

Introduction to LCA with SimaPro



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1 Introduction to LCA with SimaPro

1.1 Introducing LCA into your organization

LCA is a tool for quantifying the environmental performance of products taking into account the complete life cycle, starting from the production of raw materials to the final disposal of the products, including material recycling if needed. The most important applications for an LCA are:

- Identification of improvement opportunities through identifying environmental hot spots in the life cycle of a product.
- Analysis of the contribution of the life cycle stages to the overall environmental load, usually with the objective of prioritizing improvements on products or processes.
- Comparison between products for internal or external communication, and as a basis for environmental product declarations.
- The basis for standardized metrics and the identification of Key Performance Indicators used in companies for life cycle management and decision support.

In recent years, life cycle thinking has taken a more prominent role in environmental policy making. Renowned institutions such as the World Resource Institute (WRI), have adopted life cycle thinking and an increasing number of different stakeholders are feeling the pressure to reduce the environmental impact associated with global consumption. As a result, we are witnessing a shift from government-led initiatives towards more private-led initiatives such as the Sustainability Consortium and Product Category Rules (PCR's) developed by trade and governmental organizations. In parallel to these activities the European Commission is working on a standard for environmental footprinting with the ILCD handbook.

LCA provides the quantitative and scientific basis for all these activities. In many cases, LCA feeds the internal and external discussions and communication. Being active in LCA means being able to communicate the environmental impacts of products and business processes. This manual provides an introduction to the LCA methodology and explains how you can carry out an LCA using SimaPro, the world's most widely used LCA software.

How this introduction is written

This introduction provides general information about the background of the life cycle assessment methodology, and provides suggestions on how to perform an LCA study. 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 organizational aspects of LCA, while chapters 7 to 10 deal with the way you model life cycles in SimaPro.

Once we have introduced you to the most important concepts and the LCA terminology, we suggest that you start SimaPro and experiment with the software. We have invested a lot of effort in developing 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 at <http://www.pre-sustainability.com/manuals> or via the SimaPro Help menu.

1.2 The steps of an LCA

An LCA study consists of four main phases:

- Step 1: Defining the goal and scope of the study.
- Step 2: Making a model of the product life cycle with all the environmental inputs and outputs. This data collection effort is usually referred to as life cycle inventory (LCI).
- Step 3: Understanding the environmental relevance of all the inputs and outputs. This is referred to as life cycle impact assessment (LCIA).
- Step 4: The interpretation of the study.

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

In the past, the initiator for an LCA was usually the marketing department, who wanted to communicate the environmental benefits of the company's products. And more often than not the marketing department discovered that the LCA results were too difficult to communicate. Other departments, usually R&D or the environmental department, then took over the role as initiators leading to a common pitfall when trying to implement an LCA: the lack of a clear purpose and intended application of an LCA. Nowadays sustainability is slowly shifting from an ad-hoc activity towards an activity which is embedded in companies, whereby LCA is used to monitor and measure the environmental impacts. A recent survey by Sloan 2012 shows that 70 % of managers state that sustainability is permanently on their companies' corporate agenda. This report shows that sustainability is becoming a tool for value creation rather than a tool for cost reduction. The focus is shifting from internal activities and cost reduction strategies towards a focus on better products with higher market shares. These frontrunner companies are the so-called 'embracers' of sustainability.

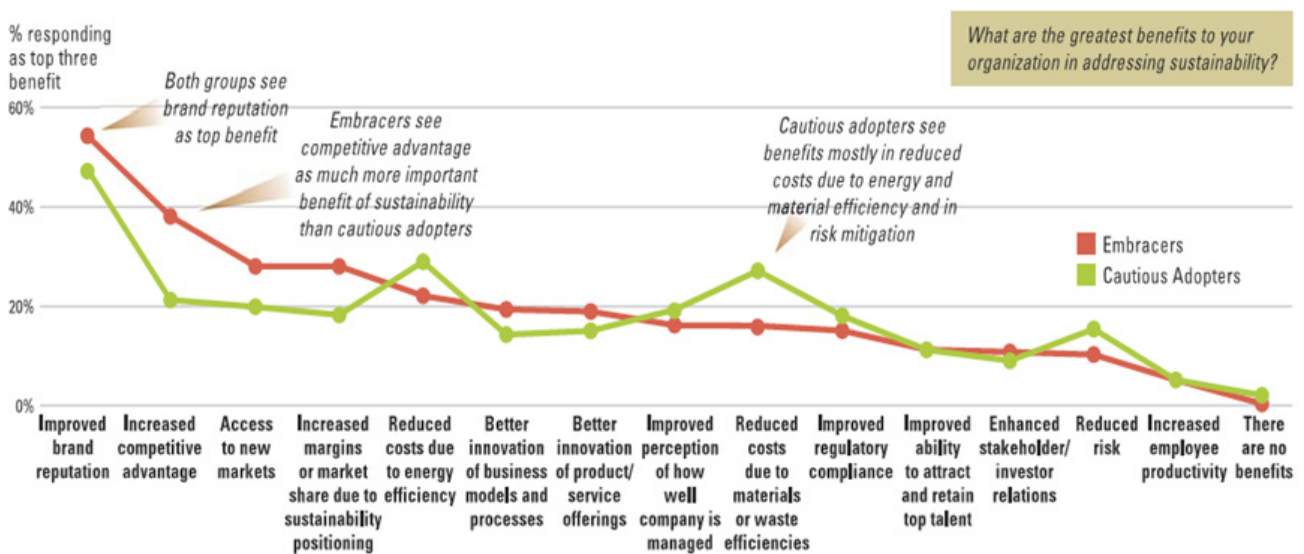


Figure 1: Sustainability nears tipping point

1.4 Standards for LCA

1.4.1 ISO standards

The leading standards for LCA are:

- ISO 14040: Principles and Framework
- ISO 14044: Requirements and Guidelines

ISO 14040 considers the principles and framework for an LCA, while ISO 14044 specifies the requirements and guidelines for carrying out an LCA study.

The ISO standards are defined in a rather vague language, which makes it difficult to assess whether an LCA has been made according to the standard. Unlike the 14000 standard, it is not possible to get an official accreditation stating that an LCA, LCA methodology, or LCA software has been made according to the ISO standard. Therefore, no software developer can claim that LCAs made with a certain software tool automatically conform to the ISO standards.

For example, ISO 14044 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 that it is your responsibility to use weighting in a proper way. A similar example can be made for issues such as allocation rules, system boundaries etc.

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

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.

1.4.2 Single issue standards

In addition to the LCA approach which includes multiple environmental issues, single issue LCA approaches have been developed lately, including carbon footprinting and water footprinting. These approaches also take a life cycle perspective but focus on one impact category only.

In response to societies' needs for transparency in the greenhouse gas (GHG) emissions of products, several carbon footprinting standards have been developed or are still under development. There are two main standards: GHG Protocol and the draft ISO 14067. The draft ISO 14046 on the quantification of water footprints for products, processes, and organizations is under development since 2009. This standard takes a life cycle approach but focuses solely on water use.

1.4.3 Product category rules (PCR)

ISO 14040/44 is the basis for many other standards. ISO 14025, for example, is based on ISO 14040/44 and introduces two concepts: Product Category Rules (PCR) and Environmental Product Declarations (EPD). PCRs are specific guidelines for the calculation of the environmental impact of products within the same product category. A product category is a group of products with similar characteristics. PCRs contain strict requirements that leave less room for interpretation than a general LCA. A PCR can specify, for example, the functional unit that should be used, or the databases that should be used, or the impact categories that should be included in the study. By following the requirements in the PCR, a company can develop an EPD, which is a concise document containing relevant environmental information about a product. PCRs require a Program Operator. Program Operators can be a group of companies, an industrial sector, trade organization, or a public authority. Examples of program operators are Environdec (located in Sweden, with an international focus), PlasticsEurope (the Association of plastics manufacturers in Europe), Institut Bauen und Umwelt (Germany), EPD-norge (Norway) and JEMAI (Japan). An overview of PCRs from various Program Operators can be found at: <http://pcr-library.edf.org.tw/index.asp>. The site of program operator Environdec (<http://www.environdec.com>) also provides PCRs and additional information can be found at the Global Environmental Declarations Network (GEDnet) <http://gednet.org/>. GEDnet is a platform for program operators to share information and cooperate on EPD's.

1.4.4 Environmental product declarations (EPD)

The development of environmental product declarations (EPDs) has become a major application of an LCA. In some countries and sectors, hundreds of thousands of products now have such a declaration. The declaration generally consists of a series of impact category indicator results.

Today, three types of environmental communication are available: Type I, II, and III. Type III is the actual environmental product declaration (EPD), for which an ISO standard (14025) provides guidelines. These guidelines are not specific enough to make EPDs. Instead the standard describes a procedure to make more specific product category rules. Without such rules one cannot produce an EPD.

Once a PCR is found, the LCA is performed according to the specification in the EPD. You will find that these rules are usually quite straightforward, and allow for rather simple procedures. Also the impact assessment method is relatively simple. In general, the impact categories are limited to:

- Non-renewable resources (with and without energy content)
- Renewable resources (with and without energy content)
- Global warming (CO₂ equivalents)
- Acidification (kmol H⁺)
- Ozone layer depletion (kg CFC11 equivalents)
- Photochemical oxidant formation (kg ethane-equivalents)
- Eutrophication (kg O₂)

These impact categories are defined in a similar way as the CML 1992 method, but there are some differences.

1.4.5 LCA guidance at the European level

At European level, the ILCD Handbook, prepared by the Joint Research Centre – Institute for Environment and Sustainability (JRC-IES) was published in 2010. This Handbook is based on the ISO 14040/44 standards, but provides much more detailed technical guidance. The ILCD Handbook contains over 400 pages, whereas ISO 14040/44 jointly contain about 60 pages. The ILCD Handbook contains detailed descriptions and requirements in order to reduce flexibility in choices and to support consistency and quality assurance of LCA results. In the period between June 2011 to February 2012, DG Environment and JRC-IES developed and tested a harmonized methodology for the calculation of the environmental footprint of products and organizations, the so-called draft Product Environmental Footprint (PEF) and draft Organization Environmental Footprint (OEF) methods. These two methods build upon ISO 14040/44 and the ILCD Handbook, but are stricter and more concise. Product Footprint Category Rules (PFCR) and Organization Footprint Category Rules (OFCR) are developed in parallel. PFCR/OFCR are based on ISO 14025 and complement the general methodological guidance for environmental footprint by providing further specification at the product level. PFCR/OFCR will increase reproducibility and consistency in environmental footprint studies. Eventually, these two methods may become part of future European policies on sustainable consumption and production.

Functionality in SimaPro

SimaPro supports EPDs, GHG protocol and the ILCD handbook. SimaPro uses the default Swedish EPD impact assessment method. The new grouping function allows you to separate contributions of energy, transport, waste, or other parts of the product system (depending on the PCR). See also the SimaPro Tutorial, lesson 2d.

2 Goal and Scope Definition

An LCA models a product, service, or system life cycle. What is important to realize is that a model is a simplification of a complex reality and as with all simplifications this means that the reality will be distorted in some way. The challenge for an LCA practitioner is to develop the model in such a way that the simplifications and distortions do not influence the results too much.

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

- The reason for executing the LCA (the questions which need to be answered).
- A precise definition of the product, its life cycle and the function it fulfills.
- A definition of the functional unit (especially when products are to be compared).
- A description of the system boundaries and the way co-production 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 helps you ensure that you have performed your LCA consistently. The goal and scope is not set in stone and can be adjusted if, during the next steps of the LCA, the initial choices reveal themselves not to be optimal or practical. Any adjustments to the goal and scope should be described.

Goal and scope definition in SimaPro

In SimaPro, a special area is available to describe the goal and scope for each project. In that area, there are two sections:

1. 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.
2. 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 off 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.

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

2.1 Defining the goal

In the ISO standards there are some specific requirements for the goal definition:

- The application and intended audiences shall be described unambiguously. This is important since a study that aims to provide data that will be used internally can be structured differently compared to a study that aims to make comparisons between two products public. For example, in the latter case ISO states that weighting may not be used in impact assessment and that a peer review process is necessary. It is therefore important to communicate with stakeholders 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 or is the commissioner intending to provide information only, etc.

Some LCA studies serve more than one purpose. The results may be used both internally and externally. In such a case the implications of the dual purpose 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.

2.2 Defining the Scope

The scope of the study describes the most important methodological choices, assumptions, and limitations as described in the sections below. An LCA is an iterative process, thus the term 'initial' is added to most of the sections below. This means that one may start with a set of choices and requirements that may be adapted later when more information becomes available.

2.2.1 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 liters 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 since it is not always obvious what function a product fulfills. For example, what is the exact function of an ice cream, a car-sharing system, or a holiday?

2.2.2 Initial system boundaries

Product systems tend to be interrelated in a complex way. For example, trucks are used in an LCA on milk cartons. 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 becomes apparent that not all inputs and outputs in a product system can be traced and boundaries around the system need to be defined. By excluding certain parts, which means leaving them outside the system boundaries, the results may be affected.

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

- Will the production and disposal of capital goods be included? For example, the production and disposal of trucks, injection molding machines, etc. As with an 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: All processes including capital goods are included. Usually the capital goods are only modeled 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 also included. If it is, one can include the CO₂ 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 are 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 are accidentally sprayed outside the field.

Some suggestions for default system boundaries

In LCAs, capital goods are often not included. For most LCAs, not including capital goods can give satisfactory results. However, capital goods sometimes contribute up to 30% of the environmental impacts. For example, in an LCA including a significant amount of hydropower, leaving out capital goods would mean that all the infrastructure (dams, pipes etc.) is omitted, resulting in a significant underestimation of the environmental impact. In more modern databases, such as ecoinvent and the USA Input Output databases, capital goods are included. We suggest to always follow this principle when using background (secondary) data. For primary data collection, capital goods are in practice only included when they have a significant contribution to the environmental impact.

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 CO₂ uptake and the impact of land use are not included, but the estimated emissions of pesticides from the agricultural area to the surroundings are included. In some impact assessment methods, such as ReCiPe, this is already taken into account.

Switching system boundaries

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

In SimaPro, you can enter this amount of steel as an input in the injection molding process. However, instead of entering 10 grams as an amount, you can enter the simple formula: $S \cdot 10 \text{ gram}$. 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. You can introduce switches throughout your model. So, by controlling one parameter you can change the system boundary throughout your dataset.

2.2.3 Criteria for inclusion of inputs and outputs

In addition to the criteria for system boundaries a threshold can be set, below which data collection for an input or an output is not considered. ISO 14044 recommends using one or more of the following criteria for such a threshold:

1. If the mass of the inflow is lower than a certain percentage. The problem is that this only works for materials and not for transport distances and energy. Moreover, flows with a low mass could still have significant environmental impacts.
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 approach is that flows with a low value could still 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 we do not know the environmental contribution before the flow is investigated. Once it is investigated, it makes no sense to exclude it. Another problem is the use of the term 'the environmental load'. ISO has not defined this, and it is not clear whether the use of aggregated single environmental impact score results is permitted or not. If not, one must determine the contribution of a flow against all relevant data and impact categories which can be a complex process.

Recently, the use of input output data has been suggested as a viable way to estimate the "missing" environmental load. The principle behind this is explained in section 3.5. In a nutshell, it provides the environmental load per unit of costs. So, if the cost of the associated flow is known (as in option 2 above), an estimate of the environmental load can be made as an alternative for the process described in option 3.

Using thresholds in SimaPro

The effect of using cut-off criteria can be analyzed in the process tree or network window in SimaPro. In many LCAs, process trees become large. LCAs with over 2000 processes are quite common. These process trees contain many processes that have negligible contribution. 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 process 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.

2.2.4 Dealing with multifunctional processes

Many processes result in more than one product being produced. When life cycles are interconnected, or in other words, when the production of one product is dependent on the production of another product and cannot be separated, there are two main ways for dealing with this in LCA:

1. System expansion, also known as consequential modeling
2. Allocation, which is applied in attributional modeling

Consequential modeling

The type of modeling you choose depends on the goal and scope of your project. Consequential modeling is applied when you want to investigate the consequences of a change compared to a baseline situation. For example, the research question can be: how does the environmental impact change when product X is replaced by product Y? The environmental load of product X is then avoided and can be subtracted from product Y's environmental load. When there are multifunctional processes in the life cycle of product X, the resulting co-products and functions are also avoided and need to be replaced by alternative products and functions. Likewise, the co-products and functions in the life cycle of product Y replace other products and functions. Multifunctional processes can thus make consequential modeling complex and data demanding.

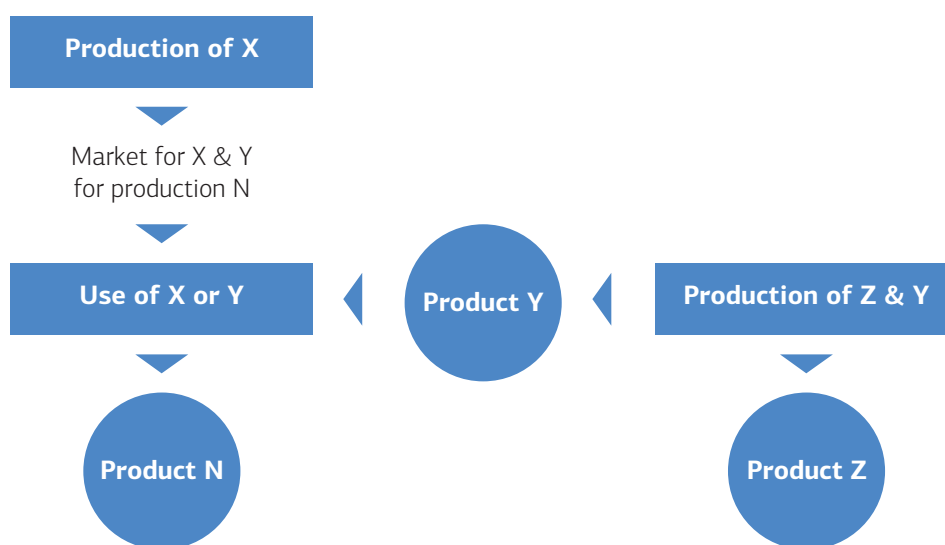


Figure 2: Consequential modeling

Moreover, it is not always straightforward which products and functions are avoided by the co-products and functions. The main requirement for choosing the avoided products and functions is that they must have the same functional unit. They should also come from the marginal processes, which can be the most outdated technique or the cheapest way of producing. Hence, this can be a rather subjective exercise. On the other hand, consequential modeling is the only way in LCA to investigate to which extent a supposed mitigation action really leads to reduced environmental impact.

