SimaPro 7

Introduction into LCA

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Abbreviations

BUWAL	Bundesamt für Umwelt, Wald und Landschaft
CML	Centre of Environmental Science, University of Leiden, the Netherlands
Daly	Disability Adjusted Life Years
DQI	Data Quality Indicator
ELMIS	Environmental Life Cycle Information System
EPS	Environmental Priority Strategy (impact assessment method)
ERP	Enterprise Resource Planning System
GRI	Global Reporting Initiative
IPP	Integrated Product Policy
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
SQL	Structured Query Language (computer language for accessing and manipulating databases)
WHO	World Health Organisation

1 Introduction to LCA with SimaPro 7

1.1 Introducing LCA in your organisation

Life cycle assessment is a technique for assessing the environmental aspects associated with a product over its life cycle. The most important applications are:

- Analysis of the contribution of the life cycle stages to the overall environmental load, usually with the aim to prioritise improvements on products or processes.
- Comparison between products for internal or internal communications.

LCA is a relatively young technique; it became popular in the early nineties. Initially many thought that LCA would be a very good tool to support environmental claims that could directly be used in marketing. Over the years, it has become clear that this is not the best application for LCA, although it is clearly important to communicate LCA results in a careful and well-balanced way.

In recent years life cycle thinking has become a key focus in environmental policy making. A clear example is the concept of IPP (Integrated Product Policy) as communicated by the EU, but also in Asia (China: Circular Economy) and the America's many countries develop strategies that promote life cycle thinking as a key concept. Another development is the sustainability reporting movement. The majority of the Fortune 500 companies now report on the sustainability aspects of their operations.

LCA provides the more quantitative and scientific basis for all these new concepts. In many cases LCA feeds the internal and external discussions and communications. Being active in LCA means to be able to communicate the environmental impacts of products and business processes. This book introduces you to the LCA methodology, It also explains how you can become involved in LCA using SimaPro, the worlds most widely used LCA software.

How this introduction is written

This introduction provides general information about the backgrounds of the life cycle assessment methodology, and provides practical advice on how to perform LCA studies. It can be read without having SimaPro in front of you. Chapters 2 to 5 describe the LCA methodology in general. Apart from some text boxes, these chapters make no direct reference to SimaPro. Chapter 6 describes organisational aspects of LCA, while chapters 7 to 11 deal with the way you model life cycles in SimaPro.

Once we have introduced you to the most important concepts and terminology, we suggest that you start up SimaPro and perform your first experiments. We have devoted much effort in developing clear help texts. If you want to know more, press F1 to get help on the issue you are currently dealing with. Other SimaPro manuals, such as the database manuals, can be found as PDF files on the installation CD-ROM or via the SimaPro Help menu.

1.2 What to do and what to avoid when starting with LCA

An interesting survey on how LCA is used [Frankl and Rubik 2000] shows that the most common reasons for the application of LCA are for internal purposes, like product improvement, support for strategic choices and benchmarking. External communication is also mentioned as application, but often this communication is indirect. The LCA report is not published but key findings are reported.

The most important pitfall in the implementation of LCA turns out to be the lack of a clear definition of the purpose and application of LCA. In many companies, the marketing department is the initiator, as it would like to show environmental benefits of products,

but usually the marketing department finds out that LCA results are difficult to communicate. Often others, usually the R&D or the environmental department, take over the role of initiator, and this can create some confusion regarding the exact purpose of the LCA project.

The most frequently encountered pattern in the early stages of LCA implementation is the start-up of an ad-hoc project. The most important goal is to learn what LCA is, what one can learn from it and how reliable the results seem.
This learning attitude is very important. Learning is often more important than the result of the first LCA. According to the study of Frankl and Rubik, an interesting situation occurs if the first LCA gives strange or unexpected results. In some organisations, the result is seen as a reason to disqualify the usefulness of LCA as a tool. Other organisations use the unexpected result as a positive learning experience.

After this first study is done companies decide whether they want to continue, and adopt a more structured approach. Success factors of LCA implementation are:

- A clear description of the reason for using LCA.
- A clear definition of the way LCAs are to be communicated internally and externally.
- A reasonable budget.

In the early stages of LCA development, much focus was given to the very long, detailed and expensive studies. From our own contact with SimaPro users, we see a clear trend towards screening and simplified studies. Such shorter studies are possible after collecting data for the most commonly used materials and processes that are relevant for the company. Most commonly used materials are already included in LCA databases. However, if the products in your company require very special products or materials, it is possible that you will have to invest in collecting data for these processes and materials.

1.3   Some remarks on ISO standards for LCA

There are four ISO standards specifically designed for LCA application:

ISO 14040:   Principles and framework
ISO 14041:   Goal and Scope definition and inventory analysis
ISO 14042:   Life Cycle Impact assessment
ISO 14043:   Interpretation

Currently (early 2006) two draft standards have been published that will replace these four standards:

ISO/DIS 14040: Principles and Framework
ISO/DIS 14044: Requirements and Guidelines

The new 14044 standard replaces the 14041, 14042 and 14043, but there have been no major changes in the contents. In this manual, we still refer to the old numbers of the ISO standards. The drafts are expected to become standards by 30 September 2006. (See www.iso.org, search for TC207/SC5)

The ISO standards are defined in a quite vague language, which makes it difficult to see if an LCA has been made according to the standard. Unlike the 14000 standard, it is not possible to get an official accreditation that states that an LCA, an LCA methodology or LCA software such as SimaPro has been made according to the ISO standard. So, no software developer can claim that LCAs made with a certain software tool automatically conform to the standards. For example, ISO 14042 does not allow weighting across impact categories for public comparisons between products. However weighting is explicitly allowed for other applications, and thus SimaPro does support weighting. This means it is your responsibility to use weighting in a proper way. Similar examples can be made for issues like allocation rules, system boundaries etc.

The most important consequence of aiming to adhere to an ISO standard is the need for careful documentation of goal and scope and interpretation issues. As an LCA practitioner you have a rather wide choice of alternative ways to perform your LCA, as long as you carefully document what you do. A second consequence of adhering to the standards that you might need to include a peer review by independent experts, as described in ISO 14040.

It is completely up to you to conform to these standards or to (deliberately) deviate. If you deviate, it is clear you cannot claim that your LCA has been made according to the international standards, and it will be more difficult to convince others of the reliability of your results.

2 Defining goal and scope

An LCA study consists of four steps:

1. Defining the goal and scope of the study.
2. Making a model of the product life cycle with all the environmental inflows and outflows. This data collection effort is usually referred to as the life cycle inventory (LCI) stage.
3. Understanding the environmental relevance of all the inflows and outflows; this is referred to as the life cycle impact assessment (LCIA) phase.
4. The interpretation of the study.

The main technique used in LCA is that of modelling. In the inventory phase, a model is made of the complex technical system that is used to produce, transport use and dispose of a product. This results in a flow sheet or process tree with all the relevant processes. For each process, all the relevant inflows and the outflows are collected. The result is usually a very long list of inflows and outflows that is often difficult to interpret.

In the life cycle impact assessment phase, a completely different model is used to describe the relevance of inflows and outflows. For this, a model of an environmental mechanism is used. For example, an emission of SO_2 could result in an increased acidity. Increased acidity can cause changes in the soil that result in dying trees, etc. By using several environmental mechanisms, the LCI result can be translated into a number of impact categories such as acidification, climate change etc.

A usually highly controversial issue is the weighting of impact categories, as this is a subjective issue.

Understanding the multidisciplinary nature of LCA

One of the complexities of LCA lies in its very multidisciplinary character. Following [Hofstetter 1998] we can distinguish three spheres that are all required in an LCA. Each sphere has very different characteristics:

*   **Technosphere**: The modelling of technical systems, such as production processes, transport processes etc. Usually, uncertainties in technosphere are not greater than a factor 2, while almost all measurements are verifiable and repeatable.

*   **Ecosphere**: The modelling of environmental mechanisms ("what happens with an emission?"). Uncertainties are often one to three orders of magnitude, and often verification is difficult or impossible, for example one cannot test-run climate change and repeat this several times to get good measurements.

*   **Valuesphere**: Dealing with subjective choices. This includes weighting of impact categories, but as we will see, values also play an essential role when an allocation procedure or a time horizon is selected. For example, in impact assessment it is important to choose if the potential damage from heavy metals is integrated over just 100 years or eternity. Value sphere is typically in the area of social sciences. In value sphere one cannot really speak of uncertainties, as one can say a "single" truth does not exist.

As LCA practitioner, you will need to understand these different ways of thinking, in order to communicate effectively with experts in each sphere, and to manage debates about uncertainty and reliability.

2.1 The need to define goal and scope

As with all models of reality, one must understand that a model is a simplification of reality, and as with all simplifications, this means that the reality will be distorted in some way. The challenge for the LCA practitioner is thus to develop the models in such a way that the simplifications and thus distortions do not influence the result too much.

The best way to deal with this problem is to carefully define a goal and scope of the LCA study before you start. In the goal and scope the most important (often subjective) choices are described, such as:

- The reason for executing the LCA, and the questions which need to be answered.
- A precise definition of the product, its life cycle and the function it fulfils.
- In case products are to be compared, a comparison basis is defined (functional unit).
- A description of the system boundaries.
- A description of the way allocation problems will be dealt with.
- Data and data quality requirements.
- Assumptions and limitations.
- The requirements regarding the LCIA procedure, and the subsequent interpretation to be used.
- The intended audiences and the way the results will be communicated.
- If applicable, the way a peer review will be made.
- The type and format of the report required for the study.

The goal and scope definition is a guide that helps you to ensure the consistency of the LCA you perform. It is not to be used as a static document. During the LCA, one can make adjustments if it appears that the initial choices are not optimal or practicable. However, such adaptations should be made consciously and carefully.

Goal and scope definition in SimaPro

In SimaPro, a special section is available to describe the goal and scope for each project. There are three sections:

- Text fields, in which you can describe the different aspects required for a goal and scope definition. The texts entered here can later be copied and pasted into your report.
- A libraries section. Here you can predefine which libraries with standard data you consider appropriate for the project you want to run. For example, if your LCA is to be relevant for Europe, you can switch of the USA-IO database that is supplied with some versions of SimaPro. By switching this library off, you will not see the data while you are running the project. This avoids accidental inclusion of data you do not want.
- A data quality section. Here you can define the data characteristics you want. After defining your profile, you will see that the DQI field in the process indexes will have different colours: Green means that a process matches exactly with your requirements, yellow means there is a small mismatch, orange means there is a considerable mismatch, while red indicates there are big deviations.

With these three sections, you have a guide in making a consistent LCA study in line with the ISO guidelines.

2.2 Defining the goal

It is obvious any LCA study should have goal. However, in ISO there are some particular requirements to the goal definition:

- The application and intended audiences shall be described unambiguously. This is important, as a study that aims to provide data that is applied internally can be quite differently structured than a study that aims at making public comparisons between two products. For example, in the latter case, ISO states weighting may not be used in impact assessment and a peer review procedure is necessary. It is also important to communicate with interested parties during the execution of the study.
- The reasons for carrying out the study should be clearly described. Is the commissioner or practitioner trying to prove something, is the commissioner intending to provide information only, etc.

Some LCA studies serve more than one purpose. The results may both be used internally and externally. In that case, the consequences of such double use should be clearly described. For example, it could be that different impact assessment methods are used for the internal or external versions of the study.

2.3   Defining the Scope

The scope of the study describes the most important methodological choices, assumptions and limitations, as described below. As LCA is an iterative procedure, the term initial is added to most of the paragraphs below. This means one starts with initial choices and initial requirements that can be adapted later when more information becomes available.

2.3.1 Functional unit and reference flow

A particularly important issue in product comparisons is the functional unit or comparison basis. In many cases, one cannot simply compare product A and B, as they may have different performance characteristics. For example, a milk carton can be used only once, while a returnable milk bottle can be used ten or more times. If the purpose of the LCA is to compare milk-packaging systems, one cannot compare one milk carton with one bottle. A much better approach is to compare two ways of packaging and delivering 1000 litres of milk. In that case one would compare 1000 milk cartons with about 100 bottles and 900 washings (assuming 9 return trips for each bottle).

Defining a functional unit can be quite difficult, as the performance of products is not always easy to describe. For example, what is the exact function of an ice cream, a car sharing system, or a holiday?

2.3.2 Initial system boundaries

Product systems tend to be interrelated in a very complex way. For example, in an LCA on milk cartons, trucks are used. However, trucks are also products with a life cycle. To produce a truck steel is needed, to produce steel, coal is needed, to produce coal, trucks are needed etc. It is clear that one cannot trace all inputs and outputs to a product systems, and that one has to define boundaries around the system. It is also clear that by excluding certain parts as they are outside the system boundaries, the results can be distorted.

It is helpful to draw a diagram of the system and to identify the boundaries in this diagram. Important choices in this area are:

- Will the production and disposal of capital goods (trucks, injection moulding machines etc) be included? As in energy analysis, one can distinguish three orders:
  1. First order: only the production of materials and transport are included (this is rarely used in LCA).
  2. Second order: All processes during the life cycle are included, but the capital goods are left out.
  3. Third order: Now the capital goods are included. Usually the capital goods are only modelled in a first order mode, so only the production of the materials needed to produce the capital goods are included.

- What is the boundary with nature? For example, in an LCA on paper it is important to decide if the growing of a tree is included. If it is, one can include the CO_2 uptake and the land use effect. In agricultural systems, it is important to decide if agricultural areas are seen as a part of nature or as a production system (technosphere). If this is seen as nature, all pesticides that are applied is to be seen as an emission. If agricultural areas are seen as an economic system, one can exclude the pesticides that remain in the area, and only include the pesticides that leach out, evaporate or that are accidentally sprayed outside the field.

Some suggestions for default system boundaries

In older LCAs capital goods are often not included, and for most LCAs this can give satisfactory results, although this may result in missing 30% of the environmental impacts. In some cases however this will give important distortions. For example in an LCA including a significant amount of hydropower, leaving out capital goods would mean that all the infrastructure, like dams, pipes etc. are omitted, and in fact there would be nothing left to model. In more modern databases, like ETH-ETH, ecoinvent and USA Input Output databases, capital goods are included. We advise you to follow this principle for the background data. For the data you collect yourselves, capital goods should only be included when they really give a significant contribution (see next paragraph).

For most LCAs of agricultural systems the boundary with nature is set to include the agricultural area within the economic system, so this means that you do include the CO_2 uptake, you do take into account the impact of land use, but you do not assume all pesticide uses are an emission; instead you only include the estimated emissions from the agricultural area to the surroundings. In some impact assessment methods such as the Eco-indicator 99 this is already taken into account.

Switching system boundaries

If you want to study the effect of different system boundaries, you can use the parameters in SimaPro to switch boundaries. For instance if you are modelling an injection moulding process, you can estimate the amount of steel in the mould (lets say 100 kg), and divide this by the number of products that is expected to be made with that mould (lets say 10.000 products). The result is the steel amount that is allocated to a product (in this example 10 gram).

In SimaPro you can enter this amount of steel as an input to the injection moulding process. However, instead of entering 10 gram as an amount, you can enter the simple formula: S*10gram. Before you calculate, you can determine a value for S. If you choose a value of 1, you include the metal, if you choose zero, you ignore the metal. The real power of this application is when you use this switch in many different places, so by controlling one parameter you can change the system boundary throughout your dataset.

2.3.3 Criteria for inclusion of inputs and outputs

Apart from the criteria for system boundaries, one can also use a certain threshold below which you consider it useless to collect data for an inflow or an outflow.
ISO 14041 recommends using one or more of the following bases for such a threshold:

1. If the mass of the inflow is lower than a certain percentage. The problem is of course that this only works for materials and not for transport distances and energy.
2. If the economic value of an inflow is lower than a certain percentage of the total value of the product system. The problem with this and the previous approach is that flows with a low value or low mass could have significant environmental impacts.
3. If the contribution from an inflow to the environmental load is below a certain percentage. This seems the most relevant choice, but the problem is that one cannot really know the environmental contribution before the flow is investigated. Once it is investigated, one may wonder why it should not be used. Another problem is the use of the term the environmental load, as ISO has not defined this, and it is not so clear if the use of single scores is permitted. If not, one must determine the contribution of a flow against all relevant data and impact categories, which can be quite complex procedure.

Recently the use of input output data has been suggested as a viable way to estimate the "missing" environmental load. The principle behind such tables is explained in section 3.5. Such tables provide environmental load per unit of costs, so if one knows the costs associated flow (option 2), an estimate of the environmental load can be made, as in option 3.

Using thresholds in SimaPro

The effect of using cut-off criteria can be analysed in the process tree or network window in SimaPro. In many LCAs, process trees become very large. LCAs with over 2000 processes are no exception. These process trees contain many processes that are not contributing very much. This can be illustrated by setting the cut-off threshold for displaying processes in the process tree at 0.1 % of the environmental load (for a single score or an impact category). In most cases, only 10 to 30 processes turn out to have a contribution that is above this threshold. Now it becomes much easier to see the relevant issues in the process tree.

A similar function can be found in the p*rocess contribution analysis.* This function gives you the relative contribution per process in a list of processes. A process that is used more than once may have a small contribution in each instance, but the total contribution of all instances can still be significant. Contribution analysis shows this total contribution.

The SimaPro database also contains input output databases that can be used to estimate "missing" impacts.

2.3.4 Allocation

Many processes usually perform more than one function or output. The environmental load of that process needs to be allocated over the different functions and outputs. There are different ways to make such an allocation. ISO recommends the following procedure in order to deal with allocation issues:

- Avoid allocation, by splitting the process in such a way that it can be described as two separate processes that each has a single output. Often this is not possible, for example wooden planks and saw dust are both an economic outputs of a saw mill, but one cannot split the sawing process into a part that is responsible for the saw dust and one that is responsible for the planks.
- Another way to avoid allocation is to extend the system boundaries and by including processes that would be needed to make a similar output. For example, if a usable quantity of steam, produced as a by-product, is used in such a way that it avoids the production of steam by more conventional means, one may subtract the environmental load of the avoided steam production. A practical problem is often that it is not always easy to say how the steam would be produced alternatively.
- If it is not possible to avoid allocation in either way, the ISO standard suggests allocating the environmental load based on a physical causality, such as mass or energy content of the outputs. For example if the sawdust represents 40% of the mass, one can allocate 40% of the environmental load to sawdust. In the case of allocating steam, we believe the mass of the steam is not a very relevant basis.
- If this procedure cannot be applied, ISO suggests using an socio-economic allocation basis, such as the economic value. For example if the saw dust represents 20% of the value generated by the saw mill one can allocate 20% of the environmental load to this output.

Although ISO mentions the socio-economic basis as a last resort, it is used very often. The advantage is that economic value is a good way to distinguish waste (no or negative value) from an output, and it expresses the relative importance of an output.

Allocation in SimaPro

In SimaPro each process can have multiple outputs and avoided outputs at the same time. This means you can combine system boundary expansion and direct allocation in any way you like.

Behind each multiple output, you can add a percentage that indicates the allocation share. When you allocate the environmental load of a wood saw mill over the main products planks and sawdust, you can allocate 50% to the planks and 50% to the sawdust (ignoring other by products). This is when you use mass as allocation basis. If you use an economic allocation basis, you could allocate 80% to planks and 20% to wood, as the value of planks is much higher than the value of sawdust. The sum of the allocation percentage must of course be 100%

It is up to you to decide on which principle you base this allocation percentage. We advise you to document how you determined an allocation percentage.

Switching allocation principles and dealing with uncertainties in SimaPro

The allocation percentages can also be expressed with parameters. These parameters can be controlled on a database or project level. This means you can easily change allocation parameters and rerun the LCA to see how the allocation influences the result.

In case you use economic allocation, you are often confronted with significant uncertainties in the prices you base the allocation on. If you define the allocation percentages as parameters, you can also define an uncertainty range, see also chapter 10.

If you use uncertainty data in allocation parameters, you must of course be sure that the total of all allocation parameters is 100%. If you would just specify the uncertainty in both allocation percentages, you would be unable to guarantee this. A simple solution is to use a formula. If the allocation percentage for product A is defined as A, you can set the allocation percentage for product B as (1-A).

2.3.5 Keeping track of Data Quality Requirements

It is important to determine in advance what type of data you are looking for. In some studies you would like to get an average of all steel producers in the whole world. In other studies you would like to have only data from a single steel producer or from a group of Electro steel producers in Germany. Likewise, you should determine if you want data on average, modern, or worst case technology.
Other Data Quality issues are completeness, consistency and reproducibility.

Data Quality in SimaPro

In SimaPro you can define a profile of the data you would like to get. In that profile, you can define your preference for:
- Time of data collection
- Region
- Representatively and type of technology
- Allocation
- System boundaries

If you also fill in these characteristics in each process you make, you can keep track of mismatches between what you wanted and what you made.

3 Inventory

3.1 Introduction

The most demanding task in performing LCAs is data collection. However much data is available in our database you will usually find that at least a few processes or materials are not available, or the available data is not representative. Depending on the time and budget you have available, there are a number of strategies to collect such data. It is useful to distinguish two types of data:

1. Foreground data
2. Background data

Foreground data refers to very specific data you need to model your system. It is typically data that describes a particular product system and particular specialised production system.

Background data is data for generic materials, energy, transport and waste management systems. This is typically dada you can find in databases and literature.

The distinction between these data types is not sharp and depends on the subject of your LCA. If you are making an LCA on Dishwashers, you will consider the truck that is used to deliver the dishwasher as background data. There is noting special about the truck, and there is no need to collect other data than the transport distance and the load efficiency. The emissions you take form the standard databases. However, If you are making an LCA of trucks, you can not use the standard truck, and you will have to investigate the emissions. In the first case one would consider the truck as background data, in the second case the truck becomes foreground data.

A practical approach to data collection

Start with making a very rough LCA in just a few hours, using the data available in SimaPro, and see how much data you already have and what you are missing. Fill in the missing data with something in your database that seems rather similar to the data you want to have. Now analyse how important this "missing" data is for the overall LCA. Based on this analysis, you can develop a much better focus on the data you really need to pay much attention to. If for example, it appears that this data will not contribute more than 0.1 to 1% to any of the impact categories, you may well forget this data source and use an estimate instead. Estimates can be made by using data from similar processes, by estimating the energy use in that process, or by using statistical data from so called input output databases, which are described in paragraph 3.5

Try literature data. There are many books that describe industrial processes and often they provide clear enough descriptions to estimate energy use, waste and in some cases some emissions. This can also be a good start for the development of questionnaires.

3.2 Foreground data collection

In many cases you will have to collect foreground data from specific companies. Most frequently one or more questionnaires are to be made to collect such data. It is important to establish good contacts with the persons that are supposed to fill in the questionnaire and to understand what these persons know, in what way data is available and what terminology is used.

3.2.1 Communicating with data providers

Collecting data from other parties is not always easy. It is useful to carefully consider the following points:

- The willingness to supply data is of course determined by the relation you have with these parties. Some parties will be interested as they may have common goals; some will see your LCA activities as a thread. In some cases most of the data collection effort is in the establishing of a good relation, in which parties have trust in each other. At least you have to be very open to state why you need the data, what will be done with it and how it will be presented.
- Confidentiality issues can be very important. Sometimes emission data can reveal certain technical or commercial secrets. One way of dealing with this is to involve an independent consultant that averages the data from different suppliers. Sometimes a branch or industry association can have this role, as they can average the data from their members.
- Terminology issues. Per industry sector, there are different ways of measuring and expressing things. If you develop a questionnaire for a party, you should try to use the terms, the units and the customs that are applicable within this sector. In order to do so you should first discuss the issues you are interested in and then produce a questionnaire.

3.2.2 Developing questionnaires

Questionnaires are often used as a means to collect data. As indicated, the development of a questionnaire should be done with great care, and should well connect to the target groups you are addressing. This means we cannot tell how to make a perfect questionnaire, but we can give some general hints and suggestions:

- Start with collecting some generic information, like annual reports, company brochures. This helps you to understand how the company is organised, and later, when you get the completed questionnaire it helps you to interpret the data.
- Be aware that a single production line often makes many different products, This means you have two options:
  - Ask for total inputs and outputs from the production line and allocate these impacts to the product you want to investigate. For this you must determine an allocation key, like the mass, the economic value, the surface (for instance with printing) etc.
  - Explain the allocation issue to the data provider, and ask him or her to make the calculations for the allocation. This is often a solution if the allocation key is confidential. However, it makes error trapping much more complex.
- For each question, do not only explain how to fill in the data, but also explain why you wan to have the data. This not only motivates, but helps to understand the question.
- Split up the questions in clear blocks that address one issue at a time. For instance have a section on all energy inputs and outputs, a section with all the material inputs, and the associated logistics, a section with all the relevant emissions, a section with all the wastes (and their destination) and a section with all outputs and logistics.
- Be interactive. Allow people to fill in estimates. Let the data provider indicate the source of the data. In the table below, we show a format that can be used for this. At the right hand side, users can indicate which of three basic sources are used. This means that we do allow for estimated data, but of course, when we see that such estimation is highly relevant for the outcome, we will go back to the data provider to ask for a better data source.
- Keep things simple for the data provider. This will reduce the risk on errors, and ease the interpretation.
- Ask what you need, but not more. Check in advance what you can really put into the database. Do not let people work for data that is not really needed. Usually it is no fun filling in questionnaires.

