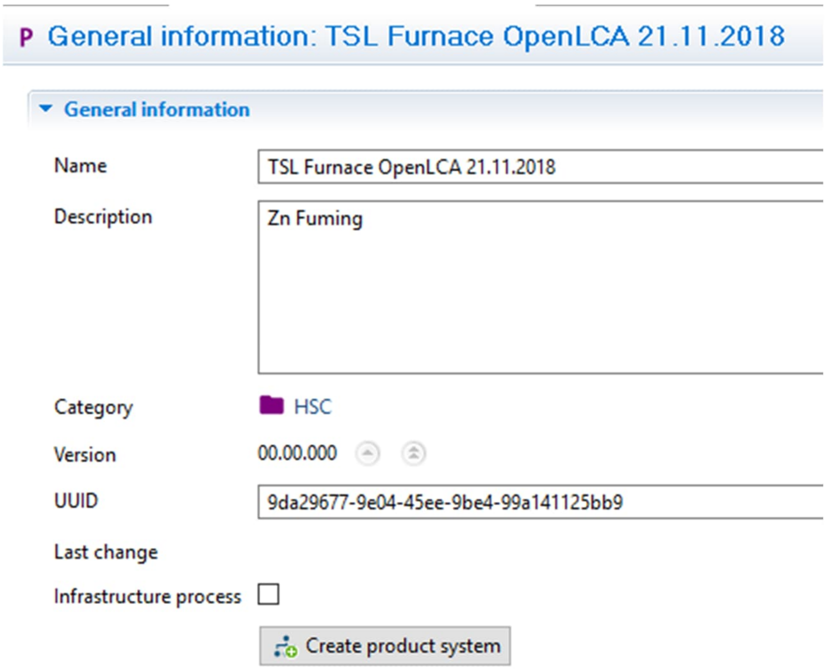


Fig. 30. New “Product System” creation.

The product system just created can be opened by double-clicking the product system from the left panel product system section. A product system model graph is available in the “Model Graph” tab (see **Fig. 31**). This is the place where the process system boundaries are defined. Which processes are included in our impact analysis?

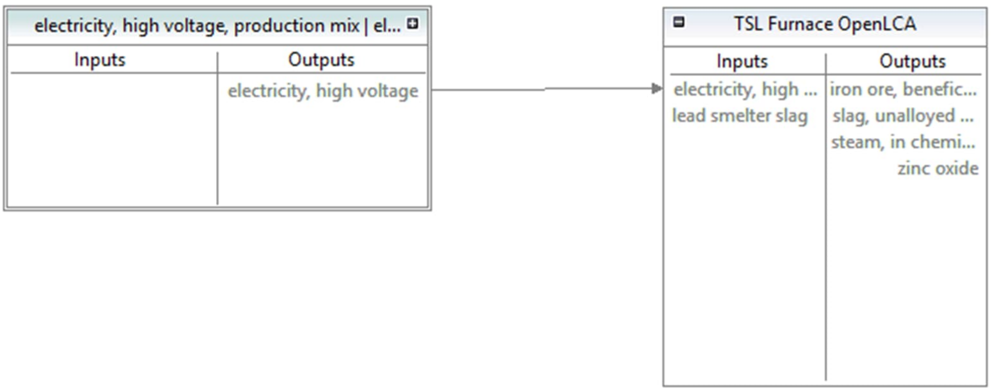


Fig. 31. Product system model graph where electricity production is linked to TSL furnace.

Calculations are performed on the created product system “General information” tab by clicking the calculate button (see **Fig. 32**). The allocation method, impact assessment method, and calculation type are defined on the Calculation properties sheet. “Analysis” calculation type gives a more detailed view of the impacts than quick results.

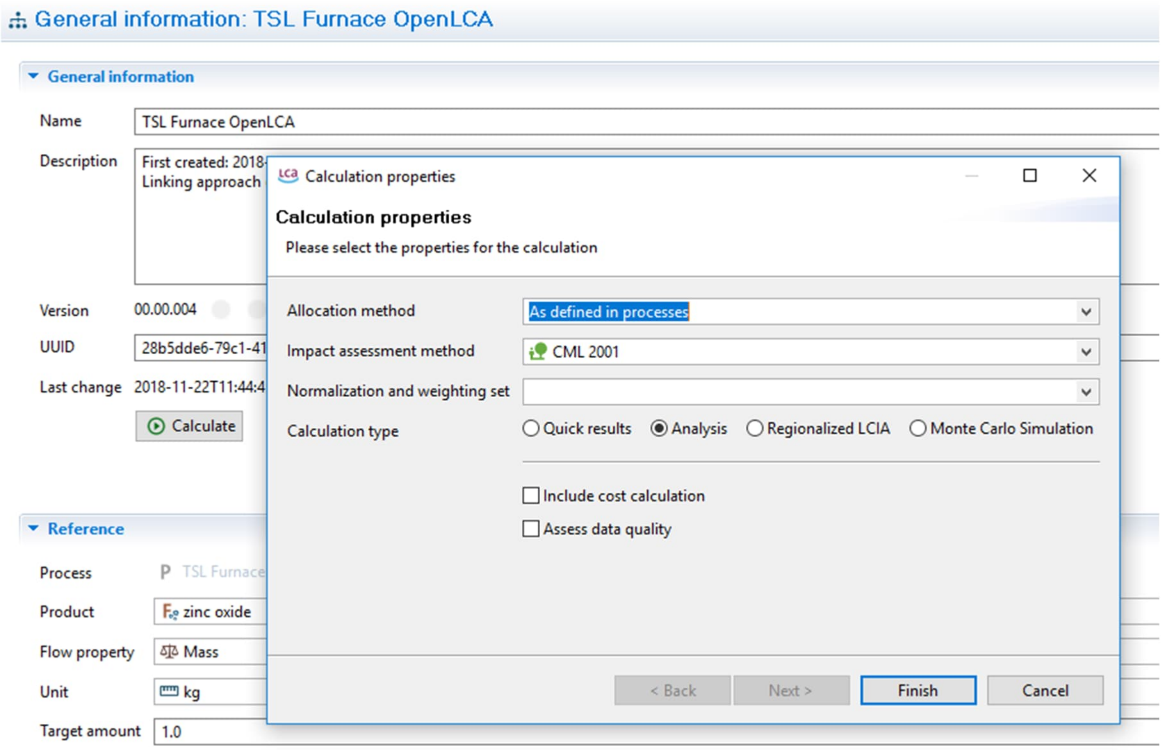


Fig. 32. Calculation properties need to be selected before calculation.

Analysis results contain general information about the top emission contributors (see **Fig. 33**). On that page we can make process level investigations for each flow and impact category. On that page results are described in bar charts. On that tab, the results can also be saved in Excel format for further analysis.

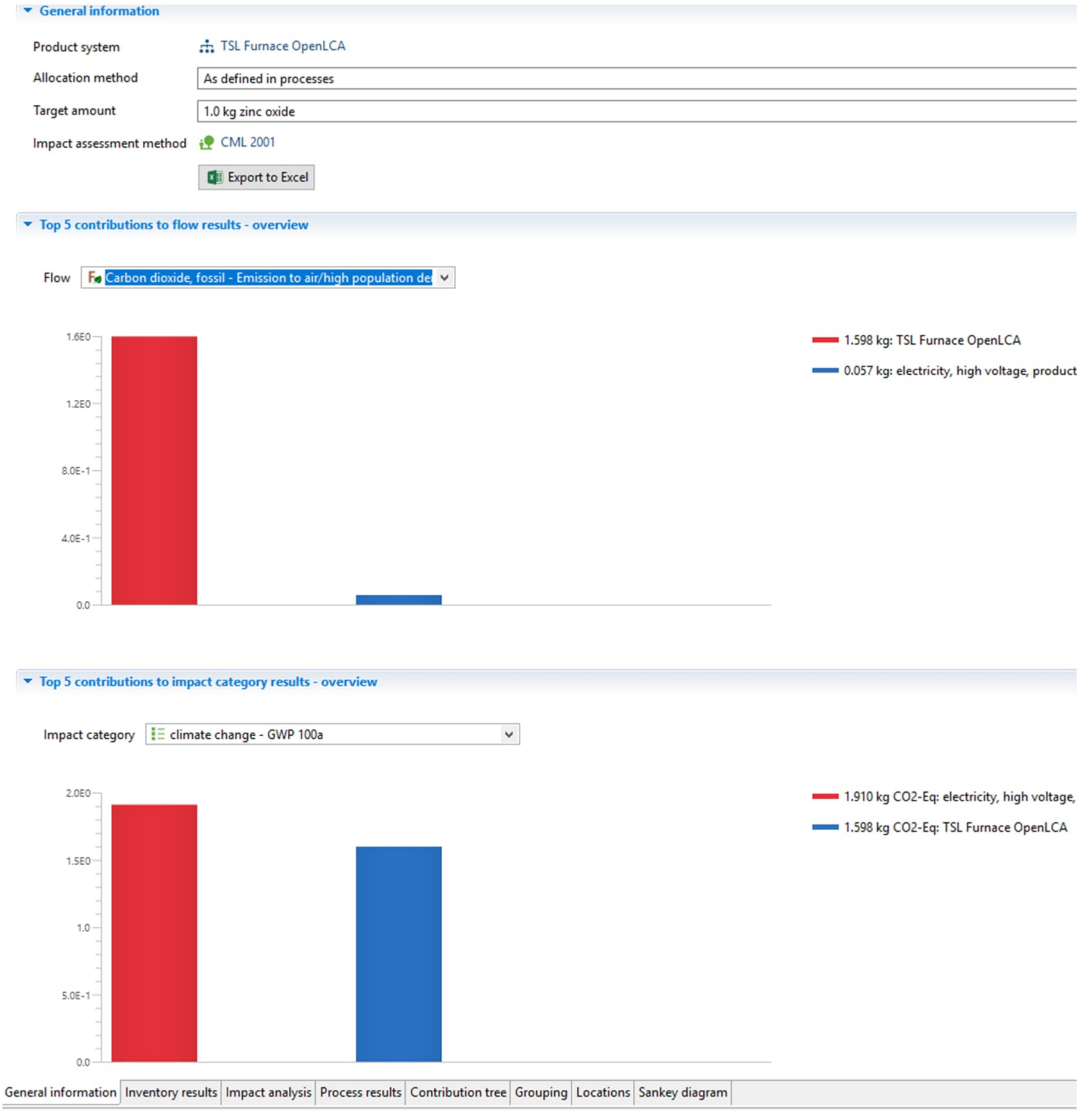
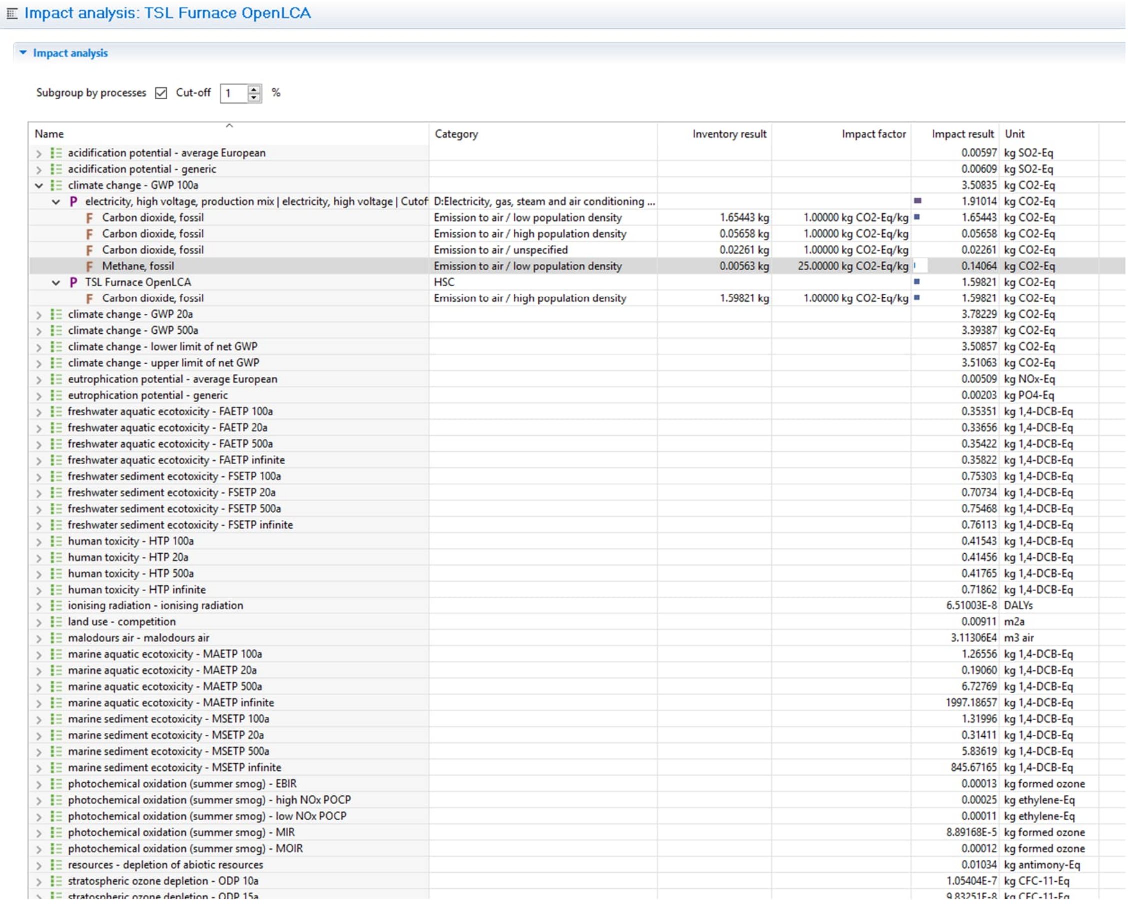


Fig. 33. Example of calculated environmental impacts.

