Module on Life Cycle Analysis

In this module, the basic principles of lifecycle analysis (LCA) are explored. It explains what LCA is, which elements it consists of and where it can be of use. An example case on PET bottles is used to explain the basic principles. These principles can later be applied to other specific cases.

Introduction

LCA is the abbreviation for Life Cycle Assessment.

An LCA is a method for mapping the influence of products and human activities on the environment. An LCA considers the entire lifecycle of a product or activity. From the extraction of raw materials over production and (re)use to waste processing (cradle to grave).

Watch this video as a general introduction to LCA.

The result of an LCA study is an environmental profile: a kind of score list of environmental effects. The environmental profile shows which environmental effects are relevant and which production steps have the greatest impact on these environmental effects.

Steps of an LCA

An LCA is performed in several steps, typically subdivided as indicated below (as in the ISO14004 standard).

Step 1: Purpose and system boundary

Determining functional unit and system boundaries

Step 2: Inventory/ data collection

Consider all steps and processes in the chain

Calculate the environmental impact of processes

Step 3: Impact assessment

Conversion of environmental impacts (e.g. CH_4 and CO_2) to environmental effects (e.g. climate change)

Possible weighing of different impact scores

Step 4: Interpretation
Conclusions and recommendations

After these steps, a critical evaluation by experts is performed, after which the LCA may need to be adjusted. This final phase is not included in this learning module, but it is important to consider.

From here on, we use the PET bottle as an example throughout the thought process.

Process knowledge

To carry out the LCA of a product, you have to know that product very well. In other words, it is important that you know what the raw materials are, how it is produced and what the product characteristics are.

Product sheet

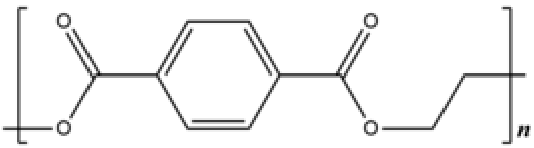
That is why we start with a product sheet. In the product sheet below, we map out the most important properties of our end product, the PET bottle.

Product Sheet PET

PET or polyethylene terephthalate is:

- a plastic
- a polyester (polymer from ester compounds)
- a thermoplastic (easily moulded when hot)

It has the following structural formula:



It is used for:

- PET bottles and other food packaging
- industrial and textile fibres (e.g. fleece)

for films, plates, kitchen utensils, etc.

Production process

More important is the production process itself. The production of raw material (petroleum) to finished product (PET bottle) can be divided into two major production steps:

1. The production of PET pellets from petroleum
2. The production of PET bottles from PET pellets.

Watch this video on how plastic pellets are generated from petroleum (step 1).

In this video, different types of preforms and eventually PET bottles are made from PET pellets (based on petroleum, recycled PET or biobased; Step 2).

We follow the process starting from PET pellets to finished PET bottles. A thorough knowledge of the production process is a firm basis for a good LCA. All inputs and outputs have to be mapped. Consider for example the energy input required to produce bottles from PET pellets. Think about the following aspects:

- Electricity consumption for cooling
- Electricity consumption for heating
- Electricity consumption for controlling machines, robots
- Gasoline consumption for transport

Energy consumption is thus clearly an important environmental aspect in the production of PET bottles. In the production process, important consumption of heat, cooling, compressed air, etc. can be identified.

Electricity from the grid, natural gas from the public pipeline system, diesel from a diesel tank, ... we call this **'primary energy'**. From this, secondary energy forms are produced, such as heat, cooling, compressed air, chemical energy from batteries. For example, 'heat' is produced by burning natural gas in a boiler or directly by electrical resistors.

When drawing up the LCA, you therefore have to take into account both the impact of the generation of primary energy and the conversion to and corresponding yield of secondary energy.

Structure of an LCA

Now you have an idea of how a PET bottle is produced and have a first insight into possible obstacles for a sustainable product (e.g. use of fossil fuels, high energy demand,...), it is time to carry out an objective life cycle analysis.

We follow the steps mentioned earlier.

Purpose and system boundaries

Define the purpose

Before carrying out an LCA, the target audience and the purpose of the study should be clearly defined.

Possible objectives are:

- Mapping the environmental impact of 1 product from cradle to grave
- Comparing the environmental impact of different products providing the same service
- To evaluate the contribution of different stages (e.g. production, consumption,...) in the lifecycle to the total environmental impact of the product

The target audience is also determined: Is the LCA intended to inform the authorities, to convince customers, to apply for a sustainability certificate, etc.?