Example of a questionnaire

The example questionnaire presented below was developed for medium sized companies that were not expected to have explicit energy consumption data for different production steps. In fact the assumption was that they would take energy data from their finance department looking at the invoices they got. Of course this creates a problem when we want to split the production energy form the overheads, like air-condition, lighting and heating.

As in this case we knew the energy use in the production was not very important, we allowed for such a rough approach. If the process you are investigating is very energy intensive, you should of course have a much more precise questionnaire.

B1 Energy inputs Please specify the total energy mix you use for the total production department. If you have data in other units than the ones proposed below, please mark them clearly. For the allocation of energy over building (climate control etc.) processing you can use a percentage.					Why we want to know this? Energy is of course an important factor in the environmental load. With the allocation columns we want to further precise the allocation of energy inputs to the production.		Data Source for total		
Total	Total use in year X	Unit	Alt. Unit	Used for climate control, and light-ing, etc.	Used for production machines		Direct data (derived directly from administrative systems)	Indirect data (Based some sort of calculation)	Estimated data
Electricity from public grid		kWh		%	%		☐	☐	☐
Natural gas		MJ		%	%		☐	☐	☐
Light Oil		MJ		%	%		☐	☐	☐
Heavy Oil		MJ		%	%		☐	☐	☐
Coal		MJ		%	%		☐	☐	☐
Heat from other suppliers (for instance steam and warm water)		MJ		%	%		☐	☐	☐
Own electric power generation from other sources (wind, water, sun and biomass)		kWh		%	%		☐	☐	☐
Total energy consumption		MJ		%	%		☐	☐	☐

Internet data search

A dedicated search engine for LCA reports can be found on www.pre.nl/LCAsearch. It references thousands of LCA reports and similar documents

There are also some specialised internet sites, such as www.ecoinvent.ch and www.globalspine.com which are a market place for LCA data. Another nice site is www.life-cycle.org.

3.3 Background data

Often 80% of the data you need is background information that you do not have to collect via questionnaires, as they are readily available in databases, or can be found in literature or internet. Using background data requires great care, as you have not personally collected the data. This means you must investigate how well the data in

databases are in line with the requirements you defined in the goal and scope. Below we describe the two most important data sources available for the LCA community.

Data libraries and projects

The (background) data in SimaPro are structured in such a way that you can distinguish between data that is relevant for your current LCA project only, and data that can be useful in any other (future) project. The latter type of data is not stored in projects but in libraries. With the release of SimaPro we introduce the very comprehensive Ecoinvent libraries. These libraries contain over 2500 processes, covering a very wide range of processes.

While performing your LCA, you enter all the new data in the *project* and not in the *library*. If you need data from the library, you can make a link to that data; if you want to edit the library data, you copy it into your project and edit the copy only. If you have collected data that could be useful for other projects, you can move it to a library. In this way, you can gradually build up high quality data in your libraries, while you have all the flexibility you need in the projects.

3.4 The Ecoinvent database

SimaPro[1] comes with the full Ecoinvent dataset covering 2500 processes. It first has been released in 2003 (see www.ecoinvent.ch). This database has been the result of a very large effort by Swiss institutes to update and integrate the well-known ETH-ESU 96, BUWAL250 and several other databases.
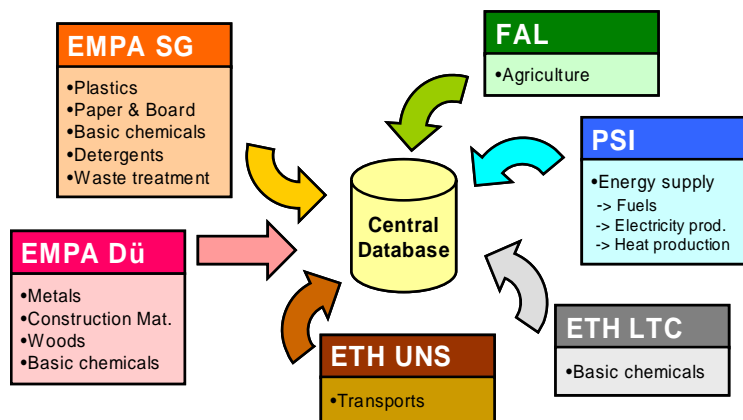

Figure 1   *The figure above shows the Swiss organisations that joined forces to create the Ecoinvent dataset. See www.ecoinvent.ch for more information.*

3.4.1 Key characteristics

The Ecoinvent dataset is extensively described on the Ecoinvent website www.ecoinvent.ch. Here we summarize a few key characteristics:

- Covers a very broad range of data.
- Available as unit processes and system processes.
- Consistent application of system boundaries and allocation.
- Well documented, a CD with extensive background reports is available.
- Consistent specification of uncertainty data, as lognormal distribution with standard deviation.
- Emissions are specified with subcompartments, for example an emission to air can be specified as emission to high or low densely populated areas, or

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[1] The Ecoinvent database is included in normal, indefinite, SimaPro licenses. For educational and temporary versions it has to be purchased separately.

stratosphere. Although at present impact assessment methods can hardly cope with this specification, it can be expected that future impact assessment methods, will make use of these compartments[2].

- Includes capital goods as standard[3], which is very important for energy systems such as wind and hydropower, but also for transport systems.
- Comes in a new EcoSpold format, which has become a de-facto standard that is very much (but not completely) in line with the IDO 14048 standard.
- Will be updated regularly by the ecoinvent center.

Especially if you need European data you will find this database a very rich resource that satisfies almost all needs for background data. The database also covers some other areas for instance for mining processes.

3.4.2 Unit processes and system processes

Each process is supplied in two versions, unit processes and system processes. You are free to choose which version you apply, as the final results are not significantly influenced. Still there are a number of important considerations to take into account when choosing between these versions.

A unit process version contains only emissions and resource inputs from one process step, plus references to input from other unit processes. So for instance, a unit process Steelmaking, contains only *transports of hot metal and other input materials to converter, steelmaking process and casting.* This means the unit process starts at the point where molten iron comes in from another process. The environmental load connected to iron making, is described in a series of other unit processes. When you select this process SimaPro will of course automatically include all these upstream processes.

When you take the system process version of this same process, you will find that all emissions from mining up to steelmaking are already in the process record. You will also find that there are no links to other processes. In fact a system process is a black box, or, one could say the result of an overall LCA on steel making.

Which version you choose depend on a number of characteristics summarized below:

Unit process	System
Very transparent (but big) process tree, that allow you to trace the contribution of all individual unit processes	Simple process tree with many black boxes
Contains uncertainty information, that allows you to run Monte Carlo analysis	No uncertainty information
Relatively slow calculation, as long as one or more processes are Unit processes.	Very fast calculation, as long as there are only system processes

In general you will use system processes in LCA screenings and unit processes in full LCAs (more information about LCA screenings and full LCAs in paragraph 6.1).

3.5 Input output databases

Input output databases are different from the normal "process databases" as they contain data per economic sector. For instance there is data on the agricultural sector, or on the banking sector, the transport and the consultancy sector. The benefit of this approach is that you can have a complete dataset for an entire economy. The disadvantage is that the information is not very specific. For instance, you cannot

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[2] Presently a joined update of the CML and Eco-indicator methodologies is being developed by RIVM, KUN, CML and PRé, that will take such subcompartments into account.
[3] SimaPro developer version has an option to run the calculations without capital goods.

compare two building materials if they both come from the same building materials sector.

Matrix inversion as calculation routine

In SimaPro 5.1 a major revision has been made in the way the software calculates the inventory. In previous versions, the sequential calculation routine was used. SimaPro started at the top of the tree, and determined how much of the underlying processes was needed. From each underlying process, it went to the next level etcetera.

In the new routine, the process structure is interpreted as a matrix that is solved (very fast) with inversion techniques. This has the advantage that we can now also calculated "looped" data structures such as input output datasets and databases as the ETH-ESU or ecoinvent database. The need for looped data can be easily illustrated, if one realises that electricity is needed to produce electricity, or truck transport is needed for the production of trucks.

Visualisation of looped datasets

The use of "looped" datasets also required us to change the traditional tree representation. SimaPro can visualise non looped data in two ways:

1. An hierarchical tree structure
2. A network structure

In a tree structure each process is shown with its inputs. If two processes link to the same process, for instance European electricity, this process will be shown twice. If ten processes refer to this electricity record, you will see this record ten times. Tree structures can easily become very large as this way and representing is not so efficient. However, it is a graph that is easily understood.

In a network structure, every process is only shown once, so if two or ten processes refer to the same process, you will see this process only once, but you will see two or ten outputs from this processes to other processes. The network structure is much more efficient in using space, but may sometimes look to be more complex.

Apart from these differences there are some other aspects that require attention:

- If a process like electricity appears ten time, you may easily overlook the relative contribution of this process. In a network you can easily recognise the contribution

- In a tree you can deliberately hide parts of the tree you are not interested in. In a network this is not possible, as network often do not have separate branches, everything seems to be related to everything

The most important difference is however that trees cannot be used if data are looped. If we would allows this, we would see a repetition of the process tree with every loop. This means the number of process would become infinitely large. In case you try to generate a tree visualisation, SimaPro will check if there are loops, and if their are, SimaPro will automatically switch to networks

With this feature, SimaPro is the only tool available that can indeed visualise the looped structure of the ecoinvent datasets.

3.5.1 The concept of an Input output table

Each national or regional economy can be described as a table in which the supplies between sectors, as well as the supply to consumers and supplies to export are registered in financial terms. In the figure below such a table is made as if there are just three different sectors: agriculture, industry and services. The role of governments has also been omitted. In practice the number of sector ranges from about 100 to 500. The supplies are noted in the rows.

A supply from one sector to the others is of course the same as the purchasing, so if you read the table in column, you will get the purchases of the sector. Of course the sectors also import, and usually the assumption is that the imported goods and services come from a same division of sectors, so also here we assumed that the countries we import from have the same three sectors.

If we add up the supplies, we get the total value generated by the sector in the right/hand column. We can also add the total value of all purchases, and put them at the bottom row. The difference between total value and total purchases is the added value of the sector. This is not the same as profit, as the sector will have to pay its wages, costs of loans etc... The added value is however an important measure for our purpose

	Agriculture	Industry	Services	Exports	Consumers	Total
Agriculture	Trade within the sector	Agriculture supplies to industry	Agriculture supplies to services	Agriculture supplies to exports	Argiculture supplies to consumers	Total value
Industry	Industry supplies to agriculture	Trade within the sector	industry supplies to services	Industry supplies to exports	Industry supplies to consumers	Total value
Services	Service supplies to agriculture	Service supplies to industry	Trade within the sector	Services supplies to exports	Services supplies to consumers	Total value
Agricultural imports	Imports of agricultural goods	Imports of agricultural goods	Imports of agricultural goods			
Industrial imports	Imports of industrial goods	Imports of industrial goods	Imports of industrial goods			
Imports of services	Imports of services	Imports of services	Imports of services			
total	Total costs	Total costs	Total costs			

Figure 2   *Schematic representation of the core of an input output table for just three economical sectors. The first three rows represents the supplies to different other sectors, to consumers and exports. The second three rows specify the imports.*

3.5.2 Adding environmental load

It is possible to collect environmental data per economic sector from statistical sources. Many researchers have done this for the most important industrial countries although this data are not always very complete. From the explanation above, it may become clear that having data from the sector alone is not enough: one also needs to trace the environmental load that comes with the supply of goods and services from the sectors.

In order to do so, all environmental data is divided by the added value of the sector, and the input output table is used to trace the supplies. In principle this allows us to trace all environmental loads throughout the whole economy. There are no system boundary problems; 'everything' is 'in' and all allocations are done based on economic value. A big problem however is what to do with the imports. There are two solutions:

1. Assume the environmental load per value from foreign products is equal to the domestic products. This may hold well for imports from industrialised countries, but is a bad assumption for imports from non-OECD countries. Nevertheless, this is done most often.
2. Develop Input Output tables for the international regions, and model the links between these regions.

In general we can say that the first solution works quite well in large economies, such as the USA that have a high domestic production compared to the trade. For small economies with large trade volumes like the Dutch this approach does not work well.

3.5.3 Using Input output tables in your LCA

One of the consequences of using IO tables, is that you no longer use mass or energy as inputs, but value. You will need to trace the price excluding taxes for components, material or services. Input Output tables are especially suited for the following purposes:

- As estimation for decisions on cut-off
- To make screening LCAs
- To include difficult to get data. such as services. For instance, you may want to add the average impact of retailing, or marketing to the life cycle of the product. If you know how much is spent on these services, it is easy to include these.
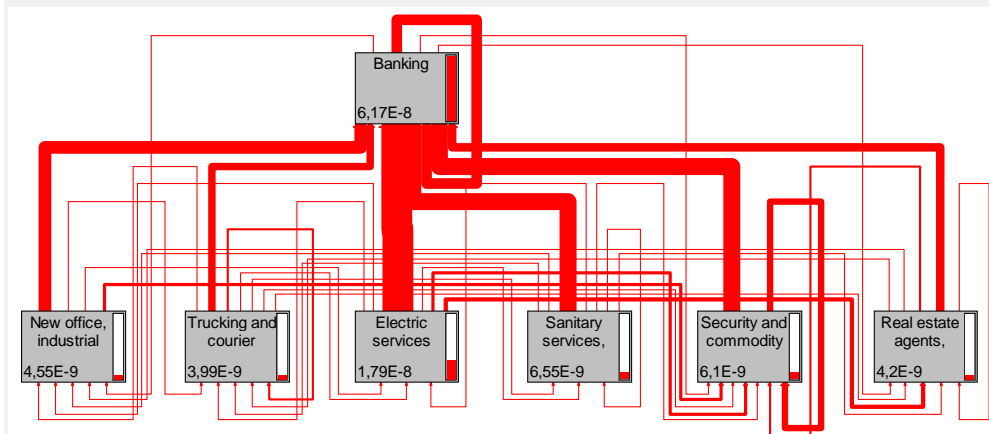
Input output databases in SimaPro

SimaPro contains a very detailed input output database that has over 500 commodities, representing the entire USA economy. This so called USA –Input Output 98 database has been licenced from CML Leiden. It was compiled by Sangwon Suh, who used a wide variety of US data sources. The database is in may ways unique compared to earlier input output databases, as it also includes estimates for diffuse emissions and small and medium sized industries. These are quite important but often missing. More information can be found in the database manual.

 Below we show the Input output database for banking. Services. The output unit is one dollar banking services provided. In the first network, we show the economic flows, without showing any environmental data, so the line thickness represents the dollar value of the commodity flow. Clearly Security services, real estate and computers are important inputs to banking services
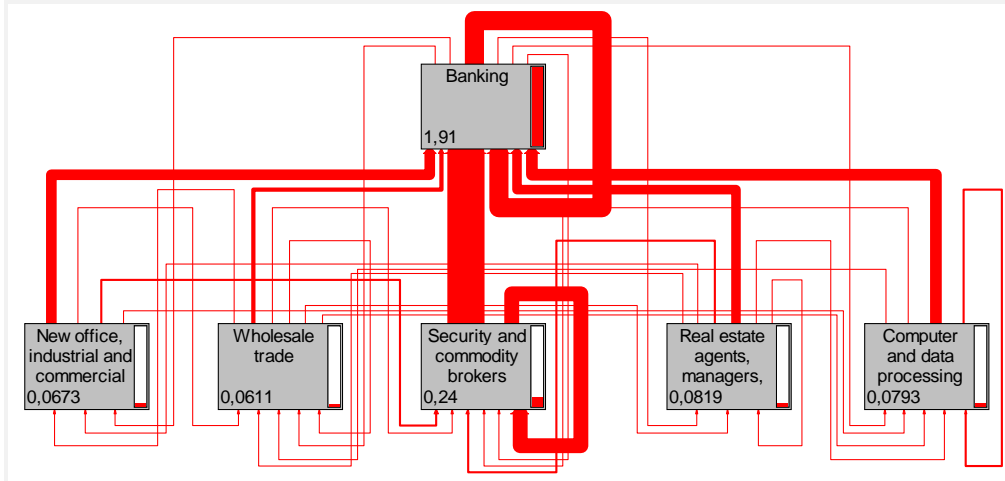
 In the figure below we use the same analysis, but now the CO2 emissions associated with the commodities are shown. The same commodities still show up as important contributors, but, we can also see that energy provided to banking are dominant.

 The example shows that Input output databases are also very useful to analyse services, or to include services in a product LCA. Until now services are often neglected in LCA, while in fact services tend to comprise two third of all economic activities.

3.6 The broader scope of sustainability

For many organisations environment is just one of the parts of a broader sustainability policy. The concept of People, Planet, Profit is often mentioned as the basis of such a policy. This means that next to environment, also social and economic issues should be managed in a sustainable way.

3.6.1 Social aspects

Social aspects relate to issues as working conditions and social security, political oppression, jobs created, and for instance the right to join unions. The problem with assessing social issues is that the issues at stake are very wide-ranging and often difficult to quantify in a meaningful way. This also explains why there is no ISO standard for these aspects.

An important initiative to bring some form of standardisation on how to manage and report on social issues is the Global Reporting Initiative (GRI). This organisation is developing more or les standard lists of social issues to keep track of, but also this organisation acknowledges that there can be big differences between sectors and even individual companies.

A practical approach towards flagging social issues

To include social issues, we propose the following simple procedures:

1. Define the social indicators you would like to include in the substance list. In many cases these issues do not have a useful quantity, so you can use a quantity as "amount" and use the unit p (pieces).
2. Add these indicators in the relevant processes. And put a value 1 under amount.
3. Develop a simple impact assessment method, in which all issues get a characterisation factor "1". You can of course use different impact categories to address different types of issues.
4. Analyse the network while this new impact assessment method is selected. The network now shows where specific issues pop up.

3.6.2 Economic aspects

The possibility of adding economic aspects to LCA methodology has been discussed among researchers for over ten year, but often these debates are confused and not really productive. The problems with adding cost and revenues to LCA models are numerous:

- Important cost factors like investment, research, overheads and marketing are usually not modelled or at least under-represented in an LCA model.
- LCA does not have a time perspective, so it is difficult to model interest rates
- The precision requirements for cost and revenue calculations are very high. An error in the calculation of a sales margin of a few percent can be fatal. This is why many companies employ a lot of people to keep track of market prices, exchange rates and sales margins. It is not realistic to assume that an LCA expert can improve on this.

3.6.3 Total cost assessment

Probably the most productive approach is to express social and environmental issues in terms of liabilities and intangible costs. For instance, bad publicity about a company caused by the discovery that child labour is involved can be very damaging to a company's reputation. Likewise, the environmental damage of a mine in a protected area can be costly.

In Total Cost Assessment a systematic procedure is used to estimate such costs and to estimate the probability that the costs occur. Based on these factors a total average cost connected to sustainability issues can be determined.

Total Cost Assessment software interfaces with SimaPro

The TCAce software (www.TCAce.com) is one of the first real Total Cost Assessment software that can calculate the potential cost associated with liabilities, intangible and societal cost. SimaPro has been fitted with an dedicated exchange mechanism that allows environmental damages that are potentially borne by society to be included in the assessment.

4 Impact assessment

4.1 Introduction

Most LCA experts do not develop impact assessment methodologies, they prefer to select one that has been published. In this manual we will not explain how to develop an impact assessment method, but how to select one, and if the method allows, how to refine one.

Like in the inventory stage, also in impact assessment the Goal and Scope definition is the most important source of guidance for the selection of the method and the impact categories.

The most important choice you make is the desired aggregation level of the results. This usually depends on the way you would like to address your audience, and the ability of your audience to understand detailed results. Figure 3 presents a schematic overview of some of the possibilities.
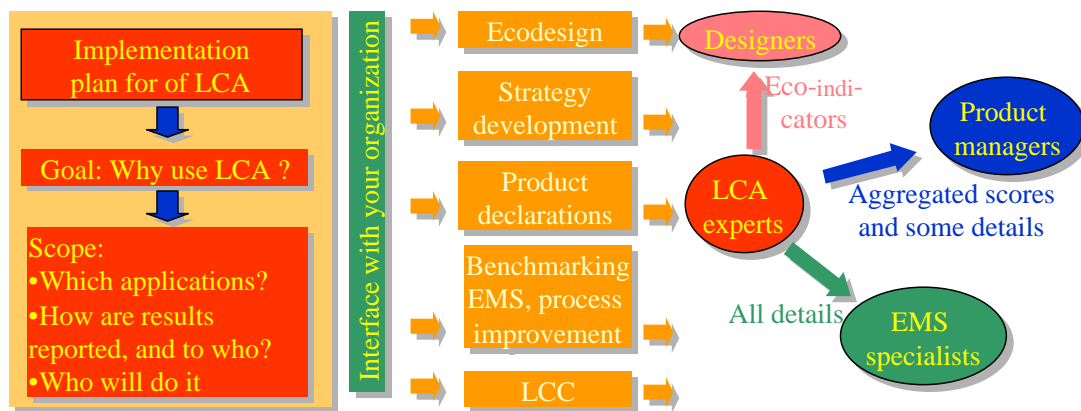
Figure 3   The choice of the impact assessment method depends largely on the addressed audience.

Impact assessment methods in SimaPro

SimaPro comes with a large number of standard impact assessment methods. We have selected the most authoritative methods. Each method contains a number (usually 10 to 20) of impact categories; some allow aggregation into a single score, and some do not.

Most users will simply select one complete method, instead of selecting individual impact categories. However, SimaPro does allow you to add or delete impact categories from or to a method. We advise you not to change the method as supplied in the impact assessment library, but to copy the method to your project and make the changes there. In this way, you can always revert to the original method. SimaPro also allows you to develop completely new methods.

4.2 ISO on impact assessment methods

The ISO 14040 standard defines an LCA as a compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system through its life cycle. In this definition, it is clear that impact assessment is an integral part of LCA. Life cycle impact assessment is defined as the phase in the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system.

The impact assessment methods themselves are described in ISO 14042. In this standard a distinction is made between:

- **Obligatory elements**, such as classification and characterisation
- **Optional elements,** such as normalisation, ranking, grouping and weighting

This means that according to ISO, every LCA must at least include classification and characterisation. If such procedures are not applied, one may only refer to the study as a life cycle inventory (LCI).
An important distinction is made between internal and external applications. If results are intended to compare (competing) products and they are to be presented to the public, weighting may not be used.

Selecting relevant impact categories

In an LCA comparing transport by truck and by rail, the following environmental issues are relevant:

- Small particulates (below PM10) from diesel engines and tyres.

- Land use needed for the road and rail surfaces.

- Noise.

Impact categories that reflect the impacts of the use of fossil fuel for electricity generation, industrial furnaces and diesel engines. These should at least include:

- Climate change.

- Acidification, eutrophication.

- Other toxic effects on humans and ecosystems, including ozone formation, which are included in existing impact categories.

- Depletion of fossil fuels and minerals e.g. zinc, aluminium, copper (power supply of trains.)

Other impacts or impact categories can be included, but seem less essential. It requires some expert judgement to make such a list, and to understand which impact categories should be defined to cover all these issues.

4.3 Selection of methods and impact categories

An important step is the selection of the appropriate impact categories. The choice is guided by the goal of the study.

An important help in the process of selecting impact categories is the definition of so-called endpoints (figure 4). Endpoints are to be understood as issues of environmental concern, like human health, extinction of species, availability of resources for future generation etc. ISO does not recommend using certain endpoints[4], but requires a careful selection and definition of endpoints first. After that impact categories can be selected, as long as the environmental model that links the impact category to the endpoint is clearly described. It is not necessary to describe this link quantitatively.

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[4] It is not easy to distinguish between impact categories and endpoints. For example, some would say seawater rise is an impact category, while others would call it an endpoint.
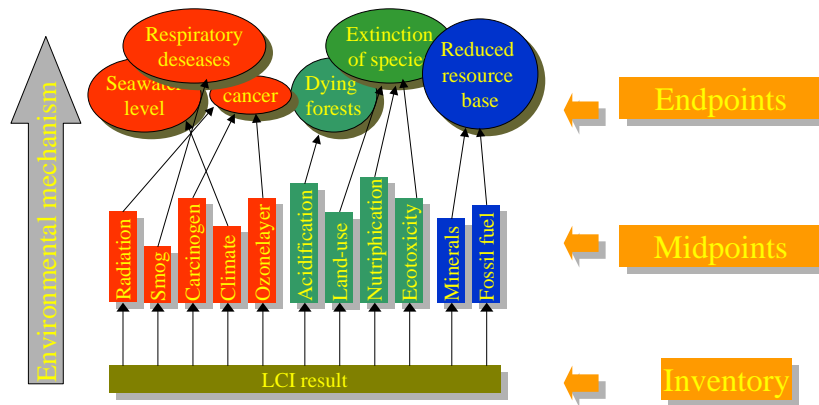
Figure 4:   *General overview of the structure of an impact assessment method. The LCI results are characterised to produce a number of impact category indicators. According to ISO, one must document the environmental relevance of each indicator by describing the link to the endpoints. Endpoints can be selected by the practitioner, as long as the reasons for including or excluding endpoints are clearly documented.*

Dealing with missing impact categories

ISO is very clear on the requirement that it is not allowed to leave out possibly important issues. For example, issues like land- use, fine particle matter and noise may not be omitted in this case. This important requirement can be used to eliminate a number of standard impact assessment methods that do not include such issues:

- **CML 92** does not include noise, land use, and fine particle matter
- **Eco-indicator 95**   does not include land use, noise and fossil fuel depletion
- **Eco-indicator 99**   does not include noise
- **EPS 2000** Includes all, but sometimes in a course manner

This example shows us that so far only EPS 2000 includes noise as an impact category, although the way it is implemented is rather course. A recent publication of [Müller-Wenk 1999] makes a proposal on how to include this impact category in the Eco-indicator 99[5].