The impact analysis tab offers detailed information about the impacts. For each impact category the contributor processes and process flows (see **Fig. 34**) are presented. The figures for the stream inventory result, impact factor, and impact result are clearly presented for each stream.



Impact analysis: TSL Furnace OpenLCA

Impact analysis

Subgroup by processes ☑ Cut-off 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
acidification potential - average European				0.00597	kg SO2-Eq
acidification potential - generic				0.00609	kg SO2-Eq
climate change - GWP 100a				3.50835	kg CO2-Eq
P electricity, high voltage, production mix | electricity, high voltage | Cutof	D:Electricity, gas, steam and air conditioning ...			1.91014	kg CO2-Eq
F Carbon dioxide, fossil	Emission to air / low population density	1.65443 kg	1.00000 kg CO2-Eq/kg	1.65443	kg CO2-Eq
F Carbon dioxide, fossil	Emission to air / high population density	0.05658 kg	1.00000 kg CO2-Eq/kg	0.05658	kg CO2-Eq
F Carbon dioxide, fossil	Emission to air / unspecified	0.02261 kg	1.00000 kg CO2-Eq/kg	0.02261	kg CO2-Eq
F Methane, fossil	Emission to air / low population density	0.00563 kg	25.00000 kg CO2-Eq/kg	0.14064	kg CO2-Eq
P TSL Furnace OpenLCA	HSC			1.59821	kg CO2-Eq
F Carbon dioxide, fossil	Emission to air / high population density	1.59821 kg	1.00000 kg CO2-Eq/kg	1.59821	kg CO2-Eq
climate change - GWP 20a				3.78229	kg CO2-Eq
climate change - GWP 500a				3.39387	kg CO2-Eq
climate change - lower limit of net GWP				3.50857	kg CO2-Eq
climate change - upper limit of net GWP				3.51063	kg CO2-Eq
eutrophication potential - average European				0.00509	kg NOx-Eq
eutrophication potential - generic				0.00203	kg PO4-Eq
freshwater aquatic ecotoxicity - FAETP 100a				0.35351	kg 1,4-DCB-Eq
freshwater aquatic ecotoxicity - FAETP 20a				0.33656	kg 1,4-DCB-Eq
freshwater aquatic ecotoxicity - FAETP 500a				0.35422	kg 1,4-DCB-Eq
freshwater aquatic ecotoxicity - FAETP infinite				0.35822	kg 1,4-DCB-Eq
freshwater sediment ecotoxicity - FSETP 100a				0.75303	kg 1,4-DCB-Eq
freshwater sediment ecotoxicity - FSETP 20a				0.70734	kg 1,4-DCB-Eq
freshwater sediment ecotoxicity - FSETP 500a				0.75468	kg 1,4-DCB-Eq
freshwater sediment ecotoxicity - FSETP infinite				0.76113	kg 1,4-DCB-Eq
human toxicity - HTP 100a				0.41543	kg 1,4-DCB-Eq
human toxicity - HTP 20a				0.41456	kg 1,4-DCB-Eq
human toxicity - HTP 500a				0.41765	kg 1,4-DCB-Eq
human toxicity - HTP infinite				0.71862	kg 1,4-DCB-Eq
ionising radiation - ionising radiation				6.51003E-8	DALYs
land use - competition				0.00911	m2a
malodours air - malodours air				3.11306E4	m3 air
marine aquatic ecotoxicity - MAETP 100a				1.26556	kg 1,4-DCB-Eq
marine aquatic ecotoxicity - MAETP 20a				0.19060	kg 1,4-DCB-Eq
marine aquatic ecotoxicity - MAETP 500a				6.72769	kg 1,4-DCB-Eq
marine aquatic ecotoxicity - MAETP infinite				1997.18657	kg 1,4-DCB-Eq
marine sediment ecotoxicity - MSETP 100a				1.31996	kg 1,4-DCB-Eq
marine sediment ecotoxicity - MSETP 20a				0.31411	kg 1,4-DCB-Eq
marine sediment ecotoxicity - MSETP 500a				5.83619	kg 1,4-DCB-Eq
marine sediment ecotoxicity - MSETP infinite				845.67165	kg 1,4-DCB-Eq
photochemical oxidation (summer smog) - EBIR				0.00013	kg formed ozone
photochemical oxidation (summer smog) - high NOx POCP				0.00025	kg ethylene-Eq
photochemical oxidation (summer smog) - low NOx POCP				0.00011	kg ethylene-Eq
photochemical oxidation (summer smog) - MIR				8.89168E-5	kg formed ozone
photochemical oxidation (summer smog) - MOIR				0.00012	kg formed ozone
resources - depletion of abiotic resources				0.01034	kg antimony-Eq
stratospheric ozone depletion - ODP 10a				1.05404E-7	kg CFC-11-Eq
stratospheric ozone depletion - ODP 15a				9.83251E-8	kg CFC-11-Eq

Fig. 34. Impact analysis results.

49.4. Using LCA Evaluation (beta) in HSC Sim

In this example we use Iron Process as an example process model (**Fig 1**).

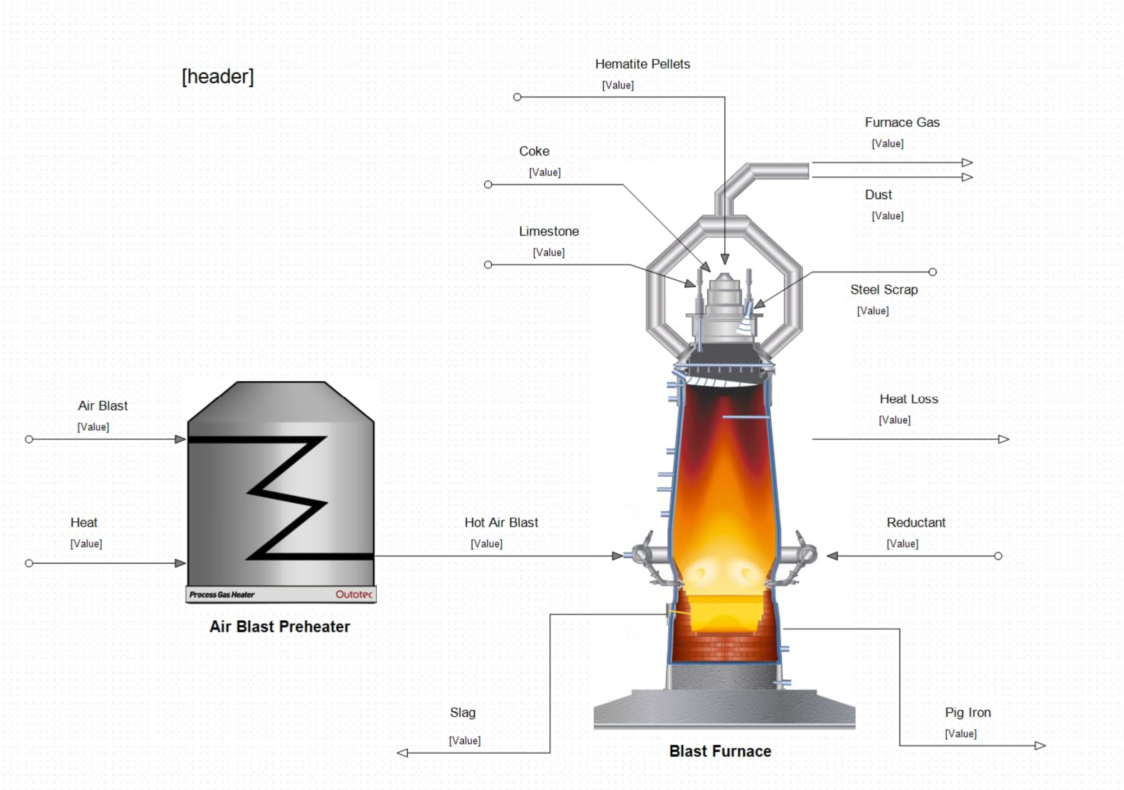


Fig 1. Iron Process

NOTE! As this tool is beta version, all might not work as expected! Before using the tool, please take back-ups from important models and in case of problems please email hsc@metso.com

49.4.1. Downloading and initializing openLCA

First, to be able to use the LCA Evaluation tool, unstable build of the openLCA needs to be downloaded. This can be done downloading the openLCA 2.0.0 zip file from Files - ownCloud (greendelta.com). Please read README file before going any further.

*"Note: This is **not a stable openLCA version** and should not be used in production. Existing databases can be used with this version but when opening a database with it **an update may be executed which is not reversible**. Thus, it is highly recommended to **backup a database before opening it** with this version. Also, there is no database compatibility guaranteed between different development versions. When you used a database with one experimental version it may not work with another. Thus, the best way to test a development version is to take a fresh database from a stable release and upgrade it (but please make a backup first)."*

After downloading the zip file, extract the contents into a folder, and start openLCA.exe by double-clicking it. If there are no databases in the software yet, restore them by clicking Database →Restore database (**Fig 2**). After that select the correct file(s). All openLCA free and purchasable databases can be downloaded from openLCA Nexus webpage openLCA Nexus: The source for LCA data sets.

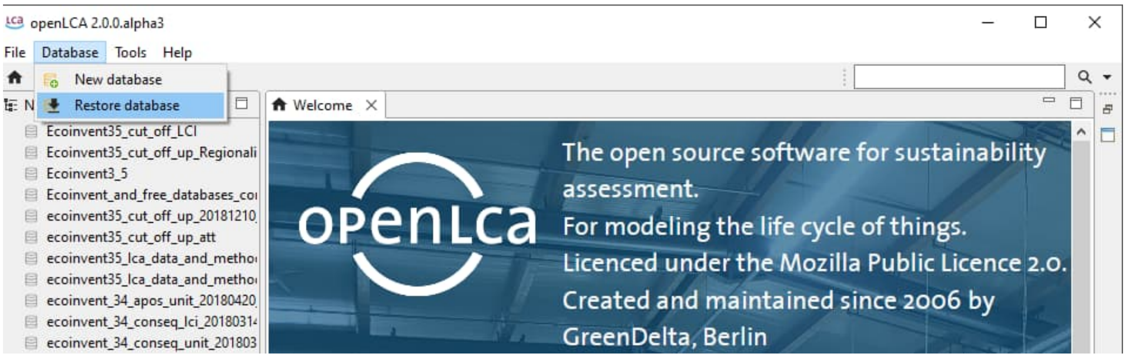


Fig 2. Restore database.

Next, open the correct database by double clicking the name or right clicking the name and selecting Open database (**Fig 3**).