Attributional modeling

Attributional modeling is chosen when you want to know the environmental impact of a product or function and the hotspots in its life cycle, or when you want to compare the impacts of two products with the same functional unit. All environmental inputs and outputs are summed from raw material extraction (cradle) to the gate of the product's or function's supplier or the waste treatment facilities (grave). The result of attributional modeling is, therefore, often referred to as an environmental footprint (or carbon footprint, water footprint, etc.). In the case of multifunctional processes the environmental load of the inputs and outputs is divided among the co-products and functions. There are three options for doing this and they must be applied in the following order:

1. Subdivide the multifunctional process
2. Determine a physical causality for allocation
3. Use the economic revenue as the key for allocation

Subdivide the multifunctional process

A process can be subdivided by identifying the inputs and outputs per sub-process. This can be a data demanding exercise and sometimes data is not available because it cannot be measured separately. For example, electricity and heat use is not always measured for each production line in a factory. Another situation where subdivision is not possible is when a raw material, such as crude oil or wheat grains, is split up into various co-products. When subdivision is not possible, a form of allocation must be applied.

Determine a physical causality for allocation

The physical causality for allocation is a relationship that determines the way in which quantitative changes of the products or functions delivered by the process, change the other inputs and outputs. This may be a physical property such as mass, volume, energy, exergy, number of units, chemical composition, or proteins. For example, when different products are transported in the same truck, the environmental inputs and outputs can be allocated based on the mass of the products as it affects the fuel consumption. However, if the limiting factor is volume, allocation based on volume may be more appropriate. In the case of combined heat and power, energy or exergy could be appropriate criteria for allocation.

Revenue as the criteria for allocation

Revenue is used as criteria for allocation when:

- a physical relationship cannot be established,
- there is no common physical characteristic (for example, for one co-product there is a relationship with its energy content and for the other there is a relationship with its mass), and/or,
- the co-products and functions are not produced by alternative single output processes.

Take, for example, a saw mill that makes wooden planks, but also produces sawdust in the process. If sawdust generates 20% of the saw mill's revenue, 20% of the environmental load is allocated to this output and 80% to wooden planks.

Although ISO mentions economic allocation as the last option, it is often used in practice. The strengths of economic allocation is that economic value is a good way to distinguish waste from an output. Additionally, it expresses the relative importance of an output. The weakness is that prices fluctuate, which can affect the results significantly, even if multiple year averages are used. Another problem in terms of data collection is that information about prices is not or cannot always be disclosed by the producer.

Allocation in SimaPro

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 could allocate 80% to planks and 20% to sawdust, 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 both in the comments section (in SimaPro) as well as in your report.

Switching allocation principles and dealing with uncertainties in SimaPro

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 section 5.3 in the SimaPro tutorial.

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 $(1-A)$.

3 Inventory

3.1 Introduction

The most demanding task in performing an LCA is data collection. Although a lot of secondary data is available in SimaPro, you will usually find that at least a few processes or materials are not available. Depending on the time and budget you have available, there are a number of strategies to collect missing data. It is useful to distinguish between two types of data:

1. **Foreground data**, which refers to specific data you need to acquire for modeling your system. Typically, it is data that describes a particular product system or a specialized production system.
2. **Background data**, which is data for the production of generic materials, energy, transport and waste management. This data you can find in SimaPro databases and from 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 probably consider the truck that is used to deliver the dishwasher as background data. The truck is probably not specifically made for transporting dishwashers, and there is no need to collect other data than the transport distance and the load efficiency. You can take the inputs and outputs of the truck's life cycle from the SimaPro databases. However, if you are making an LCA of trucks you cannot use a standard truck, and you will have to collect the inputs and outputs that are specific to the trucks as foreground data.

A practical approach to data collection

Start with making a 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 analyze 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 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 are interested in, you may use an estimate rather than collecting those data. 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 section 3.5 of this document.

Search for relevant literature data. There are many books that describe industrial processes and these often provide clear enough descriptions to estimate energy use, waste, and in some cases even emissions. This can also be a good starting point 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 need to be made to collect such data. It is important to establish good contacts with the people who are asked to fill in the questionnaire and to understand what these people know, in what way data is available, and what terminology and units are 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 depends on the kind of relationship you have with the data owners. Some parties will be interested as they may have similar goals; some will see your LCA activities as a threat. In some cases, most of the data collection effort is in establishing a good relationship in which people trust each other. At the very least you will have to be open about why you need the data, what will be done with it, and how it will be presented.
- Confidentiality issues can be important. Sometimes environmental input and output 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 play this role.
- Terminology issues. For each industry sector, there are different ways of measuring and expressing inputs and outputs. When you develop a questionnaire, you should try to use the terms and units 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, a questionnaire should be made with great care and should be focused on the target group. Here are some suggestions for developing a good questionnaire:

- **Generic information.** Start with collecting some generic information, such as annual reports and company brochures. This will help you understand how the company is organized and later, when you get the completed questionnaire, it will help you interpret the data.
- **Allocation.** 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 such as mass, volume, or revenue (see chapter 2).
 - 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 parameters are confidential. However, it makes identifying errors much more complex.
- **Explanation.** For each question, explain how to fill in the data but also briefly explain why you want to have the data in the first place. This not only motivates, but helps further explain the question. Ask what you need to know but no more. Do not let people work for data that is not really needed.
- **Data sections.** Split up the questions in clear blocks, each addressing 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.
- **Data quality.** Allow people to fill in estimates. Let the data provider indicate the source of the data. In the box, there is an example that can be used for this. At the right hand side, users can indicate which of three basic sources were used. This means that we allow for estimated data, but when we see that these estimates are highly relevant for the impact assessment results, we will go back to the data provider to ask for a better data source.
- **Simplicity.** Keep things simple for the data provider. This will reduce the risk of errors and ease interpretation.

Example of a questionnaire

The sample questionnaire presented below was developed for medium sized companies that were not expected to have explicit energy consumption data for different production steps. The assumption was that they would take energy data from their finance department by checking their invoices. This creates a problem when we want to split the production energy from the overheads, such as air-conditioning, lighting and heating.

In this case, we knew that the energy use in the production process was not important, justifying such a rough approach. If the process you are investigating is energy intensive you should develop a 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 between building (climate control etc.) and processing you can use a percentage.						Why do we want to know this? Energy is of course an important factor in the environmental load. Using these columns we want to precisely allocate the energy inputs to the production process.			Data Source for total		
Total	Total used in year X	Unit	Alt. Unit	Used for climate control, and lighting, etc.	Used for production machines	Direct data (derived directly from administrative systems)	Indirect data (based on some sort of calculation)	Estimated data			
Electricity from public grid		kWh		%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
Natural gas		MJ		%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
Light oil		MJ		%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
Heavy oil		MJ		%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
Coal		MJ		%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
Heat from other suppliers (for instance steam and hot water)		MJ		%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
Own electric power generation from other sources (wind, water, sun and biomass)		kWh		%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
Total energy consumption		MJ		%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			

Internet data search

Many LCA reports can be found on the internet. The International Journal of Life Cycle Assessment has a wealth of information as well. There are also some specialized internet sites such as <http://lca-data.org> which is a market place for LCA data. Another interesting site is www.life-cycle.org.

3.3 Background data

Depending on the goal and scope of your study, a large part of the data you will need will be background data, which you do not need to collect via a questionnaire. Background data is usually available in databases or can be found in literature. Using background data requires great care. You need to investigate how well the data found in databases fits with the requirements defined in the goal and scope. Below we describe the two most important data sources available to the LCA community: the ecoinvent database and the input-output databases.

Data libraries and projects

The (background) data in SimaPro is structured in such a way that you can distinguish between data that is only relevant for your current LCA project, and data that can be useful in any other (future) project. The latter type of data is not stored in projects but in libraries. All SimaPro versions include the comprehensive ecoinvent libraries. 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 your projects.

3.4 The ecoinvent database

SimaPro ¹ comes with the ecoinvent v3.0 database, covering over 10,000 processes. This database is the result of a joint effort by different Swiss institutions to update and integrate several life cycle inventory databases (figure 3).

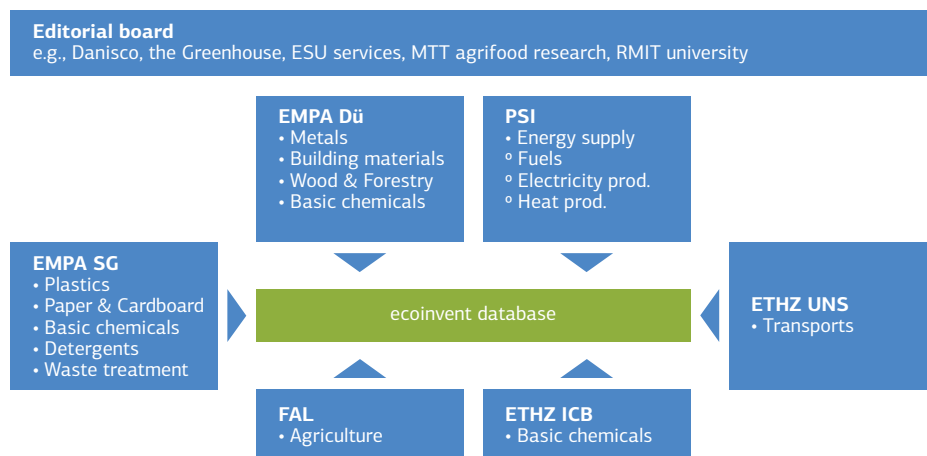


Figure 3: The Swiss organizations that have joined forces to create the ecoinvent database.

ETH Zurich, PSI, EMPA, EPF Lausanne and ART provide data for the ecoinvent database. A group of LCI experts from these institutions are responsible for the data collection. Additionally there is an "Editorial board" which is responsible for quality control. They perform the review, validation, and editing of all new datasets before their inclusion in the ecoinvent LCI database under the supervision of the LCI experts.

¹ The ecoinvent database is licensed in all SimaPro licenses.

3.4.1 Key characteristics

The ecoinvent database is extensively described on the ecoinvent website www.ecoinvent.org. You can register as a guest to see the metadata. Below is a summary of the key characteristics of the database:

- Covers a broad range of data.
- Consistent application of system boundaries and allocation.
- Well documented; the extensive ecoinvent background reports can be accessed via the SimaPro help menu, the ecoinvent website or the ecoinvent CD.
- Consistent specification of uncertainty data, usually as a lognormal distribution with standard deviation.
- Emissions are specified with sub-compartments, for example an emission to air can be specified as an emission in a high or low density population area or stratosphere. Impact assessment methods can differentiate between these specifications.
- Includes capital goods as a default, which is important for energy systems such as wind and hydropower, but also for transportation systems.
- Comes in the EcoSpold 2 format which has become a de-facto standard that is very (but not completely) in line with the ISO 14048 standard.
- Is updated regularly by the ecoinvent Centre.

This database is a rich resource which, in most cases, satisfies all your background data requirements. Version 3.0 of the ecoinvent database has a more international scope.

There are four dataset versions implemented in SimaPro:

1. Allocation default, unit processes
2. Allocation default, system processes
3. Consequential, unit processes
4. Consequential, system processes

The differences between allocation default, consequential, and unit and system processes are explained in the following sections.

3.4.2 Allocation default and consequential

An allocation dataset means that the principles of attributional modeling have been applied, whereas a consequential dataset means that the principles of consequential modeling have been applied. Default refers to the type of allocation employed i.e. mass or economic allocation, which in most cases is economic allocation (with some exceptions). The concepts of allocation and consequential modeling are explained in more detail in section 2.2.4.

3.4.3 Unit processes and system processes

Each process is provided in two versions: unit processes and system processes. You are free to choose which version you use since 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 called “Steelmaking”, contains data on “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 upstream unit processes, which you can look into. When you select this process, SimaPro will 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 through steelmaking are already in the process record. You will also find that there are no links to other processes. A system process is the inventory result of an overall LCA on steel making and gives no insight into the inputs and outputs of the separate supply chain processed in the production system. A system process is, therefore, considered as a black box. Which version you choose depends on a number of characteristics, as summarized in table 1.

Unit process	System process
Transparent (but big) process tree, that allows you to trace the contribution of all individual unit processes	Simple process tree
Contains uncertainty information, which allows you to run statistical analysis (Monte Carlo)	No uncertainty information
Relatively slow calculation	Fast calculation

Table 1: Differences between unit and 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 section 6.1).

3.5 Input output databases

Input output databases contain data per economic sector rather than per process as seen in conventional databases. For example, there is data in input-output databases on the agricultural sector, the banking sector, the transport and the consultancy sectors. The advantage of using this type of data is that you have an assessment for an entire economy. The disadvantage is that the result may not be specific enough for the research questions. For instance, you cannot compare two building materials if they both come from the same building materials sector. Please also check the manual 'Input Output in SimaPro', which can be found in SimaPro under Help > SimaPro Manuals.

Matrix inversion as calculation routine

SimaPro calculates the inventory by interpreting the process structure as a matrix that is solved (fast) with inversion techniques. This has the advantage that it can also calculate "looped" data structures, such as input output datasets and databases such as ecoinvent. The need for looped data can be easily illustrated by noticing that for example, truck transport is needed to produce trucks.

Matrix inversion as calculation routine

SimaPro can visualize non looped data in two ways:

1. A 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 large as this way of representing the data is not so efficient. However, it is a graph that can be 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 these processes to other processes. The network structure is more space efficient but is sometimes more complex.

In addition to these differences there are some other aspects that require attention:

- If a process such as electricity appears ten times, you may easily overlook the relative contribution of this process. In a network, you can easily recognize the contribution.
- In a tree, you can hide parts of the tree which you are not interested in. In a network, this is not possible, as networks often do not have separate branches; everything seems to be related to everything.

The most important difference, however, is that the tree structure cannot be used if data is looped. If we would allow this, we would see a repetition of the process tree with every loop. This means the number of processes would become infinitely large. In case you try to generate a tree visualization, SimaPro will check for loops, and if they exist, SimaPro will automatically switch to networks.

3.5.1 The concept of an input output table

Each national or regional economy can be described in a table as financial exchanges of supplies between sectors, as well as supplies to consumers, and supplies for export. In table 2, an example of an input output table is shown with three different sectors: agriculture, industry and services. The role of governments is omitted. In practice, the number of sectors ranges from 100 to 500. The supplies are noted in the rows.

Front/to	Agriculture	Industry	Services	Exports	Customers	Total
Agriculture	Supplies within	Supplies to industry	Supplies to services	Supplies to export	Supplies to consumers	Total value
Industry	Supplies to agriculture	Supplies within	Supplies to services	Supplies to export	Supplies to consumers	Total value
Service	Supplies to agriculture	Supplies to industry	Supplies within	Supplies to export	Supplies to consumers	Total value
Agriculture imports	Imports within the sector	Import to industry	Import to services			
Industry imports	Supplies to agriculture	Import within the sector	Import to services			
Services import	Supplies to agriculture	Import to industry	Imports within the sector			
Industry						
Total	Total cost	Total cost	Total cost			

Table 2: Schematic representation of the core of an input output table for just three economic sectors. The first three rows represent the supplies to different other sectors, to consumers and exports. The second three rows specify the imports.

A supply from one sector to another is the same as purchasing. So, the values in a column are the purchases of the column's sector. Purchases can be from sectors within the country or from imports. Most input output tables contain the same sectors within the country as abroad.

The total value generated by a sector is the sum of the values in the sector's 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 applying input output tables in LCA: all environmental data is divided by the added value of the sector, and the input output table is used to trace the supplies. This allows us to trace all environmental loads throughout the whole economy. There are no system boundary problems; 'everything' is 'included' and all allocations are based on economic value.

A common problem, however, is that the environmental load of imports are not always known. 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 industrialized countries, but is a bad assumption for imports from non-OECD countries. Nevertheless, this is often done.
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 well for large economies, such as the USA, which have a high domestic production compared to trade. For small economies with large trade volumes, such as the Netherlands, this approach results in large inaccuracies.

3.5.2 Using input output tables in your LCA

One of the consequences of using input-output (IO) tables is that you no longer use mass or energy as inputs, but economic value. You will need to know the prices (excluding taxes) of components, materials and services. Input output tables are especially suited for the following purposes:

- As an estimation for decisions on data collection cut-off
- To make screening LCAs
- As an estimate when it is difficult to get data

The latter is often done when services are used. 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 detailed input output database that has over 400 commodities, representing the entire USA economy. The USA Input Output database was compiled by Sangwon Suh, who used a wide variety of US data sources. The database is in many 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 manuals. These can be accessed via the help menu of SimaPro.

In figure 4, input output data for banking services is shown, called 'Monetary authorities and depository credit intermediation' in the database. The output unit is one dollar banking services provided. The economic flows are shown, without any environmental data. So, the line thickness represents the dollar value of the commodity flow. Based on this, we can conclude fuel and electricity are the most important inputs to banking services from a financial point of view, followed by services to buildings and food services.

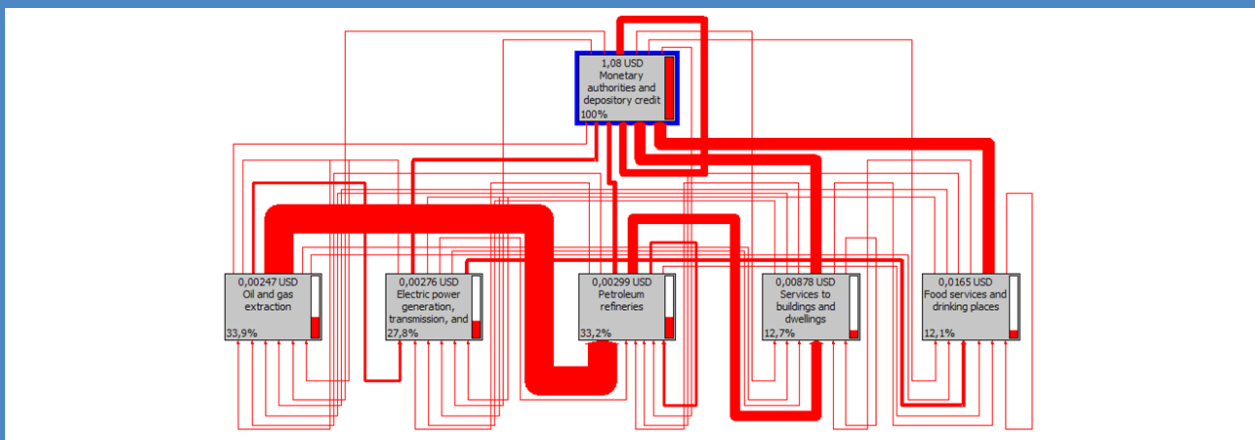


Figure 4: input output data for banking services in dollar per dollar output

In figure 5 the same analysis is used as in figure 4, but now the CO₂ emissions associated with the commodities are shown. Again electricity and food services have a high contribution, but here also air transportation and security are important.