From this example (not taken from ISO) it is clear that a description of the environmental relevance of the impact categories selected is essential for each LCA you make. One should not simply take a published method without supporting this choice carefully.

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[5] In some cases it is possible to combine impact categories from different sources. For example, the CML 1992 method could be extended by adding a published method on noise and land used. However. in such case great care must be taken to avoid overlaps in the impact categories. Usually it is also difficult to Normalize and weight such results.

Dealing with mismatches between inventory and impact assessment

An important problem is keeping track of mismatches between inventory results, as often many LCI results, do not have a characterisation factor. This can have several reasons:

- The methodology developer has deliberately decided not to include an LCI result.
- The methodology developer simply had insufficient knowledge (or budget) to include a substance.

The biggest gaps are usually in the toxicity categories, as there are so many different chemicals, it is impossible to have a characterisation factor for them all. There are two ways to check the mismatch.

You can check each impact assessment method in SimaPro, using the Check Method function. It will generate a table of all substances that occur in the inventory database and compare that with the substances that are defined in the method you selected. If you do so, you will notice that there is quite a big mismatch between the list of substances in the inventory data and the availability of characterisation factors. This feature is especially important for users that want to edit, or develop new impact assessment methods.

The second way to check the mismatch can be applied each time you calculate a result. After each calculation with SimaPro you can consult a list that specifies which substances were in the LCI result, but are not covered in the currently selected method. The advantage of this approach is that you only check the mismatch between what is in your LCI and the method, and not what is the mismatch between all substances and the method.

The mismatch between inventory and impact assessment cannot really be avoided. We advise you to check if you are not missing important parameters, en if so, document these. Of course a practical consequence is that, once you have chosen one or more impact assessment methods, you may restrict your inventory data search to substances that are indeed covered win the chosen method(s).

4.4   Classification

The inventory result of an LCA usually contains hundreds of different emissions and resource extraction parameters. Once the relevant impact categories are determined, these LCI results must be assigned to these impact categories. For example CO_2 and CH_4 are both assigned to the impact category "Global warming", while SO_2 and NH_3 are both assigned to an impact category acidification. It is possible to assign emissions to more than one impact category at the same time; for example SO_2, may also be assigned to an impact category like Human health, or Respiratory diseases.

Assignment in ISO 14042

ISO describes a procedure that can be used if a substance cannot do two things at the same time. An SO_2 molecule that is inhaled, cannot cause acidification. Usually this can be ignored, as it leads to very strange results. This can be understood when one realises that emissions cause no harm in the environment, but concentrations do. Emissions contribute to a certain concentration.

An example where such an assignment procedure is relevant can be found in the Eco-indicator 99 method, and other methods that include land use.

In the Eco-indicator method, the damage caused by agricultural practices is determined by empirical data from botanists, who have studied the bio diversity of the land. It is impossible to say if a decrease in biodiversity is caused by the use of pesticides, fertilisation or otherwise. If the impact category Land use is combined with the impact category Ecotoxicity and Eutrophication a double count can be introduced, that should preferably be avoided. (See also [Goedkoop and Spriensma 1999])

4.5 Characterisation

Once the impact categories are defined and the LCI results are assigned to these impact categories, it is necessary to define characterisation factors. These factors should reflect the relative contribution of an LCI result to the impact category indicator result.

For example, on a time scale of 100 years the contribution of 1 kg CH_4 to global warming is 42 times as high as the emission of 1 kg CO_2. This means that if the characterisation factor of CO_2 is 1, the characterisation factor of CH_4 is 42. Thus, the impact category indicator result for global warming can be calculated by multiplying the LCI result with the characterisation factor.

Endpoints and midpoints

The ISO standard allows the use of impact category indicators that are somewhere between the inventory result (i.e. emission) and the "endpoint". Indicators that are chosen between the inventory results and the "endpoints" are sometimes referred to as indicators at "midpoint level".

In general, indicators that are chosen close to the inventory result have a lower uncertainty, as only a small part of the environmental mechanism needs to be modelled, while indicators near endpoint level can have significant uncertainties. However, indicators at endpoint level are much easier to understand and interpret by decision makers than indicators at midpoint.

Examples:

The CML 92 methodology is a typical example of a midpoint method. The impact category indicators are chosen relatively close to the inventory result. For example, the impact categories for global warming and ozone layer depletion are based on the IPCC equivalency factors. The impact category on acidification is based on the number of protons H+ that could be released per kg of emitted substance. Such impact category indicators have usually rather abstract units. For example, the unit of global warming is kg CO_2 equivalence, and the unit for acidification is kg SO_2 equivalence.

In methods like the Eco-indicator 99, the indicator for climate change is expressed in Disability Adjusted Life Years (DALY). This is a unit used by the WHO and Worldbank to evaluate health statistics. The impact category indicator for Acidification is expressed in the percentage of decreased biodiversity over an area during a certain period. These indicators are of course much more difficult to calculate, as the complete environmental model has to be taken into account, and in that model many assumptions have to be made. They are thus more uncertain. On the other hand, their meaning is easier to understand and evaluate.

There is a typical trade-off between uncertainty in the model of the environmental mechanism and the uncertainty in the interpretation. It depends on the goal and scope and the ability of the targeted audiences to understand aggregated or disaggregated results, which choice is made.
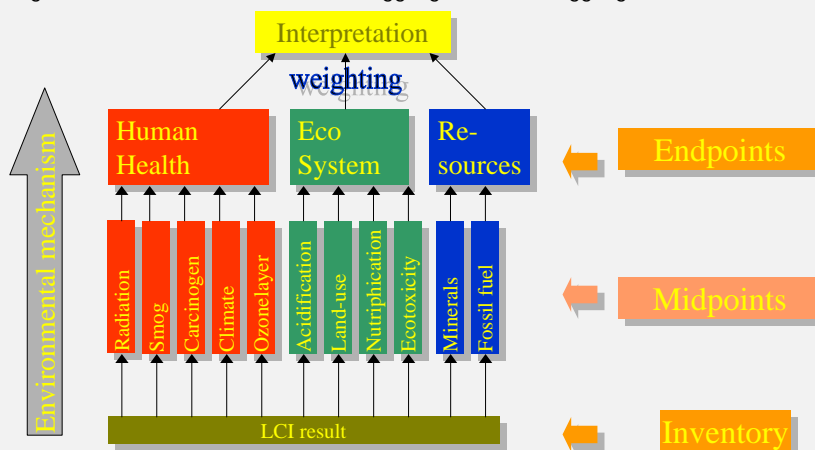

Figure 5   *Schematic overview of the methodology proposed by Goedkoop & Spriensma. The environmental models for each impact category are extended up to endpoint level, as the impact category indicators that relate to the same endpoint have a common unit, these indicators can be added. In the case of ecotoxicity, the endpoint is Ecosystem Quality, expressed as Potential Disappeared Fraction of plants.*

Environmental mechanisms

As an example, we will discuss an environmental mechanism of emissions that have an effect on human health, according to the Eco-indicator 99 methodology, a typical example of an endpoint method.

Fate analysis

When a chemical substance is released, it finds its way through the environmental compartments air, water and soil. Where the substance will go, and how long it will stay depends on the properties of the substance and the compartments. A well soluble substance will be collected in the water compartment, while a substance that easily binds to organic particles may end op in specific types of soil. Another aspect is the degradability, as most organic substances have a limited lifetime. In so called "fate analysis" models the transfer between compartments and the degradation of substances is modelled. Consequently, the concentrations in air, water, soil and food can be calculated.
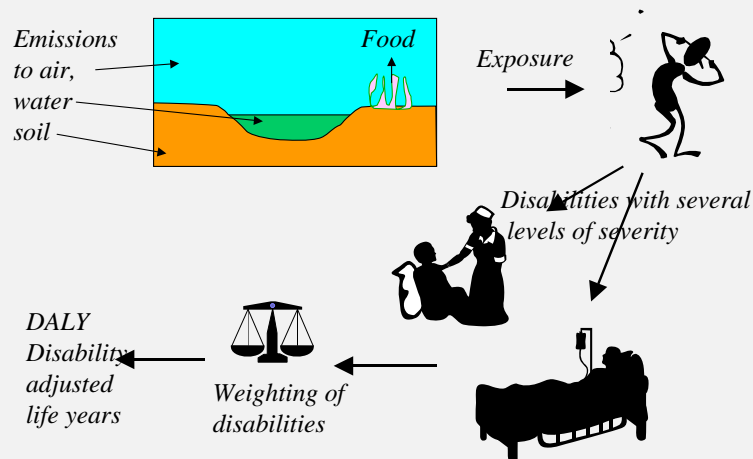
Figure 6:   Schematic representation of the environmental model used for human toxicity. For other substance types other fate models are used.

Exposure

Based on the calculated concentrations we can determine how much of a substance is really taken in by people and by plants or other life forms.

Effect analysis

Once the exposure of a substance is known it is possible to predict the types and frequencies of diseases that lead to disabilities or premature death. For example, if we know that a certain level of exposure causes ten extra cases of a certain type of cancer, we can find data on the average age people get this type of cancer and the average chance that people will die. Based on this data, we can calculate how many years of life are lost, and how many years are lived disabled, as people are ill and have to be treated in hospital.

Damage analysis

The predicted diseases can now be expressed into our damage unit, in this case the DALY (disability adjusted life years). This system is widely used in health statistics, and was originally developed for the world health organisation (WHO). The core is a list of weighting factors (see section 4.6.4) for each type of disability; the factors have been determined by several panels with doctors.

4.6 Optional steps

As indicated normalisation, grouping and ranking are used to simplify interpretation of the result. These steps are regarded as optional steps in ISO 14042.

4.6.1 Normalisation

Normalisation is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem. This is done by dividing the impact category indicators by a "Normal" value. There are different ways to determine the "Normal" value. The most common procedure is to determine the impact category indicators for a region during a year and, if desired, divide this result by the number of inhabitants in that area.

Normalisation serves two purposes:

1. Impact categories that contribute only a very small amount compared to other impact categories can be left out of consideration, thus reducing the number of issues that need to be evaluated.
2. The normalised results show the order of magnitude of the environmental problems generated by the products life cycle, compared to the total environmental loads in Europe.

Normalisation in SimaPro

For each impact assessment methods, you can define and store a number of different normalisation (and weighting) values. This allows you to have different versions of each method, without having to maintain different sets of characterisation factors. For example, we supply a Dutch, European and a worldwide normalisation set for the CML method. You can also edit or add normalisation sets. This allows you to check the influence of selecting normalisation set.

Once a Normalisation set has been defined in the impact assessment method, you choose in each graph to use the characterised results or the Normalised results. Some impact assessment methods, such as those based on monetary evaluation do not need Normalisation. In SimaPro, you can indicate this while defining a method. The result is that it is not possible to show Normalised impact categories for such methods. As you can see also in SimaPro Normalisation is an optional step.

4.6.2 Grouping and ranking

In order to avoid weighting, while making results easier to interpret, impact category indicators may be grouped and ranked:

*   Impact category indicators that have some common features may be presented as a group. For example, one can form a group of impact category indicators with Global, regional and local significance.
*   Ranking refers to a procedure, where impact categories are sorted by a panel in a descending order of significance.
*   Both procedures can be used to present the results.

Grouping and ranking in SimaPro

You can change the order in which the impact categories appear in graphs from within the impact assessment methods definition. This is an easy way to rank the results.

4.6.3 Damage assessment

The methods presented here will all still be difficult to interpret, as there is a wide range of impact category indicators. To simplify interpretation further, a grouping procedure can be used in the Eco-indicator 99 and the EPS2000 methodology. In these methods, the category indicators are defined close to one of the three endpoints to achieve an optimum environmental relevance. The impact category indicators that refer to the same endpoint are all defined in such a way that the unit of the indicator result is the same. This allows addition of the indicator results per group. This means that the indicator results can be presented as three indicators at endpoint level without any subjective weighting. Interpreting three instead of a multiple set of indicators is much easier. The figure below illustrates this procedure.
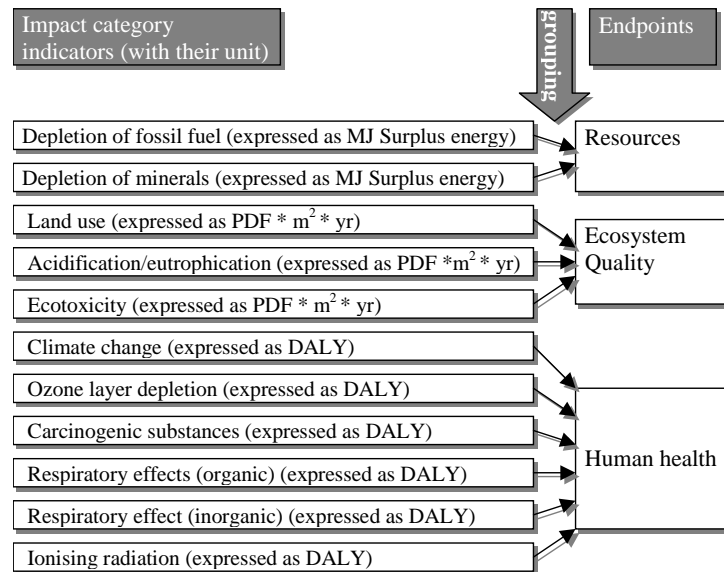
Figure 7   Illustration of the grouping option on the Eco-indicator99 method. This procedure allows to reduce the number of impact categories to just three instead of 11 without subjective weighting.

Damage assessment in SimaPro

In SimaPro, you can indicate if a method contains damage assessment. If you do so, you get the opportunity to define damage categories and damage factors. These are used to convert the impact categories before they are added. If a method has a damage assessment step, you can also display this step as a graph.

4.6.4 Weighting

Weighting is the most controversial and most difficult step in life cycle impact assessment, especially for midpoint methods. Several solutions have been proposed to solve or simplify the weighting problem:

1. Use a panel that assesses the impact category and proposes default weights. There are several problems in this approach:

   - It is very difficult to explain to a panel the meaning of the impact category indicators. They are too abstract ("CO_2 equivalency" or "proton release").
   - In a Midpoint approach, the number of indicators to be assessed is usually rather large (10 to 15).
   - Panels tend to give a very small range of weights (usually between 1 to 3). This is called *framing* in social sciences. This is a problem in both endpoint and midpoint methods.

2. Distance to target. If it is possible to set a target for each impact category and its target can be used to derive at a weighting factor. If the difference is high, the weight is high. The Ecopoint method uses targets set by the Swiss government, the Eco-indicator 95 method uses targets that reflect to necessary reduction to lower the damage to a certain level that is the same for all impact categories (this can also be interpreted as a damage approach). Also this approach has some difficulties:

   - In the case policy targets are used, it is not clear if all targets are equally important.
   - policy targets are usually formed as a compromise between interest groups, and need not to reflect the "real" need to reduce environmental impacts.
   - In case scientific targets are used, different types of damages need to be weighted.

3. Monetarisation: In EPS2000 all damages are expressed in the same monetary unit: Environmental Load Units comparable to Euros. In the methodology, the assumption is made that these different types of costs (present cost and *willingness to pay* and *future extracting costs*) can be added. This can be interpreted as a weighting step in which the weighting factors for these different types of costs equals one.

In the Eco-indicator 99 methodology, the weighting problem was the starting point of the development. Some of the problems associated with the weighting have been reduced or solved, but the weighting step will always remain difficult. An interesting approach has been developed by [Hofstetter et all 1999] using a weighting triangle (only possible after using the grouping methodology: Resources, Ecosystem quality and Human health). This triangle can be used to present the weighting problem on a case-by-case basis to stakeholders. It can be used to take a decision without actually knowing the weights.

The triangle concept as alternative to fixed weights

For those users that do not want to use the default weighting factors, we recommend using the mixing triangle developed by [HOFSTETTER 1999]. This triangle (see figure 8) can be used to graphically depict the outcome of product comparisons for all possible weighting sets. Each point within the triangle represents a combination of weights that add up to a 100%.

An important feature is the possibility to draw lines of indifference (figure 9). These are lines representing weighting factors for which product A and B have the same environmental loads. The lines of indifference divides the triangle into areas of weighting sets for which product A is favourable to product B and vice versa.

$W_{EQ} = 100\%$
$W_{HH} = 0\%$
$W_R = 0\%$

W_{EQ} Weighting factor for the damage to ecosystem quality

W_{HH} Weighting factor for the damage to human health

W_R Weighting factor for thedamage to energy resources

$W_{EQ} + W_{HH} + W_R = 100\%$

$W_{EQ} = 0\%$
$W_{HH} = 100\%$
$W_R = 0\%$

$W_{EQ} = 0\%$
$W_{HH} = 0\%$
$W_R = 100\%$
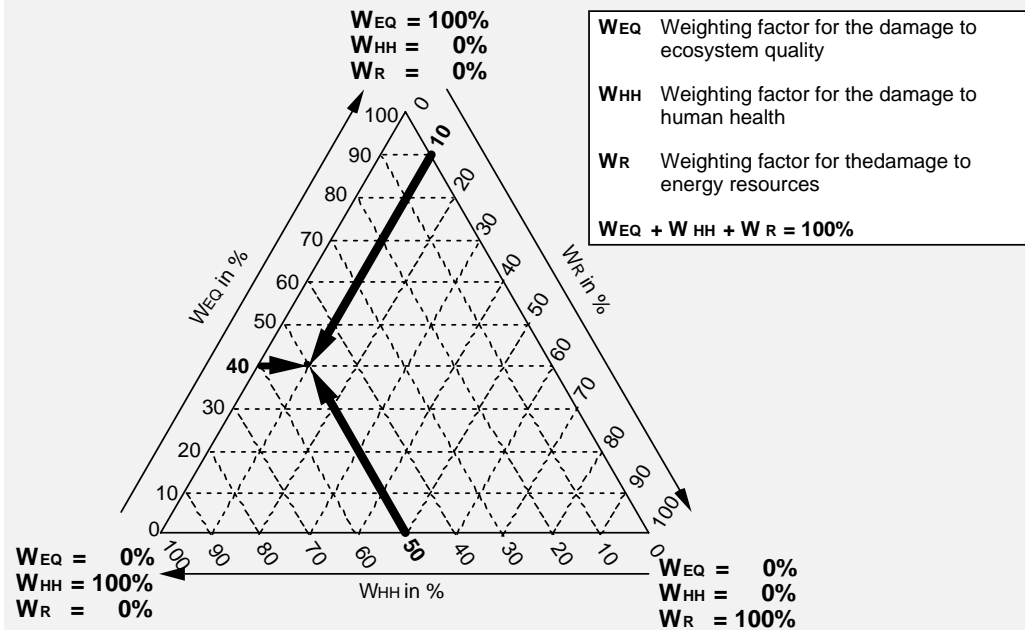
Figure 8:   The mixing triangle: The marked weighting point is positioned where Human Health is weighted 50%, Ecosystem Quality 40% and energy Resources 10%. The point is defined by following each side until the dotted flashes leave towards the point in the triangle (based on Hofstetter 1998).

The weighting triangle can display the result of an LCA without knowing the weighting factors. According to Hofstetter, such a representation is a very useful tool to enhance the transparency of the weighting process, as it shows under which conditions (which weighting factors) product A is better than B. The stakeholders do not have to set discrete weights, but they have to agree whether it is plausible that the weights would fulfil the conditions under which A is better than B or not. Such a discussion process turns LCA into a consensus building process, instead of a tool that produces simple single truths.

Our mission is not the development of a consensus-building tool, but there is no reason not to use this methodology as such, if the conditions facilitate an open discussion with the stakeholders. More information on this subject can be found in [HOFSTETTER 1999]

Figure 9:   The line of indifference in the weighting triangle and the sub-areas with their specific ranking orders (B>A means that alternative B is environmentally superior to A and the eco-index A is higher than B).
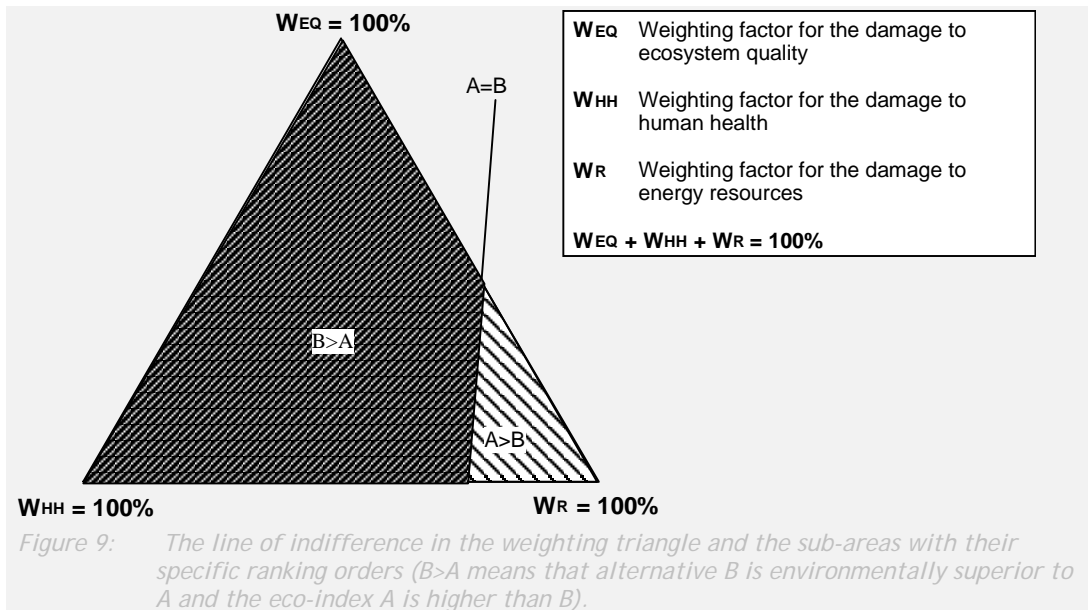
Weighting in SimaPro

You can define any number of weighting sets for each impact assessment methods. If a method contains a damage assessment step, the weighting factors apply to the damage categories, if not, they apply to the impact categories. You can also exclude the weighting option from a method.

SimaPro has an option to automatically generate a triangle. This option can only be used for impact assessment methods that use exactly three damage categories, such as the Eco-indicator 99. The triangle option can be used during the normalisation step. Please observe that if all damage categories of product A are higher than product b, the line of indifference will lay outside the triangle, which means it will have only one colour.

5 Interpretation

5.1 Interpretation according to ISO 14043

Probably the most readable and practical standard is the last of the four LCA standards on interpretation. In essence it describes a number of checks you need to make in order to see if the conclusions you want to draw from the study are adequately supported by the data and by the procedures used. This chapter describes the most important procedures, and shows how they are supported in SimaPro.

The interpretation section in SimaPro

The interpretation section in SimaPro is designed as a checklist that covers the relevant issues mentioned in the ISO standard. We suggest you fill in your observations when you are about to complete your LCA and draw conclusions.

5.2 Uncertainty

All data in life cycle models have some uncertainty. One can distinguish three main types:

1. Data uncertainties
2. Uncertainties on the correctness (representatively) of the model
3. Uncertainties caused by incompleteness of the model

5.2.1 Data uncertainties

In theory, data uncertainties are relatively easy to handle, as such uncertainties can be expressed as a range or standard deviation. Statistical methods, such as Monte Carlo techniques (see further section 9) can be used to handle these types of uncertainties, and calculate the uncertainty in the LCA results.

Data uncertainty in the ecoinvent database

The ecoinvent dataset comes out in two versions, one version with Unit processes, and one with systems. In the Unit process version, almost all data points come with a specification of uncertainty. Working with these uncertainty data requires a little background on how this uncertainty data can be interpreted, and how you can also specify uncertainty in the data you enter.

Ecoinvent always provides a value, plus uncertainty information. The value they specify can be interpreted as the "best guess" value. In case this "best guess" value is w determined by sampling many different measurements, this is usually the mean (or sometimes "average") value.

The sample of measured values often appears as a normal or log normal distribution. Ecoinvent always assumes a lognormal distribution. Lognormal distributions can be characterised by a standard deviation. A typical property of a lognormal distribution is that the square of the GEOMETRIC standard deviation covers the 95% confidence interval, so a Square geometric standard deviation of 1,2 means that 95% of all values lies between the best guess value times 1.2 and the best guess value divided by 1,2. If the square of the geometric standard deviation is equal to 1.00 this means there is no uncertainty at all. (This is an important difference with the normal distribution. In a Normal distribution the 95% confidence interval is found when you add or subtract the standard deviation times 2)

The next question is how to estimate the geometric standard deviation, as often data is not determined from a large sample of measurements. Ecoinvent uses a Pedigree matrix, originally developed by [Weidema 1996], to estimate the standard deviation. Each data point is assessed regarding six criteria plus a so-called Basic uncertainty factor. The 95% confidence interval, or the square geometric standard deviation is calculated using the following formula:

$$SD_{g95} = \sigma_g^2 = \exp^{\sqrt{[\ln(U_1)]^2 + [\ln(U_2)]^2 + [\ln(U_3)]^2 + [\ln(U_4)]^2 + [\ln(U_5)]^2 + [\ln(U_6)]^2 + [\ln(U_b)]^2}}$$

The factors U1 till U6 referring to the scores in the following table; the factor Ub refers to the basic uncertainty factor. So if you want to assess the impact of reliability (U1), and you have verified, measured data, the value of U1 is equal to 1.00, if you have obtained data from an expert that has done a theoretical calculation and some estimations, you cut give U2 a value of 1.2, etc.

