D3.4 Environmental assessment

THEGREEFA

Thermochemical fluids in greenhouse farming

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Document references

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[1] PU = Public
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CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

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Executive Public Summary

This report has been developed within the scope of EU-funded TheGreefa project, and it is providing results of the study performed within the *Task 3.4 Environmental assessment*, providing presentation of the environmental benefits related to implementation of TheGreefa technology in greenhouses.

The study was based on the real data collected from TheGreefa Swiss demonstrator (new system implemented) and the Italian case study (simulations on the real greenhouse). The analysis was further performed for 15 years long period of the greenhouses' life cycle.

The results obtained in the presented Life Cycle Analysis (LCA) have shown that the use of the new TheGreefa technology in greenhouses contributes to visible lowering the environmental impacts of the greenhouse operations. The heating, cooling and humidity control are very energy intensive processes in the greenhouse operation. The heat production and electricity consumption are responsible for most of the environmental loads. Therefore, implementation of improvements in these aspects is the right call that can help to reach the EU climate goals by reduction of the use of electricity and natural resources.

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1. Document information

This deliverable comprises the actions undertaken in T3.4 *Environmental assessment* of WP3 of TheGreefa project. It includes the Life Cycle Analysis (LCA) study performed analysing TheGreefa demonstrators and case studies. The presentation of the study and the results is preceded by a description of the demonstrators/case studies and the methodology of the study performed.

a. Purpose and goals

The study performed within the task 3.4 was conducted to present the environmental impacts of the implemented TheGreefa technology. Data from TheGreefa demonstrators and case studies were collected to be analysed in terms of energy, water, fossil fuels consumption and production of the greenhouses to compare the environmental impacts before and after implementation of TheGreefa system based on real data (demonstrators) or simulations (case studies). The LCA study allows to analyse and present overall long-term efficiency of TheGreefa technology and how it can have a positive impact on the environment and people.

b. Target audience

The deliverable *D3.4 Environmental assessment* is the public report therefore the target audience are all parties interested in the results of the LCA study. Although the aim of the report is to present the LCA results of TheGreefa project to the European Commission, other groups for whom the results presented may be of most interest are scientists and academics in the field of environmental and human impact research.

c. Relation to other activities

The activities of LCA study performed within WP3 Comprehensive assessment are in relation with technical work packages WP1 and WP2. The two WPs are a source of data needed for Life Cycle Inventory (LCI) phase of the study – WP1 gives inputs about TheGreefa technologies and demonstrators, while WP2 gives inputs from case studies and simulations.

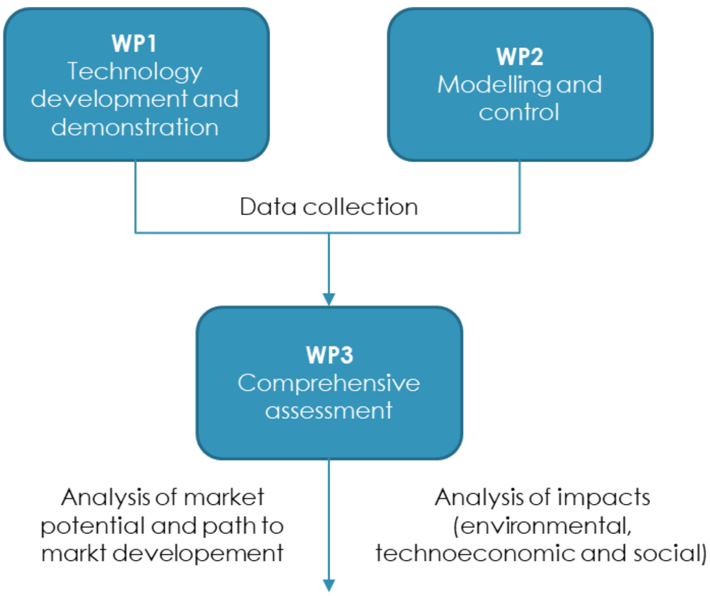

Figure 1. Relation between TheGreefa work packages in terms of LCA.

2. Life Cycle Assessment

The LCA study is conducted in accordance with the principles and framework for LCA, which are defined in the international standard for LCA ISO 14040 and ISO 14044.

a. Methodology

There are four distinct steps in an LCA study (ISO 14040, 2006; ISO 14044, 2006):

- the goal and scope definition steps, ensures that the LCA is performed consistently.
    - An LCA models a product, service, or system life cycle. 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 make sure the simplification and distortions do not influence the results too much. The best way to do this is to carefully define the goal and scope of the LCA study.
- the inventory analysis of extractions and emissions step.
    - In the inventory analysis, all the environmental inputs and outputs associated with a product or service are looked at. An example of an environmental input – something that is taken out of the environment to put into the product's life cycle – is the use of raw materials and energy. Environmental outputs – which the product's life cycle puts out into the environment – include the emission of pollutants and the waste streams. Together, they give the complete picture of the product's or process' life cycle.
- the life cycle impact assessment step.
    - In the life cycle impact assessment (LCIA), the conclusions that allow to make better business decisions are drawn. The environmental impacts are classified and evaluated by what is most important to a company, and translated into environmental themes such as global warming or human health. The most important choice that needs to be made is how integrated the results should be. There is an option of a single score to show how sustainable the product or to be able to see whether the design improves on CO_2 emissions and other climate change factors. This usually depends on the type of audience to be addressed and the ability of the audience to understand detailed results.
- the interpretation step.
    - During the interpretation phase, it is checked if the conclusions are well-substantiated. The ISO 14044 standard describes several checks to test whether conclusions are adequately supported by the data and by the used procedures.[1] [2]

[1] ISO 14040:2006
[2] ISO 14044:2006

To carry out Life Cycle Analysis studies, the professional software – SimaPro is used, in the purpose to evaluate the environmental impacts. This tool (SimaPro) incorporates the most important databases, such as: Ecoinvent, ILCD, etc. It also allows to use the most important and updated impact evaluation methodologies, such as: ILCD, CML, ReCiPe, etc.