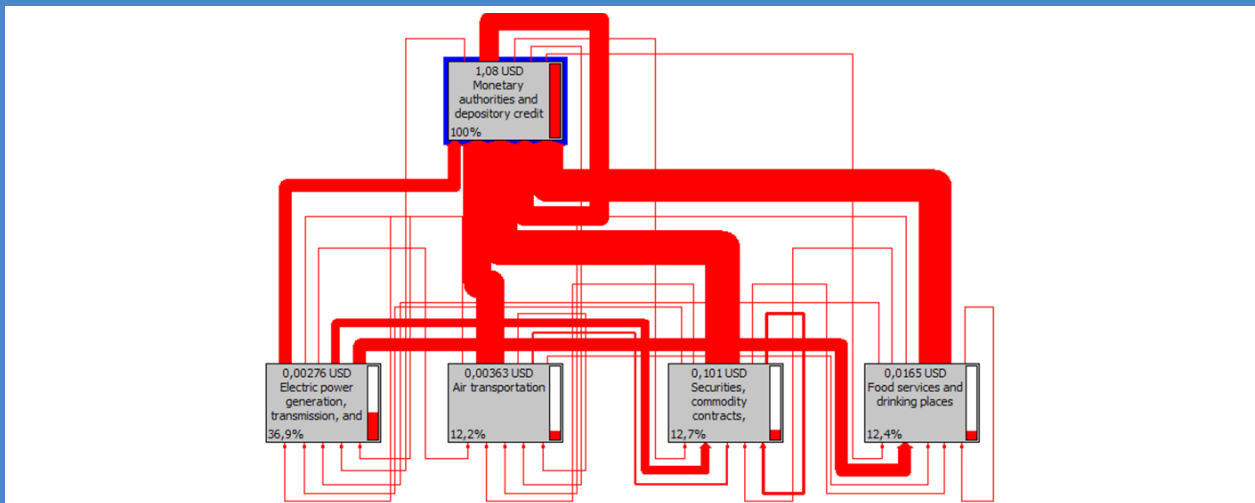


Figure 5: input output data for banking services in g CO₂ per dollar output

The example shows that Input output databases are useful for analyzing services, or for including services in a product LCA. Until now, services have often been neglected in LCA, while in some countries, services comprise two thirds of all economic activities.

3.6 The broader scope of sustainability

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

3.6.1 Social aspects

Social aspects relate to the impacts on different stakeholders groups throughout the life cycle of the product. The stakeholders that are most directly affected are employees, consumers, and local communities. Social aspects include issues like wages, health and safety, and access to education. The problem with assessing social issues is that the issues at stake are wide-ranging and often difficult to quantify in a meaningful way.

The first step to assess social impacts is the identification of the most relevant aspects. As the list of aspects increases by the day, you can consider the aspects recommended by four main references:

- The UNEP SETAC Guidelines for Social Life Cycle of Products link a list of social impacts with five stakeholder groups. The impacts are non-sector specific. In addition, the Methodological Sheets that were developed after the Guidelines propose a list of performance indicators that can be used to measure the impacts.
- The Global Reporting Initiative (GRI) also brings a form of standardization for measuring and reporting on social, environmental and economic impacts. The GRI guidelines propose a list of performance indicators, in addition to a list of cross-cutting and sector-specific aspects to keep track of.
- The United Nations Global Compact (UNGC) focuses on ten principles addressing four categories of social and environmental aspects. The issues addressed in the principles are universal, thus not sector specific.
- ISO 26000 is the ISO standard for social responsibility. It provides guidance for organizations on what socially responsible operations entail. ISO 26000 builds on seven non-sector specific core subjects covering social, environmental, and organizational aspects.

The UNEP SETAC Guidelines is the only reference that builds on product life cycle thinking. The other three references were developed at company level. Table 3 shows a sample of non-sector specific social aspects and how the references relate.

UNEP SETAC		GRI	UNGC	ISO 26000
Stakeholder	Aspects			
Worker	Freedom of association and collective bargaining	+/-	+/-	+/-
	Child labor	+/-	+/-	+/-
	Fair salary			+/-
	Working hours		+/-	+/-
	Forced labor	+/-	+/-	+/-
	Equal opportunities and discrimination	+/-	+/-	+/-
	Health and Safety	+/-		+/-
	Social benefits and social security	+/-	+/-	+/-
		Training and education		Human development and training
				Employment and relationships
				Social dialogue
Consumer	Health & Safety	+/-		+/-
	Feedback mechanism			+/-
	Consumer privacy	+/-	+/-	+/-
	Transparency	+/-		+/-
	End of life responsibility			+/-
				+/-
				Education and awareness
Local community	Access to material resources			+/-
	Access to immaterial resources			
	Delocalization and migration			+/-

	Cultural heritage			+/-
	Safe & healthy living conditions			+/-
	Respect of indigenous rights	+/-		+/-
	Community engagement	+/-		+/-
	Local employment	+/-		+/-
	Secure living conditions			
				Social investment
Society	Public commitments to sustainability issues			
	Contribution to economic development			
	Prevention & mitigation of armed conflicts			
	Technology development			+/-
	Corruption	+/-	+/-	+/-
		Public policy		Responsible political involvement
Other actors in the value chain				
	Fair competition	+/-		+/-
	Promoting social responsibility			+/-
	Supplier relationships			+/-
	Respect of intellectual property rights		+/-	+/-
		Invest. and procurement practices		
		Security practices		
		Compliance		Due diligence
		Remediation		Resolving grievances

Table 3: Sample of non-sector specific social aspects and how the references relate.

Similar to environmental LCA you will need to deal with allocation. Data at the product level is often not available. If the impact is given at a site or company level, the way to deal with allocation is either to consider the aggregated value of the life cycle stage or the amount of working hours that it requires.

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 substances in the relevant processes (under ‘known input from nature’), and put a value 1 under amount.
3. Develop a simple impact assessment method in which all issues get a characterization factor 1. You can also use different impact categories to address different types of issues.
4. You are free to add the social category in the list of normalization and weighting factors.
5. Analyze the network while this new impact assessment method is selected. The network now shows where specific issues occur.

3.6.2 Economic aspects

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

- Important cost factors such as investment, research, overheads and marketing are usually not modeled or at least under-represented in an LCA model.
- LCA does not have a time perspective; so, it is difficult to model interest or discount rates.
- The precision requirements for cost and revenue calculations are high.

An error in the calculation of a sales margin of a few percent can be disastrous for a company. Many companies, therefore, 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 labor is involved, can be damaging to a company’s reputation. Likewise, the environmental damage of a mine in a protected area can be costly.

In the Total Cost Assessment (TCA) methodology, a systematic process is used to estimate such costs and to estimate the probability that the costs occur. Based on TCA, a total average cost connected to sustainability issues can be determined.

4 Impact Assessment

4.1 Introduction

Most LCA experts do not develop impact assessment methodologies. They prefer to select one that has already 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.

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

The most important choice you have to make is the desired level of integration of the results. This usually depends on how you would like to address your audience and the ability of your audience to understand detailed results. Figure 6 presents a schematic overview of some of the possibilities.

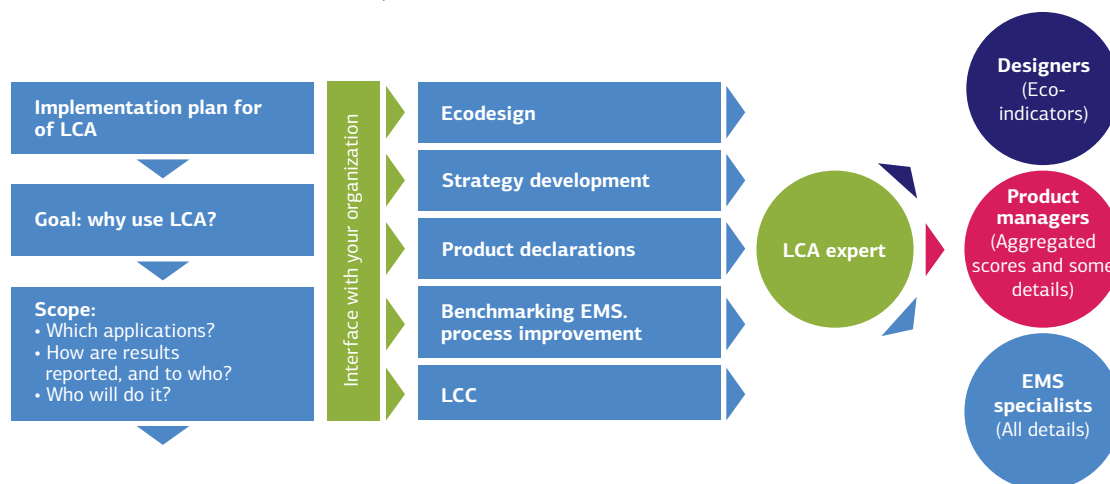


Figure 6: The choice of the impact assessment method depends largely on the audience addressed.

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 comprehensive 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. This way, you can always revert to the original method. SimaPro also allows you to create completely new methods.

4.2 ISO on impact assessment methods

The ISO 14040/44 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 plays an integral part in a LCA.

Life cycle impact assessment is defined as the phase aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. ISO 14040/44 distinguishes between:

- Obligatory elements: classification and characterization.
- Optional elements: normalization, ranking, grouping and weighting.

This means that according to ISO, every LCA must at least include classification and characterization. If these steps are not included, one may only refer to the study as a life cycle inventory (LCI).

An important distinction is made between internal and external applications. If the results are intended to compare (competing) products and they are to be presented to the public, weighting is not allowed according to the ISO series.

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 tires.
- Land use needed for the road and rail surfaces.
- Noise.

The following are 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, aluminum, copper (electricity grid)

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

4.3 Calculating an impact category indicator result

In the previous chapter we explained how you can collect your data. On the basis of this work, SimaPro can produce a table that is called the Life Cycle Inventory result (LCI). This table can contain hundreds of "elementary flows" these represent emissions or extractions to and from the environment. In order to understand what these mean, ISO prescribes a step known as classification. The elementary flows from the inventory are assigned to the impact categories according to the substances' ability to contribute to different environmental problems. Let us assume you find the following elementary flows (in this case emissions), and let's assume you have decided you want to use only three impact categories (see below for more guidance on the selection of impact categories). We can combine flows and impact categories in the following table:

Elementary flow	Climate change	Ozone layer depletion	Eutrophication
1 kg CO ₂ (Carbon dioxide)	X		
100 gram CH ₄ (methane)	X		
1 gram CFC142b	X	X	
5 gram NO ₂ (nitrogen dioxide)			X

Table 4: The result of classification, substances are assigned to the impact category they contribute to

The first three substances all contribute to climate change, CFCs only contribute to ozone layer depletion, and NO₂ contributes to eutrophication.

Having three substances contributing to one impact category, does not mean that we can now say we have 1,101 grams of climate changing substances, as these three substances all contribute differently to the problem of climate change. To determine this, we use the IPCC equivalency factors. Similarly, for other impact categories different characterization factors have been defined. We can now add these factors using the ReCiPe midpoint method as an example.

Elementary flow	Climate change		Ozone layer depletion		Eutrophication	
	CF	Result	CF	Result	CF	Result
1 kg CO ₂ (carbon dioxide)	1	1				
10 gram CH ₄ (methane)	25	0.25				
1 gram CFC142b	2310	2.31	0.07	0.00007		
5 gram NO ₂					0.56	0.0028
Impact Category Indicator Result		3.56		0.00007		0.0028
Unit of the result	kg CO ₂ equivalent		kg CFC11 equivalent		kg P equivalent	

Table 5: The result of characterization; each LCI result is multiplied with a characterization factor before they can be added. The characterization factor (CF) is determined by the impact assessment method; in this example the ReCiPe midpoint is used.

The table illustrates a number of issues of the characterization phase:

- One emission can contribute to several impact categories. Although the ISO standard does mention the possibility to split the elementary flow over two or more impact categories this is generally not done. One substance can cause several things at the same time.
- In this (and many other so-called midpoint methods) the units are defined as a reference to a substance. This results in relatively abstract units like CO₂ equivalents.
- It is very important to note that the units of the results are different, thus impact categories cannot be compared to each other and the overall magnitude of impacts cannot be determined; a low score for CFC142b for ozone layer depletion does not mean the contribution to ozone depletion is insignificant. A small emission of a substance like CFC142b can have quite a significant impact to the impact category indicator result, in this case for climate change.

Due to the rather arbitrary units, the characterization results are not always easy to interpret.

The scientific basis for characterization.

ISO requires that characterization factors are based on well understood and documented science. It prescribes to describe a scientific mechanism that links the inventory result (an emission) to what is called an “endpoint” or area of protection. This means one first has to describe what the area of protection is and how a clear endpoint of the scientific mechanism can be defined.

Let's look at the impact category for eutrophication. This impact clearly relates to the area of protection that can be described as ecosystem quality. There is a broad consensus that ecosystems need to be preserved, and therefore it is relevant to assess to what extent LCI results impact ecosystems, and possibly degrade them. A next step is how we would like to define an indicator expressing this concern, as there are different ways to do this.

ISO does not require to calculate such endpoints but suggests to take an indicator somewhere along the environmental mechanism that can represent the impact on the endpoint. Although not an ISO term, this has become known as the midpoint indicator.

Impact assessment method developers use the environmental mechanism as a basis for determining the characterization factors; such a mechanism can consist of a number of steps like:

- A fate step that models what happens to a substance after it is released. A number of factors play a role here; how long does it take before the substance “disappears” from the environment, because it decomposes or reacts with another substance. Another aspect is where the substance ends up. Some substances have characteristics that make it likely it stays in the air, some characteristics make it likely a substance ends up in water or soil. The result of this step is to find out how the concentration of the substance in air, water and soil changes when an emission occurs.
- An exposure and effect step. Once a concentration (or rather a change in concentration) is determined, it is important to assess how this effect influences the ecosystem. Also this can vary between substances.

In the figure below we illustrate this by using a representation of the environmental mechanism for Eutrophication. The LCI results (emissions to air or water) are the inputs at the top of the flow diagram, the endpoints are defined at the bottom of the flow diagram.

The oval shapes refer to commonly used impact assessment methods, and these indicate what these methods refer to, both in the sense that they identify where along the environmental mechanism they are located and the issue they try to represent. Those at the bottom are so-called endpoint methods, whereas those methods which are linked half way along the environmental mechanism are referred to as midpoint methods. Some methods, like ReCiPe and LIME have both mid and endpoints. This means the user can choose at which level the indicator should be at.

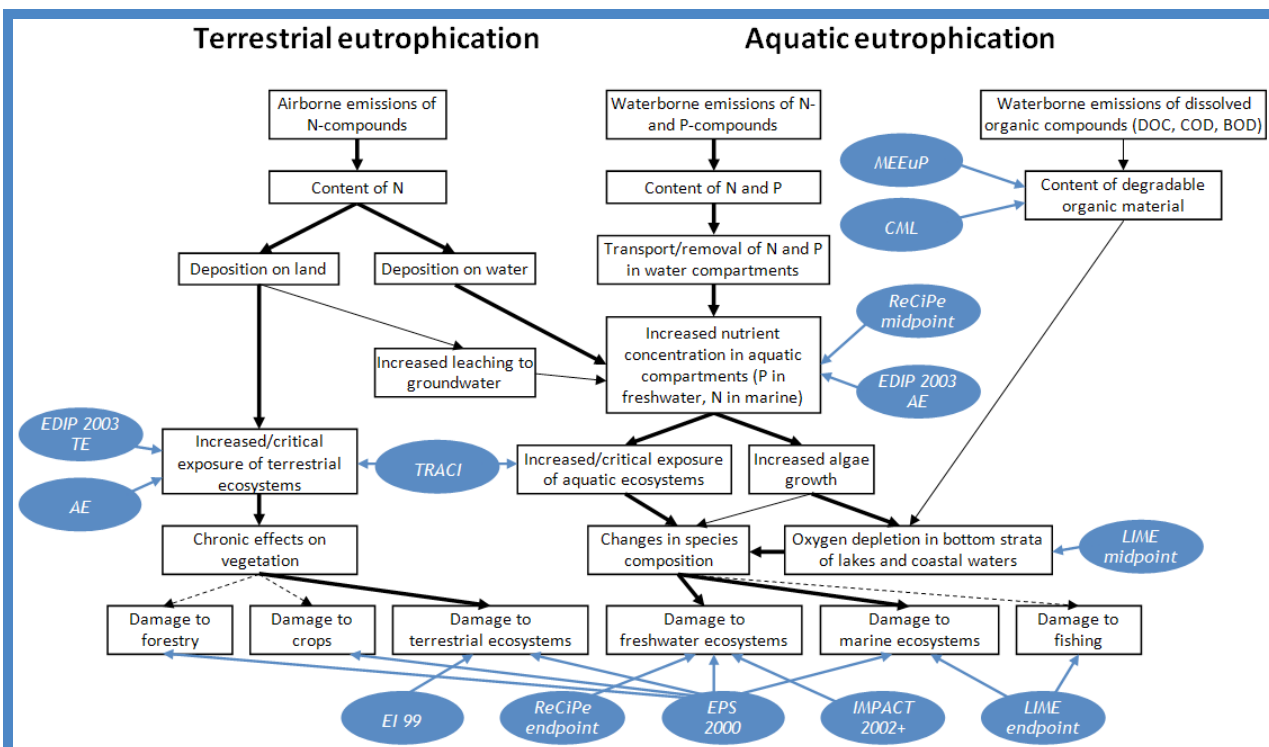


Figure 7: Overview mechanism resulting in eutrophication.

ISO requires using impact category indicators which are founded on a science-based environmental mechanism. This figure illustrates the mechanism for LCI results that contribute to Eutrophication, and identifies where commonly used LCIA methods choose the indicator. The figure illustrates there is still a lack of consensus. The methods in this picture can all be found in SimaPro, except for the Japanese LIME method. The figure comes from the EU LCIA recommendation study, discussed below.

Which method to choose?

There is a rather intimidating number of standard impact assessment methods available; this is also illustrated in the textbox above. These methods are developed by various research teams all over the world (including PRé), and there is no consensus yet on what the “best method” really is. As a result most LCA practitioners seem to choose a method on the basis of reputation, or worse, the default method in the software they use.