Score:	1	2	3	4	5
U1 Reliability	Verified data based on measurements	Verified data partly based on assumptions OR non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert); data derived from theoretical information (stoichiometry, enthalpy, etc.)	Non-qualified estimate
	1.00	**1.05**	**1.10**	**1.20**	**1.50**
U2 Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered OR >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered OR some sites but from shorter periods	Representativeness unknown or data from a small number of sites AND from shorter periods
	1.00	**1.02**	**1.05**	**1.10**	**1.20**
U3 Temporal correlation	Less than 3 years of difference to our reference year (2000)	Less than 6 years of difference to our reference year (2000)	Less than 10 years of difference to our reference year (2000)	Less than 15 years of difference to our reference year (2000)	Age of data unknown or more than 15 years of difference to our reference year (2000)
	1.00	**1.03**	**1.10**	**1.20**	**1.50**
U4 Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from smaller area than area under study, or from similar area		Data from unknown OR distinctly different area (north america instead of middle east, OECD-Europe instead of Russia)
	1.00	**1.01**	**1.02**		**1.10**
U5 Further technological correlation	Data from enterprises, processes and materials under study (i.e. identical technology)		Data on related processes or materials but same technology, OR Data from processes and materials under study but from different technology	Data on related processes or materials but different technology, OR data on laboratory scale processes and same technology	Data on related processes or materials but on laboratory scale of different technology
	1.00		**1.20**	**1.50**	**2.00**
U6 Sample size	>100, continous measurement, balance of purchased products	>20	> 10, aggregated figure in env. report	>=3	unknown
	1.00	**1.02**	**1.05**	**1.10**	**1.20**

In all ecoinvent Unit process data, you will find a list of six figures, like 1.2.1.5.1.3 in each comment field. These numbers refer to how the uncertainty was estimated using the pedigree matrix. Please not that you will not find any uncertainty data in the System processes

The *basic* uncertainty factor Ub can de derived from the table below. This basic uncertainty factor is based on expert judgement. For instance, experts often find that CO_2 emission data can be quite precise, and can be easily checked against the fuel input. As you can see the basic uncertainty is assumed to be very high for poly aromatic hydrocarbons (PAH), Fine dust (PM10 and PM2.5) and heavy metal emissions, as well as radionuclides and CO from combustion.

input / output group	Ub	input / output group	Ub
demand of:		emission to air of:	
thermal energy	1.05	CO2	1.05
electricity	1.05	SO2	1.05
semi-finished products	1.05	combustion: NOX, NMVOC total, methane, N2O and NH3	1.50
working materials	1.05	Combustion: CO	5.00
transport services	2.00	Combustion: individual hydrocarbons, TSM	1.50
waste treatment services	1.05	Combustion: PM10	2.00
Infrastructure	3.00	Combustion: PM2.5	3.00
resources:		combustion: polycyclic aromatic hydrocarbons (PAH)	3.00
primary energy carriers	1.05	Combustion: heavy metals	5.00
metals, salts	1.05	process emissions: individual VOCs	2.00
land use, occupation	1.50	process emissions: CO2	1.05
land use, transformation	2.00	process emissions: TSM	1.50
waste heat:		process emissions: PM10	2.00
emission to air, water, and soil	1.05	process emissions: PM2.5	3.00
emission to water of:		from agriculture: CH4, NH3	1.20
BOD, COD, DOC, TOC	1.50	from agriculture: N2O, NOX	1.40
inorganic compounds (NH4, PO4, NO3, CI, Na etc.)	1.50	radionucleides (e.g., Radon-222)	3.00
individual hydrocarbons, PAH	3.00	process emissions: other inorganic emissions	1.50
heavy metals	5.00	Emission to soil of:	
from agriculture: NO3, PO4	1.50	oil, hydrocarbon total	1.50
from agriculture: heavy metals	1.80	Pesticides	1.20
from agriculture: pesticides	1.50	heavy metals	1.50
radionucleides	3.00	radionucleides	3.00

(taken from: Ecoinvent report number 1: Overview and methodology)

5.2.2 Model uncertainties

Uncertainty on the correctness of the model refers to the fact that there is not one way to make a model of reality. In each LCA, one will have to make more or less subjective choices in order to make a model. Some examples are:
- Representativity. Very often, we have to use data on processes that are coming from other sources. For example, we find data of growing cotton in Pakistan, but we need data for growing cotton from India. With this, we cause an error, but it is difficult to assess how big it is.
- Allocation basis. There is no single way to choose an allocation basis.
- Future events. Many LCAs deal with products that have a long lifetime. This means these products will be disposed of in a few decades. No one really knows how waste treatment is organised by that time.
- Choice of functional unit. It is often not clear on which basis we compare products.

All these factors can have very significant impacts on the results, but it is not always easy to handle these uncertainties in a Monte Carlo approach (see section 9). In such cases we use the sensitivity analysis that is described below.

5.2.3 Data uncertainties: Incompleteness

Uncertainty caused by incompleteness refers to the unavoidable data gaps. Important issues are:

- System boundaries, as we have discussed above it is not easy to apply consistent boundaries and cut of criteria.
- Incomplete data sheets and insufficiently specified data. In many cases, data is gathered from interviews and through questionnaires, and often data will be partially available. A particular problem is that often data is gathered in sum parameters, like BOD and PAH. In the next stage, the Impact assessment is very difficult to interpret such sum parameters if one does not know which substances are involved.
- Mismatch between inventory and impact assessment. In many cases, inventory data that is collected does not have a characterisation factor, and therefore this finding is ignored in the rest of the LCA.

Especially because of the last two types of uncertainties, it is very difficult to apply a uniform system to deal with uncertainties in LCA. The best solution is to combine Monte Carlo analysis for data uncertainties with sensitivity analysis for model uncertainties.

5.3   Sensitivity analysis

In order to see the influence of the most important assumptions, it is strongly recommended to perform a sensitivity analysis during and at the end of the LCA. The principle is simple. Change the assumption and recalculate the LCA.
With this type of analysis you will get a better understanding of the magnitude of the effect of the assumptions you make. You will find that the outcome of the LCA can be quite heavily depended on some of the assumptions. This does not need to be a problem as long as the conclusions of your LCA are stable. However, if you find that under one assumption product A has a higher load than B, and under a different assumption product B has a higher load, you carefully need to explain under which assumptions your conclusions are valid. You may also conclude that there is no single answer, as everything depends on the assumptions.

Sensitivity analysis in SimaPro

Finding the most important assumptions is typically something you do in the goal and scope phase and later in the data collection phase. The SimaPro parameters provide a very efficient way to build in parameters you can use as "switches". For instance if you are in doubt about which electricity grid you want to use throughout the life cycle model, you can define a parameter called Elec_EU (or any other name). Initially you set this value equal to "1". In each process that uses electricity, you enter two lines, one line refers to the European electricity, and instead of just entering an amount of yyy kWh, you enter a formula "Elec_EU * yyy". In the next line you put in the national electricity grid mix, and now you enter a formula in the amount field "(1-Elec_EU) * yyy". As long as the value of Elec_EU is equal to "1" SimaPro will use European electricity, if the value is set to zero, SimaPro will use the national grid. This way of modelling is particularly useful when you apply this method throughout the entire LCA, and with the change of one parameter, you automatically change the electricity grid everywhere.

A similar approach can be used for switching between different allocation principles, for switching on and of parts of the life cycle you do or do not want to include in the system boundaries etc. See also the textbox in section 2.3.4 on allocation.

5.4   Contribution analysis

An important tool in understanding the uncertainty of your result is the use of the contribution analysis. With such analysis, you determine which processes are playing a significant role in your results. We have often found that in an LCA containing hundreds of different processes 95 or even 99% of the results is determined by just ten processes. With the information you can focus your attention on these processes, and analyse if

these processes are sufficiently representative, complete and if their are important assumptions within these processes.

Contribution analysis in SimaPro

SimaPro has two ways of finding the contribution from a process:
1.   Graphical representation of the process tree or network
2.   Contribution analysis section of the result screen

In the process tree, a small thermometer indicates the relative contribution of the process. The advantage of this approach is that you can exactly see what the role of the process in the life cycle is. A disadvantage is that some processes can occur many times in an LCA. For example, the process record Electricity Europe will occur many times in a European LCA.

It could well be that in each of these occurrences the contribution of this process is just a few percent, but that the total contribution from this process is very significant if the process occurs 10 or more times.

For that reason, we have developed the Contribution analysis result. Here all contributions from a single process are added. Therefore, in contribution analysis you can see the total contribution of European electricity.

5.5   Gravity analysis

Contribution analysis shows which processes create high environmental load. However this does not reveal the cause of the load. For instance if process A uses a large amount of coal based electricity, contribution analysis will show that coal electricity is important, but in fact, it is process A that causes coal to be used. In Gravity analysis we can look at the interrelations between the processes and show which processes are in fact responsible for the load, while these processes in themselves may have low impact.

Gravity analysis in SimaPro

Gravity analysis is used in the Network representation of the processes (see chapter 6). In this presentation each process is only shown once, and we can see how the environmental load is propagated through the network.

Thanks to a new innovative way of solving matrix calculations described in [Heijungs and Suh], the propagation is now calculated almost instantaneously.

5.6   The inventory results

The result of the inventory phase is referred to as the LCI or inventory results. It is a list of emissions and raw materials with an amount. In many cases, the list covers a few hundreds of substances, which make the LCI result very difficult to interpret. However, the benefit is that the result is very detailed, and it is not affected by the uncertainties introduced in impact assessment.
We believe, and ISO underlines this, that it is always useful to apply impact assessment procedures in order to better understand the significance of each LCI result.

LCI result in SimaPro

In the inventory result tables there are several functions that let you help to understand the significance of each LCI result:

- You can sort the LCI results according to alphabet, amount, unit and compartment
- You can ask SimaPro only to list LCI results form a certain component, such as airborne emissions, or raw materials
- You can ask SimaPro only to list LCI results that contribute to a certain impact category, and in fact you can also see how much they all contribute to this impact category (also as percentage)
- You can suppress or show the sub compartments, so if you have airborne emissions of NOx in high and low population densities, you can get the total airborne NOx emission instead
- Depending if your LCI model contains loops, you will not only get the total LCA results, but you will also see additional columns with results from underlying processes. This helps you to better understand where the impacts come from.
- LCI results are automatically presented in the best readable units, so instead of listing 0.00001 kg, SimaPro will list 10 mg. It can also present the results in unit such as used in the USA. However if you want to export or copy and paste the list to other software you can also get the results in the official SI units, so 10 mg will again be displayed as 0.00001 kg.

A really unique feature is that you can double click on an LCI result and ask for a specification of the process network or tree. this process network will show which processes contribute to this specific LCI result

.

6 Organising your LCA activities

The previous chapters have described LCA methodology from a more theoretical and methodological point of view. In this chapter, we will discuss some important practical issues, like planning, budgeting, data collection and presentation issues.

6.1 Estimating the workload

It is of course very important to consider how much time and money you will have available for your LCA activities. A general estimate for a typical LCA is difficult to give. In our consultancy work, the workload can vary between 2 days for a quick screening using already available information and 200 days for an extensive LCA.
Although we can make no sharp borderlines, we can distinguish four types of LCA studies:

1. Screenings
2. Short studies
3. Extensive studies
4. Continuous LCA operations

The characteristics, including a budget indication, are discussed below.

6.1.1 Screening

If you need to get a quick answer, and if speed or budget is more important than precision, you can make a screening using already available or estimated data, already in your database. For missing data, you take provisional alternatives. If you for example need data on nickel production, and you only have data on some other non-ferro-metals, you use these alternatives to get an impression of the importance of this process.

In order to work efficiently you should try to limit your goal to get only a limited set of clear conclusions, like:

- Is it likely (but perhaps not certain) that a product will have a lower environmental load if I use steel instead of plastic?
- Is the use phase dominant, and is it justified to put all efforts in the development on optimising the use phase?
- Does recycling seem to have a significant impact on the total environmental load, or is the effect negligible?

After defining your LCA and drawing your conclusions in this way, you should always include a sensitivity analysis to see if your estimates and less representative data can really influence your key conclusions.

Be careful with communicating such short screenings in external communication. Never base public statements or comparisons between your products and competing products on such screenings.

How SimaPro supports screenings

Perhaps the most important issue in screenings is to have a large database with commonly used materials and processes. Both the ecoinvent and the USA input output table are very useful resources.
 Another important feature is the ability to separate between the data in libraries and projects. Before you start to work on an LCA, you should open a specific project in which you store your data. We strongly advise you never to change the data in the libraries, especially not if you make "quick and dirty" changes for your screening. If you need to edit an existing record, first copy it into your project and make the change in that copy. This advice is also relevant in case you want to edit impact assessment methods for the screening.

In a screening, it is essential to be able to quickly identify the relative contribution of processes, in order to check them. SimaPro supports this in several ways:

The ease of tracing the origins of the results. If you generate a process tree in SimaPro, you will see small bar charts in each element of the process tree. These indicate the relative contribution of processes or parts of the process tree to an indicator, to the mass flow or to an LCI result.

Contribution analysis allows you to identify which processes really contribute most to the overall results. Often only 10 out of several hundred processes contribute more than 95% to the overall result. This allows you to critically analyse these most important processes.

Especially in a screening it can be very useful to add uncertainty estimates in a rough way, and see how important these are in a Monte Carlo analysis.

6.1.2 Short internal LCAs

If you need to take a decision that has significant influence on the product development process or communication strategy, but you do not want to use the LCA report itself for external communication, you should set up a short LCA study. For such a study, the goals could be more ambitious, like:

- What are the dominating causes for the environmental load in the production phase, the use and the disposal phase?
- How much benefit would a product take back system bring us?
- How is our product performing in relation to competitors, is it likely that our competitors could make an environmental claim that is justifiable. To what extend can we use environmental claims in our external communication?
- Would we qualify for an ecolabel?
- Which of our businesses could be considered as sustainable; that is, we earn relatively much money, at a relatively low environmental load.

A pragmatic approach is to start with a very short screening to identify the relative importance of data gaps in your database. From this you can set-up a data collection strategy, and identify which data could be collected from literature, and for which could be collected by approaching suppliers or other players in the product chain.

As this is a short study, your data will not be perfect and so it is very important to critically analyse to what extend you can really justify your conclusions. A sensitivity analysis, in which you change important assumptions and in which you test different impact assessment methods, is needed.

If you want to conform to the ISO standards, you should not directly publish this LCA report if it is not peer reviewed.

How SimaPro supports short internal LCAs

Apart from the issues mentioned in the textbox on screenings, an important tool is the Data Quality Indicator. In SimaPro, each time you define a new project, you can define the standards you desire for the data that is to be collected. These standards relate to issues as age, representatively, regional aspects, system boundaries and allocation. If the data you use from the standard database or if the data you collect does not match these requirements a colour code will warn you. Other important tools are:

- The documentation of processes. Each record can have an extensive attachment. In the standard database, these attachments have been completed for the most relevant datasheets. This allows you to clearly understand the models underlying the data in this record.

- The guidance on interpretation. A separate section allows you to type in the observations you need to make according to ISO.

- The possibility to set parameters in such a way that you can run sensitivity analysis in a semi automatic way.

- The use of Monte Carlo analysis to evaluate uncertainties. Instead of trying to get near to perfect data, you can also use preliminary data while adding an uncertainty range. If for instance you aim is to compare two alternatives, Monte Carlo analysis can help you to determine if the differences between product A and B are significant, given the uncertainties. If they are, there is no need to collect more data, if they are not you can focus your efforts on reducing the uncertainties with the biggest impact. In this way, Monte Carlo analysis can be a fantastic time saver.

6.1.3 Extensive LCA for publication

If you would like to make detailed environmental claims, and use your LCA report in the public debate, you should make a more extensive LCA. Distinguishing factors are:

- According to ISO 14040, you should include an independent peer review in the process. Experience has shown that it is best to invite a peer reviewer already at the first stage when the goal and scope is defined. This will allow the peer reviewer to give suggestions for improvement at a time improvement is still possible. The peer review statement should be published in the report.
- The requirements for the reporting are much higher. You should carefully describe all procedures, choices, data gaps etc, and you should perform an extensive sensitivity analysis. ISO 14043 provides a guideline for this.
- If your aim is to compare products, and if you want to conform to ISO14042, you should not publish weighted results.

Even after all these precautions, we advise you to be very careful with public statements that are directly based on an LCA report. Experience shows that debates about LCA reports can be quite difficult to manage.

How SimaPro supports extensive LCAs

- For extensive LCAs you will need the same tools as described in the previous boxes. Documentation, data quality and interpretation issues even become more important. SimaPro can be used to define very complex products, using a system of assemblies and subassemblies, and it can handle very complex use and end of life models. For example if auxiliary products like batteries or packaging materials are used, they can be defined as a separate additional life cycle, each with its own specific production and waste disposal model. It is also possible to model complex take-back, disassembly, reuse and recycling scenarios.

- SimaPro can also handle very large process trees. We have performed studies with 50.000 processes in a single process tree. Calculating such an LCA just takes one to a few minutes depending of the speed of your computer.

- You can make very sophisticated and precise non linear models using the parameters

- You can specify all uncertainties, even in the parameters; this enables you to accurately report the certainty or uncertainty in your results.

- You can run semi automated sensitivity analysis using parameters as "switches"

Perhaps the most important feature to support large LCAs is the availability of a multi-user version. This version will allow you to work on the same LCA project in the same database with several different LCA experts. The system is set up in such a way that one person can be made responsible for the data quality. This person can also assign user rights and passwords to others controlling the access to certain parts of the data, depending on the skill and responsibility of these persons.

6.1.4 Continuous use of LCA information

The ISO standards and many LCA specialists consider LCA studies implicitly as an ad-hoc activity. A study is done to support a decision and after this, the activity stops until a new decision needs to be supported. We now see a clear trend away from this ad-hoc approach, as more and more organisations tend to see LCA as a continuously maintained Environmental life cycle information system (ELMIS).

In such a system, the aim is to gradually develop and improve an LCA database that can be used to answer the most important issues a company or organisation could be confronted with. The benefits of developing such a system are for example:

- Your questions can be answered much more quickly once you have a database that contains the most relevant materials and processes for your organisation.
- The experience with earlier studies is not lost, but adds to the overall competence of the LCA department.
- The ELMIS information can be used in environmental reporting.
- There is more continuity in the workload for the LCA department.

Of course, also continues systems need a clear goal and scope. It is essential to carefully consider the data requirements for your systems, and think how you maintain and document the system.

How SimaPro supports continuous application of LCA

Apart from the features mentioned earlier, there are a number of special features that make SimaPro very suitable for continuous application of LCA:

- The possibility to develop a very easy to use wizard-like interface for specific target groups.
- The possibility to Link SimaPro with other information systems using a COM interface, or using parameters that are stored in excel spreadsheets or SQL databases.

Both features are further described below.

6.1.5 Some guidelines for budget estimates

Although many factors can influence the time needed to perform an LCA, the table below may give you some guidance. These estimates assume that the work is performed by experienced persons. If you start in this field, you should add a few days or weeks to get to grips with the methodology and all practical issues.

(time in working days)	Screening	internal LCA	external LCA	Continuous use
Discussions needed to formulate goal and scope.	1	2-4	10	10 + updates
Data collection	2-5	5-15	25-100	Continuously
Data processing into software and performing calculations	1	2-4	10	Continuously
Interpretation and sensitivity analysis	1	2-4	10-20	Continuously
Reporting	1-2	2-5	10-30	Continuously
Peer review	N/A.	Optional	10-30	Optional
total estimate	6-10	13-32	75-180 and up	

6.2 Operational procedures

The way you organise the LCA work clearly depends on your goals and the organisational environment you are working in. In this paragraph, we give you just some suggestions.

6.2.1 Working on your own

If you are working as the only LCA expert in your organisation, it is relatively simple to organise your work. Important issues to consider are:

- Do not edit the resources stored in libraries, unless you are completely sure.
- Be sure to make back-ups. You can run SimaPro Single user versions over a network; this means you can locate the database files on a server.

6.2.2 Working in a team

If you are working in a team of LCA experts things become a little more complex.
By far the best way to work is to use a multi-user version of SimaPro, as this allows you to work on the same database. In the Multi-user version, you can use the following facilities and features:

- All users log in using a username and password.
- The database manager can define certain user types (like expert, novice, guest etc.) and assign certain access rights to these types. Furthermore, he or she can assign a user type to each user, and he or she can determine which user has access to which project.
- The database manager is the only one who can edit the libraries, and the manager can determine which data can get the library status.

6.2.3 Working from different locations

The Multi-user version uses a so-called client server principle; this means that the calculation work is performed on the server, but the data is managed by the client computers.
Working in a team with a number of single user licenses will create a system that is impossible to manage, as sooner or later all databases will be completely different. You should avoid this at all times. If you started with a single user, you can upgrade to a Multi-user without any conversion of the databases.

6.2.4 Ownership of data and methods

By publishing LCA data, you usually include data you have not generated yourself. There are no objections to publish the data supplied with SimaPro in printed form, as long as you refer to the origin. However, it is not allowed to use this data in electronic form in other tools than SimaPro without our permission. This is due to the way we have sublicensed some of the data from other sources.

This issue has become particularly important since the emergence of the ECOSPOLD data exchange format. This format is intended to exchange your own original data, and not to redistribute data from for example the BUWAL library supplied with SimaPro.

There are no objections to using calculated results in other electronic products. For example, if you calculate Eco-indicators and you want to include these in your internal software or a marketable product there is no problem, as long as you take responsibility for the quality of this work.

For impact assessment methods a similar situation occurs. All methods have been published, however not all method developers would appreciate it if you would copy the method into other electronic tools. Please ask permission from the authors of the methods if you intend to do so.

6.2.5 Archiving old projects

Upon finishing a project, it is advisable to archive it with some care, as the data in your project usually depends on data in libraries and other projects. If you do not archive the project, you may find that after some time the results of this project are changed by changes in the libraries. The best way to archive the project is to export it in SimaPro format, while enabling all related data in libraries to be included in the export file. It is also a good practice to include the relevant impact assessment methods in this export file. Users of a Light version cannot export data.

6.3 Understanding the structure of the database

Once you start working with SimaPro you will start to change the data in SimaPro, and if you are not carefully managing the data quality in the database, you risk that this data will become increasingly unreliable. In this paragraph, we will describe some of the risks and we will give suggestions for a proper database management.

The SimaPro database is structured in three main parts:

1. Project data. Here you store all specific data for the project you are currently performing. Except for the light version you can create any number of projects in your database, in order to keep all you data apart and to facilitate the archiving of project you do not longer want to keep.
2. Library data. This contains data to serve as a resource for your projects. The structure of libraries is very similar, but the intended use is different.
3. General data. Here the common supporting data for all libraries and projects is stored, such as unit conversion factors and the central list of substance names.

Libraries and projects can both store the following data:

- Definition of the goal and scope for this particular project or library
- Definition of the desired data quality profile for this particular project or library
- Process data
- Product stage data
- Impact assessment methods
- Data on interpretation of the results
- Scripts
- and some other data types not discussed here

This means both the library and the project can contain all relevant data for a particular LCA study.

Normally you should not edit the contents of libraries, as it is important to maintain a reliable resource for your future projects. If you need to edit data, it is strongly recommended to copy the data from the library into a project, and make the change there. (Always document such changes in the comment fields). In the Light version, you

cannot change libraries. In the multi-user version, only the database "manager" can change data in the libraries.

Libraries tend to have their own "methodological character" as they are usually coming from one single source. Some libraries are typically relevant for Europe, some for the US, while others for example represent data from one country only; other differences could be in the way system boundaries are applied. For example in the ETH, library capital goods are in principle included for energy and transport systems.
The "character" is described in the goal and scope section of the library and in the setting of the data quality indicators. It is good practice to critically analyse which libraries you consider to be suited for a certain project. SimaPro supports this. In each project you can include or exclude certain libraries. If you exclude a library, this information cannot be used in the project. (You can always change this setting while the project is developing).
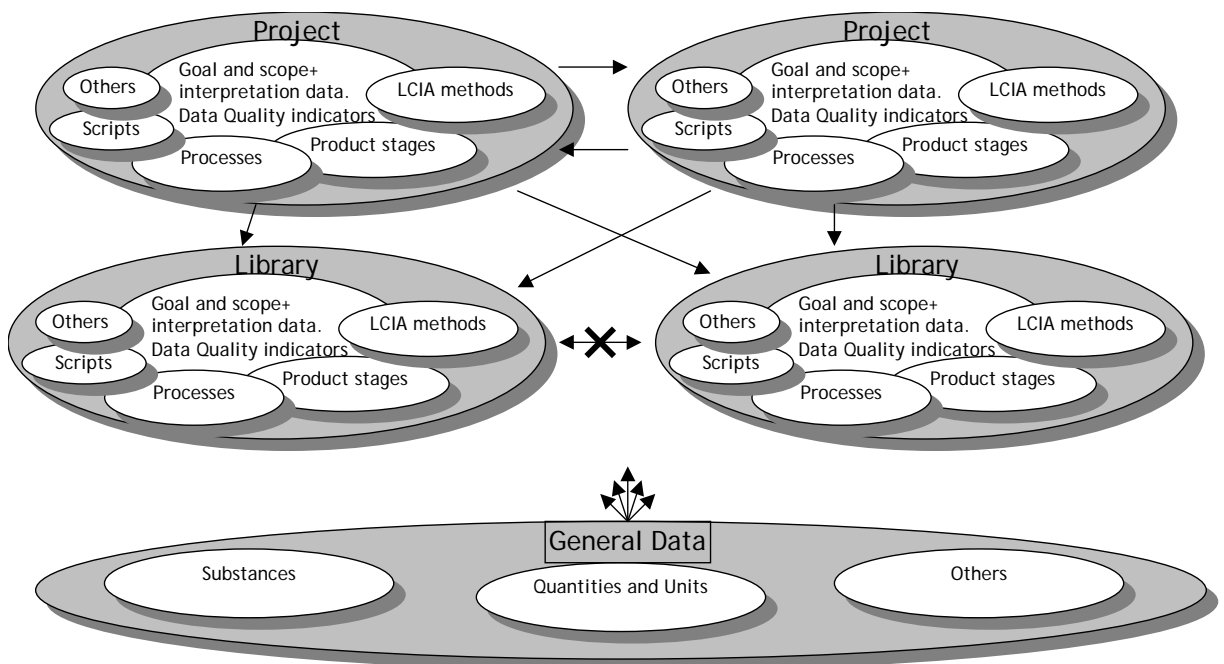
Figure 10   Graphical representation of the database structure. The arrows indicate dependencies. Not all data types are specified, they are referred to as others.