The commissioner of the LCA is also clearly indicated. Always keep this in mind when interpreting the results of an LCA made by someone else.

You will see that there are many steps in the performance of an LCA. In each of those steps, choices and assumptions have to be made. These choices should be clearly stated in the report and may have a major impact on the final result. In order to check whether the choices have been made fairly and the uncertainties are clearly presented, an assessment should be carried out by an independent expert at the end of the study. Nevertheless, it may be relevant to check the commissioner and the purpose of the study, so that you can clarify certain choices.

Exercise 1

Consider the Fontinet Case Study and answer the following questions:

1. What is the purpose of the study on PET bottles?
2. This LCA study was drawn up to support the choice of which municipality? What do they want to promote?
3. Who is the commissioner of this study?
4. What do you expect about the choices that will be made in the study?

Functional Unit

The functional unit describes the function that the product fulfils in both qualitative and quantitative terms, as well as its service life. All results of the study are related to the functional unit.

In the example on PET bottles and water filter the following functional unit was chosen:

"the provision of 1.5 litres of water, being 1.5 litres of filtered tap water or 1.5 litres of naturally produced water for domestic use".

This volume corresponds to the volume of the commonly known single-use PET bottles for bringing drinking water of natural origin to the customer.

Exercise 2

1. What would be a suitable functional unit for a study in which the impact of different carrier bags (plastic, compostable, reusable cotton...) is compared? The production of 1 carrier bag? Or a carrier bag for carrying 2 kg of groceries from the shop to home every day for 10 transports?
2. Choose the best functional unit for lighting
   - Illuminate 10 square metres up to 3000 lux for 50,000 hours.
   - A bulb that burns until its consumption is equal to 1 kWh of electricity.
   - A bulb that burns for 8 hours.

System boundaries

Time to determine the system boundaries of our system. All the previous steps help to determine these boundaries.

There are various options for an LCA study:

- Cradle-to-grave - if you want to map all processes of a product from the extraction of raw materials to the waste phase of a product
- Cradle-to-market - if you want to map the impact of the product all the way to the shop
- Cradle-to-gate - if you want to map the environmental impact of the extraction of raw materials right up to the company boundaries

The choice of system boundaries for the study depends on the purpose of the study, the target audience and the client. In order to practise these terms, consider the following exercise, which is based on real LCAs.

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Exercise 3

How would you determine the system boundaries for the applications listed below? These are all real-life examples for which LCA studies were performed.

1. The Norwegian government wants to compare the environmental impact of consuming tomatoes of different origins (imported from Spain, grown locally in vertical farms, grown locally in greenhouses), all bought in the supermarket.
2. A producer of tiles for footpaths wants to compare two production processes. The bricks meet the same quality requirements, have the same chemical composition and have the same shape and size.
3. Before drawing up a complete relighting plan for a company, one wants to compare the environmental impact between recessed spotlights with a halogen lamp with LED lighting. This way, a responsible choice can be made in the long term.

System boundaries in the PET case study

After choosing the type of LCA to be made, all relevant processes are listed. It is possible to exclude certain processes if this is clearly documented. It may be that a certain process will only account for a very small proportion of the impact, that there is too little information available about a process, or that a process is the same for both products and can therefore be ignored.