In the final study of TheGreefa environmental impact assessment only the operational phase of the greenhouses is considered. The analysis is performed to compare the impacts of the greenhouse operation before and after implementation of TheGreefa system. The aim is to show improvement of impacts on environment and people resulting from differences in heating and cooling in different greenhouses.

b. Data collection

The collection of the inputs needed for the environmental assessment started with definition of the needed and available data. Templates were distributed to TheGreefa partners responsible for the demonstrators and the case studies of the project.

The data collected for the environmental assessment is information about electricity, biomass, water and fossil fuels used by a greenhouse in a season. For the analysis purpose the collected data were processed to compare the impacts of 15 years of life cycle of the 1 ha area of the greenhouse.

The data collection was available for one TheGreefa demonstrator – Meyer Orchideen's greenhouse in Switzerland, and one case study – Sfera Agricola's tomato greenhouse in Italy. For those 2 facilities data collected allows compare the environmental impacts considering the greenhouse with and without TheGreefa technology implemented.

In the time of writing the report, the system in Tunis demonstrator is not in operation yet. However, having the data we have, it is possible to analyse effectiveness of the system in midcontinental and mediterranean climates.

c. Impact categories

Here the main impact categories are considered in the LCA are shortly defined:

- **Abiotic depletion potential** – referred to the consumption of non-biological resources such as fossil fuels, minerals, metals, water, etc. It indicates the decrease of such resources. The category is expressed in units MJ for fossil fuels and in kg Sb equivalent for other minerals.
- **Climate change / Global Warming potential** – defined as the change in global temperature caused by the greenhouse effect that the release of "greenhouse gases" by human activity creates.
- **Ozone Layer Depletion potential** – diminution of the stratospheric ozone layer due to anthropogenic emissions of ozone depleting substances. It can cause increase of ultraviolet UV-B radiation and number of cases of skin illnesses.
- **Human Toxicity potential** – a calculated index that reflects the potential harm of a unit of chemical released into the environment, and it is based on both the inherent toxicity of a

compound and its potential dose. These by-products, mainly arsenic, sodium dichromate, and hydrogen fluoride, are caused, for the most part, by electricity production from fossil sources.

- **Freshwater Aquatic Ecotoxicity potential** – the toxic effects of chemical on ecosystems, in this case in the freshwater, causing biodiversity loss and/or species extinction.
- **Marine Aquatic Ecotoxicity potential** – the toxic effects of chemical on ecosystems of marine reservoirs, causing biodiversity loss and/or species extinction.
- **Terrestrial Ecotoxicity potential** – the toxic effects of chemical on land ecosystems of marine reservoirs, causing biodiversity loss and/or species extinction.
- **Photochemical Oxidation potential (Photochemical ozone creation potential)** – defines the potential for creation of the type of smog created from the effect of sunlight, heat and NMVOC and NOx.
- **Acidification potential** – reduction of the pH due to the acidifying effects of anthropogenic emissions. It is related with emissions of gases such as NH_3, NO_x and SO_x, which mixes with water in the atmosphere and causes acid rains increasing then the acidity of water and soil systems.
- **Eutrophication potential** – defines potential for accumulation of nutrients in aquatic systems. The impact indicators are the increase of nitrogen and phosphorus concentration and formation of biomass (e.g. algae).[3]

[3] https://www.openlca.org

3. Environmental evaluation

In the section, there is presented the actual evaluation of the environmental impacts resulting from implementation of TheGreefa technologies. The evaluation is performed for two sites – the greenhouses in Italy and in Switzerland.

a. Goal and scope

The goal of the LCA study is to analyse and compare the environmental impacts resulting from 15 years of the greenhouses operation, considering the greenhouse before and after the implementation of TheGreefa climate control system.

In the study, two real greenhouses are analysed located in midcontinental (Switzerland) and mediterranean (Italy) climates.

In the analysis, for each greenhouse the 15 years long operation period is studied for 1 ha area of the greenhouse. Therefore, only the operation stage of the life cycle is considered to identify and compare the impacts. The differences are related to energy and fuel consumption by the greenhouses' energy systems in their operation.

b. Inventory analysis

In this part the study greenhouses and the data collected are presented.

i. Swiss demonstrator

The Meyer Orchideen greenhouse is TheGreefa demonstrator, where the real scale system is implemented and in operation. In the greenhouse of Meyer Orchideen AG in Switzerland, being close to the Zurich airport, there were demonstrated TheGreefa humidity control, heating and cooling in one system through a single process.

Meyer Ochideen AG is a very innovative enterprise, founded in 1937 and today produces 500,000 orchids annually on an area of 16,000 m^2 in ecologically and environmentally friendly way. Through the consistent implementation of energy-saving measures in recent years as the installation of a groundwater heat pump, a large woodchip heating system and 124 kWp photovoltaic system, energy consumption has been massively reduced.

Meyer Orchideen AG recognized the technology of TheGreefa as a huge potential to reduce further the energy consumption and increase the quote of renewable energy thanks to the possibility to have loss-free energy seasonal energy storages.

The sorptive greenhouse air-conditioning system is used to air-condition the greenhouse no. 12 of Meyer Orchideen AG in Wangen near to Dübendorf. The orchids in this greenhouse are in the flowering stage, which requires a constant indoor climate with a temperature range 18-22°C and a relative humidity between 50-70%.