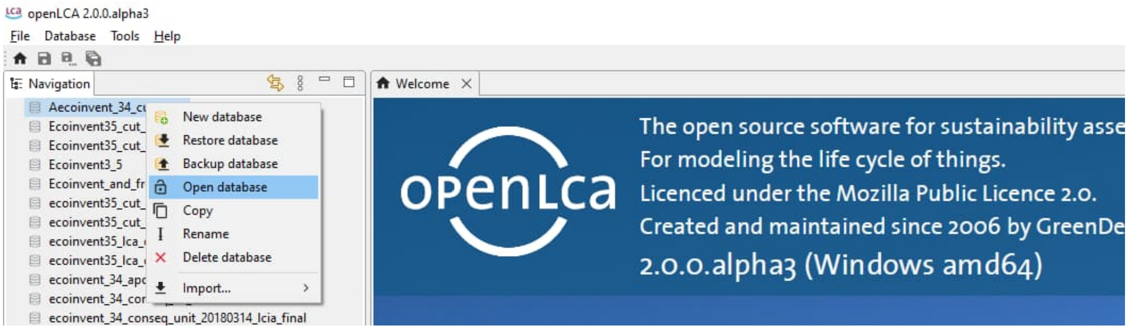


Fig 3. Select and open the database from openLCA.

NOTE! If you are using ecoinvent databases, select the system process database, i.e., it will have the abbreviation “LCI” in its name. The tool has not yet been validated with the use of unit process databases.

Next, IPC Server is started from the main menu: Tools → Developer tools → IPC Server (**Fig 4**). By checking the gRPC service (experimental) and then pressing the green run button the gRPC service will be started (**Fig 5**).

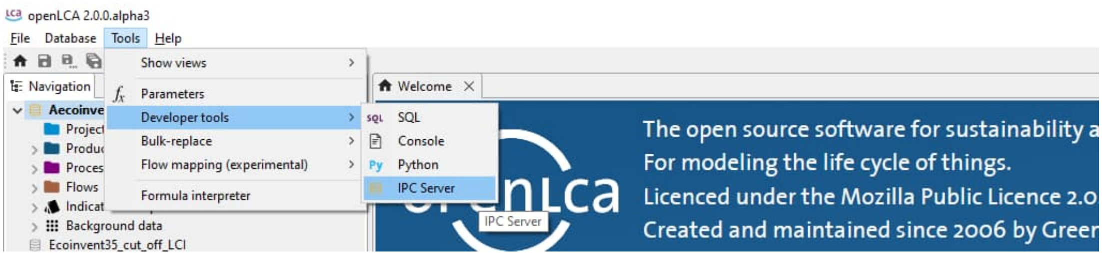


Fig 4. Select IPC Server from the main menu.

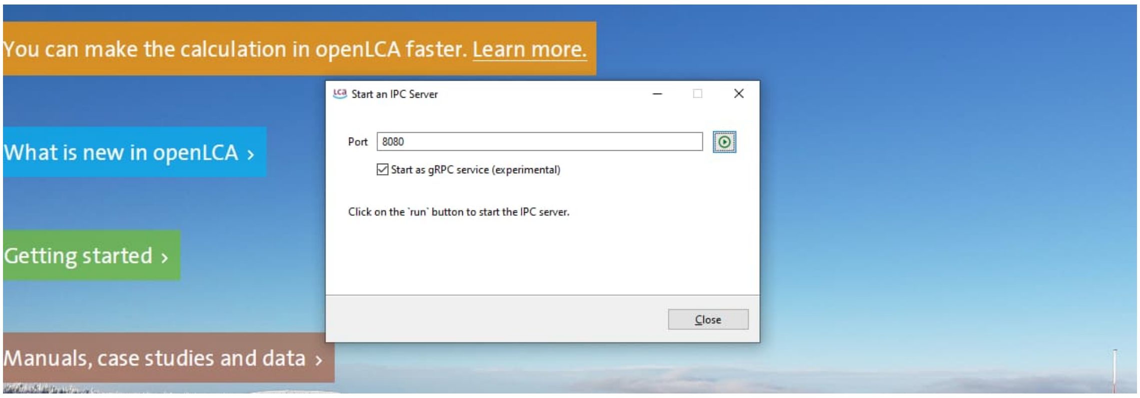


Fig 5. Start as IPC Server.

After enabling the gRPC services, the openLCA software will work on the background while all rest of the work will be done in HSC Sim.

49.4.2. Downloading flow and impact method data to HSC Sim

In HSC Sim, the first thing to do is to download the flow and impact method data to the tool. Open the LCA Evaluation (beta) by selecting Tools → LCA Evaluation from the menu (**Fig 6**).

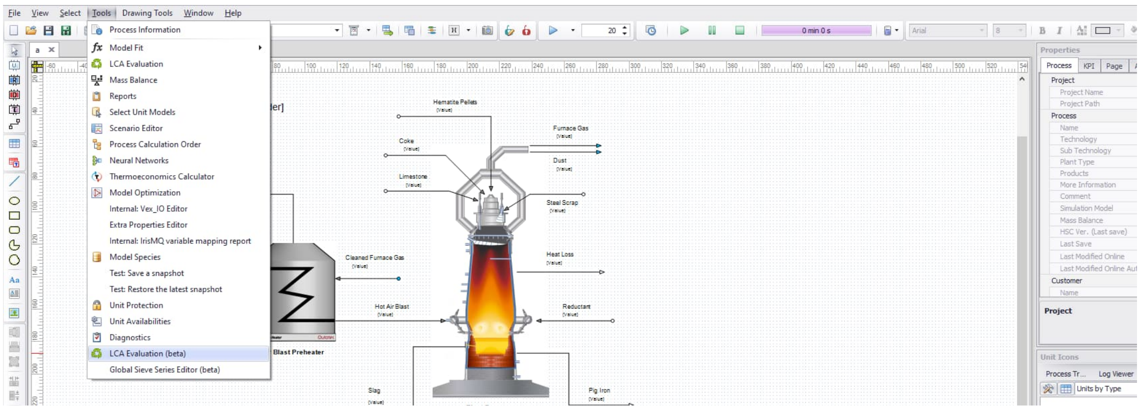


Fig 6. Start LCA Evaluation (beta) from the main menu.

Next, press the openLCA button and select either Unit or LCI (system) database (**Fig 7**). If the connection is successful, it will start downloading the flows and impact method data. This might take several minutes. In case of errors, message window will pop up and indicate the reason for the error. If the reason is “Connecting”, it is enough to re-press the openLCA button or wait for couple of minutes of the connection to be formed between HSC Sim and openLCA.

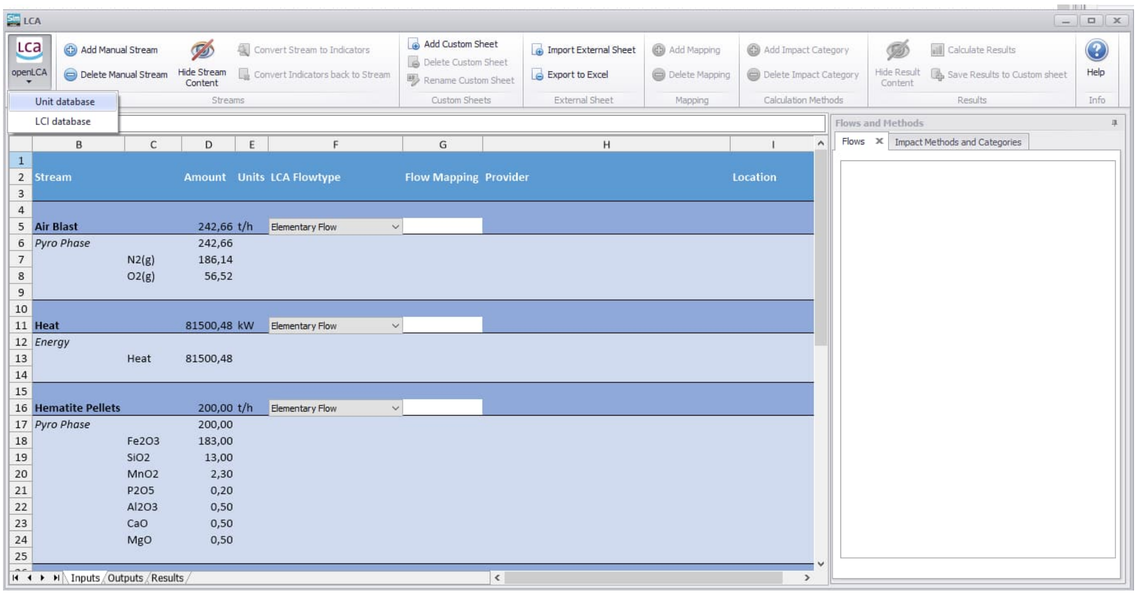


Fig 7. Start openLCA.

The flows and impact methods will be displayed in the Flows and Methods view on the right side of the tool. Successful connection will be indicated by the very first tree list node which name is *Flows (loading database)* and for methods *Methods (loading database)*. After the downloading is complete, the node names will change to include the name of the database. By pressing the plus sign next to the first node, the tree lists will be expanded. Downloading the flows for the Iron Process example is shown in **Fig 8**.

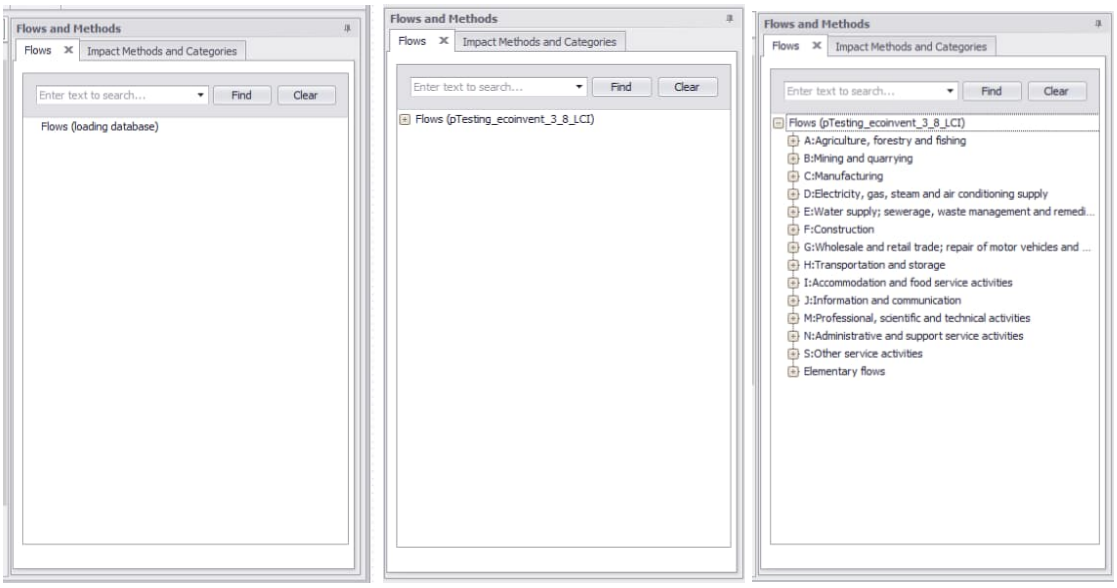


Fig 8. Downloading and showing the flows of the database in the tree list view.

49.4.3. Automatic import of all input and output streams

The LCA tool creates three sheets, named Inputs, Outputs, and Results. The Inputs and Outputs sheet show all the input and output streams for the process flowsheet. This includes stream names, amounts, units, stream species contents and their phases. **Fig 9** shows the Inputs sheet for the Iron Process.