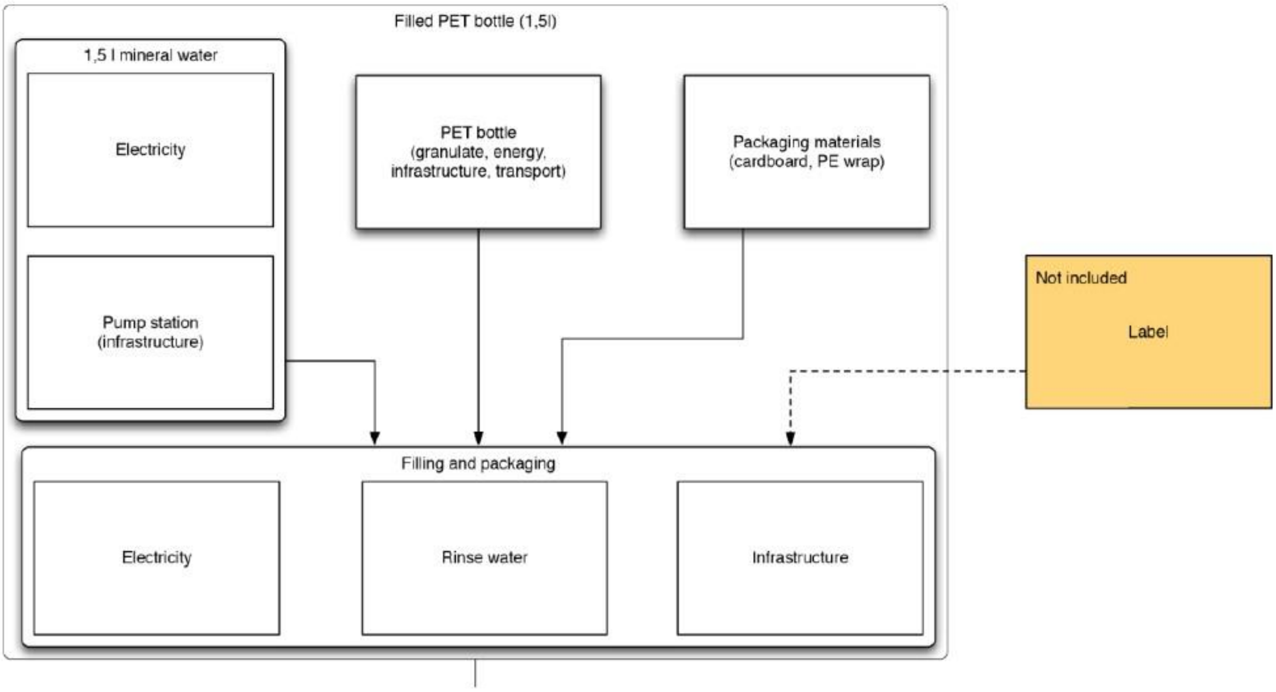
Let us analyse which system boundaries the executors of the study on sustainable drinking water supply set up for the inhabitants of Lommel. Some choices made in this study:

- The extraction and distribution of tap water and natural spring water, including infrastructure and transport of the product to the customer, is taken into account.
- The material production phase includes the extraction of the raw materials as well as the manufacturing and assembly of the material.
- Use of packaging: any disposal or recycling of waste from intermediate operations (waste products from extraction and production, or packaging waste) with a significant impact is included.

The following aspects are excluded:

- The user phase (water cooling) and the production and cleaning of the recipient (drinking cup) are excluded. It is assumed that they are the same for both LCAs.
- Recycling of the PET bottles was not included in the process diagram. The recycling of PET will be included in the impact assessment in the form of avoided emissions and raw material use.

This scheme shows some of the system boundaries when bringing water to the consumer in PET bottles.



You can see that for the production of the PET bottle, the choice was made to take into account the pellets, the energy, the infrastructure and the transport. This means that the company probably already had an idea of the environmental impact of the production of pellets. This may be because of previous LCA studies of the company or because data are already available in a database. For processes that are "standard" in the industry, databases such as the European elcd-database can be used. In this case, the inputs (such as oil, other energy sources, added chemicals, etc.) and outputs (all gasses released, emissions to water, etc.) have already been mapped so that the company itself does not have to calculate this.

In this study, infrastructure is taken into account. This is not common practice. Usually, the impact of infrastructure is limited because it only has to be produced once. If known, it can of course do no harm to take it into account. The lifetime of the infrastructure will limit the impact per product. Energy and transport will be important inputs. The impact of energy sources is already well known.

You will notice that the production of the PET bottle is not enough. It still needs to be filled with mineral water that originates from groundwater and needs to be pumped up. The bottle will be rinsed with rinsing water before being filled.

The bottles will then be packaged (e.g. by six) and this will also require additional packaging material and processing. The label on the bottle has not been taken into account, as it is assumed that the impact of the label will be less than 1% of the total impact and can therefore be disregarded.

Extra: Recycling of PET bottles

In this study, the recycling of PET bottles is illustrated in an indirect way. It is important to note that the study was set up for transparent PET bottles. These are easy to recycle. In this process, the impact of recycling is only taken into account at the end of the LCA. Here, this is done by expressing the avoided raw material consumption and the avoided emissions in the production of PET bottles from 'virgin' (new) material as a credit (or a negative value for the environmental impact). Average collection figures of PET bottles in Flanders are used to estimate how many bottles are recycled.