The greenhouse in the analysis has the area of 600 m^2, where there are 9 air conditioning units (absorbers) implemented, each of the power of 8 kW as heat/cooling capacity, each supplying approximately 50 m^2 of planting tables. The air is distributed under the enclosed planting tables. Over the tables, there are evenly distributed air intakes at ceiling height. The heating circuit and the well water system of the temperature control of the Thermochemical Fluid (TCF) are integrated in the absorber. The TCF used in the project is $MgCl_2$. All the 9 systems are served by desorber installed outside the greenhouse, including and diluted TCF-tanks. The energy systems are integrated with the renewable system of the greenhouse, including wood boiler, ground-water heat pump, photovoltaic panels and well water. To protect the crops from solar radiation and to reduce thermal losses during the night the roof is equipped with shading screens, which are operated automatically. Solar energy is used for TCF regeneration and buffer storages are installed to store diluted and concentrated TCF.

The demonstrator is operated in full-automatic mode. The TCF regeneration is performed in the desorber by connecting it to CO_2-neutral heating system of the greenhouse (wood /oil boilers, ground-water heat-pump and photovoltaic panels). Most of the water consumed is recycled, while the consumption from the water pipeline is required in the hottest period of the season. Some amount of tap water is needed to be consumed for the cooling process in TheGreefa system operating.

The data collected for the environmental evaluation was supposed to allow to compare the impacts such as environmental impacts or human health impacts between the 600 m^2 greenhouse operating without TheGreefa system and with the system implemented in a period of 15 years. The analysis has been performed for a reference unit of 1 ha of the analysed greenhouse. Therefore, the collected inputs required recalculation for 1 ha area and the designed period of time.

The focus was on inputs allowing comparison of the energy efficiency of the greenhouse, considering used electricity, water and fuels. Most of the water in the greenhouse is used in a closed cycle or is recovered from rainfall. Water needed for cooling process was included in the analysis.

In the analysis the transport data for fuels was estimated. The wood and oil burnt in the heating boilers are delivered to the greenhouse with trucks, approximately from the distance of 50 km.

Table 1. Seasonal input for the Swiss greenhouse.

	1 season for 600 m^2 greenhouse		**1 season for 1 ha greenhouse**	
	Standard greenhouse	**TheGreefa system**	**Standard greenhouse**	**TheGreefa system**
Electricity consumption (pumps, fans and heat pump)	43 178.69 kWh	39 945.54 kWh	719 645 kWh	665 792 kWh
Oil consumption	1 350 kWh	320 kWh	22 500 kWh	5 333 kWh
Wood consumption	228 150 kWh	54 080 kWh	3 802 500 kWh	901 333 kWh
Water consumption	0 m^3	23 m^3	0 m^3	383.3 m^3

In the Table 1 above the initial data provided by ZHAW are presented, with the help of which IZNAB carried out further calculations, such as the determination of the weight quantity of fuels, the number of transports. These data were necessary for the analysis with the SimaPro software. Besides SimaPro database, the Ecoinvent database was used in the analysis to provide necessary inputs and outputs in technological processes of the greenhouse lifecycle.

ii. Italian case study

The greenhouse system of Sfera Agricola represents the high technology system and one of the new methods of high-quality agriculture production. It performs a case study with water recovery and energy efficiency in greenhouses. The greenhouse is located in South Toscany in Italy.

The case study of the Sfera company represents an ideal example of the challenges of intensive and high-quality Mediterranean agriculture, particularly in the important challenge areas of water and energy efficiency. Sfera's case study performed the analysis of the collected data in its company and shared them with partner universities and companies.

The aim of the case study activities is to analyse the data collected during the year, depending on the climatic variations and the cultural needs of the greenhouse, to define the best design needs to further reduce energy costs and improve quality and productivity.

The data collected for the environmental assessment are results of simulations performed by TheGreefa project partners. The data represents a full season of operation of 1 ha greenhouse area.

The heat in the greenhouse is supplied wood and oil boilers. The system has a power of 7,000 kW. The main types of wood used as fuels are fir, pine, holm oak and chestnut. The oil consumption is approx. 600 l/h. The heating system consumes about 28% of the electricity used by the greenhouse, mainly for auxiliary equipment, such as pumps.

Table 2. Seasonal input for the Italian greenhouse.

	Standard system	**TheGreefa**
	1 season for 1 ha greenhouse	
Electricity	90 330 kWh	99 363 kWh
Oil	34 350 l	27 480 l
Wood	631 t	505 t

The wood burnt in the heating boilers is delivered to the greenhouse with trucks, approximately from the distance of 50 km.

c. Environmental assessment

In this part the results of the LCA study are presented with their interpretation. The analysis was based on the collected data presented in the previous points.

i. Swiss demonstrator

To be able to evaluate the environmental benefits resulting from TheGreefa system implementation, the Swiss demonstrator has been analysed in two scenarios:

- Scenario 1_Existing greenhouse (before modernisation). The life cycle analysis for the greenhouse has been carried out before the implementation of TheGreefa system.
- Scenario 2_Retrofitted greenhouse (after modernisation). The life cycle analysis for the greenhouse has been carried out after the implementation of TheGreefa system.

Table 3. Environmental assessment of the Swiss greenhouse.

Impact category	Units (expressed by Functional Unit)	Operational phase		Impact of TheGreefa
		Scenario 1	Scenario 2	
Abiotic depletion	kg Sb eq	9.27	4.34	↓
Abiotic depletion (fossil fuels)	MJ	5.75E+7	2.13E+7	↓
Global warming potential (GWP100a)	kg CO2 eq	4.45E+6	1.77E+6	↓
Ozone layer depletion (ODP)	kg CFC-11 eq	1.23	0.824	↓
Human toxicity	kg 1,4-DB eq	2.53E+6	1.11E+6	↓
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	1.43E+6	9.06E+5	↓
Marine aquatic ecotoxicity	kg 1,4-DB eq	3.5E+9	2.06E+9	↓
Terrestrial ecotoxicity	kg 1,4-DB eq	2.93E+4	1.45E+4	↓
Photochemical oxidation	kg C2H4 eq	1.27E+4	3.12E+3	↓
Acidification	kg SO2 eq	3E+4	9.1E+3	↓
Eutrophication	kg PO4--- eq	1.23E+4	5E+3	↓

The main processes considered in the environmental evaluation and having the key meaning in comparison of the impacts for the two scenarios were:

- Electricity production and distribution,
- Heat production,
- Water consumption,
- Road transport.