The EU-JRC has commissioned a large research project with the objective to provide guidance on this issue. In this project a team of renowned method developers was charged to assess over 150 ways to calculate an impact category indicator such as global warming or eutrophication. Before this could be done, the team developed criteria to judge the methodology used for each impact category. About 40 generic criteria were defined; these were considered to be relevant for all impact categories and about 10 to 20 specific criteria were developed for each individual impact category. The scientific criteria were:

- Completeness of scope
- Environmental relevance
- Scientific robustness and certainty
- Documentation, transparency and reproducibility
- Applicability

Next to these criteria a stakeholder acceptance criterion was introduced. These criteria have been exposed to a public consultation round, and can be found in part 2 of the ILCD handbook on LCIA.

All the methods were judged against these criteria, and a recommendation was made as to what the best methods are. There are three levels of recommendation, depending on the maturity of the method, as the science behind some impact categories are still developing and may lack the necessary maturity. No single existing method was declared the winner; the recommendation is a mixture of impact categories both at the mid and endpoint from different research groups. USEtox is recommended for toxicity; some impact categories are taken from ReCiPe, some are coming from methods not found in LCA software before.

SimaPro has implemented the recommended methodologies; we do however note that some of these indicators are becoming outdated, as the EU has not updated the assessment. For instance, while in ReCiPe some updates have been made, these have not been implemented in the ReCiPe derived impact categories in the ILCD method, as we need to stick to the original formal release. The full report can be found on the JRC website.

4.4 Selection of methods

The textboxes above provide some background to the interested reader on how characterization factors are determined, but almost all LCA method developers take these methods for granted and simply want to choose an existing method. In this section we try to provide some guidance on this issue.

The first question is on the scope of the method; if only a single issue, like embodied energy of climate effects needs to be calculated, a number of so-called single issue methods can be used. These methods are relatively easy to use and robust, but of course the clear disadvantage is that many impacts are out of the scope and thus out of sight. Single issue methods are not in compliance with ISO 14044 as this standard requires a deliberate assessment of all relevant impact categories for the study; it is not allowed to leave out impact categories that have a significant impact. For this reason ISO has started the development of single issue standards like the carbon footprint and the water footprint.

For an ISO compatible study, an important step is the selection of the appropriate impact categories. The LCA practitioner needs to justify this choice and clearly defend leaving out an impact category. The best way to do this is to look at existing studies, or assess the concerns on the relevant stakeholders; after all a study will only be accepted if the relevant stakeholders find the information about what they want to know, or understand why that information cannot be made available. In the Sustainability Consortium much work is put in documents that define the hotspots in product categories; this could also be a valuable choice. Finally, a quick screening using one or more endpoint methods can also be used to “flag” relevant issues; even if the study will not use endpoint methods for the final results.

Once it is clear what the relevant issues of concerns are, it is not always easy to find a method that addresses these issues appropriately. There are two main problems:

- Methods simply do not yet exist in LCA literature and software. Examples include the health impacts of noise (see textbox below), indoor air impacts, as well as problems that mainly occur in tropical areas such as salination from irrigation and mining, soil depletion and erosion.
- Methods that assess regional differences; which can be relevant for some impact categories as differences in population density and the sensitivity of ecosystems can have a significant impact. To date, most methods are developed to reflect the conditions in Northern and middle Europe, the USA and Japan. This also leads to the rather strange result that LCA studies report acidification and eutrophication in areas, in which these impacts do not occur. Eutrophication is even a blessing in some countries where soil erosion and soil depletion occurs.

We cannot describe a full solution here, but it is important to become aware, and develop further understanding, of these issues. Just using a default method is fine if you are new at conducting a LCA, but we encourage you to develop a critical view on this issue.

Dealing with missing impact categories

ISO is extremely clear on the requirement that issues, which might be of some importance, should not be left out. 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 2000 does not explicitly include noise, land use, and fine particle matter
- ReCiPe 2008 does not include noise, and has a very limited way of dealing with water
- EPS 2000 includes all, but sometimes in a coarse 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 coarse. A publication of Müller-Wenk [1999] makes a proposal on how to include this impact category in the Eco-indicator 99; it can also be combined with other endpoint methods that use the Human Health endpoint expressed in DALY. A similar development occurs around the water availability impact category, where a method authored by Stephan Pfister has been made compatible with ReCiPe and Eco-indicator 99.

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

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 characterization factor. This can be for 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 characterization 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. This function can be found at the screen where you select a method in SimaPro. 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 characterization factors. This feature is especially important for users who 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 the mismatch is between all substances and the method.

The mismatch between inventory and impact assessment cannot really be avoided. We advise you to check whether you are missing important parameters, and if so, to 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 by the chosen method(s).

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 modeled, 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.

4.5 Normalization

Normalization and weighting are used to simplify the interpretation of the results. These steps are regarded as optional steps in ISO 14040/44 as they contain additional subjective steps.

Normalization shows to what extent an impact category indicator result has a relatively high or a relatively low value compared to a reference. Normalization also solves the incompatibility of units. In section 4.3 we saw that each impact category has its own unit, and thus the results cannot be compared. In the table below the same example is used, but we now add a normalization step.

Elementary flow	Climate change		Ozone layer depletion		Eutrophication	
	CF	Result	CF	Result	CF	Result
1 kg CO ₂ (carbon dioxide)	1	1				
10 gram CH ₄ (methane)	25	0.25				
1 gram CFC142b	2310	2.31	0.07	7.00E-5		
5 gram NO ₂					0.56	2.80E-3
Impact Category Indicator Result		3.56		7.00E-5		2.80E-3
Unit of the result	kg CO ₂ equivalent		kg CFC11 equivalent		kg P equivalent	
Normalization value	1.12E+4 kg CO ₂ /yr		2.20E-2 kg CFC11/yr		4.15E-1 kg P/yr	
Normalized result [yr]	3.17E-4		3.18E-3		6.75E-3	

Table 5: Normalization

From the impact category indicator result, one could get the (wrong) impression that the climate change impact is high. Whether a figure is high can only be determined by comparing it with a reference (a normal value). In the table above, we selected the average annual impact of a European citizen in the year 2000. This data comes from statistics. So here we find that an average European emits around 11 tons of CO₂ equivalent and 22 grams of CFC11 equivalent, as well as 0.415 kg of Phosphate equivalent into water.

With this data we can put the results into perspective, and we do this by dividing the result by the normalized value. After that, we can see that the climate impacts are relatively low compared to the other impact categories (which does not say that they are not important - that is a weighting issue). The units now are all the same. People often think normalization results have no units, but when emissions per year are used, strictly speaking the unit of a normalized value is a year.

Normalization in SimaPro

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

Once a normalization set has been defined in the impact assessment method, you can choose to use either the characterized or normalized results in your graphs. Some impact assessment methods, such as those based on monetary evaluation (for example, EPS) do not need normalization. In SimaPro, you can indicate this while defining a method. Single issue methods usually also have no normalization.

Normalization in endpoint methods is always calculated on the basis of the endpoint characterization, even when you specify results per impact category; this means that normalization in the endpoint version of, for instance ReCiPe, has very different results compared to the midpoint version.

In order to help you define normalization values, we added process records that contain the annual emissions of European and World citizens. Once you add or change characterization factors, you can use these by having SimaPro calculate the characterization impacts for these processes. These can then be used to enter new or updated normalization values. Please note that SimaPro has a somewhat unusual way of storing normalization values. SimaPro multiplies instead of dividing, which means when you see normalization values, they are the inverse of the real normalization value. This was done because we sometimes do not have a normalization value, and would like to use a zero instead, and dividing by zero produces an indefinite result.

4.6 Weighting

Weighting is the most controversial and most difficult step in life cycle impact assessment, especially for midpoint methods. ISO does not allow weighting to be used in comparative assertions disclosed to the public, but weighting is used quite extensively for internal decision-making. Weighting is by definition not based on natural science and is very subjective. Several solutions have been proposed to solve or simplify the weighting problem, none of which are perfect:

1. Panel weighting: A panel assesses the relative importance of each impact category and determines the default weights. This approach is used in Eco-indicator 99 and the ReCiPe method. However, there are several problems to this approach:

- It is difficult to explain to a panel the meaning of the impact category indicators especially at the a midpoint method; they are too abstract ("CO₂ equivalency" or "proton release"). It is very easy to influence a panel and this is not desirable.
- In a midpoint approach, the number of indicators to be assessed is usually rather large (10 to 15), and this causes cognitive stress making it virtually impossible to get meaningful results.
- Panels tend to give a small range of weights (usually between 1 and 3). In social sciences, this is called 'framing', and is a problem in both endpoint and midpoint methods.
- It is unclear what and who the panel represents.

2. Distance to target. If it is possible to set a reduction target for each impact category, this target can be used as a weighting factor. If the difference is high, the weight is high. The Ecological Scarcity methods use targets set by the Swiss government. This approach also has some difficulties:

- In the case where 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 reflect the "real" need to reduce environmental impacts.

3. Monetization: In EPS 2000 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, willingness to pay, future extracting costs) can be added. This can be interpreted as a weighting step in which the weighting factors for these different types of cost equal one.

The weighting issue was the starting point for the development of the Eco-indicator 99 and ReCiPe methods. Some of the problems associated with weighting have been reduced or solved, but the weighting step will always remain difficult. An interesting approach has been developed by [Hofstetter et al. 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 also be used to make a decision without actually knowing the weights.

The triangle concept as an alternative to fixed weights

For users who do not want to use the default weighting factors, we recommend using the mixing triangle developed by [Hofstetter et al. 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 100%.

An important feature is the possibility of drawing 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 divide the triangle into areas of weighting sets for which product A is favorable to product B and vice versa.

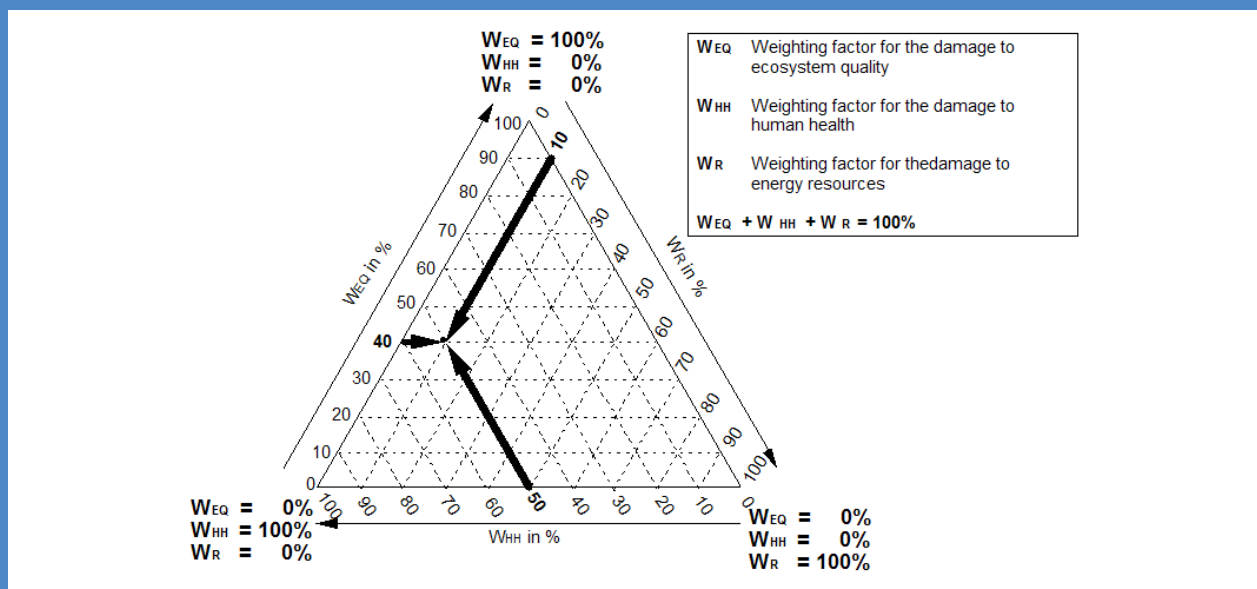


Figure 8: The mixing triangle: The marked weighting point is positioned where human health is weighted 50%, ecosystem quality 40% and resources 10%. This weighting point is defined as the point where the lines cross; the lines are drawn starting from the desired weighting factor and parallel to the axis which equals zero for that factor (based on Hofstetter 1999).

The weighting triangle can display the result of an LCA without knowing the weighting factors. According to Hofstetter, such a representation is a 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 fulfill 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 stakeholders. More information on this subject can be found in [Hofstetter et al. 1999].

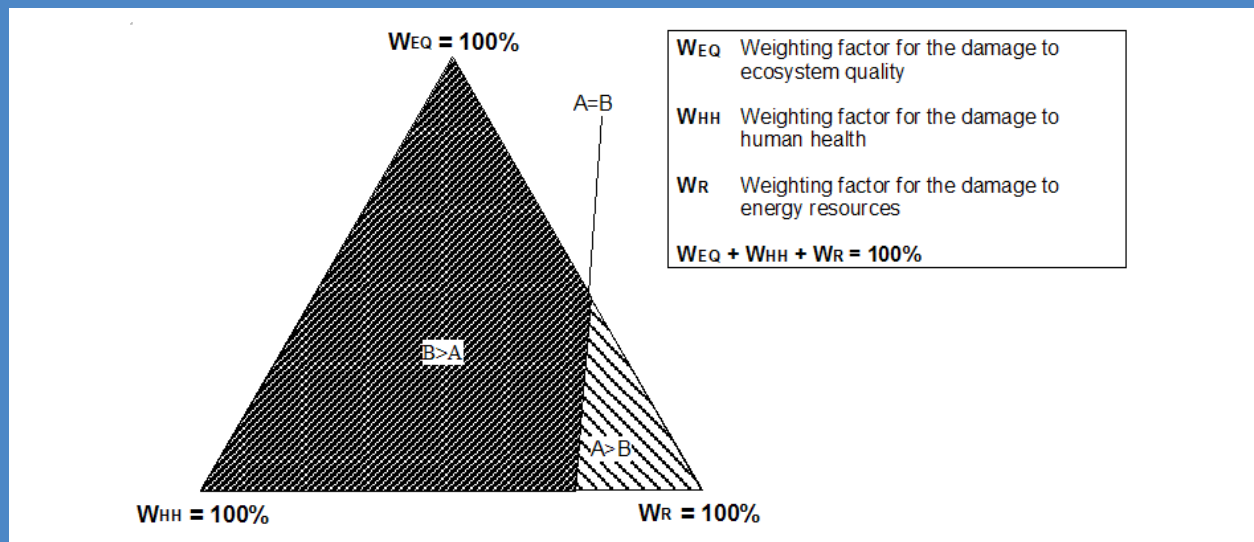


Figure 9: The line of indifference in the weighting triangle and the sub-areas with their specific ranking orders (B>A means that alternative B is environmentally superior to A and the eco-index A is higher than B).

Weighting in SimaPro

You can define any number of weighting sets for each impact assessment method. 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 normalization step. Please note that if all damage categories of product A are higher than product B, the line of indifference will lie outside the triangle, meaning it will have only one color.

5 Interpretation

5.1 Introduction

The last of the four steps in LCA is interpretation. The ISO 14044 standard describes a number of checks to test whether conclusions 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 14044 standard. We suggest you fill in your observations when you are about to complete your LCA and draw your conclusions.

5.2 Uncertainty analysis

All data in life cycle models have some uncertainty. Here, we distinguish three main types:

1. Variation in the data
2. Correctness (representativeness) of the model
3. Incompleteness of the model

5.2.1 Data uncertainties

Variation in the data can be described by a distribution, expressed as a range or standard deviation. Statistical methods, such as Monte Carlo techniques (see chapter 9) can be used to handle these types of uncertainties, and calculate the data uncertainty in the LCA results.

Data uncertainty in the ecoinvent database

The ecoinvent database is released in two versions, one version with unit processes, and one with system processes (see section 3.4). In the unit process version, almost all data points come with a specification of uncertainty. Working with this uncertainty data requires some background on how this uncertainty data can be interpreted, and how you can specify uncertainty in the data you enter.

ecoinvent always provides a standard value together with uncertainty information. The standard value can be interpreted as the “best guess” value. In case this “best guess” value is determined by sampling many different measurements, this is usually the mean value of a (log)normal distribution. Although sometimes measurements clearly show a normal distribution, ecoinvent always assumes a lognormal distribution. Lognormal distributions are characterized 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 about 95% of all measured values are between the mean value times 1.2 and the mean value divided by 1.2. If the square of the geometric standard deviation is equal to 1.0, there is no variation (all measured values are the same). This is an important difference with the normal distribution. In a normal distribution, the 95% confidence interval is found between two times the standard deviation above and below the mean.

The next question is how to estimate the geometric standard deviation, as data are often not taken from a large sample of measurements. ecoinvent uses the so-called Pedigree matrix, which was originally developed by Weidema (1996), to estimate the geometric standard deviations. Each data point is assessed based on six criteria plus the basic uncertainty factor (which depends on the type of data). The 95% confidence interval or the squared geometric standard deviation is calculated using the following equation:

$$\sigma^2 = \sum_{n=1}^6 \sigma_n^2$$

The factors σ_2^2 to σ_6^2 refer to the scores in the reliability (1), completeness (2), temporal correlation (3), geographical correlation (4) and further technology (5) (see table 6). The factor σ_1^2 refers to the basic uncertainty factor (table 7). For example, If the measured data is used and verified, reliability has a score of 1.00. If you have obtained data from an expert who has done a theoretical calculation and some estimations, U1 has a value of 1.2, etc.

Score:	1	2	3	4	5
1 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
2 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
3 Temporal correlation	Less than 3 years of difference to our reference year	Less than 6 years of difference to our reference year	Less than 10 years of difference to our reference year	Less than 15 years of difference to our reference year	Age of data unknown or more than 15 years of difference to our reference year
	1.00	1.03	1.10	1.20	1.50
4 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 area with slightly similar production conditions	Data from unknown OR distinctly different area (north America instead of Middle East, OECD-Europe instead of Russia)
	1.00	1.001	1.02	1.05	1.10
5 Further technological correlation	Data from enterprises, processes and materials under study (i.e. identical technology)	Data from processes and materials under study (i.e. identical technology) but from different enterprises	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	1.05	1.20	1.50	2.00

Table 6: Pedigree matrix (source: Weidema, 1996)

Please note that SimaPro has a sixth indicator, sample size, which was used in past versions of the Pedigree matrix. Users should now leave this indicator score as unspecified (1).

In all ecoinvent unit process data, you will find in each comment field a sequence of six figures, for example, (1,2,1,5,1,3). These numbers refer to the score given to each of the indicators of the pedigree matrix. Please note that you will not find any uncertainty data in the system processes.