6.4 Eco-indicator tools

Transparency of the data is not always required if the audience for who you develop the data has no or just a very limited interest or knowledge on environmental themes. In this case, you may wish to consider presentation of single scores such as Eco-indicators, EPS scores or Swiss Ecopoints. Such scores can be easily generated by SimaPro.

To provide these indicators in an easy to use tool, we developed ECO-it. This tool lets any user make an LCA in a few minutes, provided all required single scores are in the database. ECO-it tool comes with 200 standard indicators according to the Eco-indicator 99 method. You can extend this range, or create new databases with a simple editor called ECO-edit.

Eco-edit supplied with SimaPro

SimaPro users can obtain a free licence for ECO-edit on request. ECO-it is really a very simple tool to be used by designers and others who are not interested in the underlying data. Below a screenshot is shown. The interface just has four screens that are accessible via tabs. Currently the "production" tab is shown. Users can simple add materials or components. Results are immediately updated in the graphical representation. See www.pre.nl/eco-it for more information.
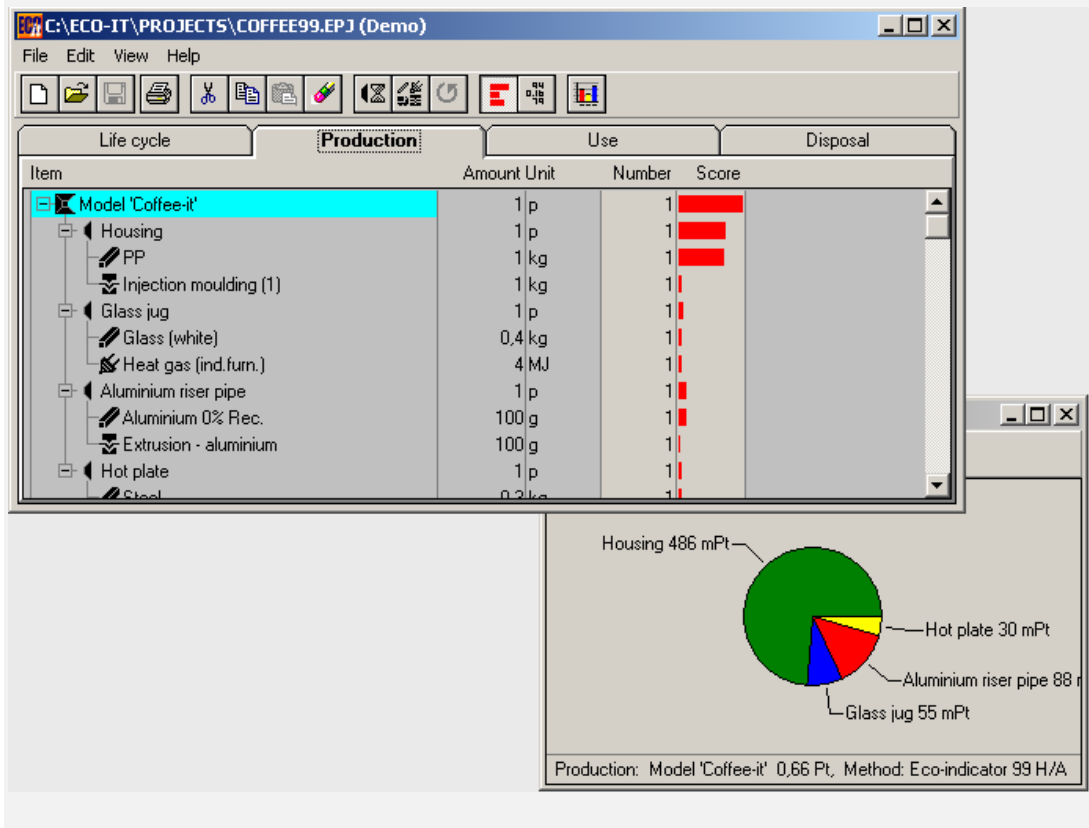
Figure 11   Example of two screens derived by using eco-edit.

7 Using SimaPro the easy way

7.1 A new approach to LCA

When you are new to SimaPro, we definitely recommend using the LCA Wizard to set up your LCA project. This will save you a lot of time. Experienced users know how much easier it becomes to develop complex life cycles, especially when you intent to develop sophisticated end of life scenarios.

Different versions of SimaPro

SimaPro is available in three different models:

1. SimaPro Compact for result oriented users, who prefer ease of use over complex functionality, and who like to use the powerful LCA wizards. The educational version of the compact, is named Campus or Classroom.
2. SimaPro Analyst for demanding LCA experts, who need all functions. The educational version of this license is named "PhD".
3. SimaPro Developer for experts that want to develop dedicated LCA Wizards or who would like to link SimaPro to other software.
4.

7.2 Starting SimaPro

Upon starting SimaPro you are asked to open a project or library:
- A project is an area in which you store the data you are about to collect and process.
- A library is a special type of project that contains the standard data supplied with SimaPro or data from other data suppliers. Libraries are a resource for all your projects. In general you should not edit this data, but link to it in your projects.

We suggest you open the Introduction to SimaPro project.

When you have a Compact licence, the next window you will get is the Wizard screen shown below; if you have another version click the word Wizard in the top left-hand corner of the screen (see below).
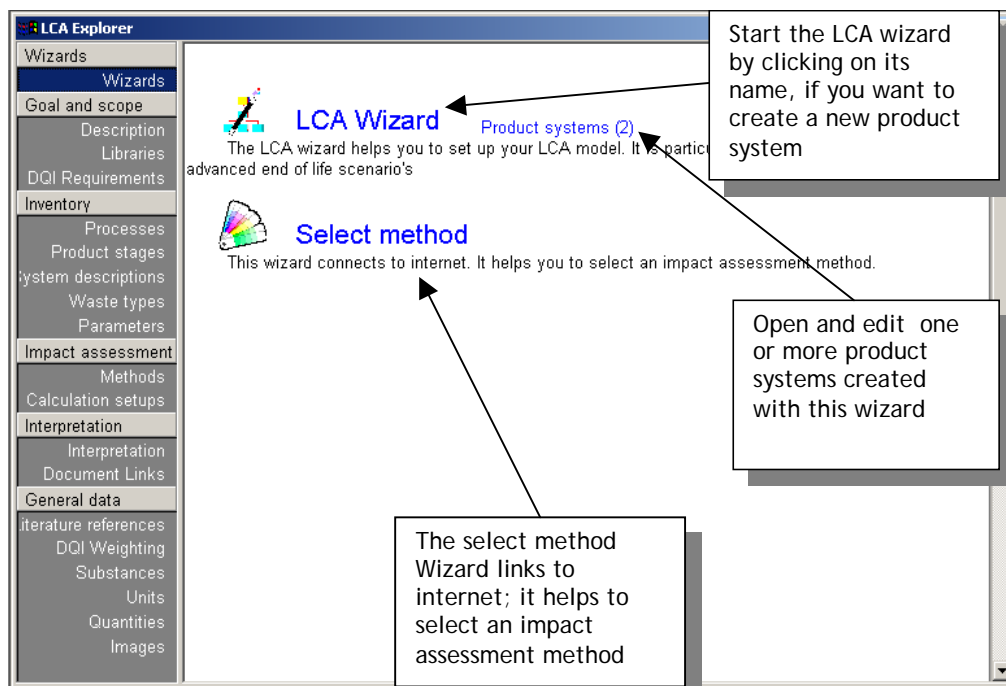
Figure 12   An overview of the Wizard screen, seen when you have a compact licence.

The Wizard screen contains a number of predefined wizards:

- The LCA wizard
- A number of links to other documents and websites

Users with a Developer licence can also add new wizards to this page, see section 11.1.

7.3 A quick start with the LCA wizard

When you click the *Set up your LCA* Wizard, a series of questions will be asked. Please follow the instructions and provide answers to the questions. During this process you will see how a process structure will develop on the background. This structure is based upon the inputs you provide, and reflects the fact that SimaPro has used your data to develop new entities in the database. When you have completed the wizard, two questions will be asked:

1. Do you want to store the product stages you created? If you do so, the product stages you created are available for further editing, as will be described in the next chapter; see paragraph 8.4. A disadvantage of storing the product stages is that you may end up with a confusingly large number of product stages. We suggest that you only save when you are certain you want to have these product stages for further editing.
2. Do you want to create a product system? A product system can be seen as a summary of all the data you have just entered, see next paragraph.

7.4 Product systems provide overview

The product system is a single sheet that contains all data needed to define the product specification the product use and the disposal. The structure of this sheet is generated by the wizard and the data you entered. The most important feature is that you can actually change the data you entered during the execution of the wizard and that you can recalculate the result. This makes it a very useful tool to analyse "what if" questions or to use in Ecodesign type applications.

Product systems can be stored under a name for future reference. In fact this opens the possibility to develop a specific use interface for a specific LCA problem.

8 Using SimaPro the conventional way

The wizards described in the previous chapter are easy to use and provide you all you need to make a basic LCA. However, if you want to use the more advanced features, you will need the traditional interface of SimaPro for particular tasks. You will find that also the traditional user interface is well structured and in fact easy to use.

The SimaPro Tutorial

The SimaPro Tutorial provides a number of exercises you can follow to get to grips with LCA. The tutorial is provided as hard copy with a SimaPro licence, but you can also find a PDF file on the SimaPro demo CD, or you can download it from www.pre.nl.

In this chapter we use the example of the coffee machine to demonstrate some key features, but we do not explain how to generate the screens shown. Use Tutorial lesson 1 to figure this out.

8.1 The LCA explorer

The bar at the left hand side is called the LCA explorer. It provides you access to all functions in SimaPro. The upper part of the explorer screen contains *project or library specific data*; the lower part contains *general data* that is not stored in projects or libraries. The buttons in the toolbar execute frequently needed commands.
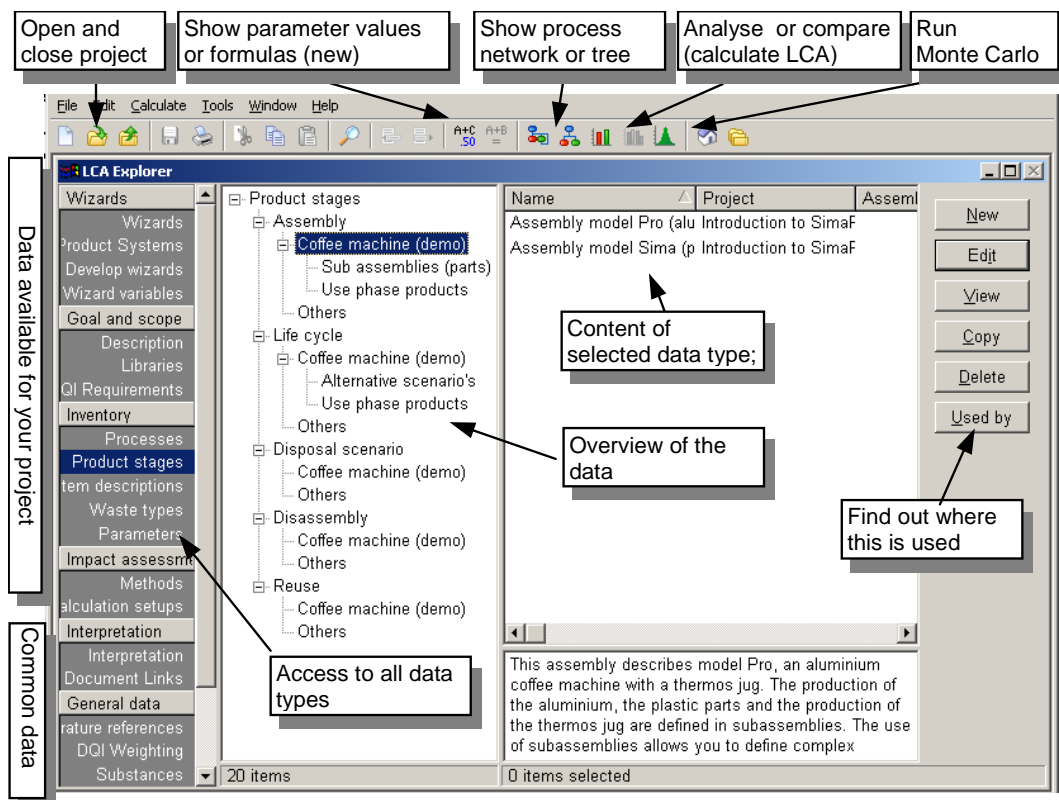
Figure 13   Overview of the SimaPro explorer on the left-hand side of the screen. This screen provides access to all data types. On top you find buttons for frequently used commands. Please note that some functions shown here are not available in the Compact or Analyst version of the software.

The SimaPro LCA explorer is structured as a checklist for your LCA, as you enter or edit data in the order defined in this list. However, LCA is an iterative process, which means you need to step back and re-evaluate your earlier actions.

- Initial calculations on a model filled with rough data can show which parts of the life cycle or which processes seem to be the most relevant, and thus need further attention.
- After a few hours of editing the database, you can check if all results are reasonable and explainable. If not you may have made one or more mistakes, or the data supplied to you may contain errors.

This means that you will go through the Goal and scope, Inventory and Impact Assessment parts in an iterative way many times.

8.1.1 Describe Goal and Scope

Under description, you find a number of text fields. These provide the structure for describing the goal and scope. See also paragraph 2.1
Libraries are used in SimaPro as resources where you store standard data and standard impact assessment methodologies.
You can select which libraries you consider to be in line with the requirements for this study.
The DQI section allow you to set a certain data requirements profile. Each process gets a colour code that indicates how much the process deviates from the profile you set. This feature is not available in the Compact version as the database provided with the Compact version is already quite homogeneous.
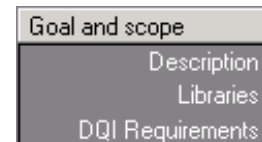
8.1.2 Inventory

This section provides access to processes and product stages; the two main data types in SimaPro (see below). System descriptions are used as additional documentation in some processes. Waste types are labels used by SimaPro when handling materials in waste scenarios this is also explained in paragraph 8.5
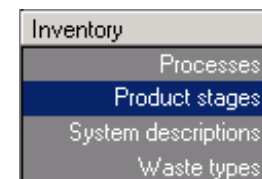
8.1.3 Impact assessment

This section provides access impact assessment methods. Under the reports section you can define which life cycles, processes and assemblies need to be repeatedly analysed and compared.
The benefit of using a report set-up is that all life cycles or assemblies always appear in the same order, with the same colours and the same scale.
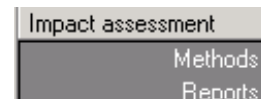
8.1.4 Interpretation

When you are nearing the end of your project, it is time to draw your conclusions and make a number of checks. The text fields under interpretation are a guide that helps you to check which issues you need to address. See also paragraph 5.1.
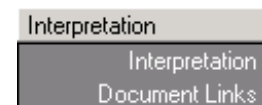
8.1.5 Other data types

The other data types like the scripts and the general data are not frequently edited during the LCA study, but contain useful supporting tables, like:
- Literature references, that you can link in your process records
- Substance names: SimaPro holds one central table in which all substance names are stored
- Units conversions as they are used in wizards and
- Units and Quantities; these are used in other parts of SimaPro
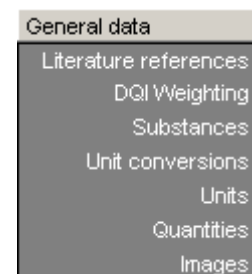
8.2 Entering and editing data

The core of the LCI phase is building a process tree that describes all relevant processes in a life cycle. In chapter 3, we have discussed the complexities of modelling the life cycles and we have described issues as system boundaries and allocation. Now we will show how you make this model in SimaPro.

The data structure in SimaPro contains two different building blocks:

1. **Processes** are the building blocks of the process tree that do contain environmental data, as well as data on economical inputs and outputs.
2. **Product stages** do not contain environmental information, but they describe the product and the life cycle.

The use of Product stages is a unique feature of SimaPro, as we will see they allow for the modelling of very complex products and life cycles

8.3 Processes

A process in SimaPro contains data on the following issues:

- **Environmental and social flows**, such as:
  - Emissions to air, water and soil
  - Solid waste (final waste)
  - Non material emissions, such as radiation and noise
  - Use of raw materials (in order to model depletion)
  - Social impacts

- **Economic flows**, such as:
  - Inputs from other processes (processes that are described elsewhere in the database).
  - Outputs; Each process must have one, and can have multiple economic outputs (In SimaPro referred to as Products).
  - Outputs of waste for further treatment, such as sewage plants, incinerators etc.
  - Avoided processes. As discussed in Chapter 2 this is one of the solutions of allocation problems, by enlarging system boundaries).
  - Economic impacts

- **Documentation**
  - A separate attachment 'documentation' with a number of text fields that are used to identify the record, such as name, Author, date and general comments.
  - A number of Data Quality indicator fields, that allow you to quickly identify how some of the methodological choices have been made, and how they compare with the profile you have set in the Data Quality section.
  - A system description. This separate attachment is available to describe the underlying model that is used when this data was defined.

- **Parameters**
  - Constant parameters, can be defined on a process, a project and database level.
  - Expressions: here you define the relationships between parameters, you can use a wide range of mathematical functions
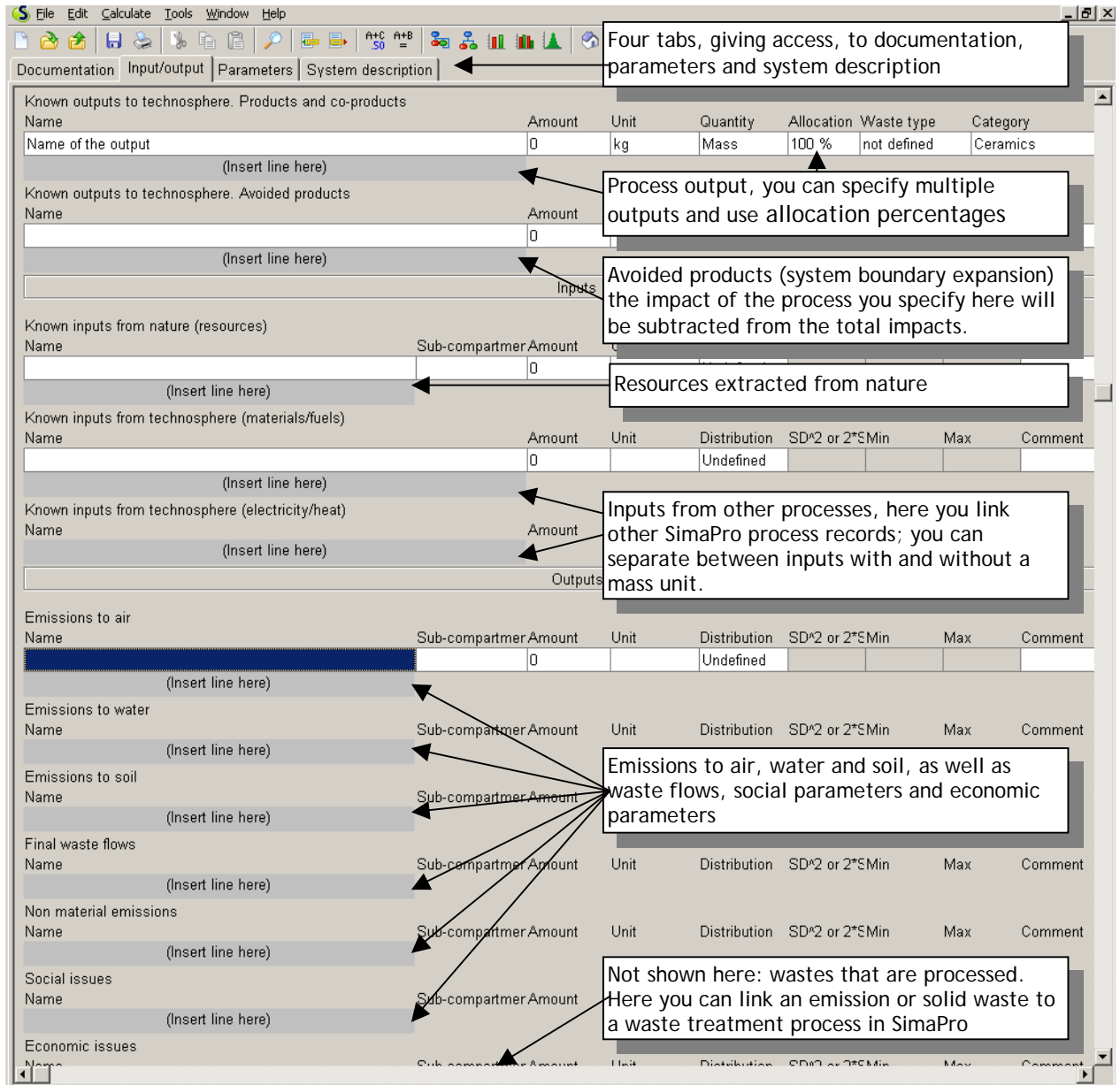
Figure 14:   *Empty process record (only upper part). This process record is the basic building*
                 block for the process trees in SimaPro.

Processes are identified in the database indexes according to their output. Processes can
be linked to each other to create networks. In SimaPro the links are defined in the
process record, and not drawn in the graphical user interface. This has the advantage
that links are maintained automatically, and safes much time when you want to use large
process structures.
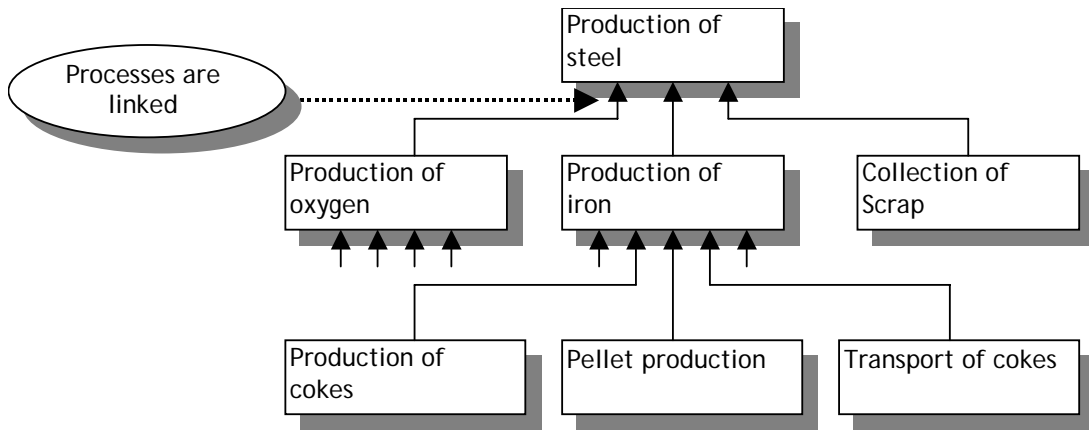
Figure 15   *Schematic overview of how processes are linked to form a process tree structure. In this case unit processes are used that describe a single process step, which provides the highest transparency.*

Process records can both describe *unit processes*, which describe one single process step as well as *systems,* which describe a combination of unit processes. For optimal transparency, it is always better to describe a system as unit processes. The ecoinvent dataset is supplied in two versions, a system and a unit process version

A graphical overview of a network is generated by pressing the [icon] button while you have selected a process or product stage. In a network, each process in only represented once, irrespective of the number of times it is used by other processes. The example below shows that process structures can have loops. The figure below shows you an example for rail transport. In addition, an indicator is used to show the relative contribution of the environmental load.
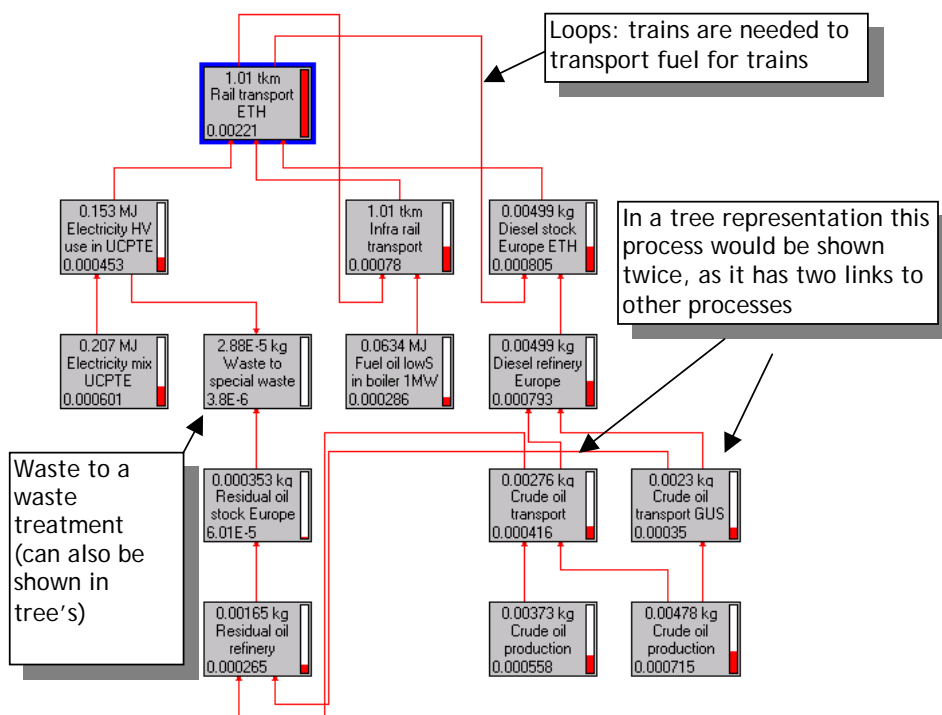
Figure 16   *Example of a network representation that contains loops. Here the average mix of electric and diesel trains is shown. Only the most relevant of in total 500 processes are displayed.*

Often the processes you need are already available in a library. In that case, you can make a link between a process record that is in your project and in the library. You do not have to copy the process from the library to the process, but of course, this means your project data has become dependent on your library. You can also establish such links between your current project and another project. However, it is not possible to link libraries, as it is desirable to keep them independent.