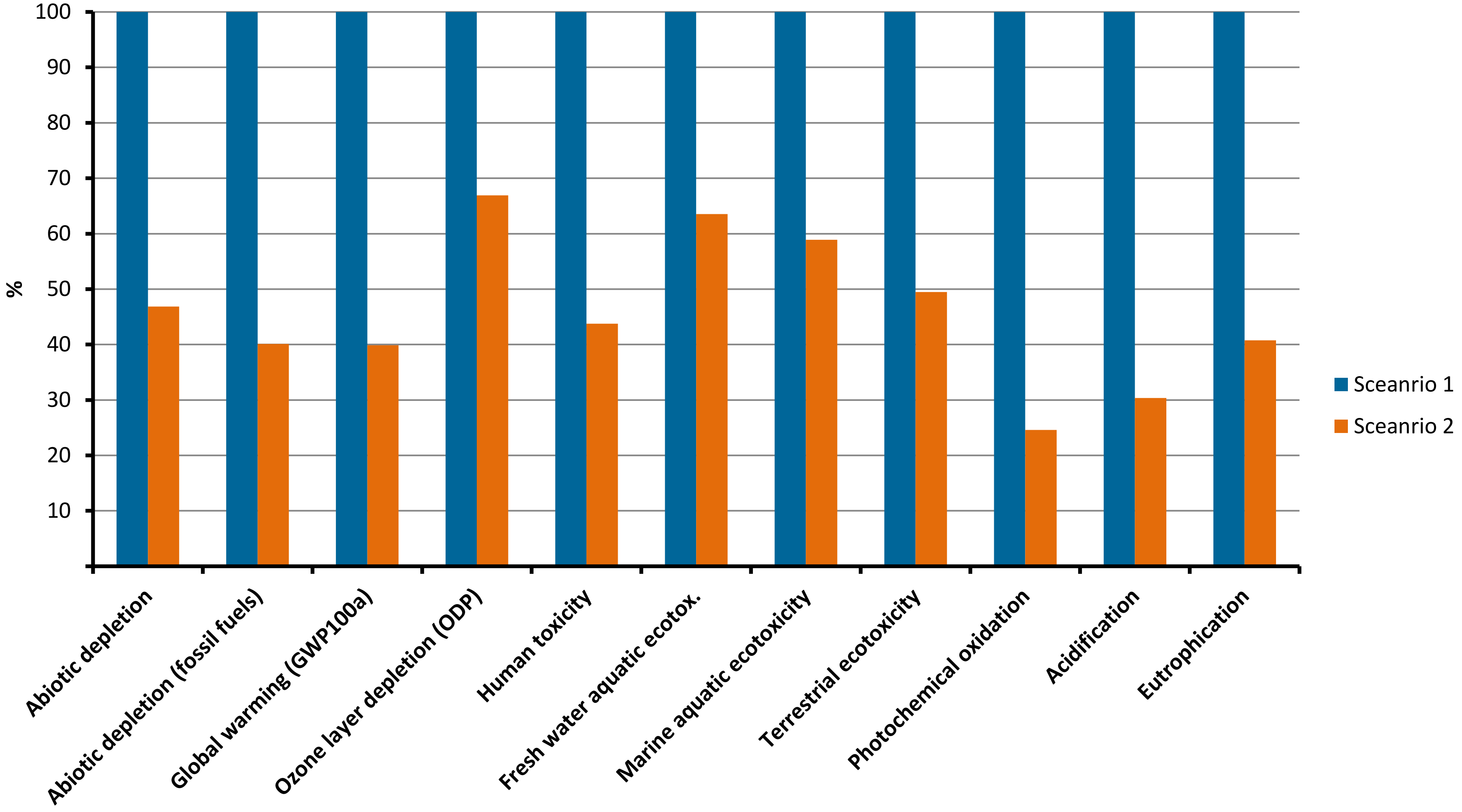

Figure 2. Environmental assessment: Swiss demonstrator – Scenario 1 & Scenario 2 compared (SimaPro 8.3.0). Method: CML-IA baseline V3.04 / EU25 / Characterisation for impact categories.

Performing the LCA calculation using CML-IA baseline methodology, the results are given for 11 main impact categories. In each category the positive impact of the implementation of TheGreefa system in the greenhouse can be observed. The impacts reduction in case of TheGreefa system operating can reach between 37% up to 76%.