The basic uncertainty factor U_b can be derived from table 7. This basic uncertainty factor is based on expert judgment. 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 high for poly aromatic hydrocarbons (PAH), fine particles (PM10 and PM2.5) and heavy metal emissions, as well as radio nuclides and carbon monoxide (CO) from combustion.

input / output group C=combustion emissions, P=process emissions, A=agricultural emissions	C	P	A
Demand of:			
Thermal energy, electricity, semi-finished products, working material, waste treatment services	1.05	1.05	1.05
Transport services (tkm)	2.00	2.00	2.00
Infrastructure	3.00	3.00	3.00
Resources:			
Primary energy carriers, metals, salts	1.05	1.05	1.05
Land use, occupation	1.50	1.50	1.10
Land use, transformation	2.00	2.00	1.20
Pollutants emitted to water:			
BOD, COD, DOC, TOC, inorganic compounds (NH_4 , PO_4 , NO_3 , Cl, Na etc.)		1.50	
Individual hydrocarbons, PAH		3.00	
Heavy metals		5.00	1.80
Pesticides			1.50
NO_3 , PO_4			1.50
Pollutants emitted to soil:			
Oil, hydrocarbon total		1.50	
Heavy metals		1.50	1.50
Pesticides			1.45
Pollutants emitted to air:			
CO_2	1.05	1.05	
SO_2	1.05		
NMVOC total	1.50		
NO_x , N_2O	1.50		1.40
CH_4 , NH_3	1.50		1.20
Individual hydrocarbons	1.50	2.00	
PM>10	1.50	1.50	
PM10	2.00	2.00	
PM2.5	3.00	3.00	
Polycyclic aromatic hydrocarbons (PAH)		3.00	
CO, heavy metals		5.00	
Inorganic emissions, others		1.50	
Radionuclides (e.g. Radon-222)		3.00	

Table 7: Basic uncertainty depending on the type of data

5.2.2 Model uncertainties

Uncertainty on the correctness of the model refers to subjective choices for modeling a system. Some examples of subjective choices are:

- Do you apply consequential modeling or do you use allocation, and what assumptions do you make on avoided products or on the type of allocation?
- What do you assume for waste treatment scenarios, especially when the product will be disposed of decades from now?
- Which functional unit do you choose, especially when products are compared?

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

5.3 Sensitivity analysis

A sensitivity analysis evaluates the influence of the most important assumptions have on the results. The principle is simple: change the assumption and recalculate the LCA. For example, you can compare the results based on different allocation principles.

With this type of analysis, you will get a better understanding of how different assumptions affect the results. You will find that the outcome of the LCA can be quite heavily dependent 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 with one assumption product A has a higher load than B, and with a different assumption that product B has a higher load, you will 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 used.

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 an 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, for example, Elec_EU. Initially you set this value equal to “1”. In each process that uses electricity, you enter two lines, one line refers to 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 modeling 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. See also the textbox in section 2.2.4 on allocation.

5.4 Contribution analysis

An important tool in understanding the uncertainty of your results is the use of contribution analysis. With this analysis you can 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 to 99% of the results are determined by just ten processes. With this information you can focus your attention on these processes and analyze if these processes are sufficiently representative, complete, and if there 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 see exactly what the role of the process is in the life cycle. 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 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 the contribution analysis you can see the total contribution of European electricity.

5.5 Inventory analysis

The inventory result is a list of substance emissions to soil, water and air, and raw materials extraction. In many cases, the list covers a few hundred substances and raw materials, which make the inventory result difficult to interpret. However, the inventory result is not affected by the uncertainties introduced in impact assessment, which makes it advisable to analyze the inventory result.

LCI results in SimaPro

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

- You can sort the inventory results according to alphabet, amount, unit and compartment.
- You can view tables containing results from a certain compartment, such as airborne emissions, or raw materials.
- You can suppress or show the sub-compartments, so if you have airborne emissions of NO_x in high and low population densities, you can get the total airborne NO_x emission instead.
- Depending on whether your model contains loops or not, you will not only get the total results, but you will also see additional columns with results from underlying processes.
- Results are automatically presented in the best readable units; so, instead of listing 0.00001 kg, SimaPro will list 10 mg. SimaPro can also present the results in alternative units, for example as used in the USA. Nevertheless, if you want to export or copy and paste the list to other software, you can also get the results in official SI units. Then, 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 inventory result.

6 Managing your Life Cycle Activities

The LCA methodology is described in chapters 2 to 5 from a methodological point of view. In this chapter, we discuss some important practical issues, such as planning, budgeting, data collection and presentation, and integrating LCA into an organization.

6.1 Estimating the workload

Estimating the amount of time it takes to perform a typical LCA is difficult. The workload can vary between 2 days for a quick screening using readily available information and 200 days for an extensive LCA. We generally distinguish between four types of LCA studies:

1. Screening LCAs
2. Internal LCA studies
3. LCA studies for external communication
4. Continuous use of LCA information

The characteristics of each type of study, including a budget indication, are discussed below.

6.1.1 Screening

If you need to get a quick answer, and speed or budget is more important than precision, you can make a screening using readily available or estimated data. For missing data, you can use proxies. For example, if you need data on nickel production, and you only have data on some other non-ferrous-metals, you can use one of the alternatives to get an idea of the relative importance of this process.

To work efficiently, you can try to limit your goal and focus to only a limited set of research questions, for example:

- 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 dedicate all our efforts in optimizing 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 formulating your research questions you can include a sensitivity analysis to see if your estimates and alternative data can significantly influence the key conclusions.

How SimaPro supports screening LCAs

Perhaps the most important issue with a screening LCA is to have a large database with commonly used materials and processes. Both the ecoinvent and the USA input output table are useful resources.

Another important feature is the ability to distinguish 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 to never change the data in the libraries, especially if you only intend to make “quick and dirty” changes for the purpose of 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 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 analyze these most important processes.

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

6.1.2 Internal LCA studies

Internal LCA studies are recommended when you need to make a decision that significantly influences the product development process or communication strategy, but you do not need to communicate the results externally. For such a study, the goals could be more ambitious, by formulating research questions such as:

- What are the dominating causes for the environmental load in the production phase, the use phase, and the disposal phase?
- How much benefit would a 'product take-back system' bring?
- How is a product performing in relation to the competitors' products? Is it likely that the competitors could make an environmental claim that is justifiable? To what extent could environmental claims be used in external communication?
- Does a product qualify for an eco-label?
- Which businesses could be considered as sustainable; that is, which profitable businesses have a relatively low environmental load?

A pragmatic approach is to start with a 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 which could be collected by approaching suppliers or other parties in the product chain.

As the data quality requirements are not as high as in case of an LCA for external communication it is important to critically analyze to what extent you can justify your conclusions. Therefore, a sensitivity analysis, in which you change important assumptions and in which you test different impact assessment methods is recommended.

How SimaPro supports internal LCAs

Apart from the issues mentioned in the textbox on screenings 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 write down 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 perfect data, you can also use preliminary data while adding an uncertainty range. If for instance your aim is to compare two alternatives, Monte Carlo analysis can help you to determine whether the differences between product A and B are significant or not, given the uncertainties. If they are, there is no need to collect more data. If they are not significant, you can focus your efforts on reducing the uncertainties with the biggest impact. This way, Monte Carlo analysis can be a fantastic time saver.

6.1.3 LCAs for external communication

LCAs for external communication are applicable in case of environmental claims, public debate, or other types of communication. The distinguishing factor is that LCAs for external communication should conform to the relevant ISO standards (14040, 14044, 14024, 14021, 14025). This means, for example, that:

- An independent external review is required in the process. An efficient way to perform such an LCA, is to invite an expert reviewer at the first stage when the goal and scope is defined. This may prevent work that is not accepted by the reviewer at a later stage.
- There are a lot more requirements for reporting. You must carefully describe all procedures, choices, data gaps, etc. You must perform an extensive sensitivity analysis (see, for example, guidelines in the ISO 14044 standard).
- If your aim is to compare products (comparative assertion), you may not publish normalized and weighted results.

How SimaPro supports LCAs for external communication

- For extensive LCAs you will need the same tools as described in screening and conducting an internal LCA. Documentation, data quality and interpretation issues become even more important. SimaPro can be used to define complex products, using a system of assemblies and subassemblies, and it can handle 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 large process trees. We have performed studies with 50.000 processes in a single process tree. Calculating such an LCA takes one to a few minutes depending on the speed of your computer.
- You can make sophisticated and precise non linear models using parameters.
- You can specify all uncertainties, even in parameter values; this enables you to accurately report the certainty or uncertainty in your results.
- You can run semi-automated sensitivity analyses 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 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, thus controlling access to certain parts of the data, depending on the skill and responsibility of these people.

6.1.4 Continuous use of LCA information

In the past, LCA studies were implicitly considered as separate activities. A study was done to support making a decision and after that, the activity stopped until a new decision needed to be supported. We now see a clear trend away from this ad-hoc type of approach, as more and more organizations start to consider LCA as part of their continuous business development process.

This process consists of four steps, which can be repeated continuously:

1. Understating your sustainability landscape (e.g. managing your brand reputation, improving resource efficiency, increasing your competitive advantage, assessing new markets).
2. Building a framework with your team (develop the infrastructure and strategy, select the best methodology and data collection strategy, define the metrics for your organization's sustainability objectives, install the IT platform and select the appropriate LCA software tools, manage ISO standards procedures).
3. Integrating LCA in your organization (assist with stakeholder engagement, drive performance measurement and strategy adoption, initiate management and employee training).
4. Creating value from sustainability metrics (transferring knowledge and being autonomous).

How SimaPro supports continuous use of LCA information

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

- The possibility of developing an easy to use wizard-like interface for specific target groups.
- The possibilities of linking SimaPro with other information systems using a COM interface and to use parameters that are stored in excel spreadsheets or SQL databases.

6.1.5 Some guidelines for budget estimates

Although a lot of factors can influence the time needed to perform an LCA, the table below gives an indication. These estimates assume that the work is performed by experienced people. If you are starting in this area, you should add a few days or weeks to get familiar with the methodology and all the practical issues.

Task	Screening (days)	Internal LCA (days)	External LCA (days)	Continuous use (days)
Defining goal and scope	1-2	2-4	10	10 + updates
Data collection	2-5	5-15	25-100	Continuously
Entering data into software and performing calculations	1	2-4	10	Continuously
Interpretation and sensitivity analysis	1-3	2-4	10-20	Continuously
Reporting	1-3	2-5	10-30	Continuously
Peer review	Not applicable	Optional	10-30	Optional
Total estimate (days)	6-14	13-32	75-180 and up	Not applicable

Table 8: Estimates of number of working days per task for the different types of LCA studies

6.2 Operational procedures

The way you organize the LCA work clearly depends on your goals and the organizational environment you are working in. In this section, we provide you with some suggestions.

6.2.1 Single-user version

If you are working with a single-user version of SimaPro, important things to consider are:

- Do not edit the resources stored in libraries, unless you are completely sure.
- Make back-ups of your database regularly.
- Locate the database files on a server if possible.

6.2.2 Multi-user version

If you are working in a team of LCA experts, managing the LCA work is a little more complex. With a multi-user version of SimaPro enables you to work in the same database with your colleagues. This means that you can use the following facilities and features:

- All users log in using unique username and password combinations.
- The database manager can define certain user types such as expert, novice or guest, and assign certain access rights to these types of users. Furthermore, the manager 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 library status.

The multi-user version uses a so-called client server principle. This means that all the data is stored in a database on the server, which is accessed 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 version, you can upgrade to a multi-user version while still keeping your original databases.

6.2.3 Ownership of data and methods

By publishing LCA data, you usually include background (secondary) data. There are no objections to publishing the data supplied with SimaPro in printed form, as long as you refer to the source. 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 ecoinvent 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. Please notify PRé if you want to do so.

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

6.2.4 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 a SimaPro format, while enabling all related data in libraries to be included in the export file. It is also good practice to include the relevant impact assessment methods in this export file. Users of a SimaPro Compact, Faculty or Classroom version cannot export data. On the PRé website, you can compare between the different versions at: www.pre-sustainability.com/content/the-simapro-family

6.3 Understanding the structure of the database

Once you start changing the data in SimaPro, you need to manage the data quality in order to avoid the risk of your database becoming increasingly unreliable. In this section, we describe some of the risks and provide suggestions for database management.

The SimaPro database is structured in three main parts:

1. Project data. In projects, you store all specific data for the project you are currently working on. You can create any number of projects in your database, to keep all of your data separated and to facilitate the archiving of projects, which you no longer want to keep.
2. Library data. Libraries contain data to serve as a resource for your projects. The structure of the library data is similar to the structure of the project data.
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.

In both libraries and projects the following data can be stored:

- Goal and scope definition
- Data quality profile
- Process data
- Product stage data
- Impact assessment methods
- Data on results interpretation
- Scripts
- Other data types not discussed here

This means that both a library and a project can contain 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 that you copy the data from the library into a project, and make the change there. We recommend that you always document such changes in the comment fields. In the Compact version you cannot edit libraries. In a multi-user version only the database manager can change the data in the libraries.

Libraries tend to have their own “methodological character” as they are usually derived from a single source. For example, some libraries are typically relevant for Europe, while others represent data from only one country. Other differences could be how the system boundaries were applied.

The “character” is described in the goal and scope section of the library, where you should also set the requirements for the quality of the data. It is good practice to critically analyze which libraries you consider to be suitable for a particular project. SimaPro supports this function. In each project you can include or exclude certain libraries. If you exclude a library, this information cannot be used in the project. However, you can always change this setting while the project is developing.

6.4 Data exchange

Since LCA software tools became commercially available, multiple efforts have been made to develop an internationally accepted data format. Unfortunately there is no consensus and we are faced with three important standards:

- EcoSpold is the format developed for the ecoinvent database. This format has been accepted by six leading LCA software companies.
- ISO 14048 (Spine) format is not a standard but rather a Technical Reference (TR). The original ISO version published at the end of the nineties never made it as a software exchange format, as the text allowed for many degrees of freedom. The Swedish SPINE project developed a more specific implementation but the acceptance of this implementation is not yet widespread. The new version of ISO 14048 TR published in 2005 has not changed this situation.
- The European LCA center has developed its own format in 2006 and 2007. Unfortunately this format does not adequately connect with other formats. The concept is also different. Instead of describing how data must be stored, it specifies a core format that should be used by all software, but allows data to be stored in all kinds of software-specific fields. This makes it easy to create new data sets, but difficult to develop a consistent set of data.
- The ILCD data format

In spite of all the efforts invested in the development of formats, the real problem is not the format, but the differences in the software models used in different commercial packages. If a software program has data that is not available in other software, that data has nowhere to go and will be lost.

A pragmatic solution is offered by GreendeltaTC, a company offering a free data conversion tool.

7 Using SimaPro the Easy Way

7.1 A new approach to LCA

When you are new to SimaPro, we recommend using the LCA Wizard to set up your LCA project. This will save you a lot of time. It can help develop complex life cycles, especially when you intend to develop sophisticated end-of-life scenarios.

Different versions of SimaPro

SimaPro is available in three different versions:

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 versions of the SimaPro Compact are named SimaPro Faculty or SimaPro Classroom.
2. SimaPro Analyst for demanding LCA experts who need all functions. The educational version of this license is named "SimaPro PhD".
3. SimaPro Developer for experts who want to develop dedicated LCA Wizards or who would like to link SimaPro to other software.

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 standard data supplied with SimaPro or data from other data suppliers. Libraries are a resource for all of your projects. In general you should not edit a library, you should link to it from your projects instead.

We suggest you open the project 'Introduction to SimaPro'. If you have SimaPro Compact, the Wizard screen below will then appear. If you have another version please click 'Wizards' at the top left-hand corner of the screen (see figure 12).

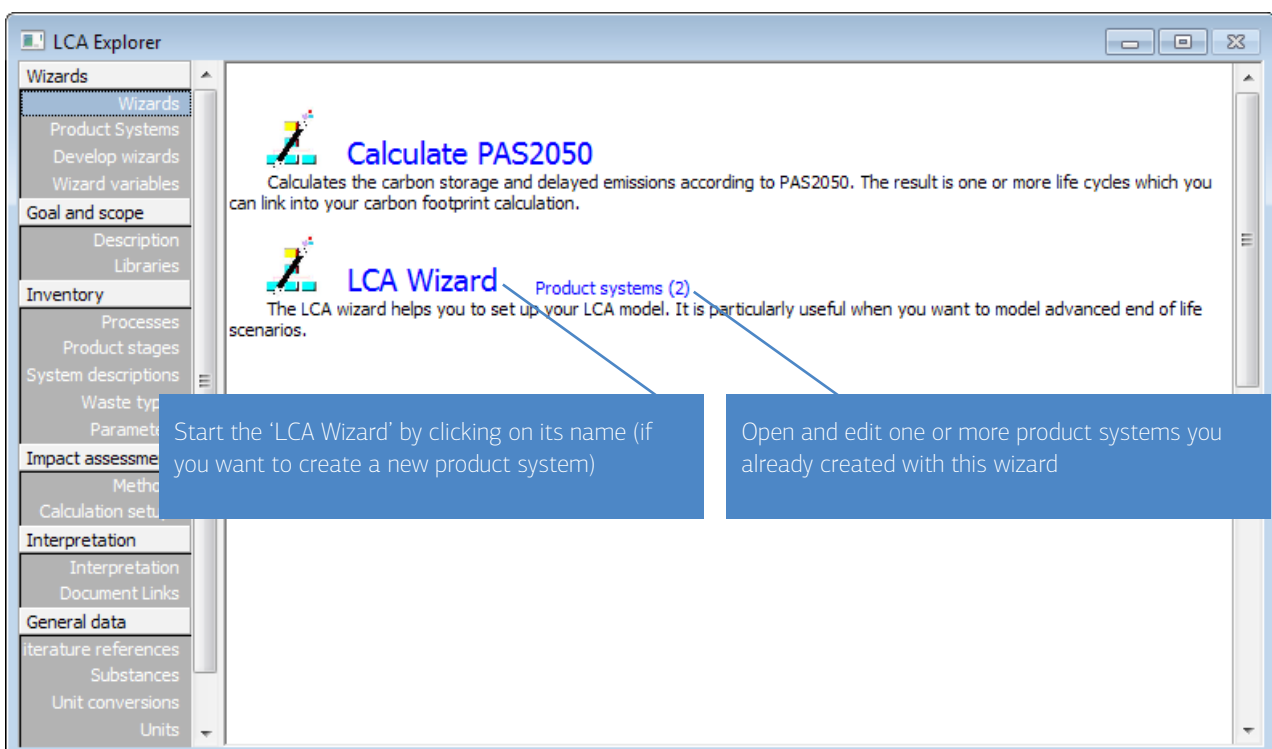


Figure 12: An overview of the Wizard screen, as seen if you have SimaPro Compact.