In terms of the environment, it has to be noted that PET bottles for food are rarely reproduced as the quality requirements and safety standards are too high. In recent years, companies such as SPA and Evian have started to add more and more recycled PET to their bottles. However, this usually remains at a percentage of 25-50%.

The recycling of PET in Belgium is usually done by grinding and remelting the PET bottle, a process that does not meet the requirements of the food industry. The recycled PET can be used for other applications (dishes, fleece, etc.). Chemical recycling of PET is also possible, and is of sufficient quality, but much more complicated. In Flanders, there is no active plant yet that applies chemical recycling on a large scale. There are indications that such a plant will be set up in the near future.

In order to make the recycling of PET worthwhile, as few other layers as possible need to be applied to or in the bottle, and it is best to work with colourless PET.

The energy input and impact of the recycling of PET has not been considered in this study. It was stated that the cut-off rule was used. This states that if a process accounts for less than 1% of the total impact, it may be left out of consideration. This is to avoid making the LCA unnecessarily complicated.

An alternative approach would have been to include plastics recycling as a process in the process diagram and to include all inputs and outputs in the analysis here, too.

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The part relating to waste processing that is included in the process diagram is the separate collection of household waste in Flanders, as is the processing of the plastics that end up in residual waste and are largely incinerated with energy recovery.

Inventory/ data collection

Data collection

The most time-consuming part of the LCA is the data collection. Based on your scheme of system boundaries, you consider all inputs and outputs of the system.

You list the inputs to your system and determine how much of those inputs are needed to produce a certain amount (if possible, the amount defined in the functional unit) of the desired product. For example, you can determine the inputs for 1 empty PET bottle quite unambiguously.

It is best to collect this data from the producer of the product. Sometimes this is impossible, in which case you look for data in literature. These can be articles about the production process, benchmarks in the industry or previously conducted life cycle analyses (in Europe for products often called Product Environmental Footprints). In addition, there are databases that list typical inputs for known and common processes. If no specific data are available, you have to make assumptions. These will have to be clearly stated.

In the PET bottle study, you will find an overview of the data collected on pages 17 and 18. In the left-hand column, you will find the process/material about which information is collected. This corresponds to the items in the process diagram. Next to this is the quantity that is needed to produce 1 bottle. In this study, this information was largely taken from the ecoinvent database. The specific description of the name of the data item is given in data record. For example, you can see that for electricity (line 1) the average electricity mix in Belgium was taken. In addition, in the comments table you can see which assumptions were made and on which study these assumptions were based. The origin of all input data must be clearly displayed.

Let us focus on the data listed for the production of the PET bottle. These should correspond to the ones we have listed in the question above.

Determining the emissions

If you go through the list of input data thoroughly, you notice that there is a whole list of input data to be collected. If you have to determine the emissions of all possible gases, substances in the wastewater, leaks to the environment, etc. too, this is an impossible job.

Fortunately, there are databases and software that collect these data for the LCA specialist and present them in a clear manner. An example of open source software is openLCA. In this software, you can insert process diagrams drawn up at system boundaries and load databases with conversion factors.

Extra

If you want to get more insight into this, you can get started on your own with the tutorial Basic Modelling in openLCA explained using a PET bottle case study. This is beyond the scope of this module, but is certainly an exciting experience.

A difficulty you may encounter in practice is the availability of data and the fact that specialised databases are often behind paywalls (order of magnitude of €100 to €1000 per licence). The openLCA software is free to use and various databases within it can be consulted free of charge. For studies that are very thorough or based on new processes or are more complex, you should check beforehand whether sufficient free data is available. Other software (such as GABI) releases versions for students, but limits the information available compared to the ones they make available for companies.

Impact assessment

In the life cycle impact analysis, we take the steps from all inputs and emissions to the environmental effects they cause. In other words, a life cycle impact analysis groups the emissions according to a certain environmental impact, e.g. global warming, and weighs them according to their contribution to this impact.

For other impact categories, it is much more difficult to correctly assess the impact of all substances. A good indicator must be found and the conversion factors for all substances must be known. This is complex and can be done in different ways. That is why the LCA software contains a list of standard impact models. A widely used impact model is the RECIPE model. This is the model used in the Fontinet case study.