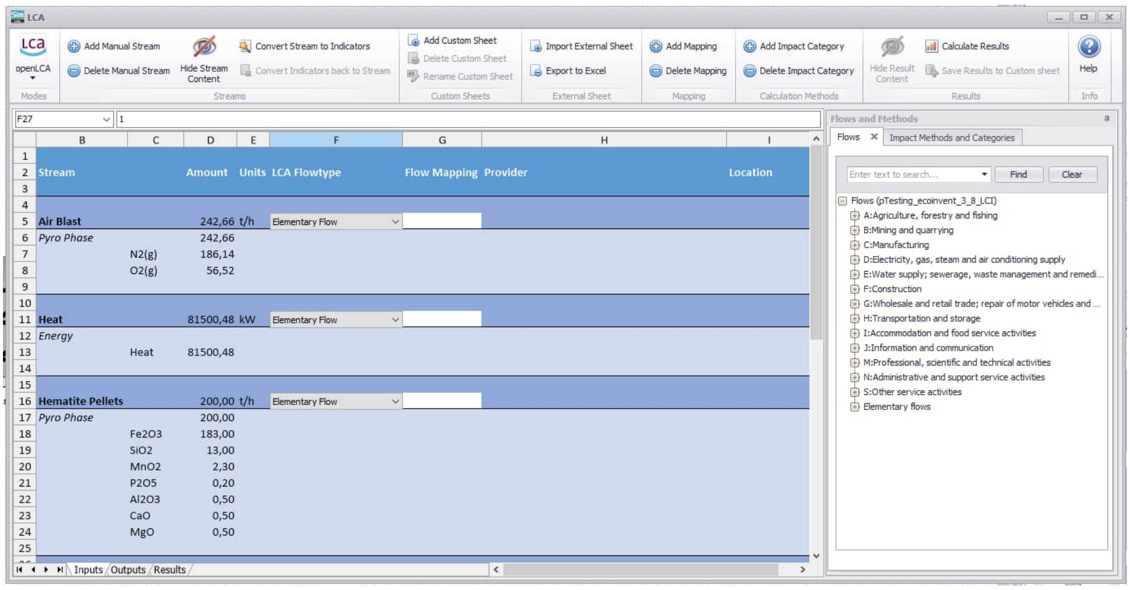


Fig 9. Input streams and their contents for the Iron Process.

The stream content can be hidden by pressing the Hide Stream Content button from the toolbar. The button will hide/show the stream contents both from the Inputs and Outputs sheets at the same time. If the stream content is hidden, then only the stream name row is displayed (**Fig 10**).

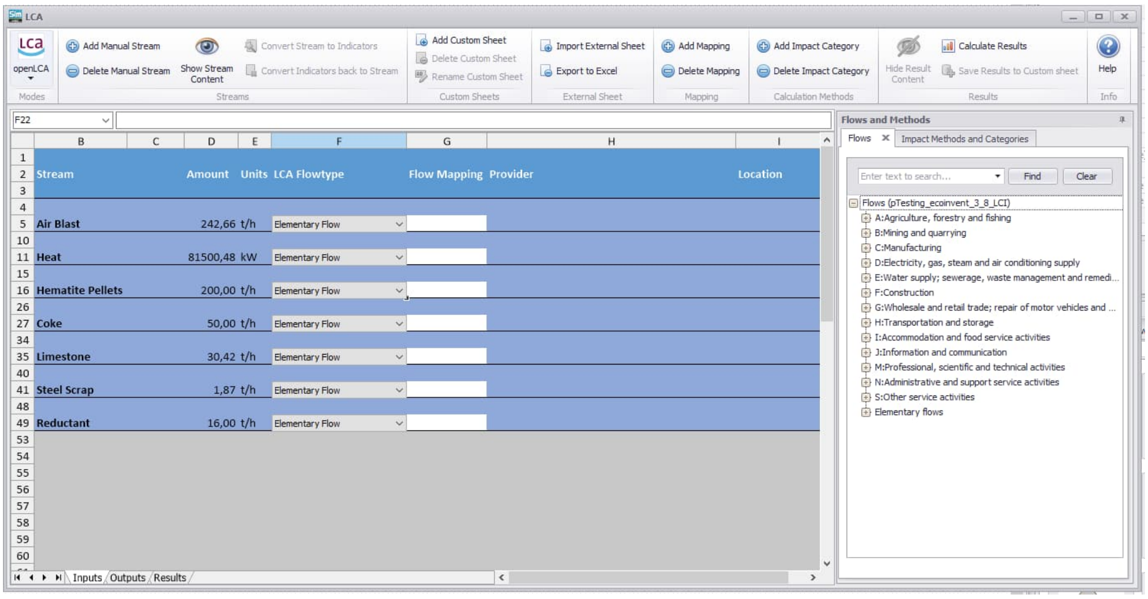


Fig 10. Input stream contents hidden.

NOTE! No intermediate streams are shown in the sheets, as only streams that can interact with the environment are used in LCA calculations.

49.4.4. Adding manual streams

Sometimes, during LCI compilation in HSC Sim, some missing streams may be identified. The best and recommended way is to add missing streams directly to the process simulation model. This typically would include all fugitive emissions, additional power, leakages from the system, etc. In some cases, it is also appropriate to add streams for LCA purposes only. Adding these is done by pressing the Add Manual Stream from the toolbar, which will create new manual stream on bottom of the automatic streams either on the Inputs or Outputs sheet, depending which one is open. **Fig 11** shows adding manual streams to the Inputs sheets.

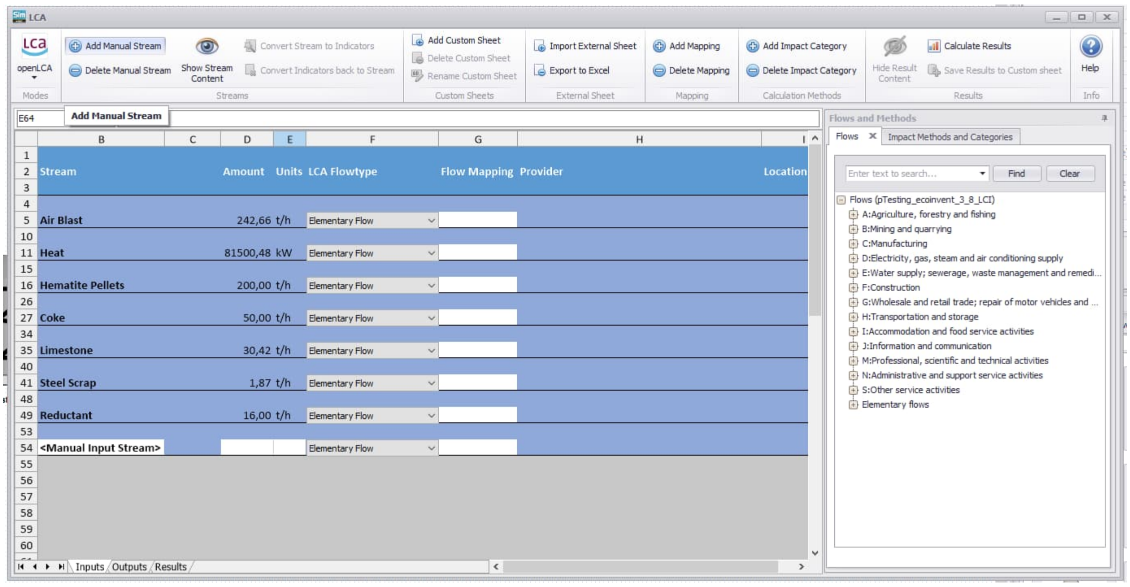


Fig 11. Adding manual streams to the Inputs sheet.

The manually inserted stream can be deleted on the Delete Manual Stream button. To be able to delete specific stream, the manual stream row needs to be selected (

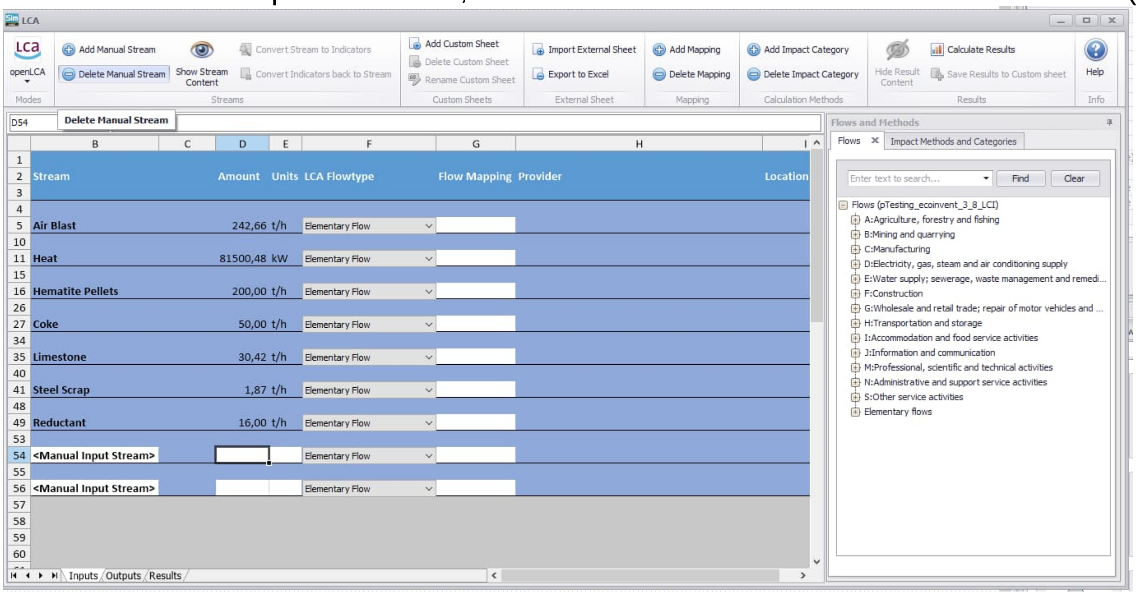


Fig 12). If manual stream name row is not selected, window with error message “Manual stream is not selected” will pop up.

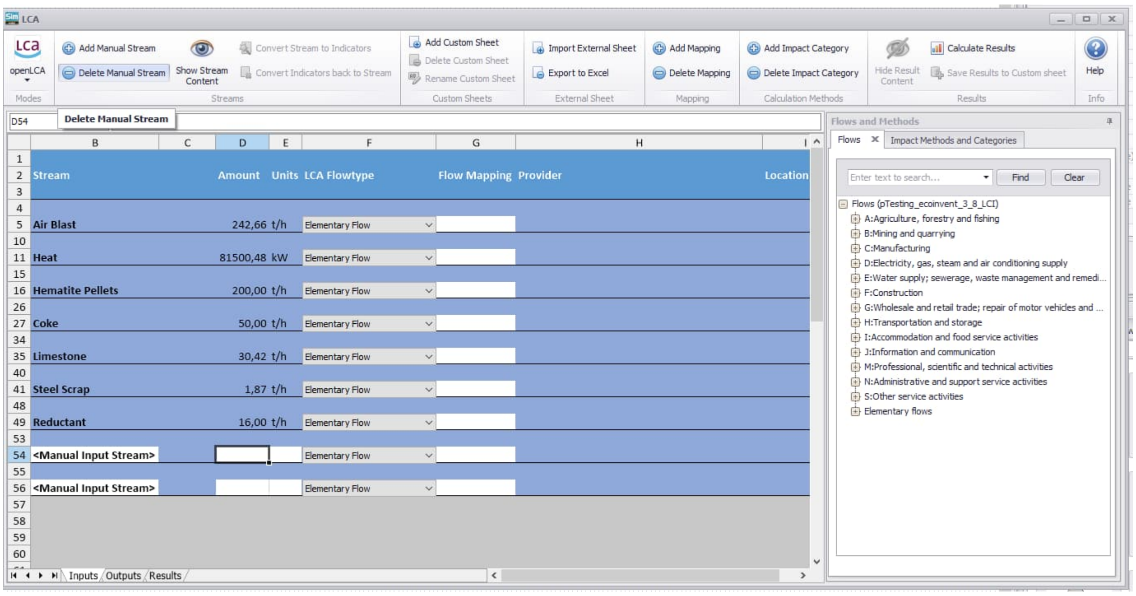


Fig 12. Deleting manual stream.

To be able to utilize the manual streams in the evaluation, amounts and units need to be added to the stream. Manual streams can also be named, and this is highly recommended as the interpretation of results can get complicated if there are several manual streams with same name. Adding the name, amounts, and units is easy – just write it on the cells. The current possible units to be used are **t/h** for mass and **kW** or **MJ** for energy. Examples of ready set manual stream is shown in **Fig 13**. It is also possible to use cell references in the manual streams.

Fig 13. Manual stream with name, amount and unit inserted.