The Wizard screen contains a number of predefined wizards:

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

Users with SimaPro Developer can also add new wizards to this page.

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 in 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 will be available for further editing (see section 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, as explained in the following section.

7.4 Product systems provide overview

The product system is a single sheet that contains all the data needed to define the product specification, product use and 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 recalculate the result. This makes it a useful tool to analyze "what if" questions or to use in ecodesign applications.

Product systems can be stored under a name for future reference. In fact this opens up the possibility to develop a specific user 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 with all you need to carry out a basic LCA. However, if you want to use the more advanced features, you will need the traditional interface of SimaPro. You will find that the traditional user interface is also well-structured and easy to use.

The SimaPro Tutorial

The SimaPro Tutorial provides a number of exercises you can follow to get to grips with LCA. You can open the tutorial as a PDF file from SimaPro (Help> Manuals), or you can download it from www.pre-sustainability.com. 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 (please refer to Lesson 1 in the tutorial for that).

8.1 The LCA Explorer

Looking at figure 13, the bar at the left hand side is called the LCA Explorer. It provides 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.

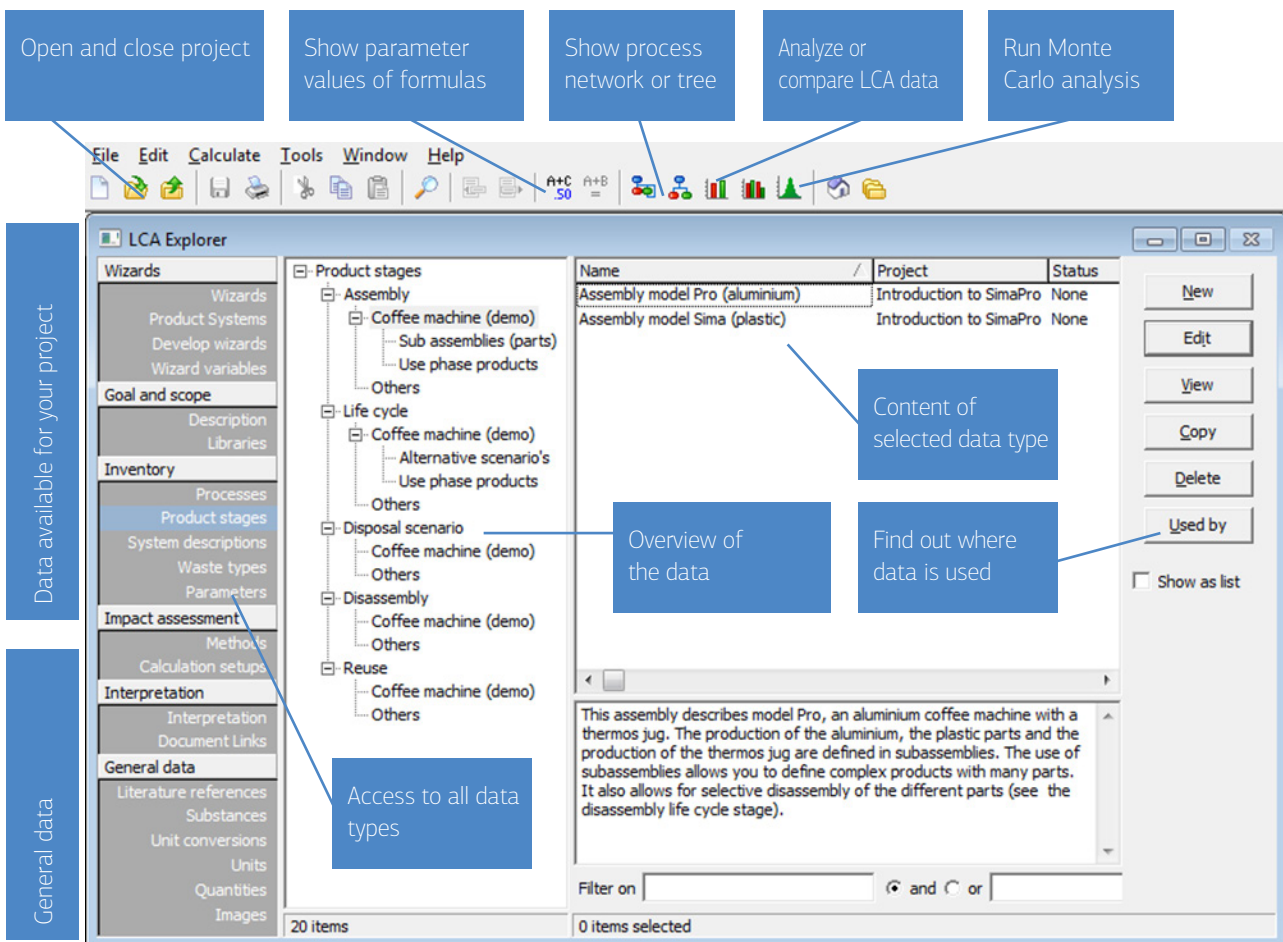


Figure 13: Overview of SimaPro Explorer on the left-hand side of the screen. This screen provides access to all data types. On top you find buttons for frequently used commands. Please note that some functions shown here are not available in the Compact or Analyst version of the software.

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 a few times.

- 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 justifiable. If not, you may have made some mistakes or the data supplied may contain errors.

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

8.1.1 Describe Goal and Scope

Under description, you will find a number of text fields. These provide the structure for describing the goal and scope. 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 of your study.

Goal and scope
Description
Libraries

8.1.2 Inventory

This section provides access to processes and product stages; the two main data types in SimaPro. 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 section 8.5.

Inventory
Processes
Product stages
System descriptions
Waste types
Parameters

8.1.3 Impact assessment

This section provides access to impact assessment methods. In the calculation setup section you can define which life cycles, processes and assemblies need to be repeatedly analyzed and compared. The benefit of using a calculation setup is that all life cycles or assemblies always appear in the same order, with the same colors and the same scale.

Impact assessment
Methods
Calculation setups

8.1.4 Interpretation

As you near the end of your project, it will be time to draw your conclusions and make a number of checks. The text fields under interpretation act as a guide that help you check which issues you need to address. See also section 5.1.

Interpretation
Interpretation
Document Links

8.1.5 General data

The other data types like scripts and 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.
- Unit conversions as they are used in wizards.
- Units and Quantities; these are used in other parts of SimaPro.

General data
Literature references
Substances
Unit conversions
Units
Quantities
Images

8.2 Entering and editing data

The core of the LCI phase is building a process tree that describes all the relevant processes in a life cycle. We previously discussed the complexities of modeling the life cycles and described issues like system boundaries and allocation. Now we will show you how to 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 contain environmental data, as well as data on economic 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 Product stages allow for the modeling of 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 system description. This separate attachment is available to describe the underlying model that was used when this data was defined.
- **Parameters**
 - Constant parameters. These can be defined on a process, project and database level.
 - Expressions: Here you define the relationship between parameters. You can use a wide range of mathematical expressions.

File Edit Calculate Tools Window Help

Documentation Input/output Parameters System description

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category
Name of the output	0	kg	Mass	100 %	
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount
(Insert line here)	

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount
(Insert line here)		

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max
(Insert line here)					

Known inputs from technosphere (electricity/heat)

Name	Amount
(Insert line here)	

Emissions to air

Name	Sub-co Amount	Unit
(Insert line here)		

Emissions to water

Name	Sub-compartment	Amount	Unit
(Insert line here)			

Emissions to soil

Name	Sub-compartment	Amount	Unit
(Insert line here)			

Final waste flows

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max
(Insert line here)						

Non material emissions

Name	Sub-compartment	Amount	Unit
(Insert line here)			

Social issues

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max
(Insert line here)						

Economic issues

Name	Sub-compartment	Amount	Unit
(Insert line here)			

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max
(Insert line here)					

Four tabs give access to documentation, input/output, parameters and system description

Process output, here you can specify multiple outputs and use allocation percentages

Avoided products (system boundary expansion) are subtracted from the total impacts

Resources extracted from nature

Inputs from other processes; here you link to other SimaPro process records. You can separate between inputs with and without a mass unit

Emissions to air, water and soil, as well as waste flows, social parameters and economic parameters

Wastes that are processed. Here you can link to an emission or solid waste to a waste treatment process in SimaPro

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 saves a lot of time when you want to use large process structures.

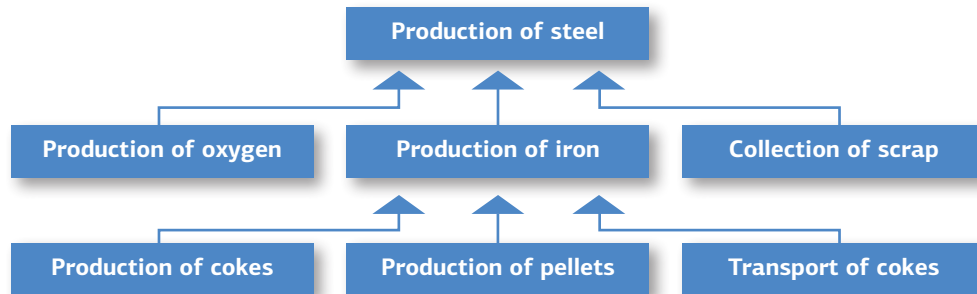



Figure 15: Schematic overview of how processes are linked to form a process tree structure. In this case unit processes are used that describe a single process step, which provides the highest transparency.

Process records can describe unit processes, which describe one single process step as well as system processes, 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  button when a process or product stage is selected. In a network, each process is only represented once, irrespective of the number of times it is used by other processes. The example below (for rail transport) shows that process structures can have loops. In addition, an indicator is used to show the relative contribution of the environmental load.

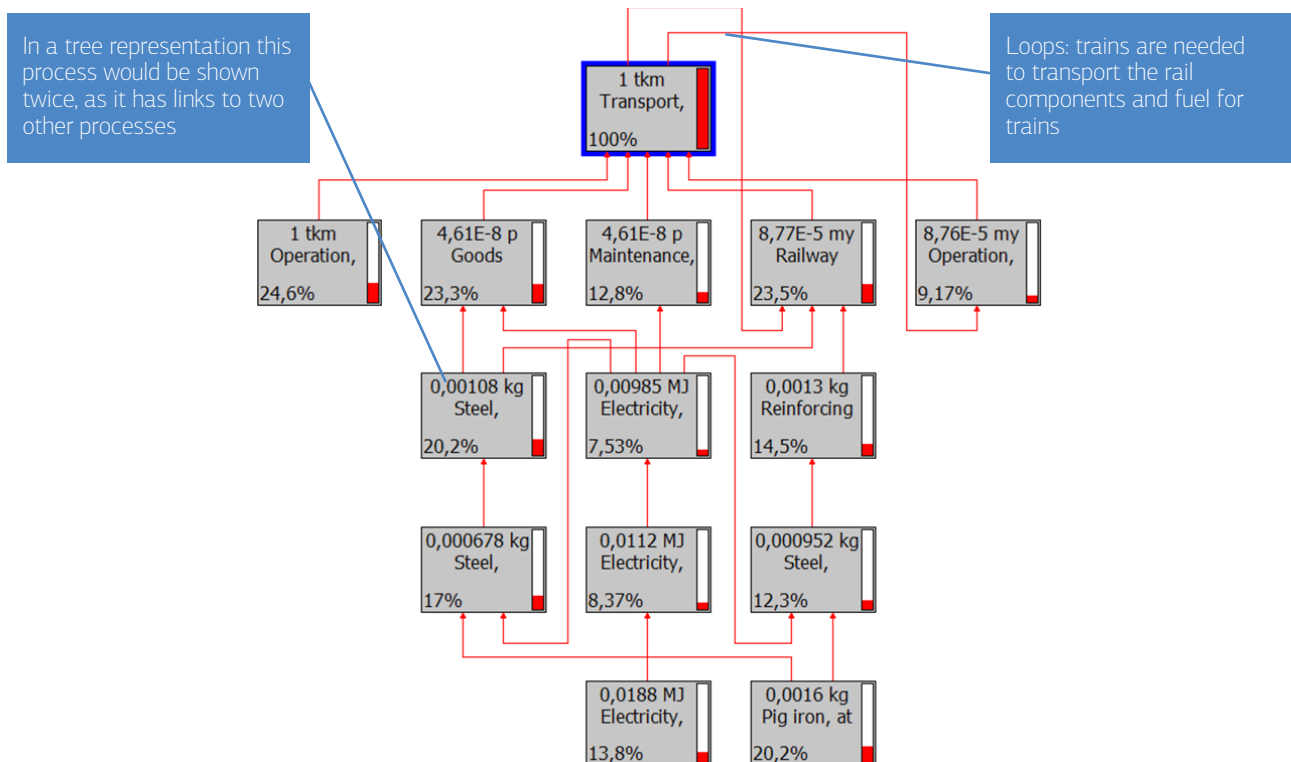


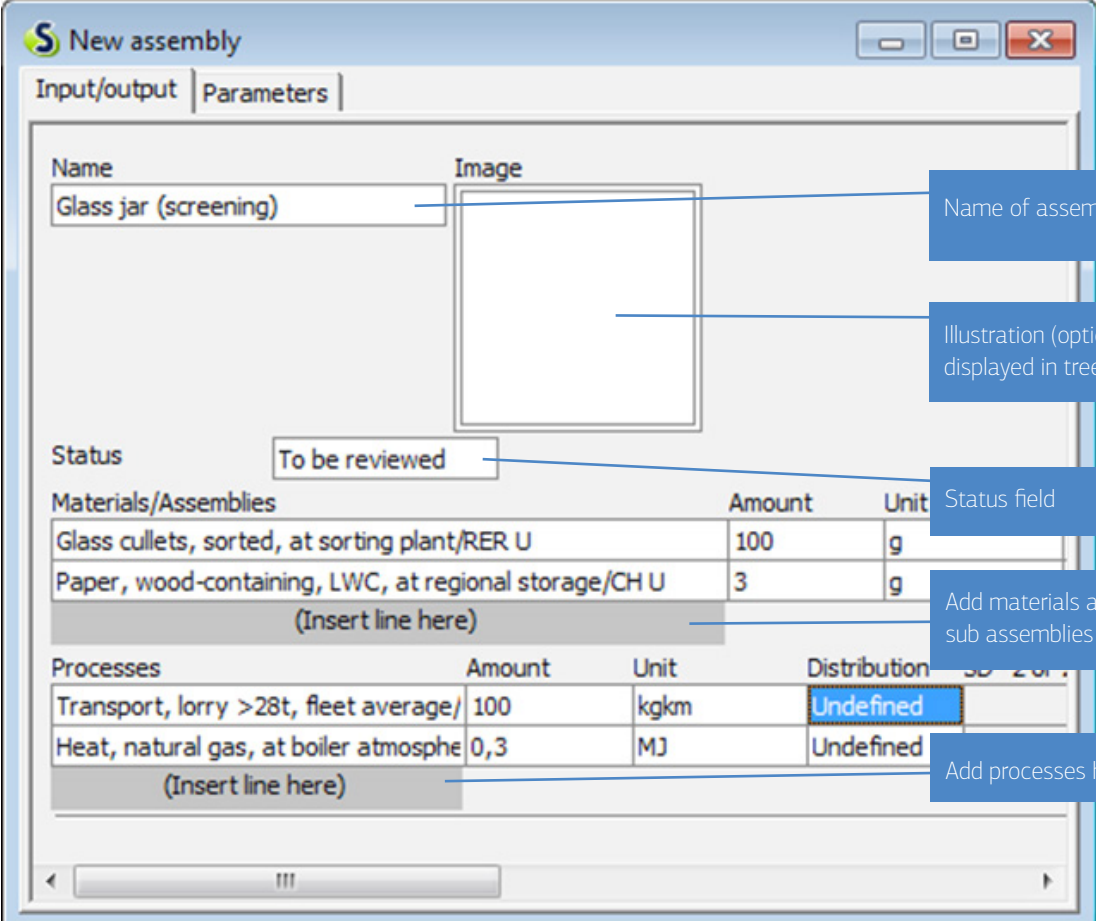
Figure 16: Example of a network representation that contains loops. Only the most relevant of in total 1999 processes are displayed.

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 one that is 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. It is not possible to link between libraries or between projects, as it is desirable to keep them independent.

In case you would like to modify data in a library, we strongly recommend copying such a record into your project and making any changes in the copy. This is an important guideline, as by changing libraries you may also change LCA results in other projects. (In SimaPro Compact, Classroom and Faculty it is 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 that a product contains 1 kg of steel, you make a link to the process that describes steel production and you specify 1 kg as the quantity. Some product stages can also link to other product stages.



New assembly

Input/output | Parameters

Name: Glass jar (screening)

Image: 

Status: To be reviewed

Materials/Assemblies	Amount	Unit
Glass cullets, sorted, at sorting plant/RER U	100	g
Paper, wood-containing, LWC, at regional storage/CH U	3	g
(Insert line here)		

Processes	Amount	Unit	Distribution
Transport, lorry >28t, fleet average/	100	kgkm	Undefined
Heat, natural gas, at boiler atmosphere	0,3	MJ	Undefined
(Insert line here)			

Callouts:

- Name of assembly
- Illustration (optional) can be displayed in tree or network
- Status field
- Add materials and sub assemblies here
- Add processes here

Figure 17: An example of a product stage, in this case the assembly.

New life cycle

Input/output | Parameters

Name: Lifecycle glass jar (screening)

Image: [Empty box]

Status: Draft

Assembly: Glass jar (screening)

Amount	Unit	Distribution	SD ² or 2*SDMin	Max
1	p	Undefined		

Processes: (Insert line here)

Waste/Disposal scenario: Curb side collection/NL U

Additional life cycles: (Insert line here)

Number	Distribution

Callouts:

- Name of life cycle
- Illustration (optional)
- Status field
- Assembly in this life cycle
- Add use processes here
- Select waste scenario
- Add additional life cycles (boxes, pallets, etc.)

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, all with their own structures.

- **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. Analyzing 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 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, tires, 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 flows. 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** describes 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.