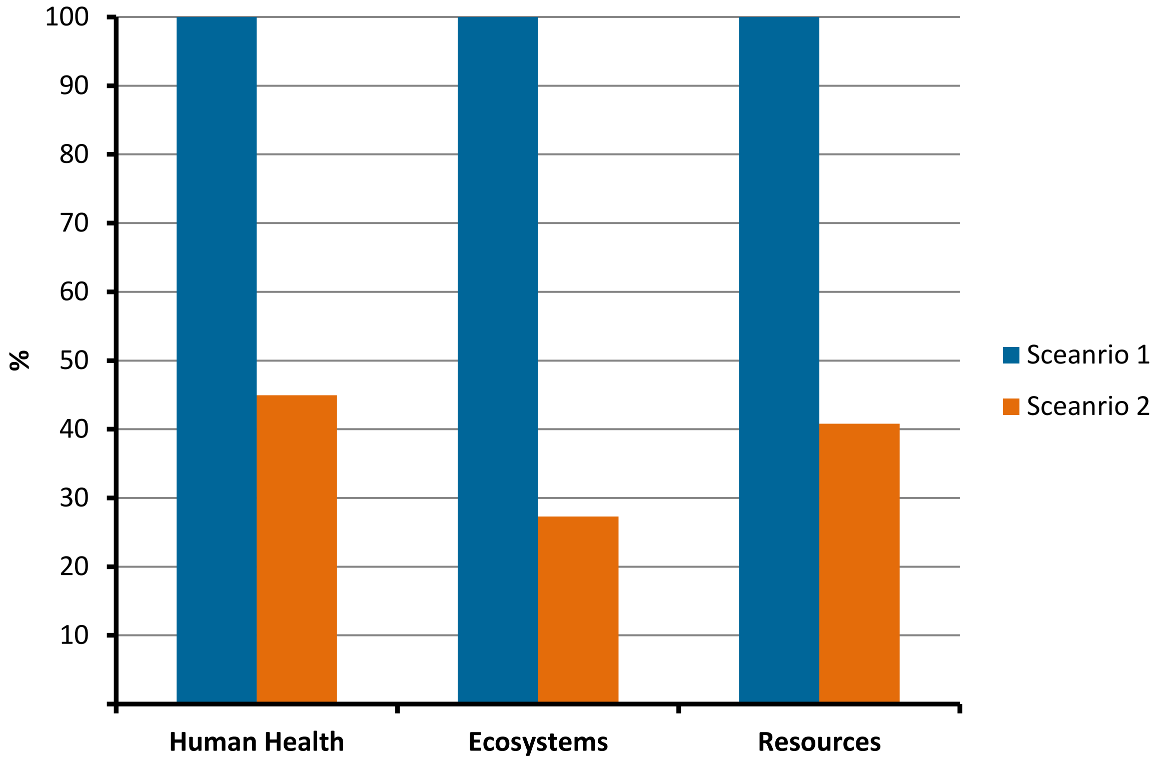

Figure 3. Comparing the damage assessment: Swiss demonstrator – Scenario 1 & Scenario 2. Method: ReCiPe Endpoint (E) V1.13 / Europe ReCiPe E/A

The European ReCiPe Endpoint methodology results in the presentation of the impacts grouped in 3 main factors – Human Health, Ecosystems and use of Resources. Such presentation can be more understandable for general audience.

15 years of TheGreefa system operation in the Swiss greenhouse may result in approx. 55% reduction in the human health impacts, 60% reduction in case of the resources depletion and approx. 73% reduction of the impacts on ecosystems.

The compared operational stages for both scenario and their environmental impacts are mainly dominated by the energy consumed in the greenhouse in different forms – electricity and heat.

Another way to present the comparison of the environmental impacts is the single score comparison presented below (Figure 4). It presents how much points each category has, in another way how big burden it has on the environment. The bigger the number of points the bigger the impact. For the Swiss demonstrator the overall impact of the greenhouse with TheGreefa system in operation is by almost 1.25 MPt (1 250 000 points) lower than for the greenhouse without the improved climate and humidity control system.

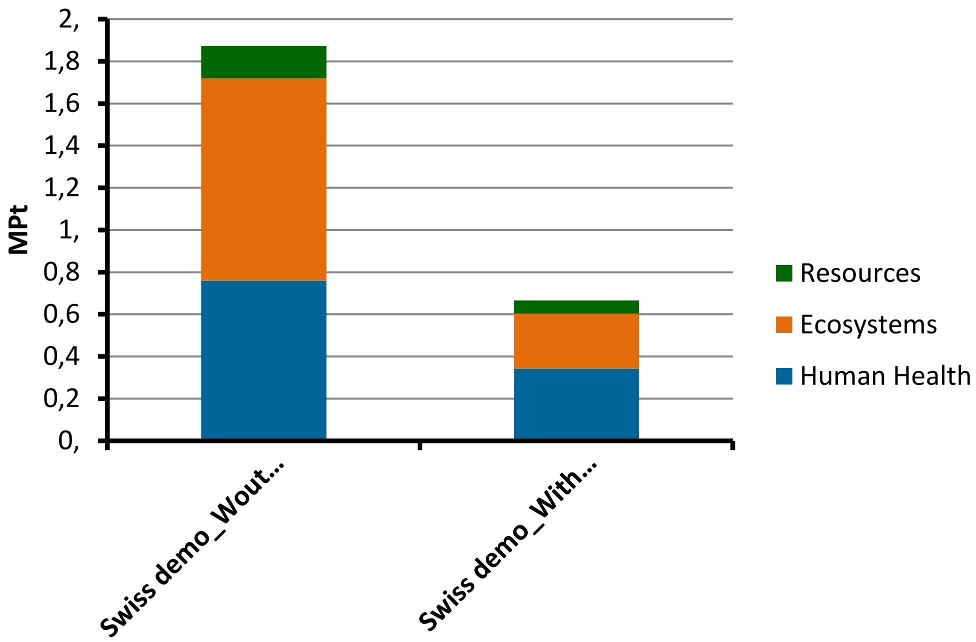

Figure 4. Single score analysis of the environmental impacts of the Swiss demonstrator in both scenarios. Method: ReCiPe Endpoint (E) V1.13 / Europe ReCiPe E/A