In case you would like to modify data in a library, we strongly recommend to copy such a record into your project and make any changes in the copy. This is an important guideline, as by changing libraries you may also change LCA results in other projects. (In the Light version it is even not possible to change the data in libraries, in the multi-user version only the database manager can make such changes).

8.4 Product stages

Product stages are used to describe the composition of the product, the use phase and the disposal route of the product. Each product stage refers to processes. So for instance if you specify a product contains 1 kg of steel, you make a link to the process that describes steel production and you specify 1 kg as quantity. Some product stages can also link to other product stages.

Figure 17   An example of a product stage, in this case the assembly.
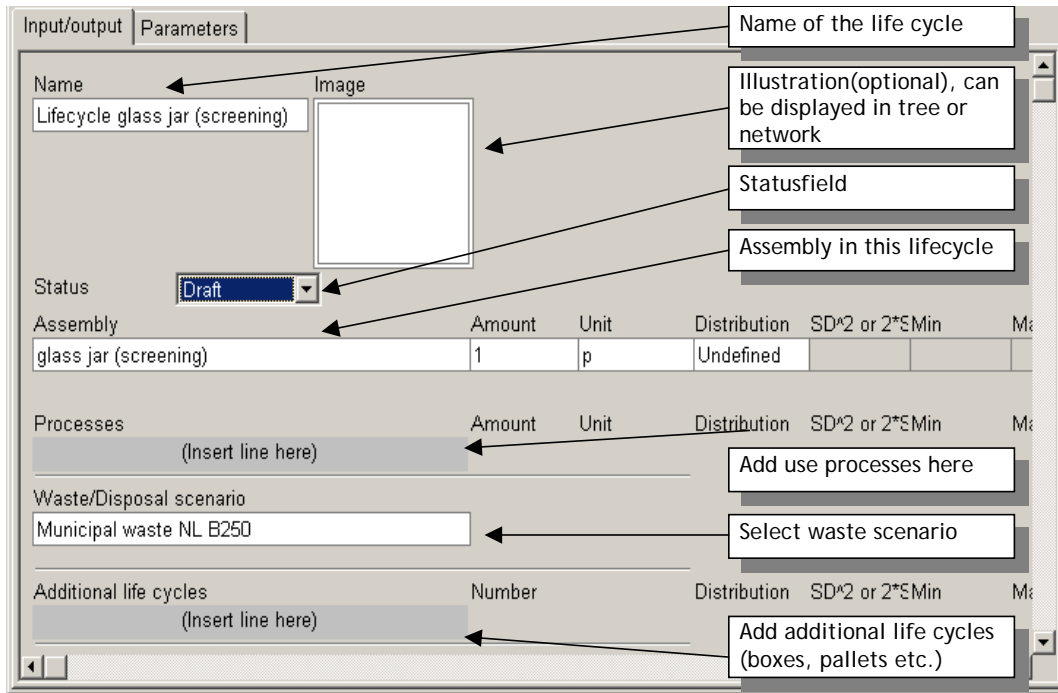
Figure 18   An example of a product stage, in this case the assembly (top) and life cycle (bottom). The life cycle links the product specification (the assembly) with the use processes and the end of life scenario.

There are five different product stages, each with its own structure.

- **Assemblies** contain:
  - a list of materials and subassemblies
  - a list of production or transport or energy processes

  The assembly can be understood as the definition of a product. Analysing an assembly is equivalent to a Cradle to Gate LCA. For complex products, assemblies can be linked to other subassemblies. This allows for the definition of very complex products with many different parts.
- **Life cycles** are the central product stages. They contain links to:
  - One assembly, representing the product (this assembly can have subassemblies)
  - A number of use processes, such as energy use.
  - A disposal or waste scenario.
  - An additional life cycle.

  Life cycles can also link to other life cycles, allowing the creation of models in which products use other products like batteries, filters, tyres, and packaging
- **Disposal scenarios** describe the end of life route of entire products that may still be reused or disassembled. They contain:
  - A number of processes, representing the environmental load connected to the scenario
  - A number of links to disassemblies, disposal scenarios , waste scenarios or reuse records, that specify to which destinations the product flow. The amounts are expressed as a percentage. The total of all percentages must add up to 100%.

  Please note that SimaPro also has waste scenarios that describe waste streams in terms of materials, and not in terms of products. For instance the reuse of bottles would be described using disposal scenarios while the recycling or land filling of glass from (broken) bottles would be described with a waste scenario.
- **Disassemblies** describe the disassembly of components. These components have to be defined as subassemblies, It contains:
  - A reference to the assembly that is being disassembled
  - A number of processes representing the environmental load connected to the disassembly operations

- A number of destinations of dismantled parts (subassemblies), and the disassembly efficiency
- A destination for the remains, usually a disposal scenario or a waste scenario
- **Reuse** describe the way products can be reused. It contains:
  - A number of processes representing the environmental load connected to the reuse operation
  - A reference to the assembly that is being reused. This may also be a disassembly, allowing you to specify reuse of components
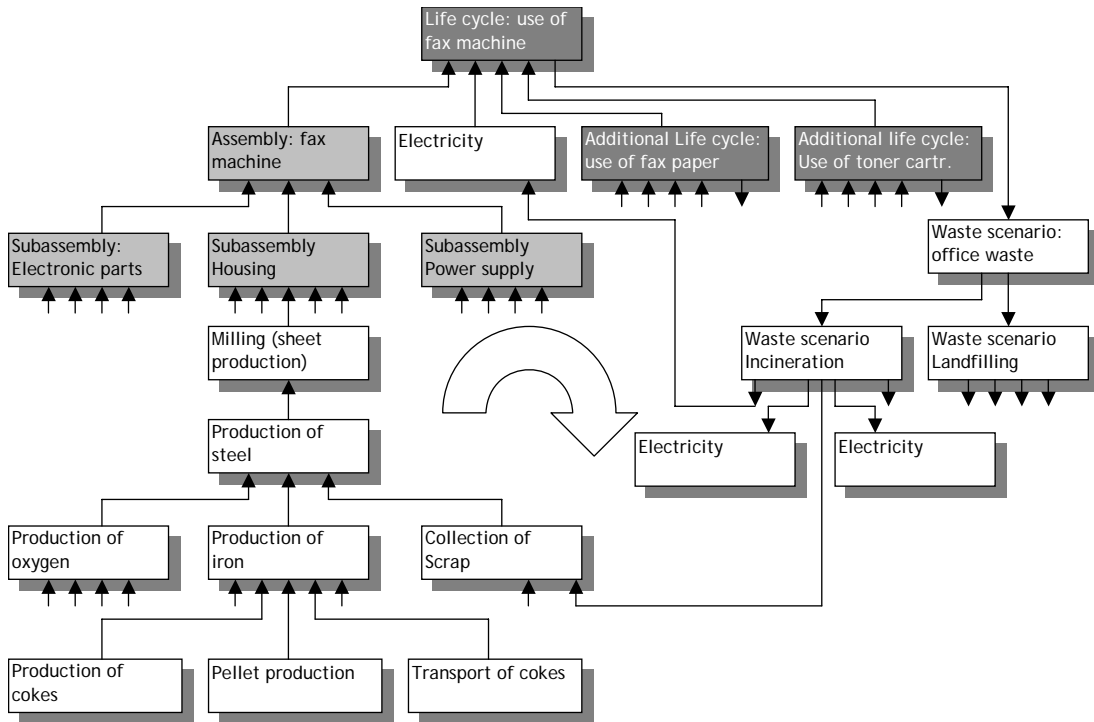
Figure 19   Schematic overview of the life cycle of a fax machine; the grey boxes are product stages, the white boxes are Processes

The top, dark grey box is also a product stage called Life cycle. As you can see, a life cycle can link up to:

- One assembly (which may have subassemblies).
- One or more use processes, in this case electricity.
- One or more life cycles of auxiliary products, such as paper and cartridges. These auxiliary life cycles are defined just as any other life cycle; they also have an assembly and an end of life stage. This allows you to model a different end of life scenario for paper, cartridges and fax machines.
- A waste or disposal scenario (in this case a waste scenario is assumed).
- Additional life cycles.

SimaPro can generate such process tree graphs automatically. You cannot directly edit this tree graph. Editing is done in process records or product stages. Figure 20 shows how SimaPro would generate this process tree.
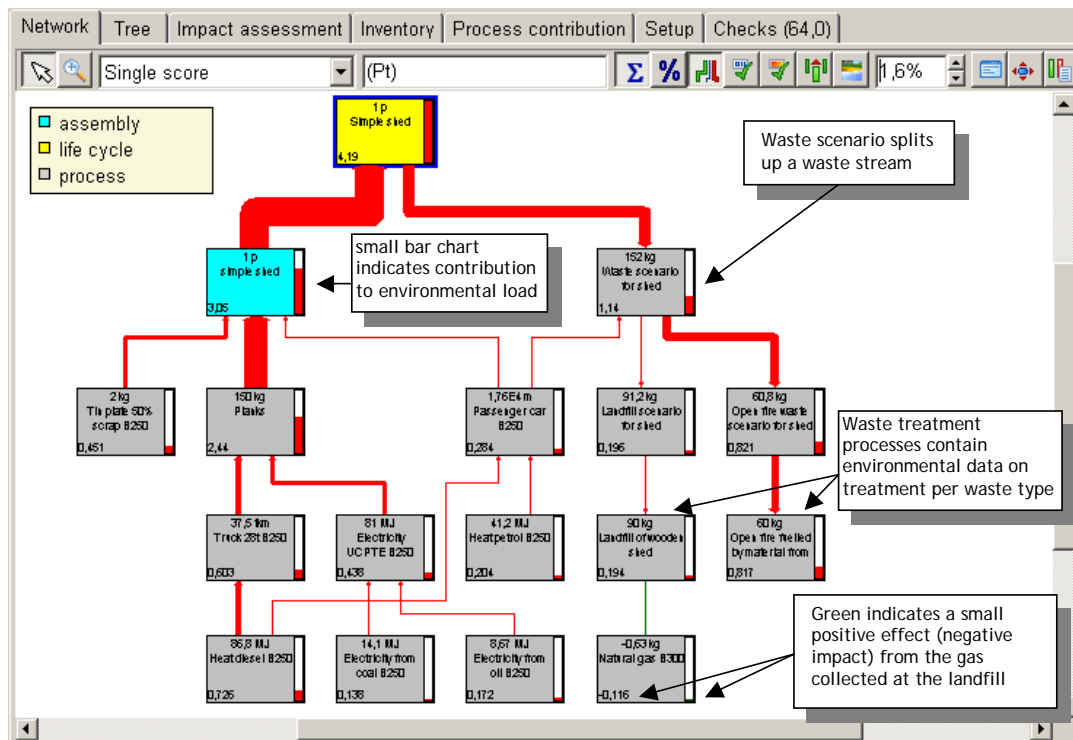
Figure 20   Schematic overview of a process tree (example taken from tutorial)

8.5 Modelling of waste and disposal scenarios

Working with waste and disposal scenarios is seen by many users as one of the more complex steps in SimaPro. An important reason is that the model is an upside down version of the production model that sometimes feels like counter intuitive. The LCA wizard is particularly useful if you want to develop a complex waste scenario.

8.5.1 Waste and disposal scenarios

SimaPro has a very advanced set of tools to model the end of life phase. As most LCA practitioners are not working in the end of life industries, but in the production sectors, it is important to be acquainted with the way waste processes need to be modelled. In a way, the modelling is more complex than modelling the production phase. The following paragraphs attempt to give you an overview of the terms and concepts used by SimaPro.

A distinction is made between waste and disposal scenarios:

- **Waste scenarios** are processes that refer to material flows, without observing any product characteristics. In waste scenarios, information on how the product is split up in different components (subassemblies) is lost, only information of the materials in the waste stream is maintained.
- **Disposal scenarios** are product stages that refer to product flows. Information on the way the product can be split up in components (subassemblies) is maintained, and this means you can model selective disassembly and (partial) reuse operations.

To illustrate this: glass recycling, by throwing a bottle in a glass collection container would be modelled with a waste scenario. Returnable bottles, which are washed and reused, should typically be handled in a disposal scenario. The product properties are maintained.

8.5.2 Waste scenarios

In waste scenarios, a waste stream is split up in different waste types, and these waste types are sent to waste treatment processes. Waste treatments actually document the emissions and other impacts you get from land filling burning, recycling, composting etc. Waste streams can also be split up according to the waste type. This allows you to build waste treatments for a specific waste type.

Figure 21   A waste scenario is used to split a waste stream. Splitting can be done per waste type or in a generic way.

For example, you can define a waste scenario called Municipal waste; to describe what happens if a consumer puts a product into the waste bin. This waste scenario splits up the waste stream in a part that is land filled and a part that is incinerated. The municipality recycles probably also some of the waste, but for the clearness of the example, we disregard this now.

When waste is incinerated, many different emissions can occur. Usually an LCA practitioner would like to know which material in the product is responsible for which emissions. Furthermore, in an LCA, one would like to see the dependence between the material composition and the emissions that occur. To allow for this SimaPro can also divide the waste stream in different waste types or materials. A waste type is a general name, such as paper, plastics, PVC or ferro metals. For the waste modelling, it is usually not so important to know which paper, as the atomic composition is about equal for all kinds of paper. In SimaPro, you can define your own waste types and you can specify which materials belong to a waste type.
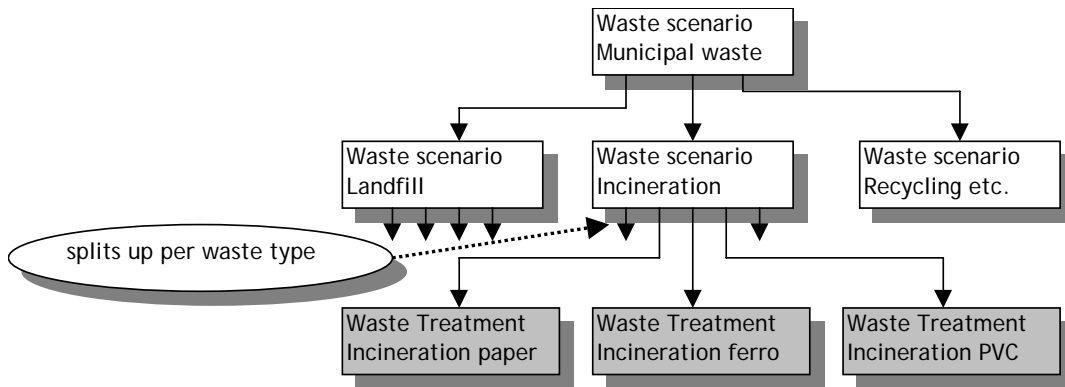
Figure 22   A waste scenario specifies how a waste stream is split up and send to other waste scenarios or waste treatments. This splitting can be specified per waste type or material. A waste treatment specifies what actually happens if a material is land filled, incinerated or recycled, etc.

With the waste types well defined, you can specify how the waste stream that is to be incinerated is split up according to the waste types. Each waste type is now "send" to a specific waste treatment. For example the waste type paper is send to the waste treatment process called "incineration of paper". This waste treatment specifies the average emissions that can be allocated to the incineration of one kg of paper.[6] Similarly, the waste type PVC can be send to a waste treatment that describes the incineration of PVC materials.

Making detailed waste scenarios

The emissions from waste treatment are dependent of the composition of your product. If you specify that there is 2kg of material, which is labelled as belonging to the waste type PVC, and if 50% of the waste is incinerated, the waste treatment called incineration will receive 1 kg of material as input.

Working with waste types simplifies you modelling, but also creates some distortions. Not all PVC contains lead as a stabiliser, and if you have only waste type PVC, you cannot see the difference between PVC with and without such stabilisers. Two solutions can solve this:

1.   Introduce more waste types for PVC.
2.   Do not use waste types at all, and let the waste scenarios divide the waste streams per individual material.

The latter solution is certainly the most precise, and this option is supported by SimaPro. One of the consequences is however that you will have to adjust all waste scenarios if you define a new type of PVC in the database.

How you define waste types and waste scenarios depends on how you would like to make the trade-off between precision and practicability. Ultimately this depends on your goal and scope.

Waste treatments sometimes do have useful outputs, such as heat or materials that are reclaimed for incineration or recycling processes. SimaPro allows you to specify these useful outputs as a close looped recycling procedure. This means if you generate one kWh of electricity due to the incineration of a certain amount of waste, the environmental load that would "normally" occur if such an amount of electricity would be generated is

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[6] Allocating emissions to a specific material is usually done by separating between process and product specific emissions. For example the amount of CO typically depends on the way the incinerator is designed and operated, and not of the chemical composition of the waste. This is a process specific emission. The amount of CO_2 is typically determined by the content of the product that is incinerated, for every kg Carbon in the product, 4,4 kg of CO_2 is produced. This is a product specific emission. Process specific emissions are usually allocated to the materials according to the flue gas amount they create.

subtracted[7]. The Ecoinvent and the ETH datasets do not use this form of system boundary expansion, the useful by products of incineration are ignored.

Switching between waste scenario system boundaries

If you want to investigate the impact of ignoring or including useful by products, you can use a switch parameter: add a line in the avoided processes (near the top of the waste treatment process), and select an electricity mix. In the amount field you enter the amount of electricity that is generated from this amount and this type of waste. However, instead of just entering the amount you enter the amount multiplied by a parameter. If the parameter is set to zero, this electricity generation is ignored, if the parameter is set to "one" the electricity impacts are subtracted. In the ecoinvent processes you can find the estimated amount of generated electricity and heat in the comment field.

8.5.3 Disposal scenarios

In disposal scenarios a stream of disposed products is also split up, but this is done in three routes:

1. Products that are disassembled in a "disassembly".
2. Products that are reused.
3. Products that are treated in a waste scenario (see above).

For example, suppose you have organised a take back system for fax machines and that you expect the following scenario:

- 50% of the fax machines will not be collected. This means these are send to a waste scenario, which describes what happens to fax machines when they are disposed of. This scenario could for example describe that a certain percentage is incinerated and land filled. The emissions from land filling, incineration and if applicable materials recycling are described in waste treatments.
- 10% of the fax machines are in such a good condition that they can be reused directly. In SimaPro, you can define in a reuse record what efforts (processes, transports, etc) are needed to make this reuse actually possible. SimaPro will consider the reused products as being recycled in a closed loop model. By reusing 10% of the fax machines the production needed to fill the functional unit is reduced with 10% (this does not imply the actual production is reduced, the reduction refers to the production needed to have a proper functional unit).
- 40% of the fax machines are dismantled in a specialised dismantling facility. In SimaPro you use a Disassembly record to specify which parts are taken out of the returned machines, such as the drum, the housing and the power supply. In this record, you can specify the destination of these parts, and what happens with the remaining parts. Often these are send to another waste scenario, which describes how you deal with the remainder. The destinations of the disassembled parts are specified in other disposal scenarios. This means you can now define a further dismantling operation. For example, you can specify that the power supply is split into a fan, a transformer and to an electronic circuit.

Note that disassemblies can only work properly if you have defined the product as a set of subassemblies. So in the example describe here, you should for example specify the power supply as a subassembly, which consists of subassemblies like the fan, the transformer and the electronic components.

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[7] This also explains why there are frequently negative environmental loads in the end of life product stages

Managing uncertainties in recycling rates

Also in disposal scenario, disassembly and reuse boxes, you can use parameters. For instance, you can define a parameter called recycling rare, and use this to influence the way the scenario works. A particularly useful application is to use parameters with an uncertainty range. In previous versions of SimaPro uncertainty could not be used for splitting up a waste stream in a recycled and non recycled parts, as the sum of both percentages must always be 100%. This requirement cannot be met if an uncertainty range was added to both percentages. However, by putting an uncertainty range on the recycling parameter, and by defining the remaining waste stream as 100%-recycling percentage, we can fulfil the requirement that the sum of both waste streams is equal to 100%.
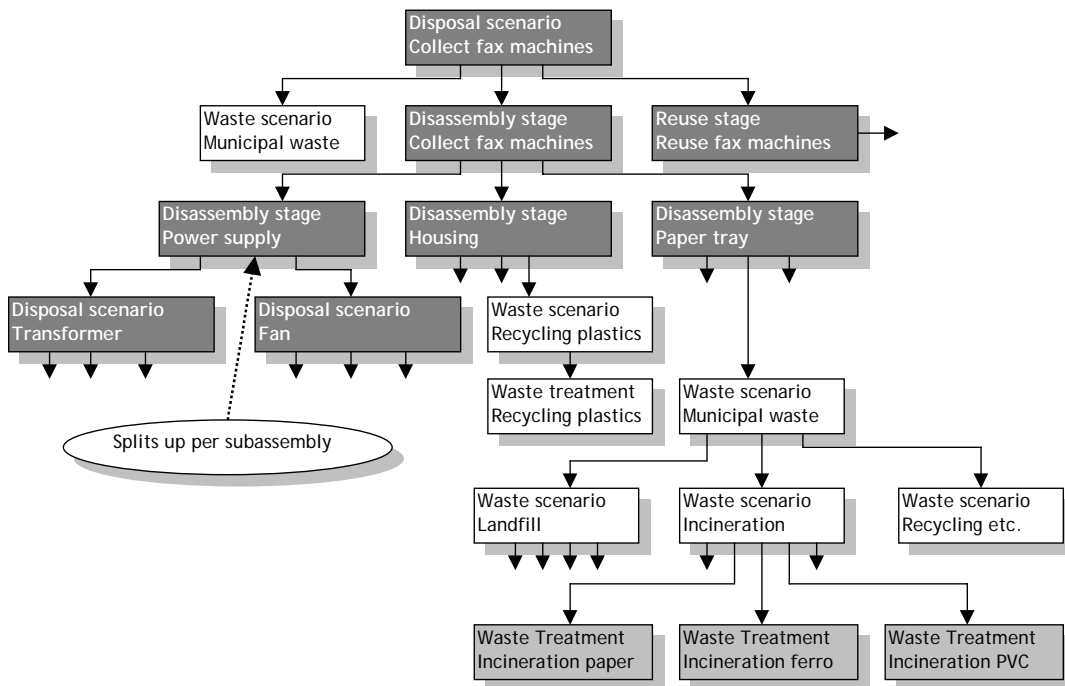
Figure 23   A disposal scenario specifies how products are distributed over different end of life options, such as disassembles, reuse and waste scenarios. A disassembly specifies how products are split up in different components, and to which destinations these are send to.

With the disposal scenario, the Reuse and the Disassembly options in SimaPro you can make very detailed and complex models of the end of life. It will require some experimenting to get to grips with these issues, but it is certainly one of the more powerful capabilities of SimaPro.

Therefore, as a summary we can present the following procedure to build up life cycles:

1. Define a new product stage of the *assembly* type, and give it a name.
2. Specify the materials that are in this product, by linking material production processes to the assembly. In many cases, such processes have links to other processes. SimaPro will automatically maintain these links.
3. Specify the production and transport processes needed for this assembly.
4. Define a new product stage of the *life cycle* type and give it a name.
5. Link the assembly you just created to the life cycle.
6. Enter the use processes, such as transport for distribution and energy use, by linking energy or transport processes to the life cycle stage.
7. Enter waste or disposal scenarios to the life cycle stage. Waste scenarios are processes; disposal scenarios are other types of life cycle stages, which shall be

described below. Waste scenarios are normally linked to waste treatment processes. It is sufficient to link the waste scenario, SimaPro will maintain the links to the waste treatment processes.