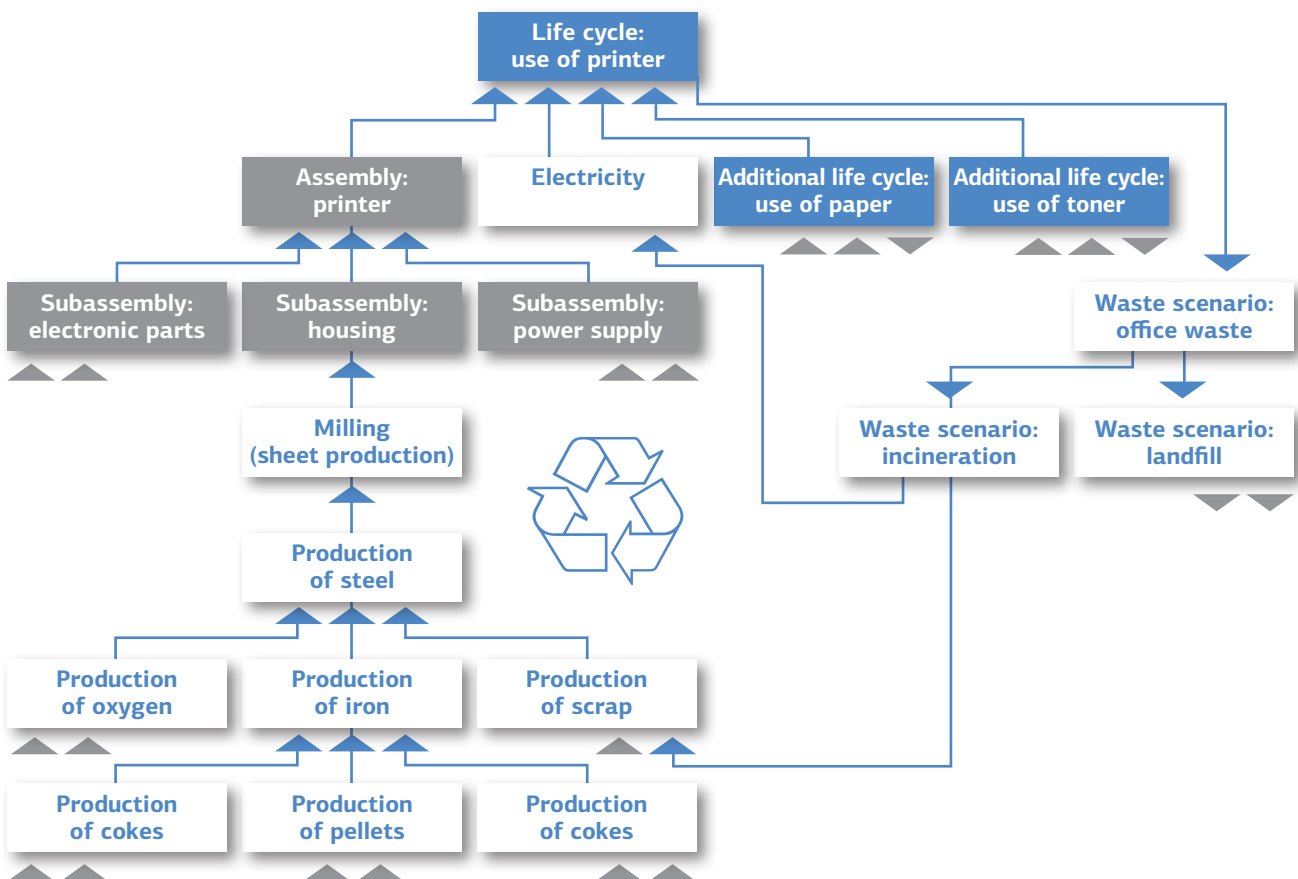


Figure 19: Schematic overview of the life cycle of a fax machine; the grey boxes are product stages, the white boxes are Processes.

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.

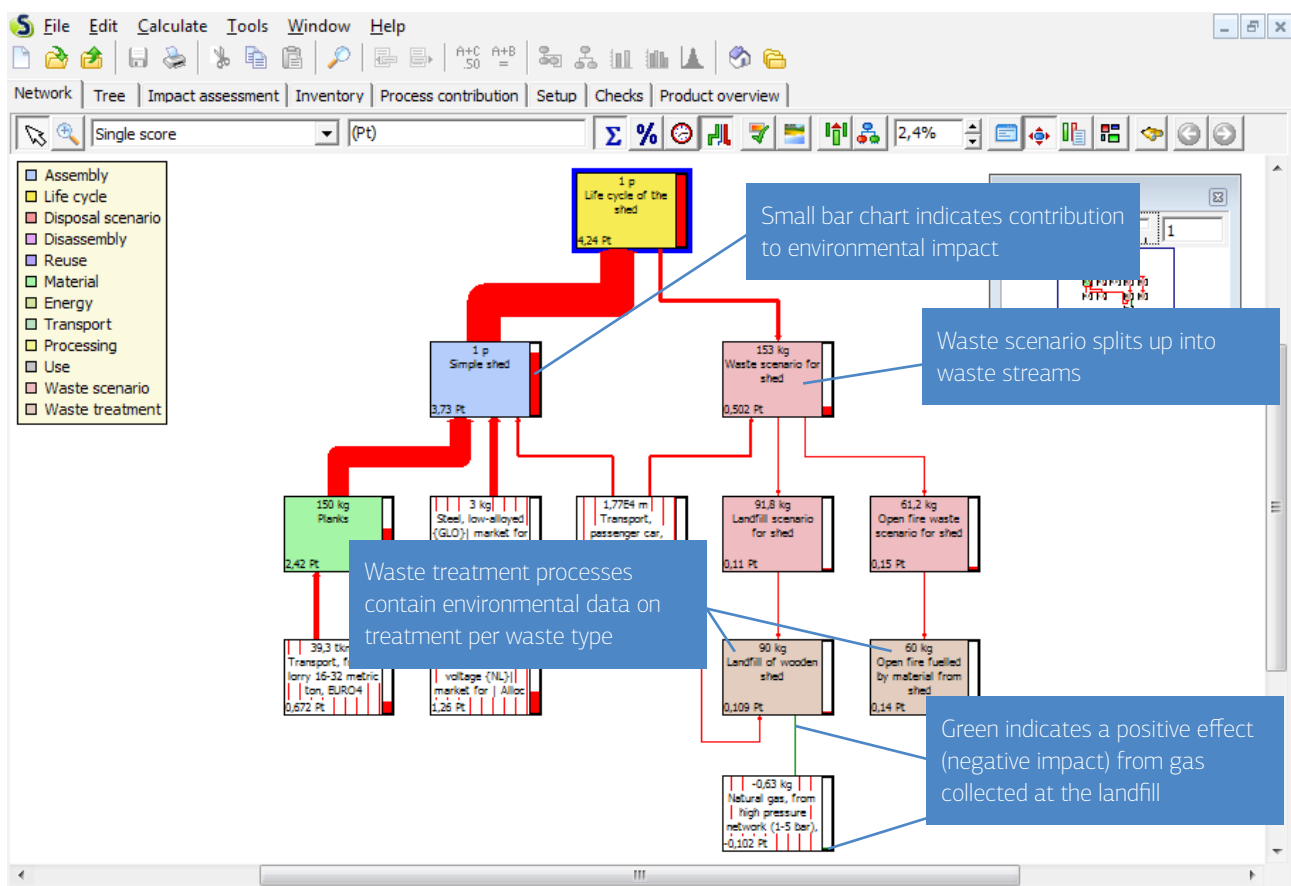


Figure 20: Schematic overview of a process tree (example taken from tutorial).

8.5 Modeling 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 which sometimes feels 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 an 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 modeled. In a way, modeling here is more complex than modeling the production phase. The following sections attempt to give you an overview of the terms and concepts used in 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 disassembly and (partial) reuse operations.

An example is the recycling of glass; throwing a bottle in a glass collection container would be modeled in a waste scenario whereas 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 document the emissions and other impacts which arise 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.

The screenshot shows the 'New waste scenario process' dialog box with the following sections and callouts:

- Products:** A table with columns: Name, Amount, Unit, Category, Comment. A callout points to the 'Name' column: "Name of the waste scenario and the amount of input it refers to."
- Inputs:**
 - Known inputs from technosphere (materials/fuels):** A table with columns: Name, Amount, Unit, Distribution, SD^2 or 2*SD Min. A callout points to the 'Name' column: "Materials and energy/transport needed for this scenario per unit of waste input."
 - Known inputs from technosphere (electricity/heat):** A table with columns: Name, Amount, Unit.
- Outputs:**
 - Materials and/or waste types separated from waste stream:** A table with columns: Waste scenario/treatment, Material / Waste type, Percentage, Comment. A callout points to the 'Material / Waste type' column: "Waste stream per waste type (i.e. paper, aluminum, glass). These are sent to different waste scenarios or treatments. For instance 50 % of glass is collected separately."
 - Waste streams remaining after separation:** A table with columns: Waste scenario/treatment, Percentage, Comment. A callout points to the 'Percentage' column: "Waste streams independent of the waste type. For instance, 40% of the remaining waste is landfilled and 60% is incinerated."

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

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 link between the material composition and the emissions that occur. To allow for this SimaPro can also divide the waste stream into different waste types or materials. A waste type is a generic term, such as paper, plastics, PVC or Ferro metals. For the waste modeling it is usually not so important to know the specific type of 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.

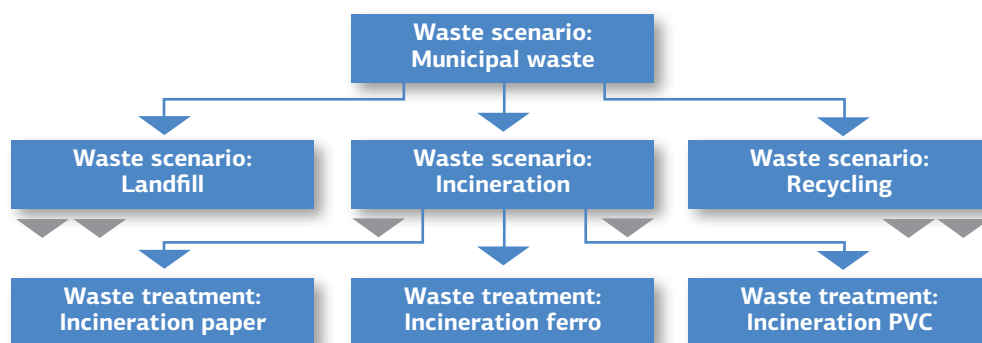


Figure 22: A waste scenario specifies how a waste stream is split up and sent to other waste scenarios or waste treatments. This splitting can be specified per waste type (as seen in this figure) or material. A waste treatment specifies what actually happens if a material is land filled, incinerated or recycled, etc.

With well-defined waste types, you can specify how the waste stream that has to be incinerated is split up according to these types. Each waste type is now “sent” to a specific waste treatment. For example, the waste type paper is sent 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.² Similarly, waste type PVC can be sent to a waste treatment describing the incineration of PVC materials.

Making detailed waste scenarios

The emissions from waste treatment depend on the composition of your product. If you specify that there is 2kg of material, which is labeled 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 your modeling, but also creates some distortions. Not all PVC contains lead as a stabilizer, and if you only have a waste type PVC, you cannot see the difference between PVC with and without such stabilizers. 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 more precise, and is also supported by SimaPro. One of the consequences however is 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 practicality. Ultimately this depends on your goal and scope.

² 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 CO₂ is typically determined by the content of the product that is incinerated, for every kg carbon in the product, 4.4 kg of CO₂ 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.

Waste treatments sometimes 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 subtracted ³.

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 section 8.5.2).

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

- 50% of the fax machines will not be collected. This means these are sent 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 a good condition and 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 by 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 specialized 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 sent 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 described here you should, for instance, specify the power supply as a subassembly, which consists of subassemblies like the fan, the transformer, and the electronic components.

³ This also explains why there are frequently negative environmental loads in the end-of-life product stages.

Managing uncertainties in recycling rates

You can use parameters in disposal scenarios, disassemblies, and reuse boxes. For instance, you can define a parameter called recycling rate, 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 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 adding an uncertainty range to the recycling parameter, and by defining the remaining waste stream as 100% recycling percentage, we can fulfill the requirement that the sum of both waste streams is equal to 100%.

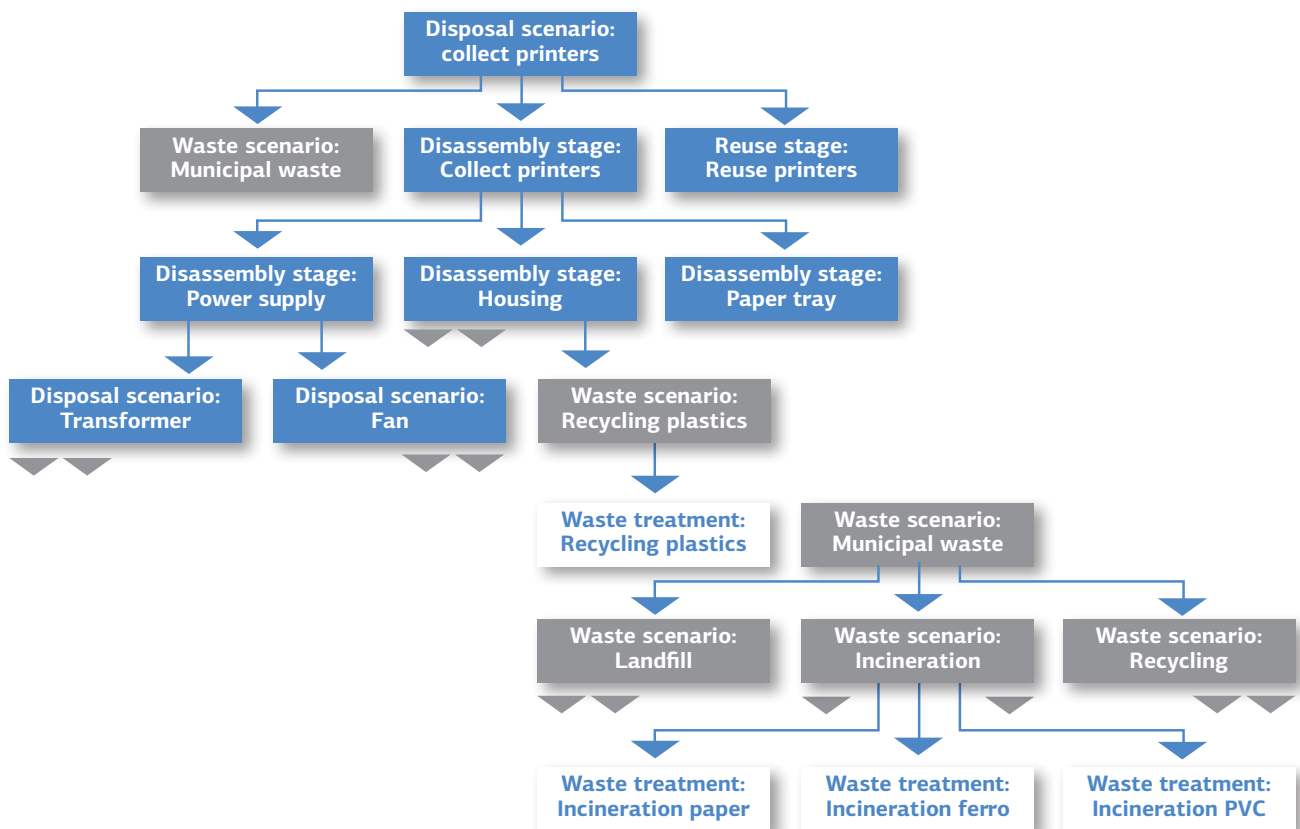


Figure 23: A disposal scenario specifies how products are distributed over different end-of-life options, such as disassemblies, reuse and waste scenarios. A disassembly specifies how products are split up in different components and to which destinations these are sent to.

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

To summarize we will describe the steps involved in building a complete life cycle.

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 are described in section 8.5.3. 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 above).

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 selecting the process or product stage you want to link. This is assuming 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 modeling. 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. Each process or product stage has a status field. Processes 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 indicates, nothing to be done anymore

When you fill in these status fields, you will be able to recognize the status of each process in the tree or network, by clicking the “show status” button; the boxes in the tree will be colored 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 calculated results.

Example Monte Carlo analysis

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

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

- SO₂ emission from burning 1 kg of heavy oil is 10 grams on average, but in 95% of the cases the value lies between 5 and 15 grams, depending on the sulphur content of the oil.
- The oven in which you burn this oil generates 40 MJ of heat per kg of 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 and 15 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 of 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, the computer takes a random variable for each value within the uncertainty range we specified and recalculates the results. The result is stored. Next the calculation is repeated by 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 form an uncertainty distribution.

9.1 Distribution types

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

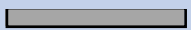
Distribution	Data needed	Graphical presentation
Range	Min and max value	
Triangular	Min and max value plus best guess value	
Normal distribution	Standard deviation and best guess value	
Lognormal distribution	Standard deviation and best guess value	

Table 9: Different distributions

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 outcome of throwing a single dice. The range is between 1 and 6, and there is an equally big probability for each outcome.
2. Triangular. This distribution is sometimes used as an alternative for the normal distribution. The advantage is that extremely 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 center) and the standard deviation (SD). However, in SimaPro you are asked to specify the 2*SD value. This is useful as the 95% confidence interval lies between -2*SD and +2*SD. 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 2*SD.
4. Lognormal distribution. This is the most important distribution in 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 needs to be entered into SimaPro in the following way:

- SO₂ emission from burning 1 kg of heavy oil is 10 grams on average, but in 95% of the cases the value lies between 5 and 15 grams, 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 grams. The choice for the distribution depends on your knowledge about the likelihood that the emission per kg of oil is close to 10 grams.
- The oven in which you burn this oil generates 40 MJ heat per kg of 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 no strict maximum or minimum value. A property of this type of 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 deduce that the standard deviation is 1 MJ and that double the standard deviation is 2 MJ. In SimaPro you enter the value 2 as the double standard deviation, as this is what SimaPro expects 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 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 use 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 to the amount of fuel used). This type of correlation is 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 of 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.

SimaPro does not show overlapping distributions when comparing two products. There are two ways to see the “real” difference between product A and B:

- We calculate how many times the Monte Carlo runs show 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 mostly positive, you can see that product A has a higher impact than product B; if the outcome is mostly 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 analyze and use the Monte Carlo 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.

While calculating, SimaPro will report on the progress of the calculation. You can stop the calculation at any time, before the stop criterion or the maximum number of runs is reached.