49.4.5. Converting streams to indicators

By converting streams to indicators, it is possible to examine how much of the single stream species affect the LCA results. This is especially useful if no LCA equivalent is found in the database for the stream, but for the species is. For an example, **Fig 14** shows Furnace Gas in the output sheet with complex composition in the Iron Process. It is impossible to find LCA equivalent for this kind of stream in the databases, but it is possible to find for the equivalents for CO(g) CO2(g), H2O(g) etc. species.

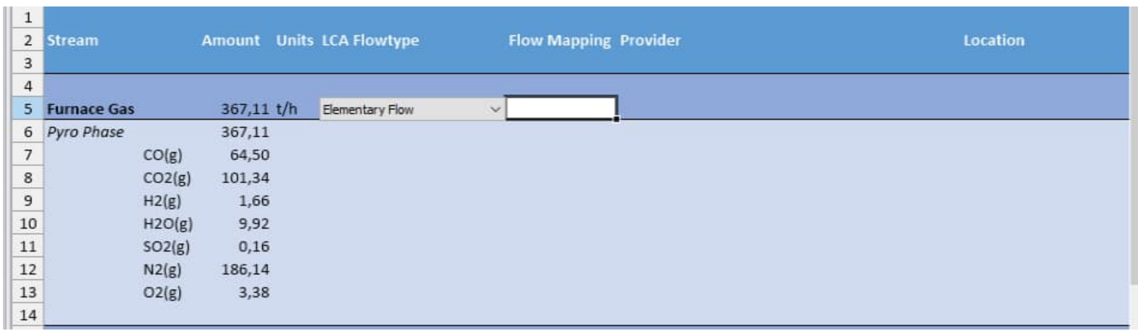


Fig 14. Furnace Gas stream in Iron Process.

Converting streams to indicators happen by selecting the stream row and then pressing the Convert Stream to Indicators button (**Fig 15**). The button will be disabled if something else than the stream row is selected (e.g., manual stream row – they cannot be converted to indicators).

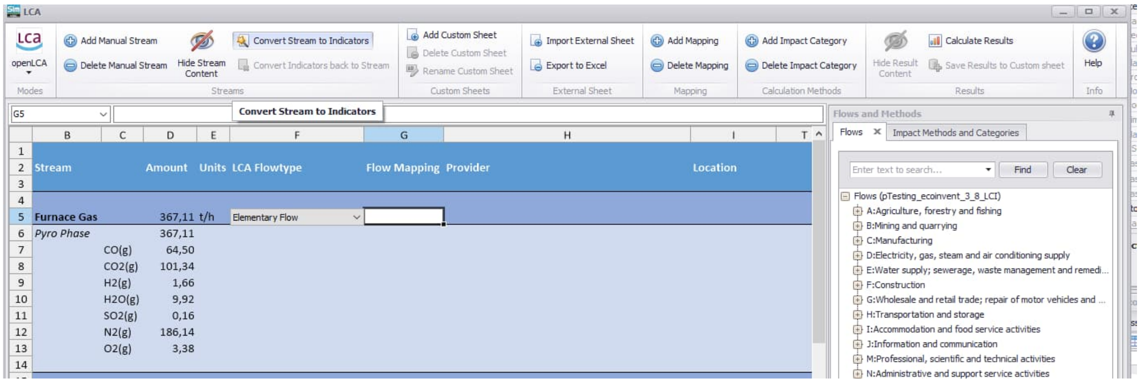


Fig 15. Converting stream to indicators.

Indicators can be converted back to normal streams by selecting the indicator row and pressing the Converting Indicators back to Stream (**Fig 16**). Again, the button will be disabled if correct row is not selected.

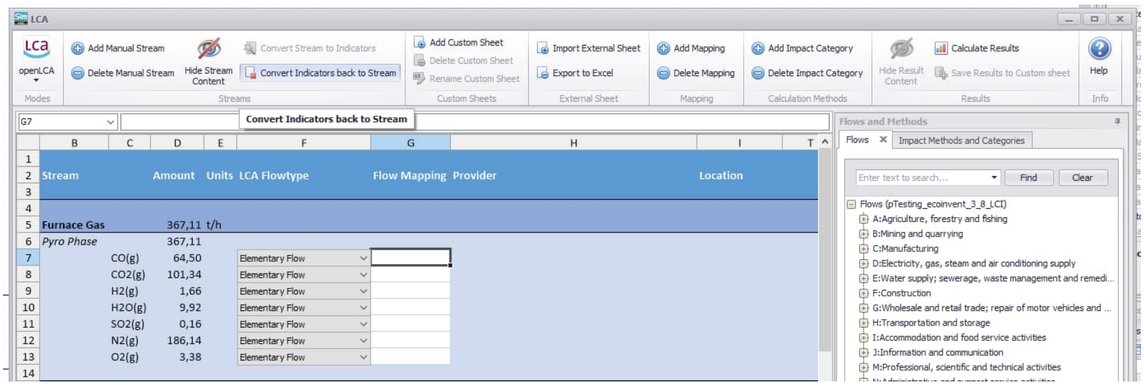


Fig 16. Converting indicators back to normal stream.

If the stream or indicator has already flow mapping, then when trying to convert it, error message will pop up and indicate that flow mapping will be lost if conversion is done.

49.4.6. Adding and deleting custom sheets

It is possible to add custom sheets to the tool. This can be beneficial if some additional calculations are needed to be performed, for an example, to calculate manual stream amounts from other streams.

Adding custom sheets happens by pressing the Add Custom Sheet button (**Fig 17**). The created sheet can be deleted by opening the sheet and then pressing the Delete Custom Sheet button (**Fig 18**). If there are some data on the sheet, all of it will be deleted.

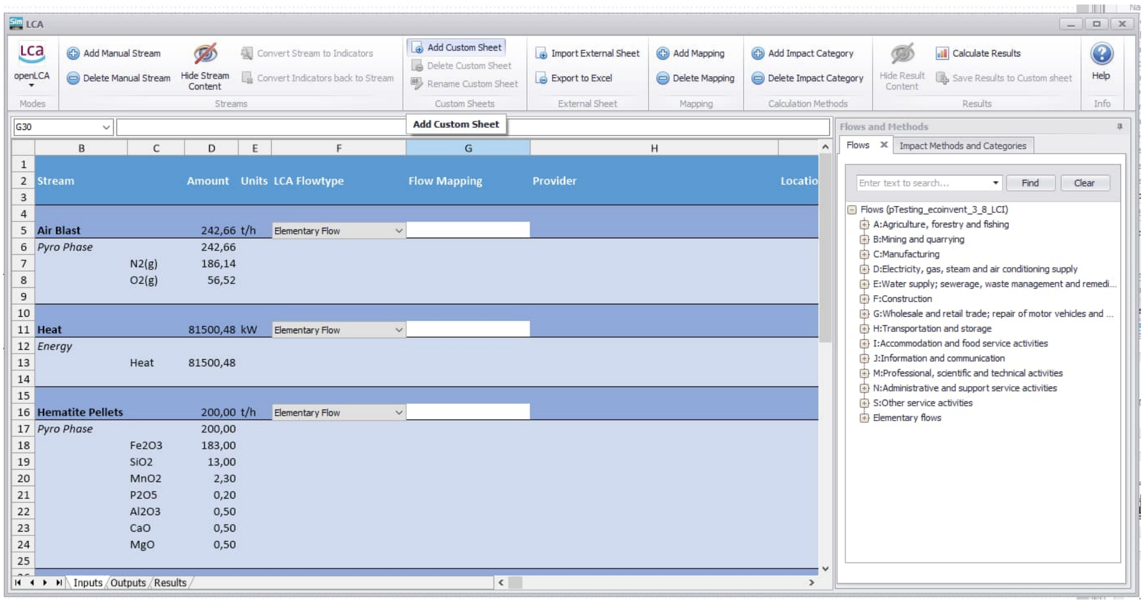


Fig 17. Adding custom sheet.

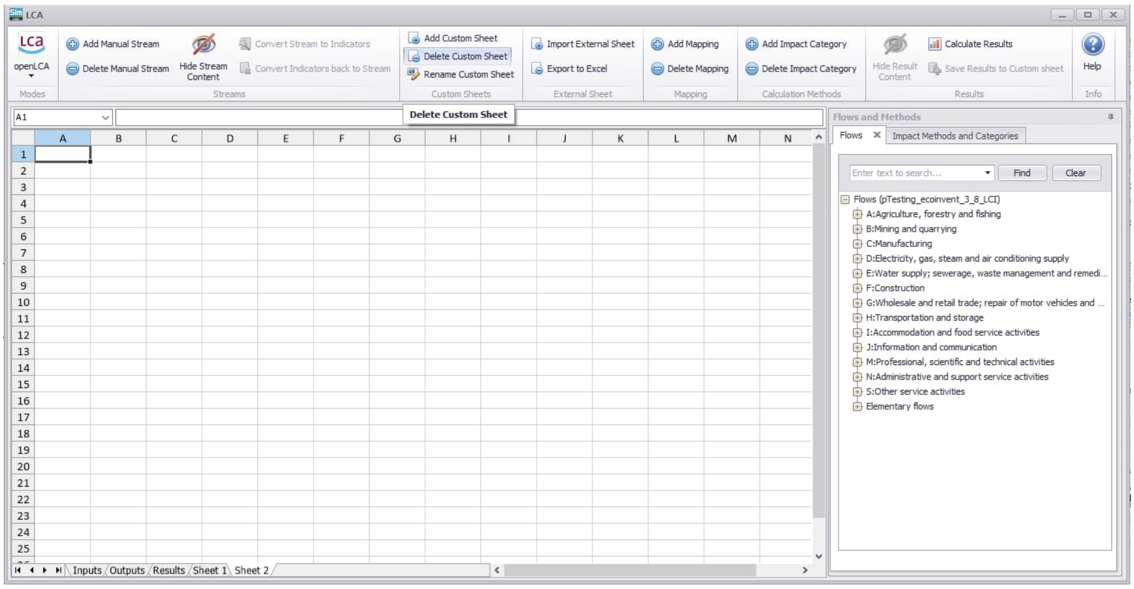


Fig 18. Deleting custom sheet.

The custom sheets can be renamed. First the sheet is opened and then pressing the Rename Custom Sheet button is pressed (**Fig 19**). Next, the desired name is written and OK pressed. There cannot be identical sheet names, and the sheet's name cannot start with 'Saved', 'Norm', or 'Ext'.

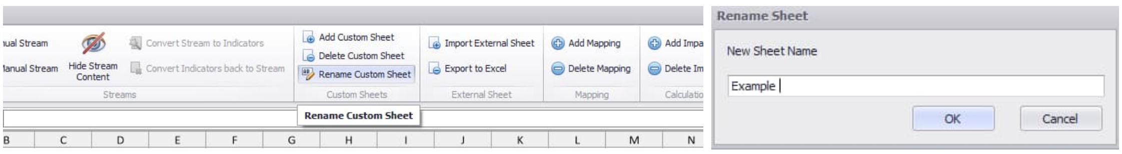


Fig 19. Renaming custom sheet.

49.4.7. Importing and exporting Excel sheets

It is possible to import and export Excel workbook sheets to/from the LCA Evaluation tool. This feature is intended for the comparison of results from different flowsheets.

However, the feature can be used for other cases also, for an example, it might be beneficial to do further analysis in Excel with the exported LCA result sheets.

Importing the external sheets happens by pressing the Import External Sheet button (**Fig 20**). Next, the correct file is selected. To be able to import the file, it needs to start with 'LCA_exports' name. Next, the sheets inside the workbook file are selected from the list and the green Apply and close button is pressed. After this the imported sheets need to be renamed.

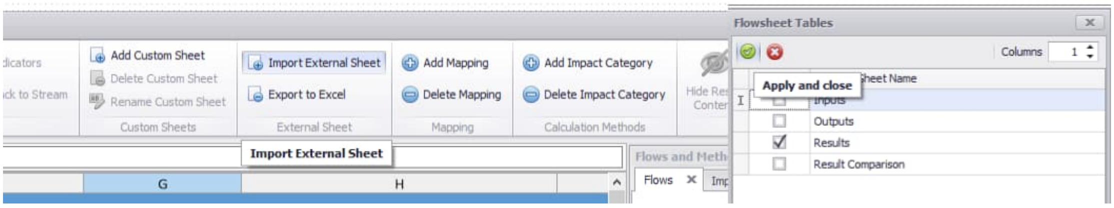


Fig 20. Importing external sheets.