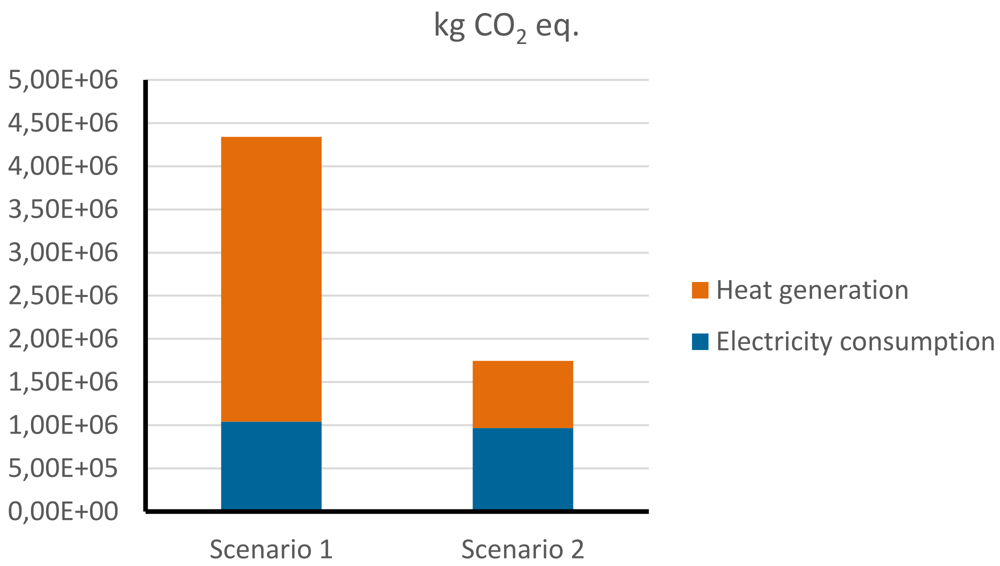

Figure 5. Global Warming Potential (GWP) of the Swiss demonstrator in both scenarios.

In terms of CO_2 savings (Figure 5), which defines the assessment of the global warming potential (GWP), during the 15 years TheGreefa technology will allow to save 2 680 tons of CO_2 emissions from 1 ha of the greenhouse. In terms of percents it gives a global warming potential reduction of around 60%. However, the mass of CO_2 and the percentage should also make it clear what an intensive industry greenhouse cultivation is.

It can be observed that transport of fuels, like wood and oil, is almost meaningless in the analysis, as processes for energy and heat supply are the main cause of the impacts.

ii. Italian case study

To be able to evaluate the environmental benefits resulting from TheGreefa system implementation, the Italian case study has been analysed in two scenarios:

- Scenario 1_Existing greenhouse (before modernisation). The life cycle analysis for the greenhouse has been carried out before the implementation of TheGreefa system.
- Scenario 2_Retrofitted greenhouse (after modernisation). The life cycle analysis for the greenhouse has been carried out after the implementation of TheGreefa system.

Table 4. Environmental assessment of the Swiss greenhouse.

Impact category	Units (expressed by Functional Unit)	Operational phase		Impact of TheGreefa
		Scenario 1	Scenario 2	
Abiotic depletion	kg Sb eq	4.36	3.59	↓
Abiotic depletion (fossil fuels)	MJ	3.74E+7	3.28E+7	↓
Global warming potential (GWP100a)	kg CO2 eq	2.89E+6	2.53E+6	↓
Ozone layer depletion (ODP)	kg CFC-11 eq	0.383	0.335	↓
Human toxicity	kg 1,4-DB eq	1.32E+6	1.1E+6	↓
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	5.45E+5	4.81E+5	↓
Marine aquatic ecotoxicity	kg 1,4-DB eq	1.65E+9	1.47E+5	↓
Terrestrial ecotoxicity	kg 1,4-DB eq	1.37E+4	1.14E+4	↓
Photochemical oxidation	kg C2H4 eq	8.39E+3	6.76E+3	↓
Acidification	kg SO2 eq	2.1E+4	1.78E+4	↓
Eutrophication	kg PO4--- eq	6.88E+3	5.75E+3	↓

The main processes considered in the environmental evaluation and having the key meaning in comparison of the impacts for the two scenarios were:

- Electricity production and distribution,
- Heat production,
- Road transport of fuels.

Performing the LCA calculation using CML-IA baseline methodology, similarly as for the Swiss demonstrator, in each category the positive impact of the implementation of TheGreefa system in the greenhouse can be observed for the Italian case study too. However, in the Italian greenhouse the reduction of impacts is much more visible in the graph, as for each category the reduction varies between 10-20%.