8. In case you want to include auxiliary products or packaging, you can also define a life cycle for these products, and link this life cycle to the life cycle you are currently building. (not shown in the figure below).

The operations needed to link processes and product stages are relatively straightforward. You do this by double clicking the appropriate fields in the process and life cycle stages and then by selecting the process or product stage you want to link. This assumes the process you want to link to is already available. Consequently, you typically define process trees in SimaPro "bottom up".

8.6   Status fields

Collecting data is not only a time consuming process, but also a process that is difficult to manage, especially because you usually do not have all the data available before you start modelling. This means that you often have a mixture of processes in draft status and completely finished processes. In larger LCA projects this can become difficult to manage. SimaPro has a convenient feature to help you. In each process or product stage has a status field. Each process can have the following stages of development:

- **Blank**: this is the default value when you create a new process or product stage
- **Temporary:** This is meant for processes you put in as a quick fix, but that should ultimately disappear. For instance, if you are still waiting for some data, you can insert a temporary record with a rough estimate.
- **Draft**: Indicating that you are not finished and still working on this
- **To be revised**: Also a draft status, but this indicates that you are aware of the fact something needs to be done
- **To be reviewed**: Also draft status, but now you indicate a colleague, or more formal, an internal or external reviewer should check this process
- **Finished**: As the word says, nothing to be done anymore

When you fill in these status fields, you will be able to recognise display the status of each process in the tree or network, by clicking the "show status" button, the boxes in the tree will be coloured according to their status.

9 Monte Carlo analysis

Monte Carlo analysis is a numerical way to process uncertainty data and establish an uncertainty range in the result of the calculation.

Example Monte Carlo analysis

Monte Carlo is a miniature state south of France that is famous for its gambling halls. Monte Carlo analysis has an element of gambling in it, and that explains the strange name.

The basic concept of Monte Carlo Analysis can be explained using a simple example. Suppose you are interested in the SO2 emission from a oil fired furnace that is used to dry wood and that you have the following data:

- SO2 emission from burning 1 kg heavy oil is 10 gram on average, but in 95% of the cases the value lies between 5 and 15 gram, depending on the sulphur content of the oil.

- The oven in which you burn this oil generates 40 MJ heat per kg oil. Due to differences in maintenance and age, the value will vary about 5%. The actual value will be between 38 and 42 MJ.

- The process that is operated requires on average 10 MJ, but there is an uncertainty of about 50%. This means that the actual requirement can be between 6.7 and15 MJ.

Now we want to know the overall uncertainty of the SO2 emissions from operating these production steps. A simplistic way to do this is to combine the lowest SO2 emission per kg oil with the highest oven efficiency and the lowest energy requirement. This would give a theoretical lowest SO2 emission. Similarly, one could combine all ranges to get a theoretical maximum. The problem with this approach is that in real life the chance that a combination of all extremes occurs at the same time is negligible, so the result you get is a gross overestimate of the uncertainty.

In the Monte Carlo approach we let the computer for each variable take a random value within the uncertainty range we specify, and we execute the calculation. The result is stored. Next the calculation is repeated taking different samples within the uncertainty range, and also this result is stored. After repeating the procedure for instance 1000 times, we get 1000 different answers. These answers in themselves form an uncertainty distribution.

9.1 Distribution types

In order to apply the Monte Carlo approach, we need to translate our information on uncertainty to a standard distribution type. In SimaPro, you can use four different distributions, as listed in the table below.

Distribution	Data needed	Graphical presentation
Range	Min and Max value	
Triangular	Min and Max value plus best guess value	
Normal distribution	Standard deviation and best guess value	
Lognormal distribution	Standard deviation and best guess value	

The key characteristics are:

1. **Range**. It is used when you know that there is an equal probability that a value lies between a minimum and a maximum value. A simple example is the result of throwing a single dice. The range is between 1 and 6, and there is an equally big chance on every outcome.
2. **Triangular**. This distribution is sometimes used as alternative for the normal distribution. The advantage is that very high or low (even negative) values cannot occur. In SimaPro you need to specify the range as well as the best guess value, as

this determines the point with the highest probability. This allows you to specify an asymmetrical distribution that can also be used to simulate a lognormal distribution.

3. **Normal distribution**. This distribution requires you to specify the best guess value (the centre) and the standard deviation SD. However, in SimaPro you are asked to specify the 2xSD value. This is useful as the 95% confidence interval lies between –2xSD and +2XSD. In practice this means that only 2.5% of the data points lie above or below these points, and 95% lie between these points. This means that if you have an estimate for the upper and lower value, you can often use these to estimate 2xSD.

4. **Lognormal distribution**. This is the most important distribution for LCA. Lognormal distributions occur when values with a normal distribution are multiplied. As this happens often in LCA, this distribution can be considered as the default. The 95% confidence interval is defined by dividing or multiplying the best guess value with the squared geometric standard deviation. In SimaPro you are supposed to specify this square of the standard deviation, often written as σ^2.

Determining the distribution type and entering uncertainty data.

For the examples quoted above, data need to be entered into SimaPro in the following way:

- SO2 emission from burning 1 kg heavy oil is 10 gram on average, but in 95% of the cases the value lies between 5 and 15 gram, depending on the sulphur content of the oil. For this type of uncertainty we can use the linear or triangle distribution, In both cases the upper and lower value is 5 or 15 gram. The choice for the distribution depends on your knowledge about the likelihood that the emission per kg oil is close to the 10 gram.

- The oven in which you burn this oil generates 40 MJ heat per kg oil. Due to differences in maintenance and age, the value will vary slightly. In 95% of the cases it will be between 38 and 42 MJ. But in some cases it is considerably lower or higher. Here we can use a normal distribution, as there is not a strict maximum or mininium value. A property of this distribution is that the 95% confidence interval is approximately defined by subtracting twice the standard deviation and adding twice the standard deviation . So from the data, we can deduct that the standard deviation is 1 MJ and the double standard deviation is 2 MJ. In SimaPro you enter the value 2 as the double standard deviation, as this is what SimaPro expect you to enter.

- The process that is operated requires on average 10 MJ, but there is an uncertainty of about 50%. This means that the actual requirement can be between 6.7 and 15 MJ. Here the distribution is not symmetrical and we can reflect this by using the lognormal distribution. A typical characteristic of the lognormal distribution is that the 95% confidence interval is defined by dividing or multiplying the best guess value with the squared geometric standard deviation. This means that if there is no uncertainty, you should enter a value equal to one. The geometric standard deviation cannot be lower than one. For this example, we can enter the value 1.5 as the squared geometric standard deviation.

Please note that the standard deviation SimaPro calculates is not the geometric standard deviation but the normal standard deviation. So if you calculate a distribution using only lognormal distributions, the result will be a lognormal distribution, but the standard deviation reported is not the geometric standard deviation. So you cannot enter the calculated distributions directly in a new process record.

9.2 Correlations

When you perform an uncertainty calculation, it is very important to keep track of the correlations in the data:

- **Correlations in a process tree**. Suppose that several processes in a process tree refer to the same electricity process. In this case we must take into account that for each Monte Carlo run, the Monte Carlo samples set for this electricity are the same irrespective of which processes uses the electricity. If we would not do so, we would overestimate uncertainty. In SimaPro this has been taken into account.

- **Correlations within a process record**. When the fuel efficiency of a car is uncertain, the uncertainty of the petrol consumption and the CO2 emission is heavily correlated, while the emission of CO is only weakly correlated (CO

emissions tend to depend on the way the engine is controlled, the maintenance of the engine etc, and not directly on the amount of fuel used). This type of correlation is very difficult to model, as things become quite complicated. (If a power plant uses two fuels, it is difficult to define how CO2 emissions correlate with both fuels). SimaPro does not support this correlation.

A special case occurs when 2 products are compared. Suppose that product A is made of 10 kg steel and product B is made of 11 kg of the same steel, and that the uncertainty on steel data is 30%. If we would calculate the uncertainty distributions of product A and B individually, we would see two distributions that almost completely overlap.
You could get the impression that it is impossible to determine if product A is preferable over product B. With a little common sense we can determine that this is a flawed result and that product A is preferable over B, as it simply uses 1 kg less steel.

In SimaPro we have avoided to show overlapping distributions when comparing two products. Instead we have developed two ways to see the "real" difference between A and B:

- We calculate how many times the Monte Carlo routine shows that product A is better than product B. This can be determined for every individual inventory result, as well as for impact category indicators.
- We show the distribution of the difference (A-B). If the difference is largely positive, you can see that A has a higher impact than B; if the outcome is largely negative, the opposite is true.

9.3 Monte Carlo analysis in SimaPro

To execute a Monte Carlo calculation, select the product stage or process you want to analyse and use the 🌲 button instead of the normal 📊 calculation button.
A message will appear in which you can specify some important parameters:
- The impact assessment method used;
- The criteria to stop the calculations;
- A fixed number of runs;
- A stop criterion: this criterion halts the Monte Carlo calculation when SimaPro notices that the standard error of mean reaches the level you specify. The standard error of mean indicates how much the mean is changed by the last Monte Carlo run. The lower the standard error of mean, the more reliable your results are.

While calculating, SimaPro will report the progress of the calculation. You can stop the calculation at any time, before the stop criterion or the maximum number of runs are reached.
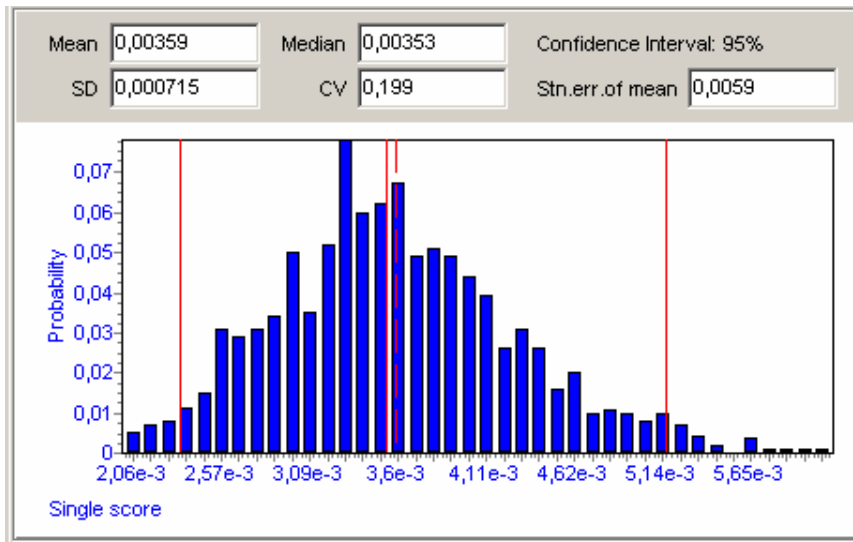
*Figure 24   Progress status window during Monte Carlo calculations. Especially the value of the
                  standard error of mean is important to keep track on.*

How many runs you want to make, or at what standard error of mean you would like to
stop the calculation depends on what you want:

- For obtaining a quick impression, a standard error of mean below 0.01 is quite
  acceptable. In general such a level is reached in about 50 to 100 runs. This will
  take a few minutes in general.
- When you want to present graphical distributions, as seen in figure 24, you will se
  that at 100 runs the figure does looks strange.
- If you want to have a really good impression of the standard deviation, and if you
  want to present graphical representation of distributions, you should at least use
  over a 1000 runs. Depending on the speed of your PC, this can take about an
  hour. More runs usually results in a slightly lower standard deviation.

*Hint: While Monte Carlo is running, you can still use your computer for other tasks,
although you will notice the computer reacts quite slowly. If you have sufficient
technical knowledge about Windows, you may lower the priority of the SimaPro tasks in
the Windows task manager.*

9.3.1 Uncertainty in the inventory table

All features discussed on the level of impact assessment are also available for each
individual substance, so you can also plot the difference in the emission of benzene for
two product systems or you can analyse the absolute uncertainty for any specific
emission as discussed below.

9.4   Interpretation of the results of an analysis

There are several ways to view the results. Please note that results for comparisons are
presented differently than results from the analysis of a single process or product stage.

9.4.1 Impact assessment profile with confidence interval (not for comparisons)

Per impact category a bar chart is shown with an uncertainty range. The range expresses
the 95% confidence interval. This means that 95% of the results lay within this range. You
can change the percentage of the interval.
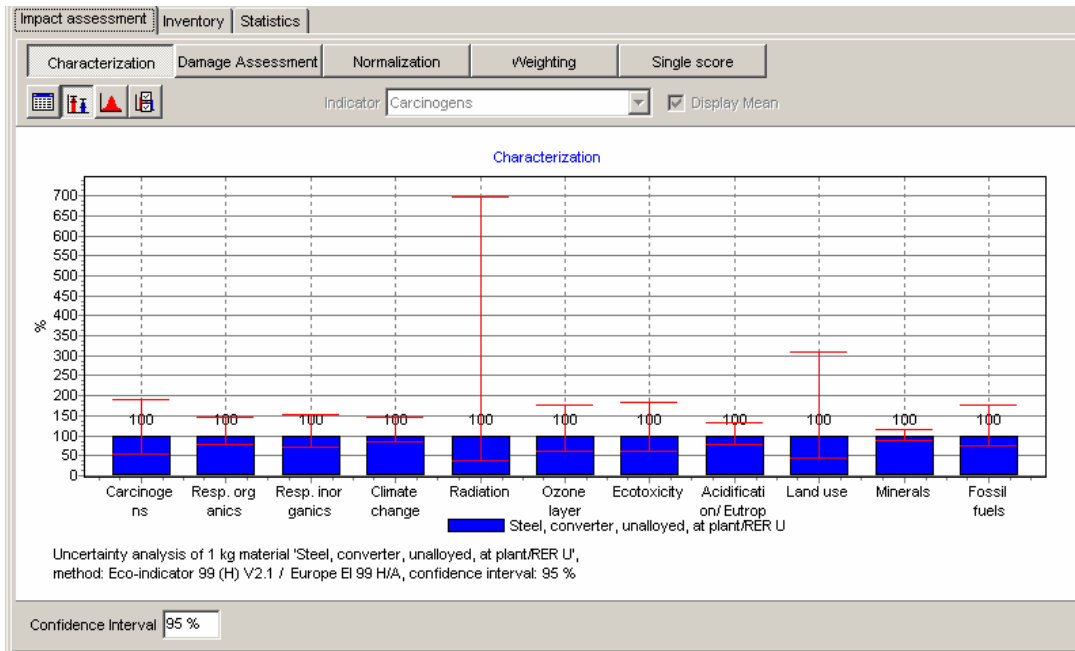
Figure 25   Graphical representation of the Characterization screen for the Converter steel process from the ecoinvent data set. The red lines indicate the 95% confidence intervals. Clearly the score for radiation has a very high uncertainty. Also the uncertainty on the Land-use score is high. The other scores have an uncertainty of about 100%, which is also still very high.

In general, you will find the absolute uncertainties on the characterisation level are quite high. Please consider that the uncertainties in the characterisation scores themselves are not taken into account. This is only the uncertainty in the inventory.

This type of graph is not available for comparisons. This is not a technical limitation but a deliberate decision. Showing two overlapping distributions makes no sense due to the correlation between uncertainties (see paragraph 9.2). The absolute uncertainty is of no use when making comparisons. We need to know the uncertainty of the difference between two products.

9.4.2 Graphical and tabular representation of a distribution

All inventory results and all impact assessment results can also be shown as a distribution for each individual substance, impact category, damage category or single score. The distribution can be shown as a graph (see figure 26) or as a table. In these graphs and tables a number of new terms are used:

- Median value. Imagine we can sort all results of the calculations. The middle value is the median value. This is often the most useful parameter to use when we want to report the "best guess" value.
- Mean. This is the average score or all results (the sum of all results divided by the number of results). This value can be heavily influenced by outliers (extreme high or low results). For this reason it is not so useful to report the value. In SimaPro you have to click the "Show mean" option to get it.
- Standard error of mean. This is in fact the stop criterion above. It is the amount with which the last calculation influenced the mean.
- CV (coefficient of variability) This is the ratio between the standard deviation and the mean. It is a useful parameter if you want to sort data in a table by the relative magnitude of the uncertainty.
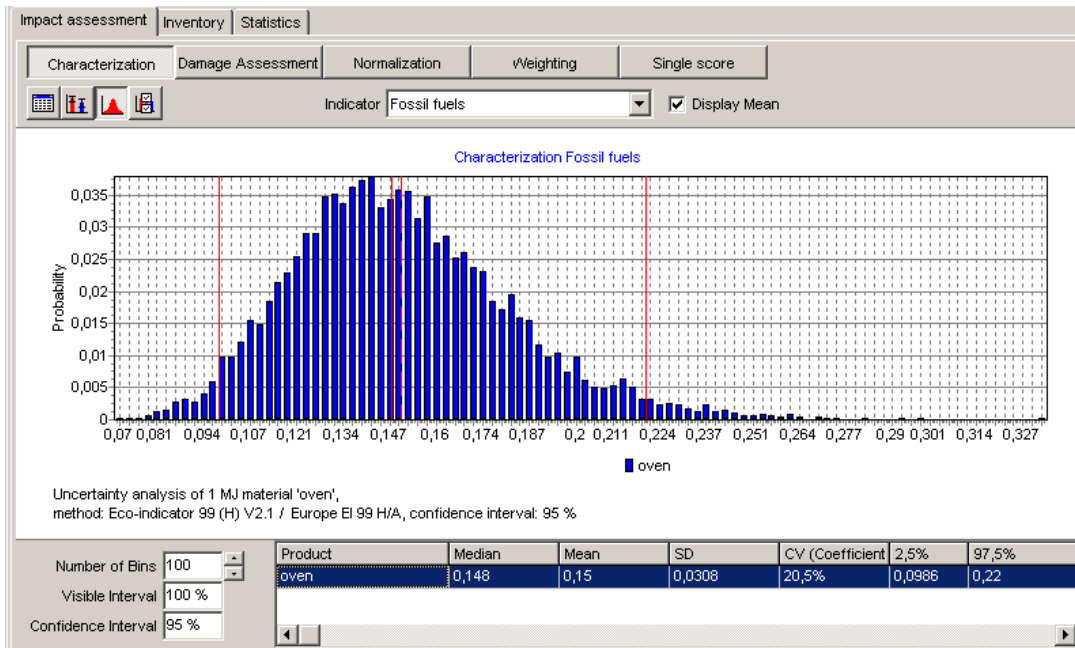
Figure 26   *Graphical representation of a distribution. The horizontal axis displays the value of*
the calculation, in this case the fossil fuel use. The vertical axis displays the
probability that a certain value is reached. Four red lines are shown. The middle
ones represent the mean and median value. The two other lines represent the 95%
confidence interval; this percentage can be changed in the lower left field.

9.5 Interpreting comparisons

To avoid interpretation errors related to correlations, SimaPro has two additional
features to support the interpretation of comparisons:

1. Count the number of comparison runs in which product A is larger then B. This is
   a relatively simple way to present the differences. The benefit is that this
   presentation can be used for all impact categories, or even for the entire
   inventory result in a table.
2. Show the graphical distribution of the difference between product A and product
   B. If the difference is entirely positive or negative, it is clear there is a
   significant difference between A and B[8].

In the example below, we compare two types of steel production and we will analyse if
the differences between these processes are indeed statistically significant. First we will
analyse the traditional comparison results.

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[8] In principle it would also be possible to show the quotient A/B, but this gives strange results if B is
near zero, or if A or B becomes negative. Tests show that this occurs frequently. This is why the
A/B function has not been implemented.
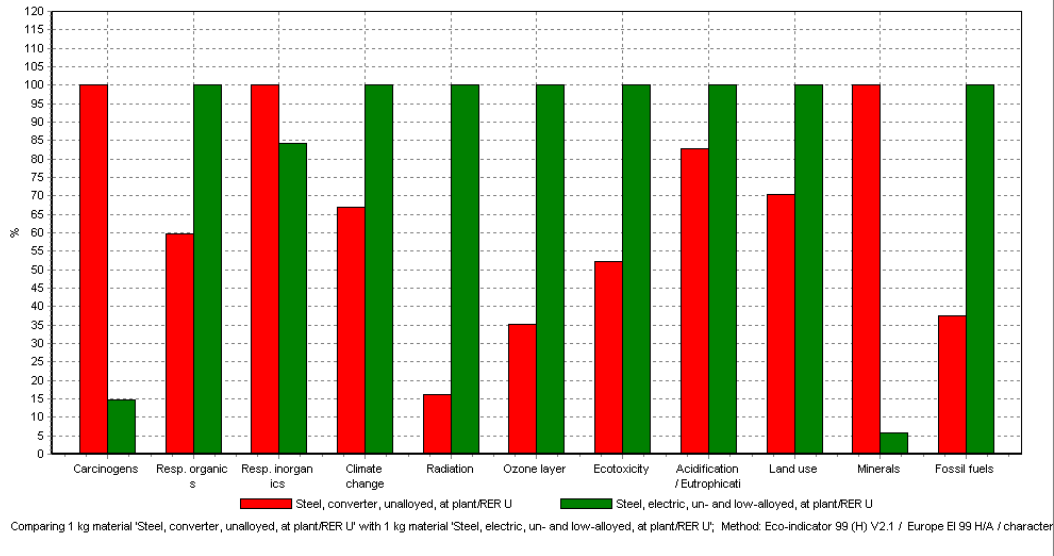
Figure 27   Standard comparison between two ways of producing steel. We see that Electro steel has a lower impact on Carcinogens, Respiratory Inorganic and Minerals
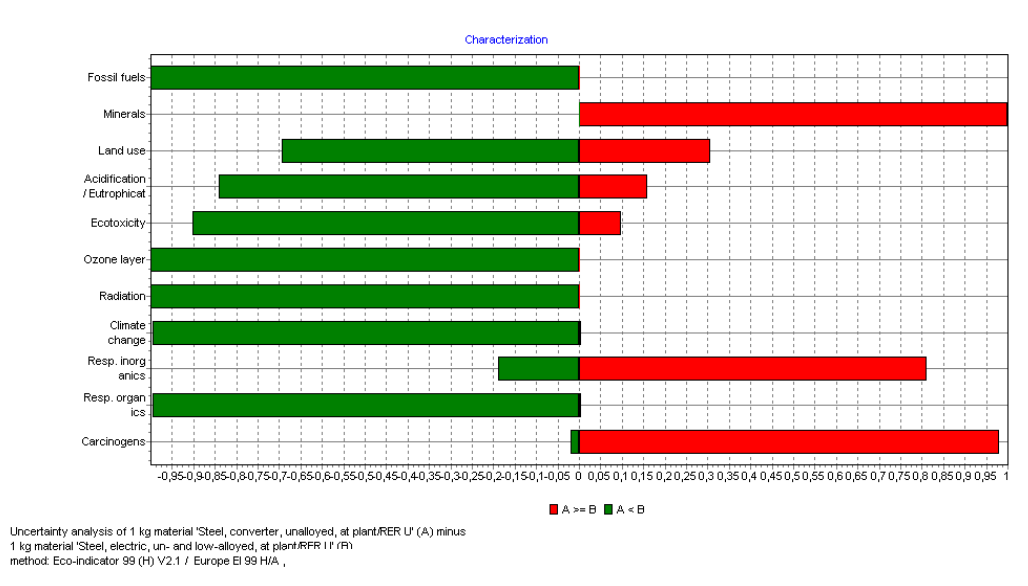
Figure 28   Monte Carlo results of a comparison. In this figure the number of outcomes where converter steel has a higher score than the electro steel are shown per impact category. This allows us to see whether the differences shown in the previous figure are indeed significant. In general we can assume that if 90 to 95% of the Monte Carlo runs are favourable for a product, the difference may be considered significant. Applying this rule means that only the difference between the two processes are not significant for Land use, Acidification and Respiratory inorganic

Figures 27 and 28 show that although the absolute uncertainties for each impact category are high, this way of comparing results does indeed lead to useful conclusions. Again this is only possible because SimaPro does keep track of the correlations between the two systems. Similar graphs can also be made for damage scores and single scores.

Finally, SimaPro can also show a graphical distribution of the uncertainty in the differences between two product systems. This gives a better understanding of the difference, but usually it will give no other insights than the previous figure.
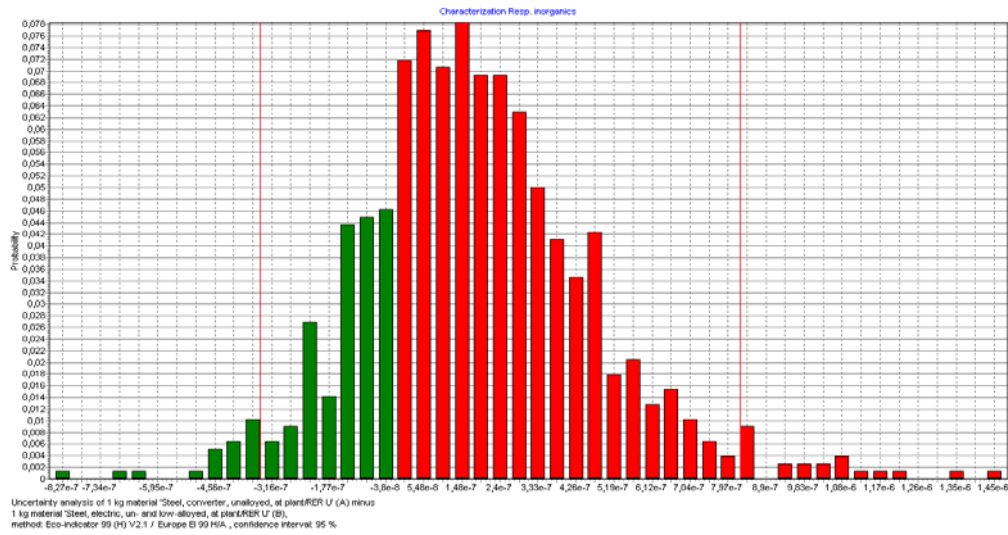
Figure 29　　*Graphical representation of the difference between Converter and Electro steel during each calculation run. The bars that represent a negative value are plotted in a green colour. A negative value means in this case, Converter steel has a lower score than Electro steel*

10 Parameters and scenarios

In several textboxes of this manual we describe the possibility to use parameters in the inventory model. In this chapter we shall describe them in some more detail.