All the imported sheets will have the 'Ext' in beginning of their name. Deleting (as well as renaming) the imported sheets works the same way as in deleting the custom sheets.

Exporting the sheets to Excel workbook happens by pressing the Export to Excel button (**Fig 21**). Then the file can be saved to desired location. The file name is automatically 'LCA_exports.xlsx'. This will export all the sheets inside the LCA Evaluation tool.

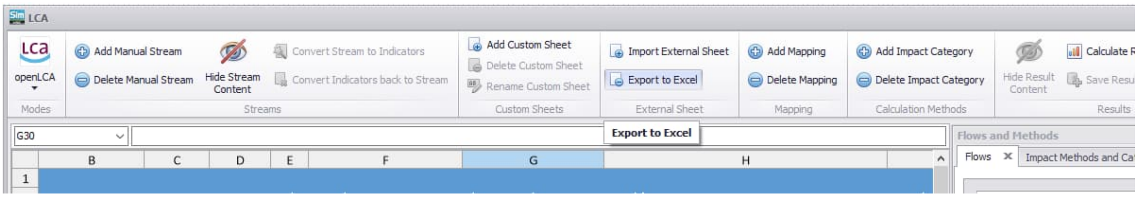


Fig 21. Exporting the sheets to Excel workbook.

49.4.8. Mapping streams to LCA flow equivalents

All the streams to be included in the LCA evaluation must be mapped to the LCA equivalents found in the *Flows* treelist. For default *Flow Mapping* cell in the stream/indicator row is empty, meaning that the stream/indicator will be excluded from the evaluation.

To be able to do the mapping, the stream and LCA equivalent need to be of the same LCA Flowtype. The different types are elementary, product, waste, or reference flows. These types describe the origin or destination of the stream from the process. The origin/destination can either be from/to the nature (elementary flow) or from/to the technosphere, i.e., from/to other processes (product/waste flow). The reference flow is the main product of the process, the results are calculated based on this.

The type for the stream is selected from the drop-down menu (**Fig 22**). At default the type is elementary. The flowtypes differ by Product and Waste Flow for the input and output streams.

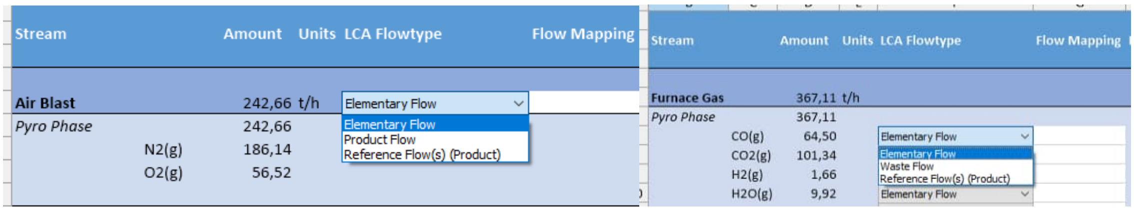


Fig 22. Different LCA flowtypes for input and output streams.

The flowtype for the LCA Equivalent is shown with initial before the name of the flow in the *Flows* tree list data (**Fig 23**).

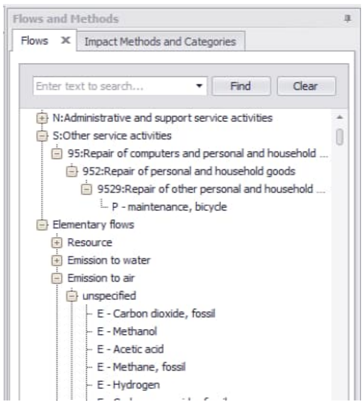


Fig 23. P for product flow, E for elementary flow.

The different flowtypes are summarized in **Table 2**.

Table 2. LCA flowtypes summarized.

	Elementary Flow	Elementary Flow	Product Flow	Waste Flow	Reference Flow (Product)	Reference Flow (Product)
Stream	Input	Output	Input	Output	Input	Output
Origin / Destination	From the nature	To the nature	From another process	To another process		
Initial in *Flows*	E	E	P	W	-	-
Note					Results calculated based on this. Can only be one for whole process	

The flow mapping starts by selecting the correct flowtype for the stream (**Fig 22**). Next, the correct LCA Equivalent with the same flowtype is chosen from the *Flows*. The LCA Equivalent can be selected either by expanding the different nodes and looking for the correct flow under the categories, or directly searching with possible name in the search box and pressing enter or Find (**Fig 24**). After searching, the nodes need to be expanded.

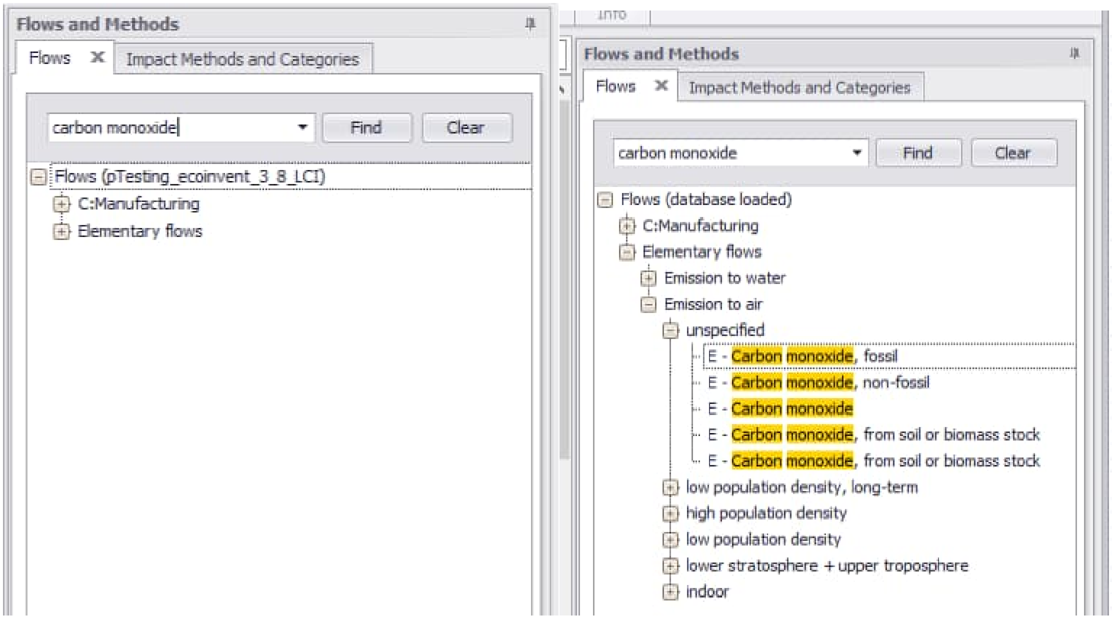


Fig 24. Search specific flow by writing name or part of into the search box.

After finding suitable LCA equivalent, mapping is done by selecting the stream/indicator row and then double-clicking the node or clicking the flow node and then pressing the Add Mapping (**Fig 25**).

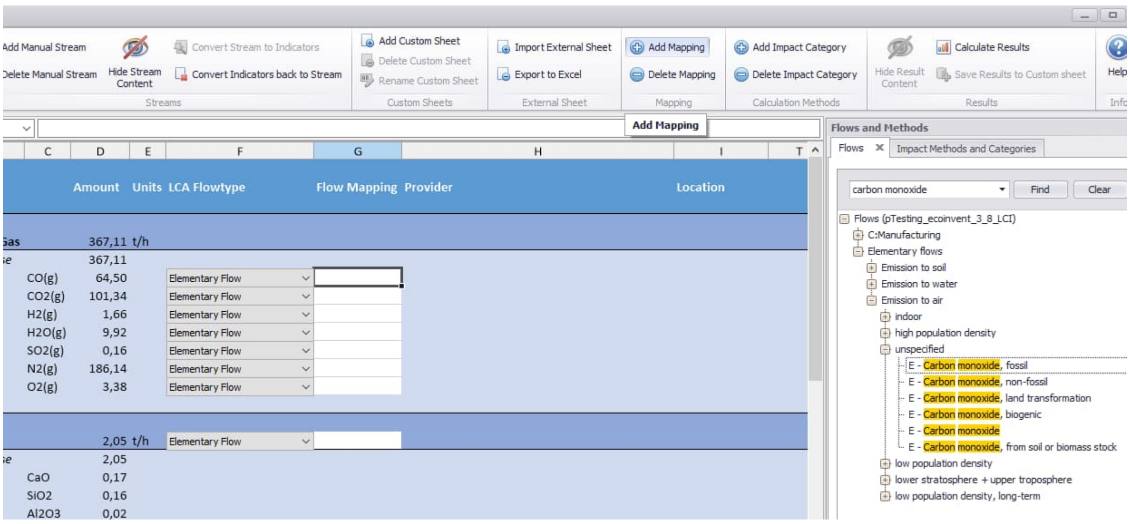


Fig 25. Adding new flow mapping.

Besides the LCA flowtypes, the unit of the stream/indicator must be the same as for the LCA equivalent. Now only **kW**, **MJ**, and **t/h** are supported for the streams. If the units are different error message will pop-up.

For elementary flow mapping it is just enough to add new mapping. However, for the product and waste flows, providers and locations need to be selected also. This happens by selecting the correct provider from the drop-down menu next to the flow mapping (**Fig 26**). The selection can also be done based on the location. Changing the location/provider will change the other one automatically. Most of the locations are in two letter abbreviations, however; depending on the original database, there might be some additional abbreviations.

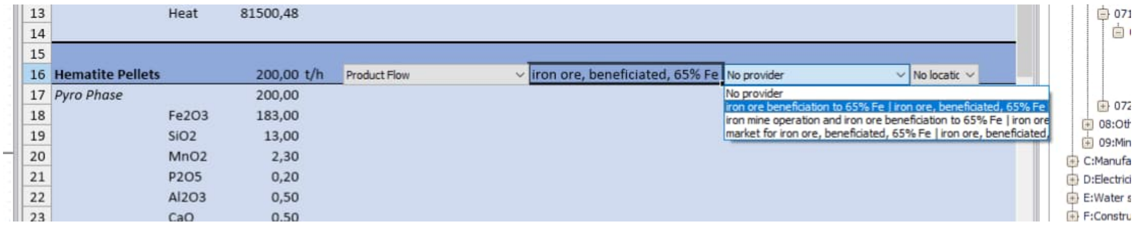


Fig 26. Selecting provider for the flow based on the provider's name.

If there are more than 15 providers, then the location needs to be selected first. In this case, the provider drop-down menu will only show the providers in that location (**Fig 27**).

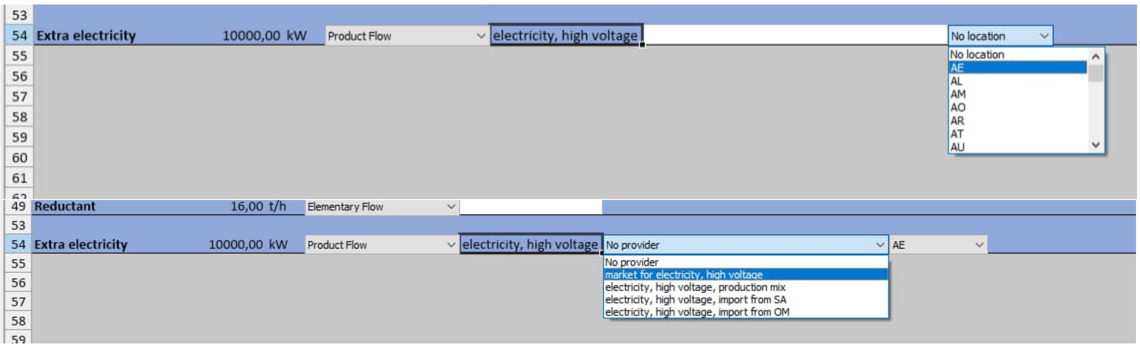


Fig 27. If there are more than 15 providers, location needs to be selected first.