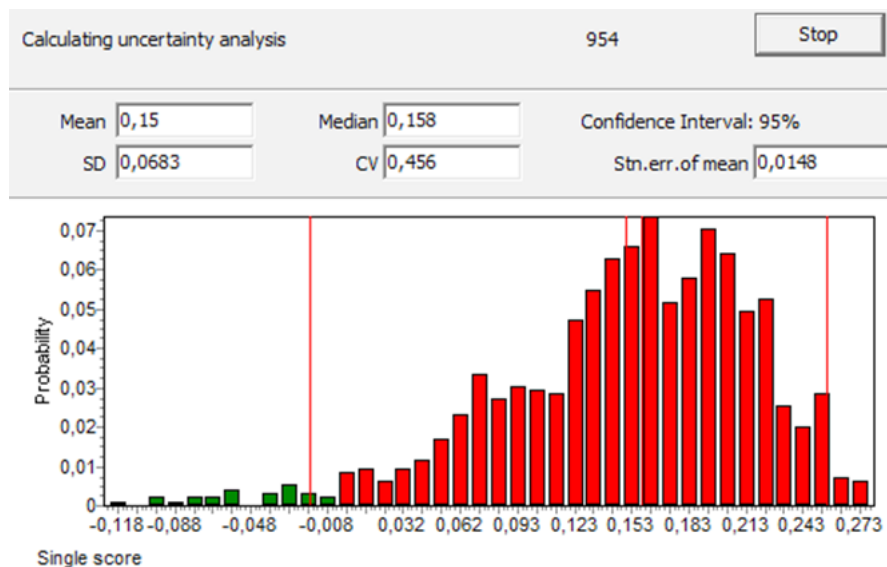


Figure 24: Progress status window during Monte Carlo calculations. It is especially important to keep track of the value of the standard error of mean.

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, and within a few minutes.
- When you want to present graphical distributions, as seen in figure 24, you will see that at 100 runs the figure 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 1000 runs. Depending on the speed of your PC, this can take about an hour. More runs usually result 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.

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 analyze 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.

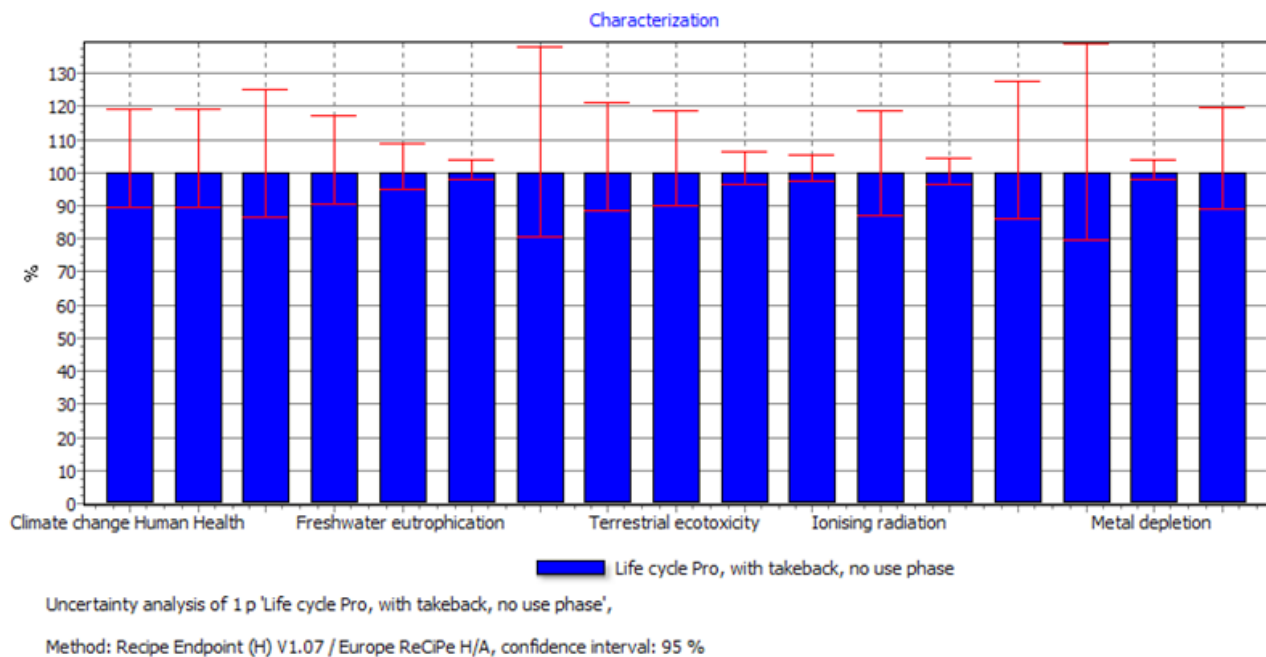


Figure 25: Example from tutorial: graphical representation of the Characterization screen for the modelled coffee machine. The vertical T-lines indicate the 95% confidence intervals. Clearly certain scores have a high uncertainty.

In general, you will find that the absolute uncertainties on the characterization level are quite high. Please consider that the uncertainties in the characterization 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 section 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:

- Mean. This is the average score of 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). This is the most useful parameter to use when we want to report the “best guess” value.
- Median value. Imagine we can sort all of the results of the calculations. The middle value is the median value. This is useful if outliers are significantly influencing the mean value.
- Standard error of mean. This is in fact the stop criterion mentioned above. This is the amount by 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.

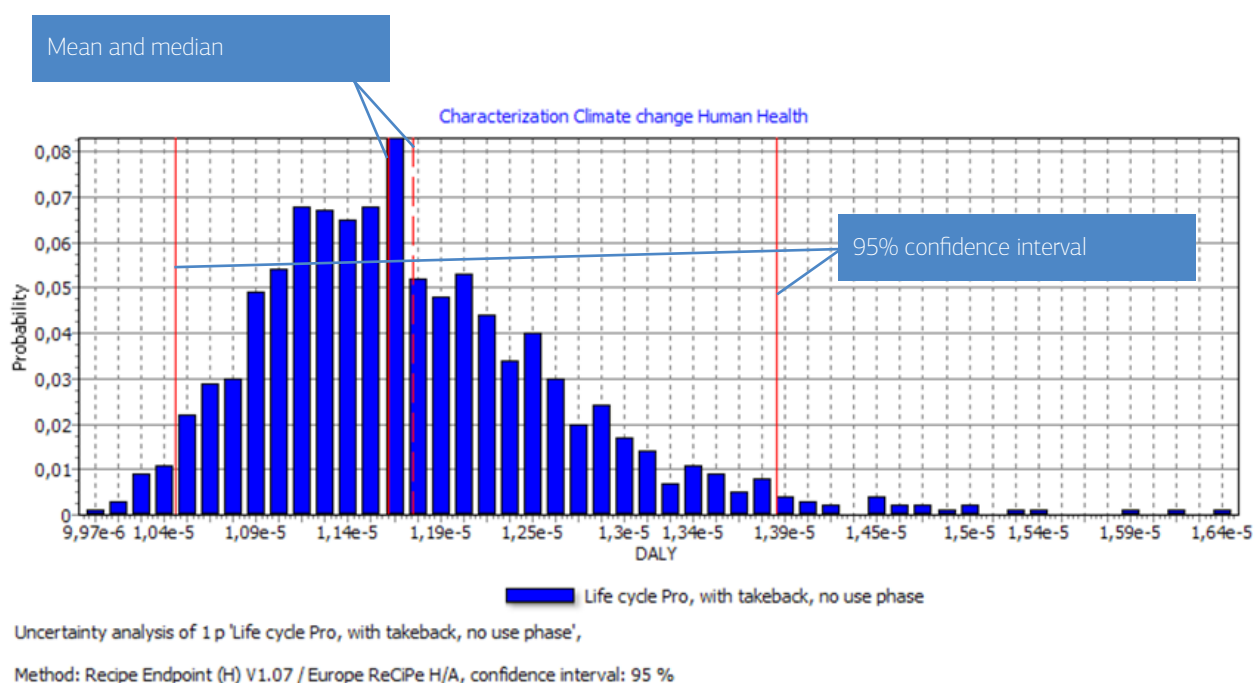


Figure 26: Graphical representation of a distribution. The horizontal axis displays the value of the calculation, in this case Climate Change Human Health. The vertical axis displays the probability that a certain value is reached. Four lines are shown. The middle ones represent the mean and median value. The two other lines represent the 95% confidence interval.

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 than 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 ⁴.

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

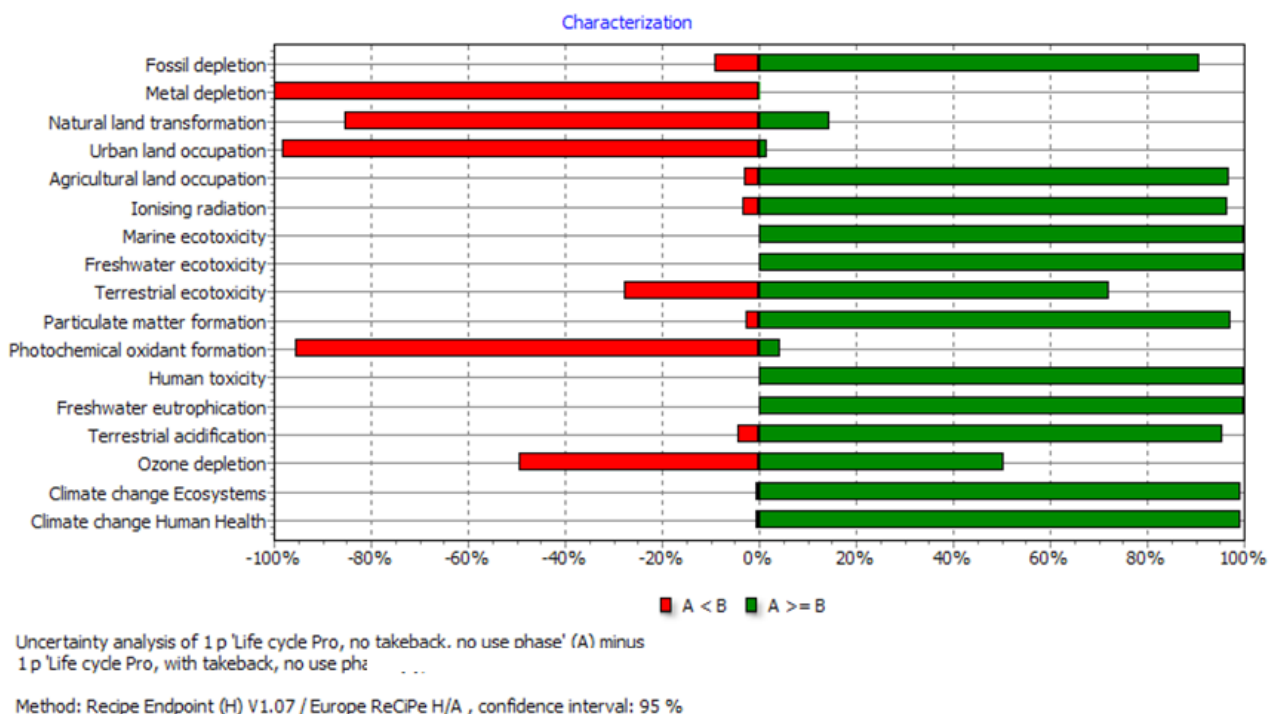


Figure 27: Example from tutorial: Monte Carlo results of a comparison. In this figure the number of outcomes where one life cycle has a higher score than the other life cycle is shown per impact category. This allows us to see whether the differences shown in the previous figure are indeed significant. In general we can assume that if 90 to 95% of the Monte Carlo runs are favorable for a product, the difference may be considered significant. Applying this rule here means that only the difference on four effects is not significant.

Figure 27 shows that although the absolute uncertainties for each impact category are high, this way of comparing results does lead to useful conclusions. Again this is only possible because SimaPro keeps 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 gives no further insight (than figure 27).

⁴ 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.

10 Increasing your Productivity

10.1 SimaPro Easy, the web tool to disseminate your results

With SimaPro Easy, you can easily share your LCA results with your relevant stakeholders. SimaPro Easy helps provide insight into the sustainability performance of your products and helps your team make more informed decisions. This can be achieved without having in-depth LCA knowledge or modeling skills.

SimaPro Easy can be used for:

- product development and modification,
- environmental performance goal setting and benchmarking,
- streamlined LCA studies across a product group,
- supporting documents and data for external communication.

Product, carbon, water, and energy footprints, toxicity analysis and air quality impacts are just some of the metrics covered by SimaPro Easy. SimaPro Easy can be customized to an organization's specific needs and to different stakeholder groups allowing them to seamlessly integrate existing environmental efforts and strategies.

Once you determine your objectives and customize the SimaPro Easy's settings, you can easily:

- Access SimaPro Easy scenarios via a web interface, providing easy-to-interpret information to an unlimited number of users throughout your organization. Real-time information allows users to quickly and efficiently understand the results.
- Adapt the scenarios to see how various changes influence the results. SimaPro Easy is a flexible software program that allows product configurations to be assessed individually or to be compared side-by-side.

Delivery as Software-as-a-Service

SimaPro Easy is built on the Microsoft .NET platform and hosted by PRé, providing the most sophisticated capabilities and secure cloud-based global access and scalability available today.

10.2 Quickly update your reports with Report Maker

Whenever an LCA model changes, the results change as well. In practice, this happens continuously throughout a project. This involves updating the tables and graphs for your reports, which can be time consuming. The Report Maker add-on for SimaPro can quickly recalculate your results and automatically update your graphs and tables in Word and Excel, thereby saving time.

If you have a template for your Environmental Product Declarations, Report Maker can also be used to fill these templates with the data for the corresponding products.

The Report Maker add-on works with Office 2007 and 2010 and is available for all business versions, plus the educational PhD version. A free 30 day trial for licensed SimaPro users is available at www.pre-sustainability.com/report-maker.

10.3 Integrating SimaPro with other software

The COM interface in the SimaPro Developer version allows you to link SimaPro with other software. This opens the possibility to link all kinds of data sources to the LCA data in SimaPro, and also to show the results from SimaPro in other tools. For instance:

- Your CAD application sends a command to SimaPro: Calculate the CO₂ score for 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. An LCA profile can be automatically generated by sending these data to SimaPro. The monthly progress results can be shown in a dashboard in your ERP system.

The results can easily be disseminated throughout the intranet or internet. An important feature in the SimaPro multi-user version is that the LCA expert can continuously work to update the database, while the system is running.

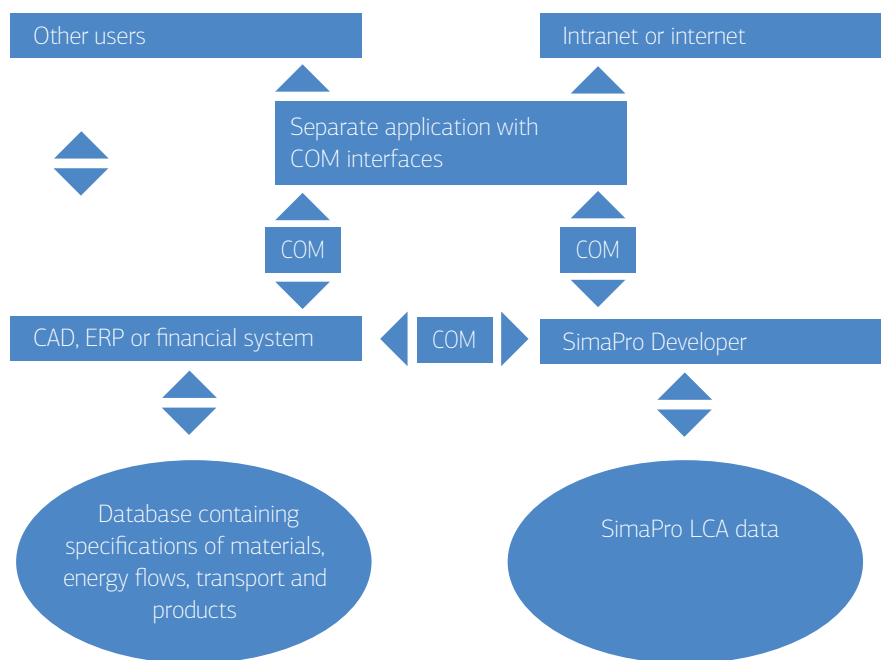


Figure 28: Multi-user version of SimaPro.

To demonstrate the COM feature a .NET desktop and a Java web application were developed by our partner GreenDeltaTC. You can download these open source connectors from <http://sourceforge.net/projects/sp-connector> and use them to create your own applications.

An alternative way to link SimaPro to outside data sources is the use of external parameters, as described in the tutorial in section 5.3.

Abbreviations

BOD	Biological Oxygen Demand
CML	Centre of Environmental Science, University of Leiden, the Netherlands
DALY	Disability Adjusted Life Years
ELCD	European Life Cycle Database
ELMIS	Environmental Lifecycle Management Information System
EPD	Environmental Product Declaration
EPS	Environmental Priority Strategy (impact assessment method)
ERP	Enterprise Resource Planning System
GRI	Global Reporting Initiative
ILCD	International Reference Life Cycle Data System (Handbook or Format)
IPCC	Intergovernmental Panel on Climate Change
IPP	Integrated Product Policy
LCA	Life Cycle Assessment (or Analysis)
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
OECD	Organization for Economic Co-operation and Development
PCR	Product Category Rules (for EPDs)
PAH	Polycyclic Aromatic Hydrocarbon
R&D	Research and Development
SQL	Structured Query Language (computer language for accessing and manipulating databases)
WHO	World Health Organization

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:	An old database from the Swiss Agency for the Environment, Forests and Landscape (Bundesamt für Umwelt, Wald und Landschaft). (not supplied with SimaPro any more)
Capital goods:	Goods that are a one-off investment, like trucks or machines.
Category endpoint:	An attribute or aspect of natural environment, human health, or resources, identifying an environmental issue of concern (ISO 14040).
Cut-off criteria:	Specification of the 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 are affected and the severity of the disease).
ecoinvent:	The Swiss centre for Life Cycle Inventories. It is responsible for extending, updating and to preserving the high quality of the ecoinvent database. The data in this database is derived from different older 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 (what kind of diseases) with a specific concentration.
Endpoint:	A term introduced in (but unfortunately not defined in) ISO 14044. It 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:	An older LCI database created by the former energy-materials-environment group (Energie-Stoffe-Umwelt, ESU) at the Swiss Federal Institute of Technology (Eidgenössische Technische Hochschule, ETH). (not supplied with SimaPro any more)
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:	A 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 use, land use, etc. that are collected, before impact assessment is applied.
Midpoint:	An indicator that is somewhere along the environmental mechanism and the LCI parameter. For instance the CO ₂ equivalents that express the radiative forcing is a midpoint. It is needed to calculate an endpoint indicator, such as increased seawater level, but additional modeling steps are needed. See also Endpoint.
Monte Carlo analysis:	An analytical method that randomly generates values for uncertain variables by running a model fitted to an experimental dataset.
Normalization:	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:	The process by which various indicators, resulting from an LCA study, are aggregated into one single figure (or a limited number of figures) through the use of subjective weighting factors.
Weighting factor:	A factor that is coupled to a certain impact category, which is determined by a panel, based on subjective opinions. The factor reflects the importance of the category.

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