Impacts are defined at midpoint level. Midpoints indicate the contribution of a product to a specific environmental impact. Examples of midpoints are climate change and acidification. You can also choose to look only at the endpoint level. In that case, one usually talks about:

- environmental impact
- resource depletion
- impact on human health

To look at the endpoint level of environmental impact, we need to add up the different environmental impacts (global warming, ozone layer depletion, ecotoxicity...) and assign a weighting factor to all of them. This again creates extra uncertainty, so usually impact assessments end at midpoint level. This level is also easier to interpret and gives a more accurate description of the results.

The final step in the impact assessment is to determine the total impact categories. To do this, you need to aggregate the information collected.

A very simple example - applied only to the consumption of natural gas and its greenhouse effect: The table below shows the emissions associated with the consumption of 1 kg of natural gas. It is important to note that according to LCA methodology, emissions must be represented from the "cradle" = the extraction phase to the "grave". The emissions (related to greenhouse effect) that occur during the extraction and purification of 1 kg of natural gas and the transport of this kg of natural gas to the consumer are shown in the first row of the table below. These were taken from the elcd database.

For 1 kg of natural gas:	Emissions		
	Kg CO_2	Kg CH_4	Kg N_2O
Production to consumer	0.28	0.00691	0.000724
Combustion	2.61	0	0
Total	2.89	0.00691	0.000724

You can see that when natural gas is produced, there is also an emission of natural gas. This is due to potential leaks of methane during the production process and subsequent transport.

To determine the greenhouse effect of natural gas on global warming in CO_2 equivalents, you have to transform the values in the table using their global warming potential. These values can be found here.

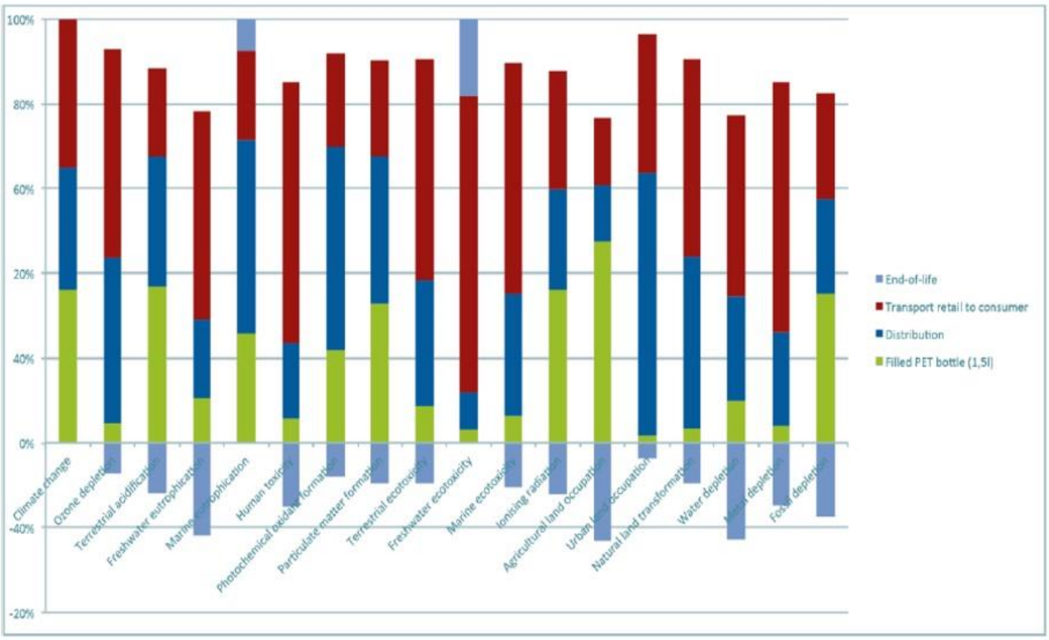
For 1 kg of natural gas:	Emissions		
	Kg CO_2	Kg CH_4	Kg N_2O
Production to consumer	0.28	0.00691	0.000724
Combustion	2.61	0	0
Total	2.89	0.00691	0.000724
Global Warming Potential (GWP)	1	28	265
Total kg CO_2 equivalents	2.89	0.19	0.19
Total	3.28		

The production, transport and subsequent combustion of 1kg of natural gas thus has an emission of 3.28 kg CO_2 equivalents. This value indicates the greenhouse effect and can therefore be used to determine the total environmental effect of natural gas on global warming.