The flow mapping can be deleted by selecting the stream name row and then pressing the <u>Delete Mapping</u> (**Fig 28**).

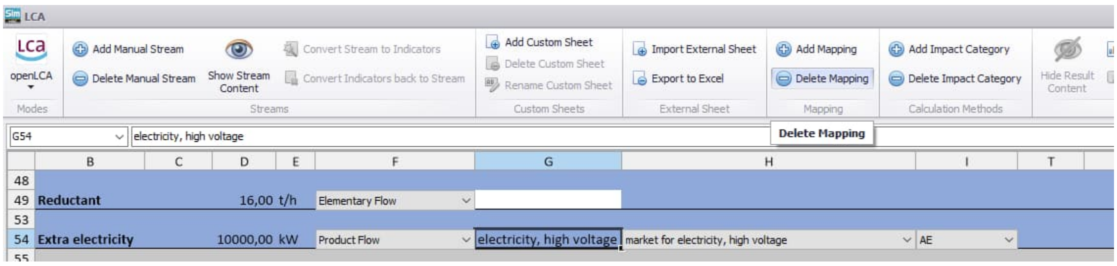


Fig 28. Deleting flow mapping.

For every process the main product i.e., Reference Flow (Product) needs to be selected. Main product is not mapped.

49.4.9. Selecting impact methods and categories for calculation

The third sheet, <u>Results</u>, which is inherently empty (**Fig 29**), will eventually show the LCA results. Before calculating the results, the impact method and categories need to be selected. The results will be calculated based on the selected method. All the methods available in the database for calculation are in the *Methods* tree list. By expanding the different nodes in the tree list the methods and categories under these can be seen. Searching methods/categories works the same way as searching for the flows.

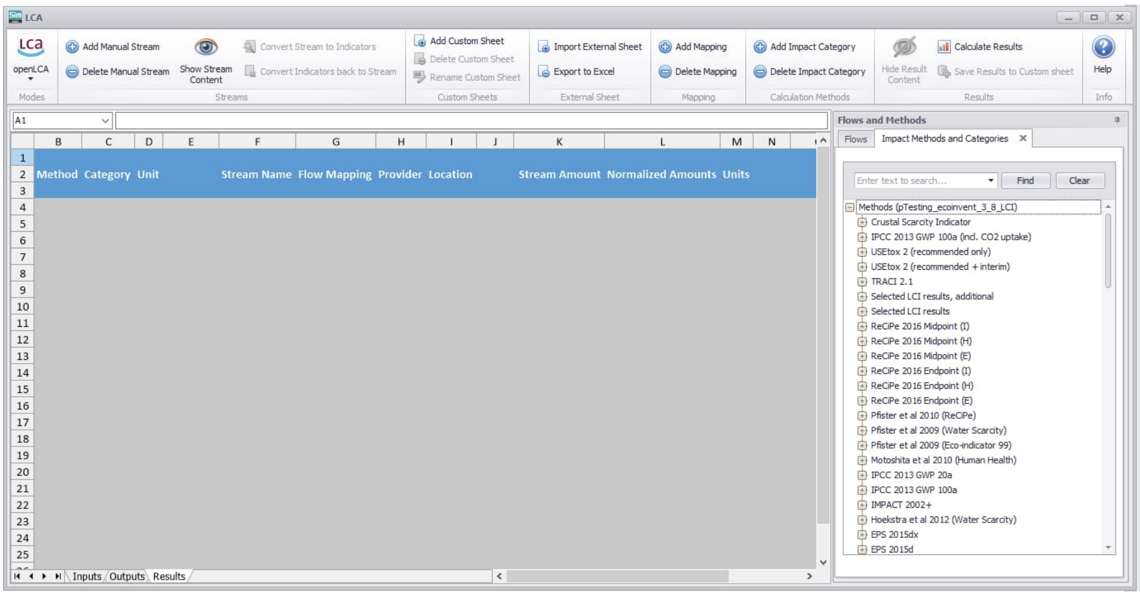


Fig 29. Empty result sheet and expanded *Methods* tree list on the right.

Selecting the impact methods and categories happens similarly as for the selecting the flows, i.e., selecting the correct node and then pressing the Add impact category button as (**Fig 30**) or double-clicking the node. It is possible only select categories inside the same impact method.

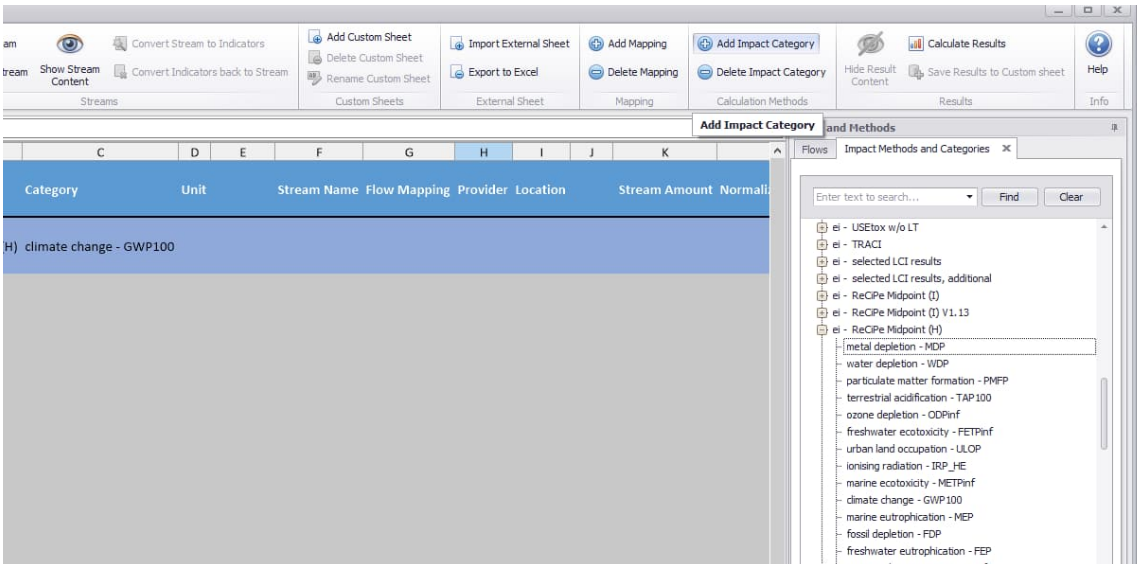


Fig 30. Selecting impact category.

If too many impact categories are added to the sheet, extra ones can be deleted by selecting the impact category name row and pressing Delete impact category button (**Fig 31**).

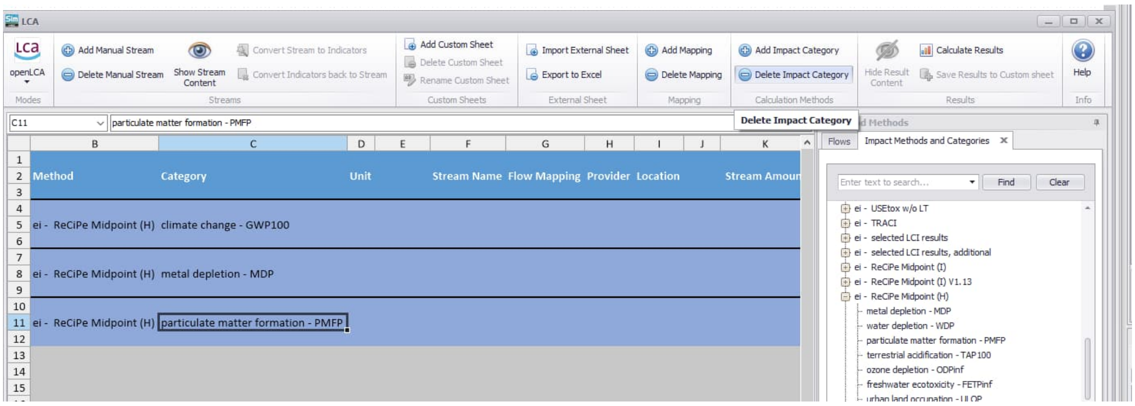


Fig 31. Deleting impact category from results sheet.

49.4.10. Calculating results

In the result calculation all the stream information (amounts, units, flow types and mappings) will be inserted into the database in the openLCA as a process. Also, a product system is created from the process. Then, the results are calculated using either the product system or the process (depending on whether the database is unit or system). The results are calculated based on the impact method selected to the result sheet. Finally, the results are sent back to HSC Sim where they are displayed in the result sheet.

The calculation of results can be started by pressing the Calculate Results button in the toolbar (**Fig 32**). Error windows will pop-up if not all necessary steps for result calculation have been done. These are selecting providers for product and waste flows, choosing reference flow as well as selecting the impact methods and categories. The result calculation might take some time, depending on the size of the process and size of the database.

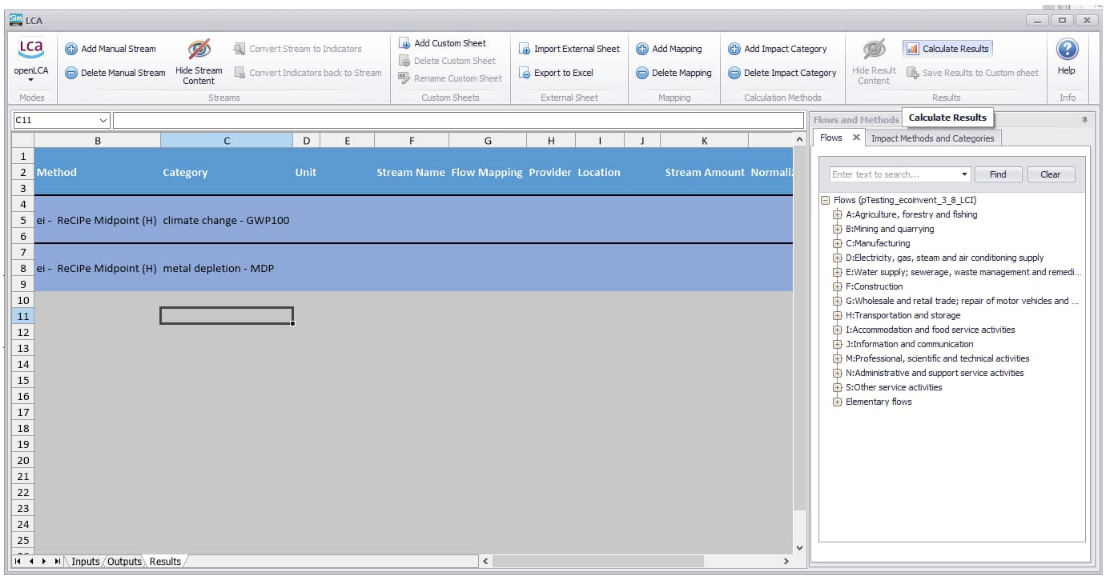


Fig 32. Calculating results.

Calculated results for the Iron Process example are shown in **Fig 33** and **Fig 34**.

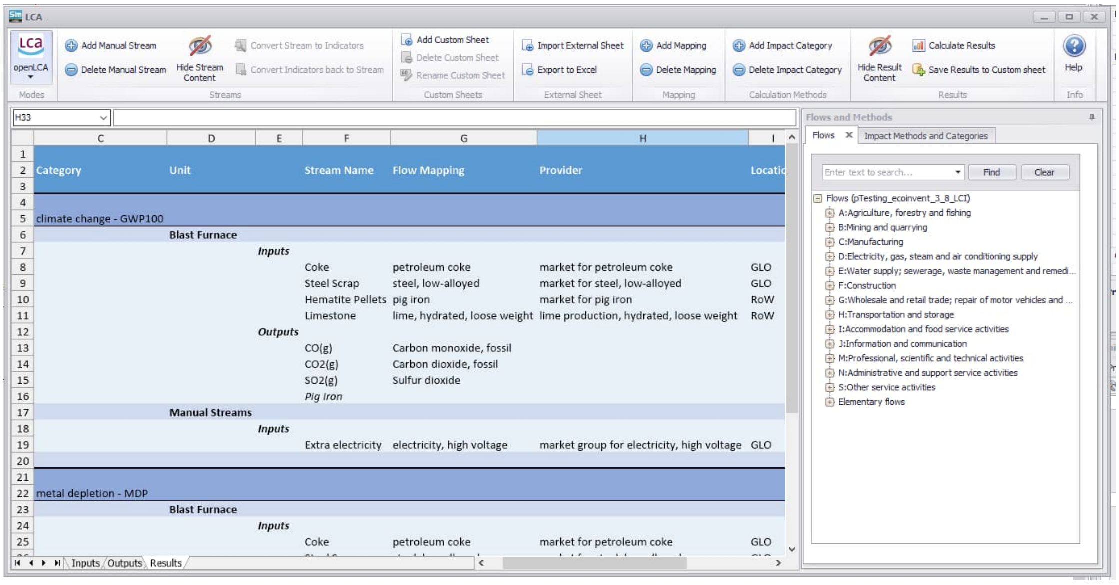


Fig 33. Results displayed.