10.1 Applications of parameters

10.1.1 Parameterise the product you are analysing

In the guided tour manual a very simple LCA of a wooden shed is used as example. In the example only fixed figures are used to describe mass, painted surface and the plastic roof.

This example can also be defined with parameters that define the dimensions and the shape of the shed, like:

dimension	Value	Unit (remark)
width	3	Meter
length	2	Meter
height	2	Meter
roof_slope	0,5	slope expressed in radials (57,3 degree =1)
roof_overhang	0,2	Meter
wall_thickness	0,0022	M3
sp_mass_wood	800	kg/m3
roof_thickness	0,003	Meter

With these parameters, SimaPro can do a number of calculations, like:
The wall surface, that can be calculated as twice the front and back wall (2 x height x width) plus the two side walls (2 x height x depth). If the roof is sloped, we can also add the triangular parts just under the roof. The size depends on the roof angle, and those who remember the old formulas know that you need to calculate the tan (roof angle) to get to the surface of that area.
In fact the angle also determines the roof area, and for this you need to know the cosinus of the roof angle. See the Tutorial for more details.

The table below summarises the calculations SimaPro can do for you; it calculates the surface of roof and walls, it can calculate the volume of the wood needed and the mass of the wood needed.

result	Formula	Remark
wall_surface	2*width*height + 2*length*height + 2*width*tan(roof_slope)*width = 29,8	the last part refers to the triangular part of front and back under the roof
roof_surface	2*(length + 2*roof_overhang) * (2*roof_overhang + width/cos(roof_slope)) = 18,3	the size depends on overhang, roof sloop, length and width
wood_volume	wall_thickness * wall_surface + roof_thickness*roof_surface = 0,121	m3
wood_mass	wood_volume * sp_mass_wood = 96,5	Kg

These tables can also be entered in each assembly, and this looks like the figure below.

Figure 30   The entered parameters in a wood process. (example taken from the tutorial, lesson 2c)

Once these parameters are defined, you can now very easily determine:

1. the total amount of wood that will go into the shed
2. the surface that needs to be painted
3. the amount of roofing material needed

In SimaPro, you can do this as shown below

Figure 31   An overview of an assembly of a product stage.

This way of developing the shed has the big advantage that, by changing just one or a few parameters, you can analyse many different versions of the same product, and find out the most optimal solution.

Further sophistication

In general planks come in standard size width and length. If you design a wall with a length of 2 meter, while a standard length is 2.10, you loose 10 centimeter, or 5% of each plank. if you design a 1.90 meter wall you lose even more.

In SimaPro you can calculate how much you loose by taking the "modulo" of the designed wall length and the nearest standard length. The modulo is the part of the result of a division. You can also do this for the roof panels and the width of the planks.

10.1.2 Parameters for sensitivity analysis

For sensitivity analysis you often want to rerun the LCA calculation with different system boundaries or allocation principles. In the tutorial we show how you can switch between allocation based on a mass and on value. The example is a saw mill that produced both planks and sawdust. Below we show a way to define parameters for this application. this example also illustrates, how you can define uncertainty ranges. Note that the way we modelled uncertainty ranges in the allocation, respects the rule that the sum of both allocation percentages is always equal to 100%.

Figure 32   The use of parameters for sensitivity analysis.

Once the parameters are defined in this way, they can be used in a process record, as shown below.

Figure 33   Using parameters in a process record.

Note that, by simply switching the value of the parameter econ_all from one to zero and back, you switch between economic and mass based allocation. Especially if you have an allocation choice in several places in your LCI, this way of modelling becomes very convenient.

10.2 Scenarios

The strength of parameters is in the possibility to quickly make different versions of your model. The parameter sets option allows you to compare two or more versions of the same model. You can define parameter sets (scenarios) using the "calculation setup" boxes.

In the example below (figure 34) you see two different version of the same shed, each with different dimensions. You can also see that both sheds use the same economic allocation, but also this can be changed in each model.

Different scenarios are really very useful in making semi automatic sensitivity analysis. In the Goal and scope you can plan ahead which assumptions you would like to change, and based on this, you can already define parameters during the data entry phase.
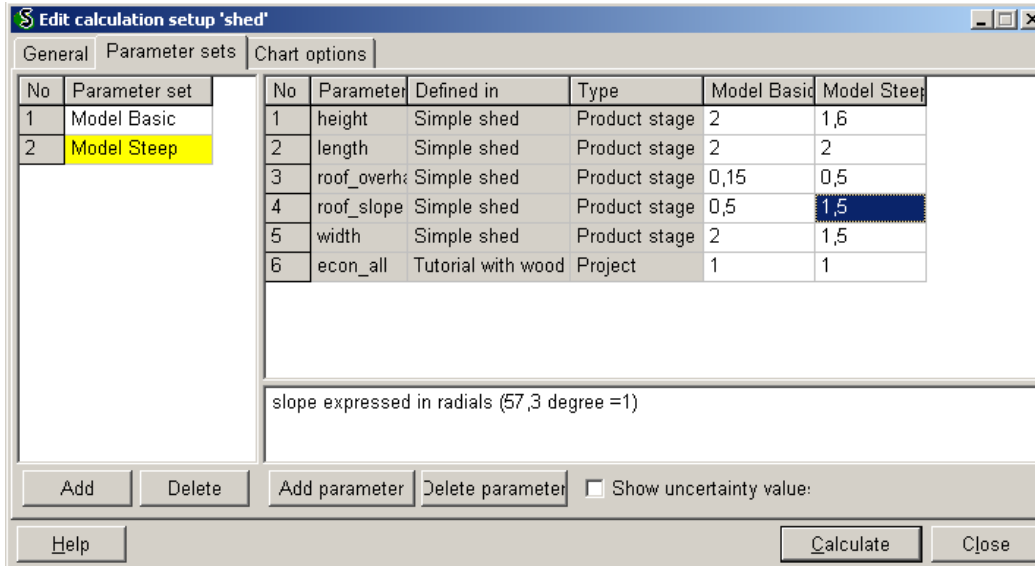

Figure 34   Defining different scenarios for the same shed, using the option parameter sets.

10.3 Link parameters to outside data sources

In the SimaPro developer version, you can also store the values of fixed parameters in spreadsheets or SQL databases. This opens up many possibilities, like:
* Ask people to provide data in excel on a regular basis, and refer to this excel sheet instead of typing over the data into SimaPro
* Link to an SQL database that has recent emissions, or recent production data, and get an updated LCA whenever you need it
* Link to a financial system and assess the environmental load connected to expenditures. A very convenient way to do this is to use input output data.

Figure 35   *An overview of how links can be implemented. A spreadsheet contains some emission data, and the processes record links to the spreadsheet. Links to an SQL database can be made in a very similar way.*

10.4 Some more details about parameters

10.4.1 Parameter types

There are two types of parameters:

1. Constant parameters. These are parameters that can have a value, but this value is independent of other parameters. Example: Total_distance=300
2. Expression Parameters. These are parameters that dependent on other parameters, through an expression (or formula). Example: Truck_distance= Total_distance – Boat_distance, assuming Boat distance is defined elsewhere.

The expressions do not need to be a simple as in this example. In fact you can use a wide range of expressions.

10.4.2 Parameter names

Expressions can be given any name as long as it only contains alphabetic characters, numbers or underscores, and as long as the name does not start with a number. This means that there can be no spaces in a name; instead you can use the underscore (_). The length of a parameter name cannot be longer than 15 characters.

Another important aspect of parameter names is that they are not stored on a central location, like substance names or waste types. This adds to the flexibility of the system, but introduces the risk that a typo in a parameter name may case a parameter not to be recognised. For instance in the example introduced in 10.4.1 there would be a problem if you would Write Truck_distance=Total- Boat_distance. SimaPro would not recognise that with Total, you intent to refer to Total_distance.

As soon as you have entered an Constant or an Expression parameters, SimaPro will attempt to calculate the numerical value and display this. If you made an error in an expression parameter, you will see a question mark, instead of a nummerical value, or an error message will appear.

10.4.3 Operations and expressions

The table below gives an overview of the operations you can perform with parameters:

Symbol	Explanation	Symbol	Explanation
+	Add	And	Logical And
-	Substract	Or	Logical Or
*	Multiply	Xor	Logical Xor
/	Divide	Not	
^	Power		
Div	Divide Int, returns only the integer part of a division	Pi	Pi
Mod	Modulo (what remains after a Div)	True	True
>	Greater Then	False	False
<	Smaller Then	(	Bracket Open
=	Equal	)	Bracket Close
<>	UnEqual		
>=	Greater Or Equal Then		
<=	Smaller Or Equal Then		

You can also use the following mathematical and logic functions:

Symbol	Explanation	Symbol	Explanation
SQR	square value for x (= x^2)	POWER	x to a power of y (y is floating point value)
SQRT	square root value for x	IPOWER	x to a power of y (y is integer value)
ABS	absolute value of x	SIN	sine value of x
TRUNC	integer part of x (same as Int(x))	COS	cosine value of x
INT	integer part of x	TAN	tangent value of x
FRAC	fractional part value of x	COTAN	cotangent value of x
ROUND	Rounds x to the nearest integer value	ASIN	arcsine value of x
CEIL	ceil integer value of x	ACOS	arccosine value of x
FLOOR	floor integer value of x	ATAN	arctangent value of x
IIF	if L<>0 then A else B	SINH	hyperbolic sine value of x
MAX	maximum value of input values x1 x2 x3 …	COSH	hyperbolic cosine value of x
MIN	minimum value of input values x1 x2 x3 …	TANH	hyperbolic tangent value of x
EXP	exponent value for the x	NOT	logical NOT of x (if x=0; 1 else 0)
LN	natural logarithm value of x		
LG	decimal logarithm value of x		

10.4.4 Parameter levels

Parameters can be defined on three levels:

1. Database parameters; these parameters have a meaning throughout all libraries and projects. For instance if you define a parameter A and you give it a value 3, you will find that in all libraries A is an available parameter, and it has a value 3
2. Project parameters; these parameters have a meaning, only in the project you are working in. For instance, you can define a parameter B in one project, and you can also define it in another project or library. In each project, it can have a different meaning; they are independent. In the example above the parameters for allocation were defined on this level.

3. Local parameters; these are parameters that only have a meaning in a single process record or product stage. For instance you can define a local parameter C in many different processes, and they all can have a different meaning or purpose. In the example above the parameters for the shed were define defined on local level, in the assembly.

The use of levels greatly simplifies the maintenance of parameters. As a general advise we recommend to be careful with database levels, because they can influence the outcome of all you projects, and this may be annoying if you want to archive data.

When you define a parameter, you have the option to tick a box in the field "hide" if you do so, you will not be able to see this parameter, when you define a scenario. This function is implemented to limit the complexity of the scenarios

10.5 Some details on scenarios

You can define a scenarios as part of a calculation set-up. It is also possible to define a scenario after you press the calculate result command. The calculation setup box that appears has three tabs, and the last tab has the scenario definition fields.

The figure below shows the calculation set-up box with an example of the Tutorial. On the fore ground you see the box from which you select parameters you want to add. The box is empty when you open it the first time, but will be filled when you click the scan button.
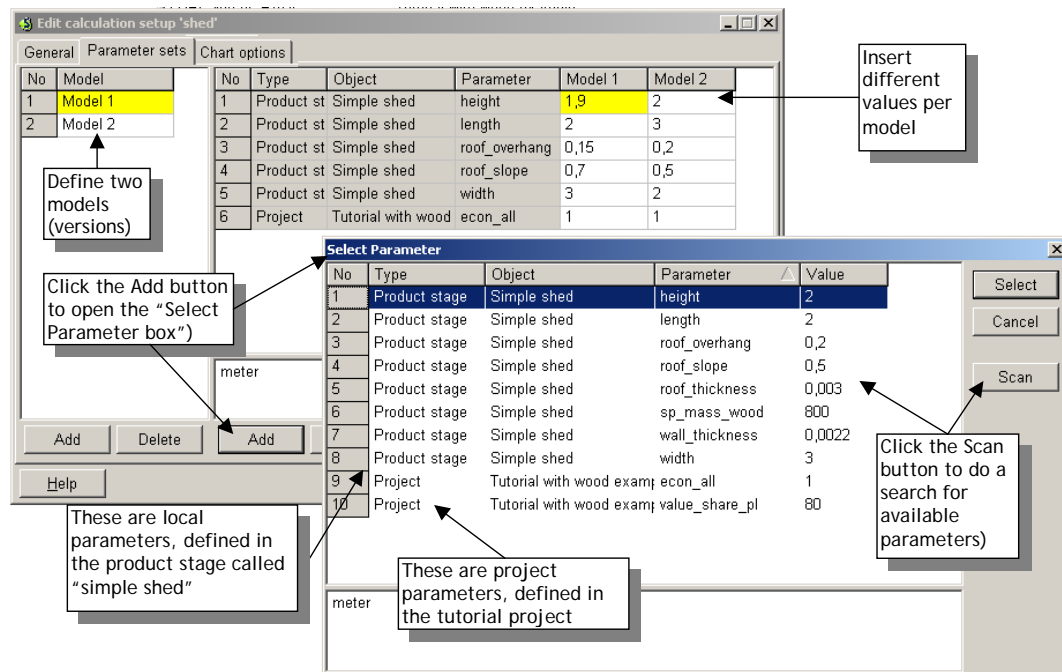
Figure 36   Overview of a calculation set-up box.

11   Developing advanced applications

11.1 Developing Wizards

Any LCA expert with a SimaPro Developer licence can develop new wizards. The LCA expert can assume the responsibility that the Wizard results in a methodologically correct LCA, while the user can take the responsibility that the product and life cycle are properly defined.

Wizards are run as an extra layer on SimaPro. Although the user only sees the questions and the results of the LCA, underneath the Wizard the full SimaPro database and all the intermediate results are available for further inspection the results are thus completely transparent.

The concept of Wizards

Wizards present themselves as a series of questions to the user. The questions focus on the functional unit, product composition, use and some basic assumptions. By answering the questions, the user can perform its own LCA, without actually having to understand all the details of LCA methodology, or how SimaPro works.
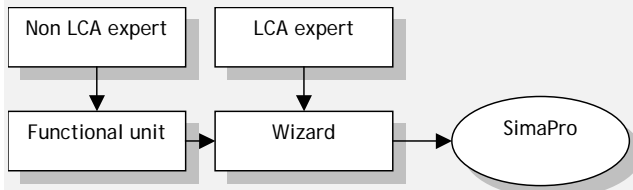
The LCA expert can develop an interface between the non-expert user and the tool. The expert is responsible for developing the interface and the database in such a way that the results are methodologically correct. The user is responsible for submitting correct data on the product composition and the life cycle.

Wizards as alternative to an LCA report

 Writing Wizards is often not more costly than writing a report, and we believe Wizards are a very good alternative to a report. The Wizards can be presented in the low cost SimaPro Compact version. On www.pre.nl some examples of projects using Wizards can be found.

 Compared to an LCA report a Wizard solution has the following advantages:

- In an LCA report, usually only a few alternative scenarios are presented. With a Wizard tool, the user can calculate all alternatives
- The Wizard tool can also be used for new product development

The Wizard tool is much more transparent, no need to search in endless data annexes.

Structure of the Wizard-programming language

When you run a Wizard, you see a number of screens with questions and usually some predefined answers. Each screen is defined in a *Node*. Apart from the visible nodes, there are some invisible nodes. Nodes are placed in a logical order to from a Wizard.
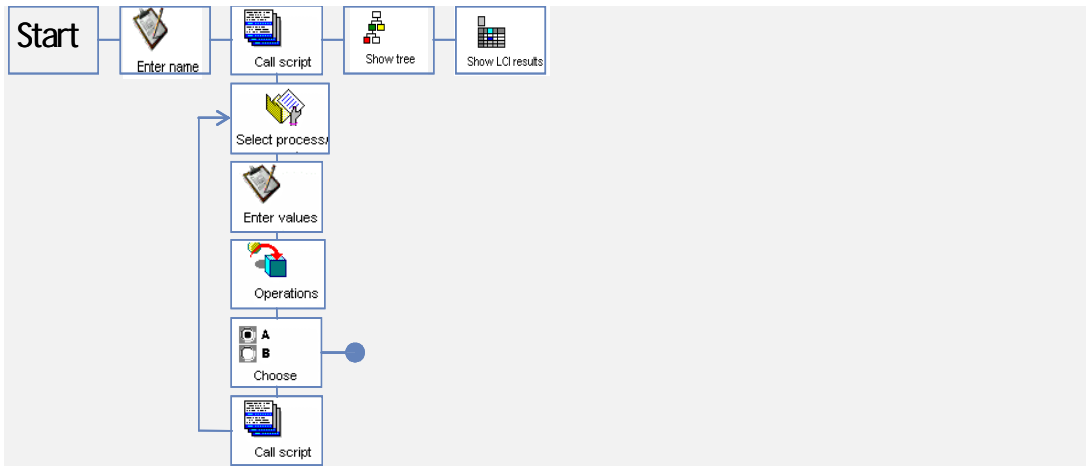
A useful feature in the Wizard language is the possibility to jump from one node into another. This allows for efficient programming, as you can define a number of sub-wizards that perform some tasks that can be repeated. This jumping also allows you to design alternative routes or branches through the Wizard. For example, you can ask the user in a certain node if he wants to compare two products, or to define another product. Depending on the answer, another Wizard is activated as the next node.

The main task in Wizard programming is defining nodes. Most nodes are quite easy to define, although there are also some more complex nodes:

General node

Message node: displays a message to the user.

Data entry node

- Enter text node, allows user to give enter a name; for example the name of an assembly.
- Enter value node, allows user to enter a value; for example the amount of steel in an assembly.
- Select process node, allows user to select a process into an assembly; for example, he can choose between the different types of steel in the database.
- Choose Wizard route node, allows a user to decide which is the next task.

Processing nodes (usually invisible nodes)

- Call Wizard node, jumps to and activates another Wizard, or jump to a document or website.
- Operations node, This is one of the most complex and advanced nodes. It allows you to include arithmetic operations within the Wizard. For example, you ask the user for the height and width, and you let the operation node calculate the surface.

Result nodes

- Calculate node, lets SimaPro perform calculations.
- Show Graph node, lets SimaPro show the results of impact assessment in a predefined way.
- Show Substance node, lets SimaPro show the LCI results.
- Show process tree node, lets SimaPro display a graphical process tree representation.

While the user goes through the Wizards, he enters data. This data is stored in variables. In addition, the Wizard nodes themselves can create new information that need to be stored in variables. A debugging window is available to see how the contents of the variables change during test runs of the Wizards during the development. It is also possible to define conversion factors for the Wizard variables. These are defined under the general data section. In the help file, you will find more information on the specifics of these nodes. A Wizard manual is available from PRé Consultants.

11.2 Integrating SimaPro with other software

The SimaPro Developer version has a COM interface. This interface can link SimaPro and other software. This opens the possibility to link all kind of data sources to the LCA data in SimaPro. For instance:

- Your CAD application sends a command to SimaPro: Calculate the CO2 score for the steel in part x. SimaPro will perform this calculation directly, as if it forms a part of the CAD system.
- Your enterprise resource planning system (ERP) or accounting system provides a monthly update of all material energy and transport flows in a department and an LCA profile can be automatically generated.

The results can easily be disseminated throughout the intranet or internet. A very important feature is that while SimaPro is available as multi user version, the LCA expert can continuously work to update the database, while the system is running.
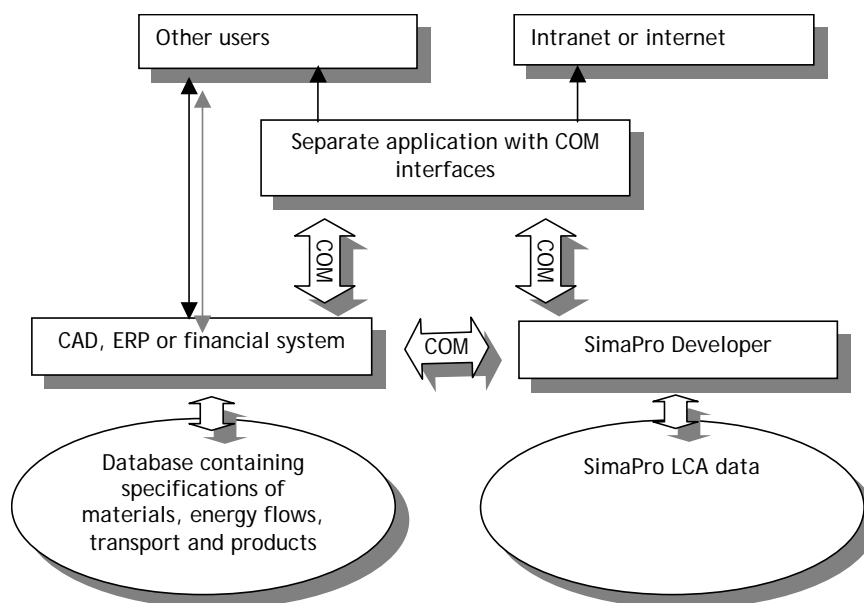
An alternative way to link SimaPro to outside data sources is the use of external parameters, as described in section 10.3.

Glossary

Allocation	Partitioning the input or output flows of a process or other product system to the product system under study (ISO 14040).
Assembly	Can be understood as the definition of a product, containing all materials, transport, energy processes and subassemblies.
BUWAL database	Database from the Swiss Agency for the Environment, Forests and Landscape (Bundesamt für Umwelt, Wald und Landschaft).
Capital goods	Goods that are a one-off investment, like trucks or machines.
Category endpoint	Attribute or aspect of natural environment, human health, or resources, identifying an environmental issue of concern (ISO 14040).
Cut-off criteria	Specification of amount of material or energy flow, or level of environmental significance associated with unit processes or product system to be excluded from a study (ISO 14040).
Damage analysis	To find out the total damage a chemical substance can cause (how many people, the severity of the disease).
Ecoinvent	The Swiss center for Life Cycle Inventories. It is responsible for extending, updating and to preserve the high quality of the Ecoinvent 2000 database. The data in this database derives from different LCI databases, mainly BUWAL and ETH-ESU 96, and covers many areas.
Eco-it tool	A tool to make an LCA in a few minutes, when all required single scores are in the database.
Effect analysis	To find out what effect a chemical substance can cause (kind of diseases) with a specific concentration.
Endpoints	Term introduced in (but, unfortunately not defined in) ISO 14042 refers to the final outcome of an environmental mechanism. For instance the outcome of climate change can be an increase of seawater level. In older LCA literature this was referred to as the safeguard subject; the issue society wants to protect (see also category endpoint).
ETH-ESU database	A database derived the former energy-materials-environment group (Energie-Stoffe-Umwelt, ESU) at the Swiss Federal Institute of Technology (Eindgenössische Technische Hochschule, ETH).
Fate analysis	To find out in which environmental compartment (air, water, soil) a chemical substance finally will turn up.
Functional unit	Quantified performance of a product system for use as a reference unit (ISO 14040).
Impact category	Class representing environmental issues of concern to which LCI results may be assigned (ISO 14040).
Library	A place used to store background data and methodologies. This data can in a further stage serve as a resource for a project.
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to final disposal (ISO 14040).
Life Cycle Assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040).

Life Cycle Impact Assessment   Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (ISO 14040).

Life Cycle Inventory analysis   A phase of life cycle assessment involving the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle (ISO 14040).

Life Cycle Inventory Results   A list of emissions, resource uses, land use, etc. that are collected, before impact assessment is applied.

Midpoints See also Endpoint.   The term midpoint refers to an indicator that is somewhere along the environmental mechanism and the LCI parameter. For instance the CO2 equivalents that express the radiative forcing is a midpoint. It is needed to calculate an endpoint indicator, such as increased seawater level, but additional modelling steps are needed

Monte Carlo analysis   An analytical method that randomly generates values for uncertain variables by running a model fitted to an experimental dataset.

Normalisation   A procedure to show to what extent an impact category contributes to the overall environmental problem.

OECD countries   Those countries (in total 20) who signed the Convention on the Organization for Economic Co-operation and Development.

Product stages   Stages that are used to describe the composition of the product, the use phase and the disposal route of the product.

Product system   Collection of unit processes with elementary and product flows, performing one or more defined functions that models the life cycle of a product (ISO 14040).

Reference flow   Measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit (ISO 14040).

Weighting   Is the process in which the various indicators, resulting from an LCA study, are aggregated in one figure (or a limited number of figures) through the use of subjective weighting factors.

Weighting factor   A factor that is coupled at a certain impact category, which is determined by a panel based on subjective opinions and reflects the importance of the category.

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