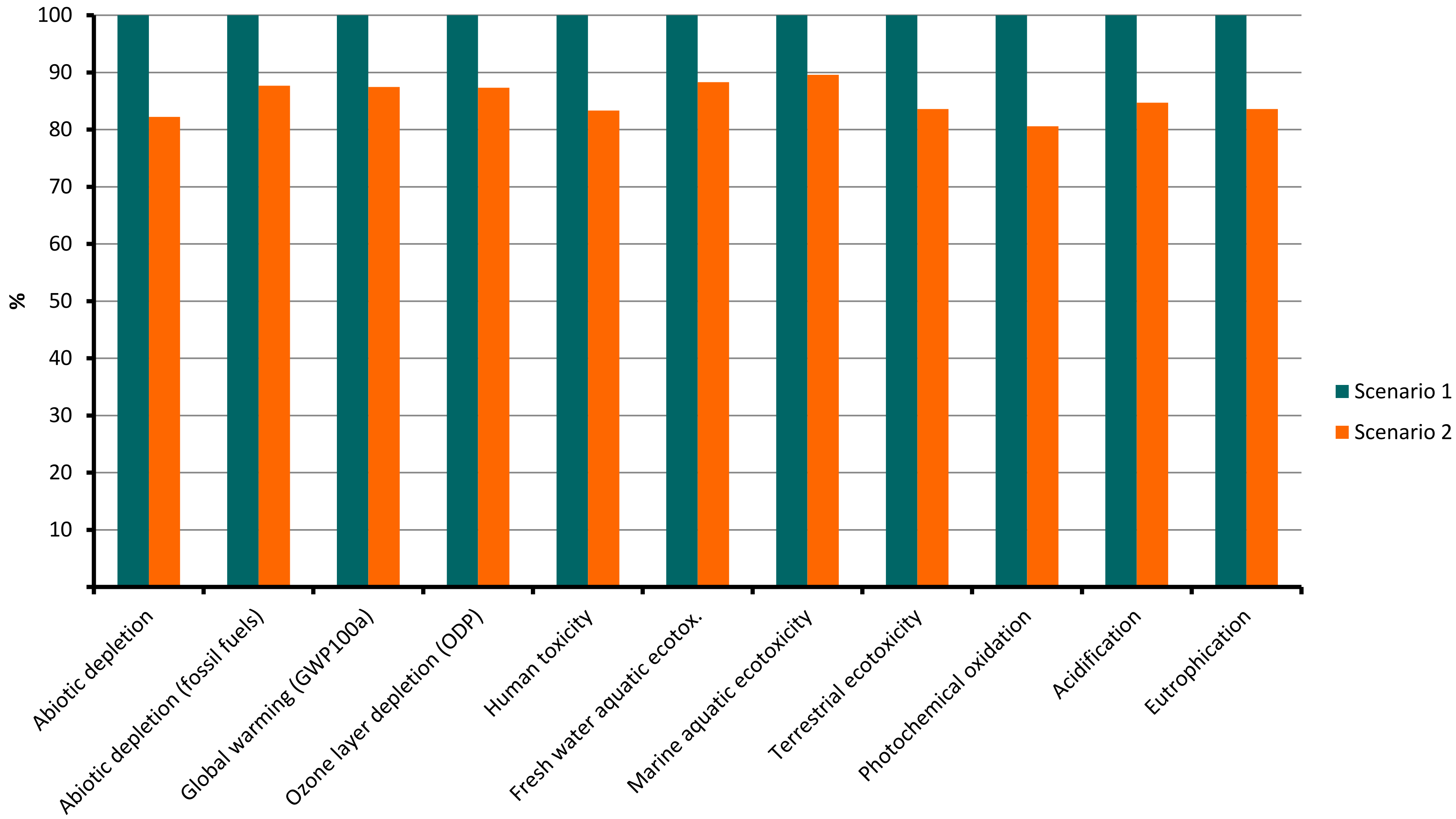

Figure 6. Environmental assessment: Italian case study – Scenario 1 & Scenario 2 compared (SimaPro 8.3.0). Method: CML-IA baseline V3.04 / EU25

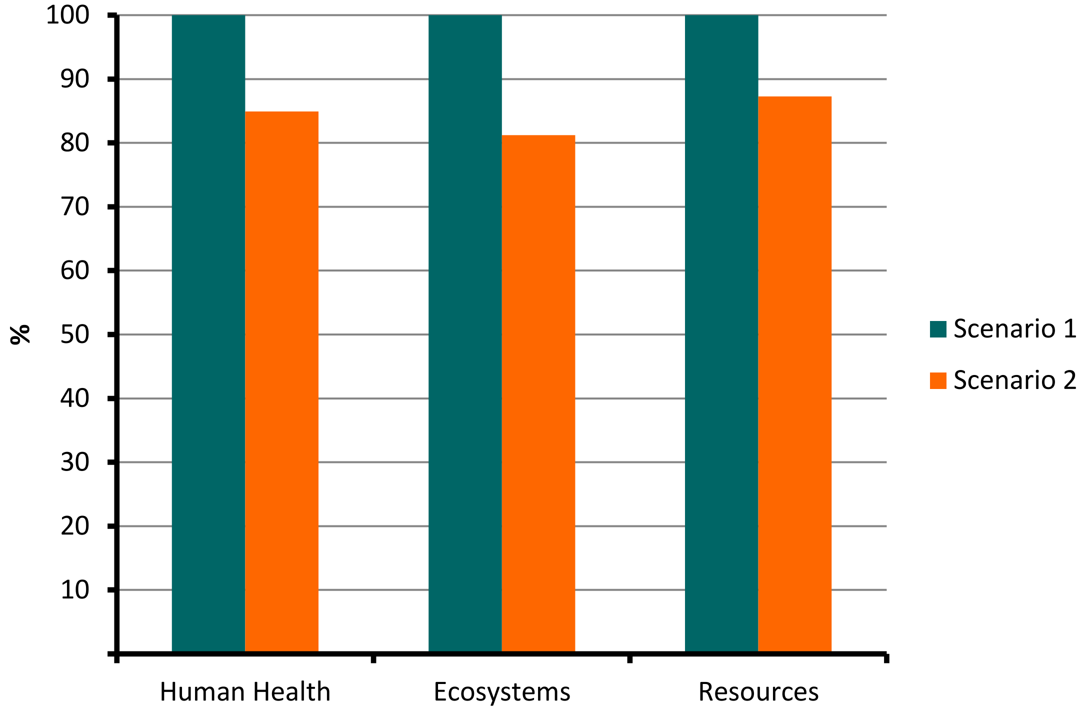

Figure 7. Comparing the damage assessment: Italian case study – Scenario 1 & Scenario 2. Method: ReCiPe Endpoint (E) V1.13 / Europe ReCiPe E/A

The European ReCiPe Endpoint methodology results in the presentation of the impacts grouped in 3 main factors – Human Health, Ecosystems and use of Resources.

15 years of TheGreefa system operation in the Italian greenhouse may result in approx. 15% reduction in the human health impacts, 13% reduction in case of the resources depletion and approx. 19% reduction of the impacts on ecosystems.

The compared operational stages for both scenario and their environmental impacts are mainly dominated by the energy consumed in the greenhouse in different forms – electricity and heat.

In the single score comparison presented below (Figure 8) it is presented how much points each category has, meaning how big load it has on the environment. For the Italian case study the overall impact of the greenhouse with TheGreefa system in operation is by almost 0.19 MPt (190 000 points) lower than for the greenhouse without the improved climate and humidity control system.