Unit		Stream Name	Flow Mapping	Provider	Location	Stream Amount	Normalized Amounts	Units		Normalized Results	Units
									Total	16883,27	kg CO2-Eq per t/h of Pig Iron
Blast Furnace									**Total**	3419,04	
	Inputs								**Total**	2685,82	
		Coke	petroleum coke	market for petroleum coke	GLO	50,00	0,36	t/h		136,60	
		Steel Scrap	steel, low-alloyed	market for steel, low-alloyed	GLO	1,87	0,01	t/h		25,57	
		Hematite Pellets	pig iron	market for pig iron	RoW	200,00	1,45	t/h		2326,72	
		Limestone	lime, hydrated, loose weight	lime production, hydrated, loose weight	RoW	30,42	0,22	t/h		196,93	
	Outputs								**Total**	733,22	
		CO(g)	Carbon monoxide, fossil			64,50	0,47	t/h		0,00	
		CO2(g)	Carbon dioxide, fossil			101,34	0,73	t/h		733,22	
		SO2(g)	Sulfur dioxide			0,16	0,00	t/h		0,00	
		Pig Iron				*138,22*	*1,00*	*t/h*			
Manual Streams									**Total**	13464,22	
	Inputs								**Total**	13464,22	
		Extra electricity	electricity, high voltage	market group for electricity, high voltage	GLO	10000,00	72,35	kW		13464,22	

Fig 34. Results for the climate change category.

As from the above figures can be seen, the result sheet shows the total contribution to the different categories, as well as the unit (as well as both inputs and outputs streams of that unit specified) specific contributions to that category. Also, the individual contributions of each stream to the specific category can be seen. All these results are normalized based on the reference flow. For that reason, the unit of the normalized results is defined by reference flow. In this example, the unit for the climate change is 'kg CO2-eq per t/h of Pig Iron'.

In addition to the normalized results, the result sheet shows the flow mappings and possible provider and location for the stream. The original stream amount as well as normalized stream amount is also shown. The normalized stream amount unit is defined also by the reference flow as in the results. However, for simplicity, this unit is not shown in the result sheet.

The results details can be hidden in the Result sheet, similarly as the stream content can be hidden. This happens by pressing the Hide Result Content from the toolbar. The details can be again shown by pressing the Show Result Content button. Hidden results for the Iron Process are shown in **Fig 35**.

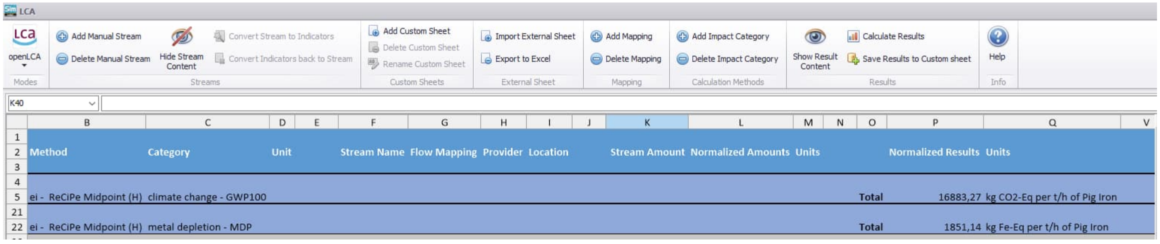


Fig 35. Hidden results for the Iron Process.

49.4.11. Automatic update of the result sheets

The result sheet is updated automatically if the values of the streams (which have flow mappings i.e., are included in the result calculation) in the input or output sheets change. This makes it possible to calculate results at the same while running the simulations. At this point, the gRPC connection to the openLCA does not need to be open anymore.

However, if some other information is changed, for an example flow mapping for a stream or totally new stream is added, these are not added to the results automatically. In this case, the results need to be calculated again, otherwise there will be old process in the result sheet. Changing, adding, or deleting impact categories will delete all the old results.

49.4.12. Saving results to custom sheets

It is possible to save the snapshot of the results into a custom sheet. This can be useful if the original results are needed later or if the results will be compared later with other results. Saving results to custom sheets happens by pressing the <u>Save Results to Custom Sheet</u> button (**Fig 36**).

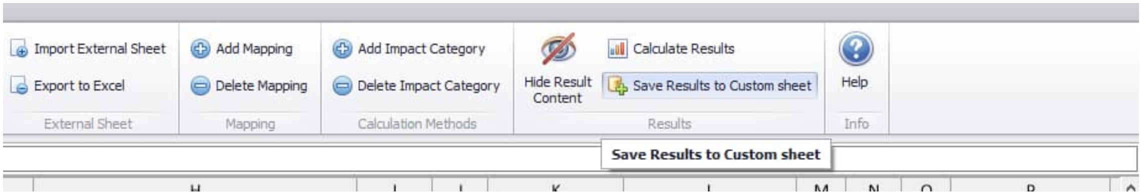


Fig 36. Saving results to custom sheet.

All the saved results sheets will have the 'Saved' in beginning of their name. Deleting as well as renaming the saved result sheets happens similarly as with the custom sheets.

49.4.13. Further analysis in openLCA

After results have been calculated in HSC Sim, the process and product system created in openLCA can be used to further analyse the example.

First, whenever something is done in HSC Sim side, the database in openLCA needs to be refreshed. Refreshing happens by clicking the three dots in the left side of the navigation bar and the selecting the <u>Refresh</u> (**Fig 37**).

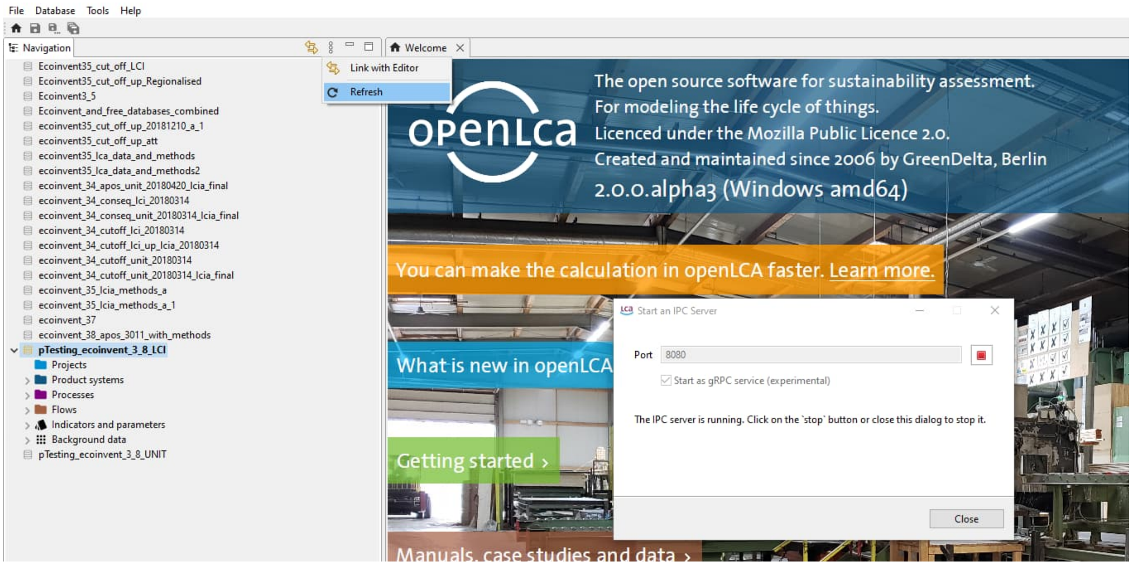


Fig 37. Refreshing the database.

For this example, under the *Product systems* and *Processes* three new processes (one for the main process and two for the unit processes) and one new product system have been added (**Fig 38**, **Fig 39**, **Fig 40**). The main process connects all the unit processes together. The unit processes are units of the HSC Sim flowsheet. Product system is created from the main process.

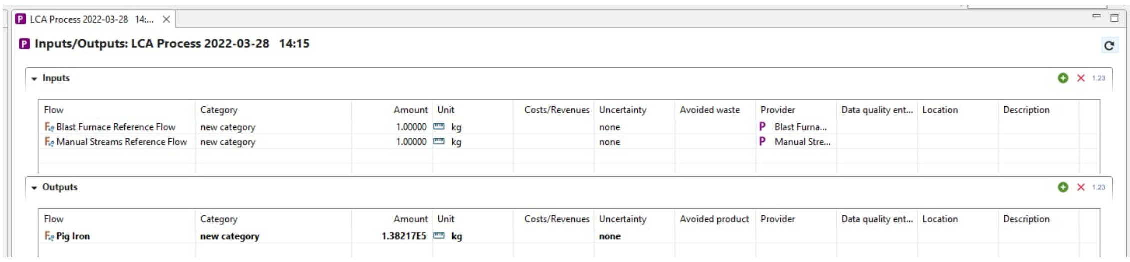


Fig 38. The “main” process.

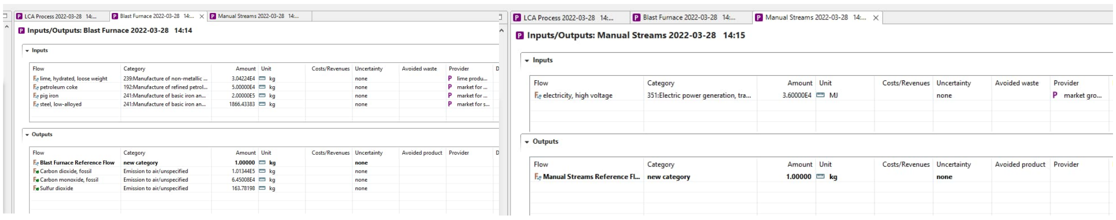


Fig 39. The unit processes.

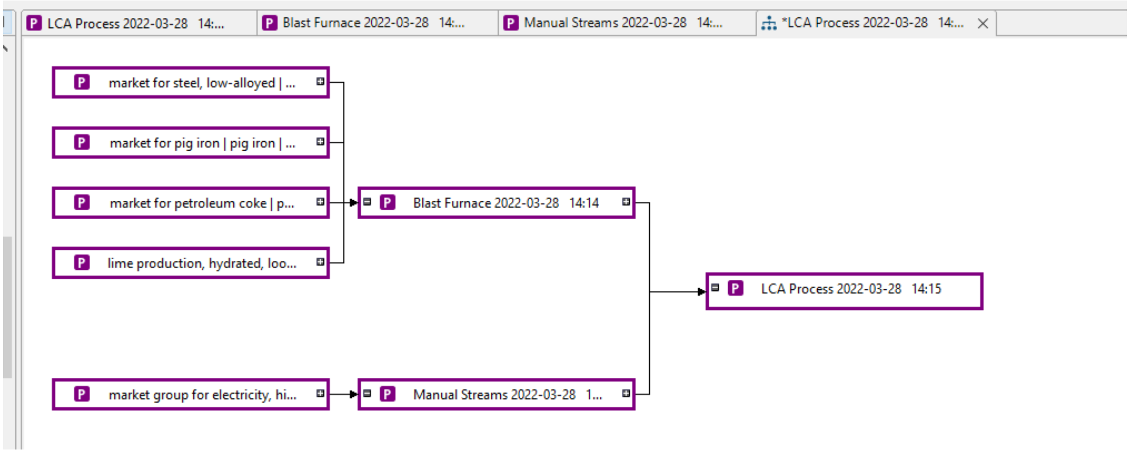


Fig 40. Produt system based on the main process.

49.5. Bibliography

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