Interpretation

The graph below shows the 18 different impact categories studied in the Fontinet case study in the 4 different life cycle stages. Take a closer look at 3 specific impact categories:

- climate change
- freshwater eutrophication
- fossil fuels



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We cannot compare the different impact categories with each other (other units, other importance...), but we can make a classification of impact per life cycle stage.

For each impact category, the impact is defined at 100%, whereby characters represent the % share of the 4 classified life cycle phases:

- filling the PET bottles, i.e. the production phase
- packaging and transport of the filled bottles to the point of sale, i.e. the distribution phase
- transporting filled bottles to the consumer, i.e. the transport phase
- collecting and processing of the waste of the PET bottle, i.e. the end-of-life phase.

You see that the end-of-life phase can sometimes be negative, meaning a positive effect or environmental gain, on quite a few of the impact categories investigated. A major advantage of a PET bottle is that it can be recycled very well and can thus make a positive contribution as raw material for new purposes. On the other hand, incineration with energy recovery is also an option.

For the impact 'climate change', we find that the first three phases have a similar impact and that end-of-life is negligible.

With regard to the impact 'surface water eutrophication', we note that the production of PET has a major impact because it requires a great deal of oil extraction for the production of raw materials and electricity. End-of-life also has a negative score here because by recycling PET, new production of PET is avoided.

The impact of 'fossil fuels' is largest during the production phase, when filling the bottles. This is because PET bottles are made from petroleum. A lot of energy is needed to convert petroleum into raw materials to make PET, then to convert pasty PET into PET pellets, then from pellets to preforms and finally to blow the PET bottles. Energy for the chemical industry is usually produced on using fuel oil and natural gas.

The same calculations were made for the water filter, so that both systems can be compared.

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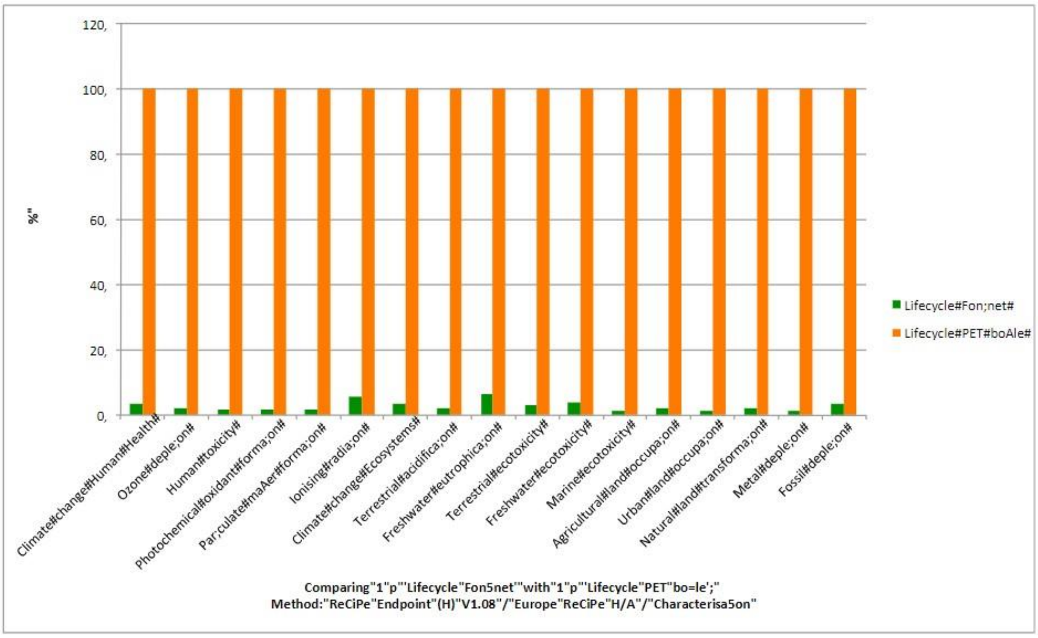

This comparison shows that for all impact categories, the water filter is much better than drinking water from PET bottles. The impact of the water filter (green) is only a small fraction of the impact caused by the use of PET bottles (orange, shown as 100% for comparison).

References

- Fontinet Case Study
- Study unit Grenzeloos Biobased Onderwijs – LCA module, developped by Katrijn Cierkens, Gert Hooft and Bram Marynissen
- OpenLCA software
- ELCD database