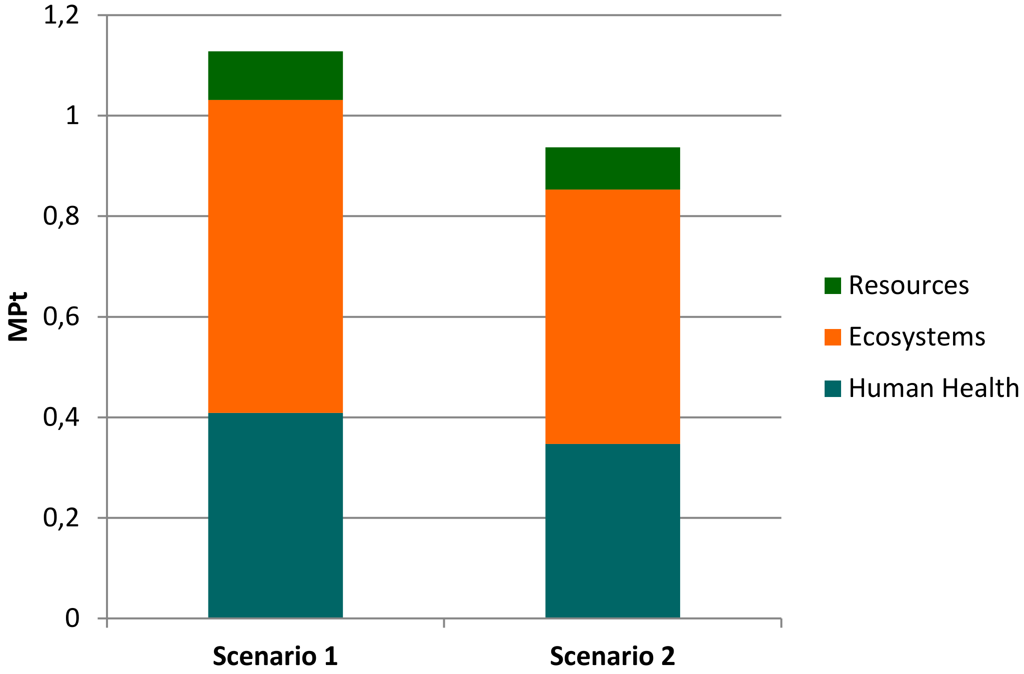

Figure 8. Single score analysis of the environmental impacts of the Italian case study in both scenarios. Method: ReCiPe Endpoint (E) V1.13 / Europe ReCiPe E/A

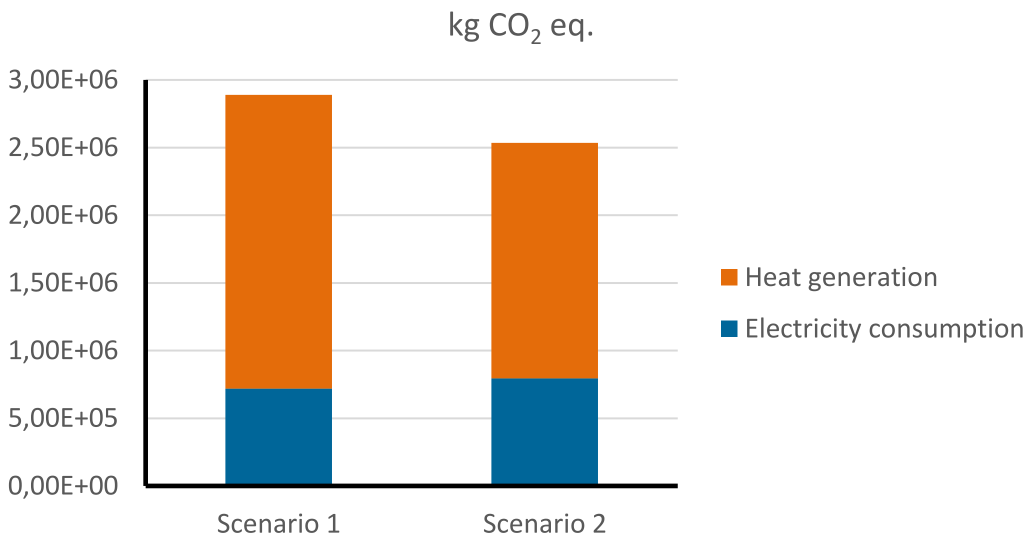

Figure 9. Global Warming Potential (GWP) of the Italian case study in both scenarios.

In terms of CO_2 savings, which defines the assessment of the global warming potential (GWP), during the 15 years TheGreefa technology will allow to save over 360 tons of CO_2 emissions from 1 ha of the greenhouse. In terms of percents it gives a global warming potential reduction of almost 13%. Also in this case, the mass of CO_2 and the percentage should make it clear what an intensive industry greenhouse cultivation is. Because the climate is much warmer in Tuscany compared to Switzerland, there is lower environmental loads related to the heating process.

4. Conclusions

The results obtained in the presented Life Cycle Analysis (LCA) have shown that the use of the new TheGreefa technology in greenhouses contributes to visible lowering the environmental impacts of the greenhouse operations. The highest positive impact of TheGreefa technology is observed in Switzerland due to the higher environmental loads related to the heating processes. The heating, cooling and humidity control are very energy intensive processes in the greenhouse operation. The heat production and electricity consumption are responsible for most of the environmental loads. Therefore, implementation of improvements in these aspects is the right call that can help to reach the EU climate goals by reduction of the use of electricity and natural resources. Besides lower greenhouse gases emissions (CO_2 savings) are not the only benefits of the implementation of TheGreefa system. They are of course responsible for the climate change. But there are other aspects where TheGreefa brings improvements in the long-term period of operation. By big reduction of such factors as human toxicity or photochemical oxidation potentials, the use of the new system can result in 20% to over 50% reduction of the overall human health negative impact. Use of resources like wood and oil are lower, but can be lowered more when more renewable energy sources is implemented in the greenhouses' energy systems – heat pumps, geothermal energy, etc.