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DELIVERABLE

Report on Life Cycle Analysis

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Executive Summary

This report presents Deliverable "C1.3 Report on Life Cycle Analysis" of the LIFE GAIA Sense project, which has been prepared as part of the monitoring activities of Action C.1. The deliverable presents a detailed description of the phases of the LCA methodology, including the goal/scope and boundary definition, the development of the LCA Inventory and the selection of the LCA Impact Assessment methodology. The assumptions made throughout the analysis are also reported in order to facilitate reproducibility of the results. The LCA results are displayed in the deliverable in the form of informative diagrams and tables for the reference and treatment areas and for the years 2020 and 2021 for each field case. The interpretation of the results focuses on the comparison between the reference and treatment areas for each studied case and year. Additionally, for a more integrated approach and in order to conduct LCA studies of also comparing specific crop fields between their baseline and a SF year, one field for each country, comparisons between LCA results for the baseline (2019) and the 1st SF (2020) years of 3 crop fields (Aigina 03/Greece, Confagri/Portugal 02 and Costeira/Spain 01) were implemented indicatively. Lastly, for Spain (Vina Costeira) and Portugal (Confagri), because no field sample analysis and environmental simulation modeling took place, no other LCA study could additionally be carried out.

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Definitions, Acronyms and Abbreviations

Acronym	Title
AUTH	ARISTOTELIO PANEPISTIMIO THESSALONIKIS (Aristotle University of Thessaloniki – Special Account of Research Funds)
ILCD	International Life Cycle Data system
LCA	Life Cycle Analysis
LCIA	Life Cycle Impact Assessment
LHTEE	Laboratory of Heat Transfer and Environmental Engineering
SF	Smart Farming

1. Introduction

Sub-action C1.2 is led by the Laboratory of Heat Transfer and Environmental Engineering of AUTH and focuses on the integrated assessment of environmental and socio-economic impacts of the suggested SF solution in agricultural practices. The most suitable tool for performing this analysis is Life Cycle Assessment (LCA), which is endorsed by the EC as a structured, comprehensive and internationally standardized method (certified by ISO 14040 and 14044 standards) for assessing the environmental, resource depletion and health impacts associated with products or services. It quantifies all relevant emissions and resources consumed and the related impacts using a "from cradle to grave" approach, by examining a product's full life cycle: from the extraction of resources, through production, use, and recycling, up to the disposal of remaining waste.

LCA in LIFE GAIA Sense project will be implemented to quantify the comparative advantage of the SF solution as opposed to the conventional agricultural practices, in terms of environmental performance, sustainability potential and health improvements of farmers and population in agricultural areas. Socio-economic indicators such as yield, will also be considered. As the SF system suggested in the project includes mainly advice for irrigation and fertilizer/pesticide application, the LCA model will focus on the impacts of these processes, but it will also take into account all other processes reported in the agricultural calendars which took place in the pilot fields during the studied cultivation period.

Based on this analysis, in combination with data from the field calendars (extracted from ICM), field sample analysis and environmental simulation models, the actual impact of the SF system on the environment will be quantified and its efficiency as a sustainability promoting tool in the agriculture sector will be holistically assessed. The results of this integrated assessment will be further interpretated to suggest Best Management Practices and recommendations for farmers and policy makers, presented in Deliverable B.7.3 "Report of guidelines for best management practices".

1.1. Project Summary

The main objective of the LIFE Gaiasense project is to demonstrate Gaiasense, an innovative "Smart Farming" (SF) solution that aims at reducing the consumption of natural resources, as a way to protect the environment and support Circular Economy (CE) models.

More specifically, this project will launch 18 demonstrators across Greece, Spain and Portugal covering 9 crops (olives, peaches, cotton, pistachio, potatoes, table tomatoes, industrial tomatoes, grapes, kiwi) in various terrain and microclimatic conditions. They will demonstrate an innovative method, based on high-end technology, which is suitable for being replicated and will be accessible and affordable to Farmers either as individuals or collectively through Agricultural Cooperatives.

Moreover, LIFE Gaiasense aims to promote resource efficiency practices in SMEs of the agricultural sector and eventually, contribute to the implementation of the Roadmap to a Resource Efficient Europe. This project will demonstrate a method on how the farmer will be able to decide either to use or avoid inputs (irrigation, fertilizers, pesticides etc.) in a most efficient way, without risking the annual production. The focus is on the resource consumption reduction side of CE, and the results will be both qualitatively and quantitatively, considering the resources' efficiency in agricultural sector.

1.2. Document Scope

The scope of this document is to present in detail the methodology used for and the results produced by the LCA study performed by AUTH, aiming to compare the environmental and socio-economic impacts of the suggested SF solution with those stemming from conventional agricultural practices carried out by the farmers in the pilot fields.

1.3. Document Structure

This document is comprised of the following chapters:

Chapter 1 Introduction, which includes the project summary, the document scope and structure

Chapter 2 Description of the LCA methodology and its individual phases used, including 2.1 Explanation of the general methodology; 2.2. Description of the most suitable LCA software; 2.3. Goal and scope definition; 2.4. Preparation of the LCA Inventory and 2.5. Selection of the LCIA method applied

Chapter 3 Results and Interpretation

Chapter 4 Conclusions

2. LCA Methodology

2.1. General Methodology

In order to ensure consistency and quality assurance, the LCA methodology and its individual components will be applied according to the provisions of the International Reference Life Cycle Data System (ILCD) Handbook, as a recommended guide by the European Commission to support the legitimacy of results of a LCA study. For this purpose, a detailed protocol has been prepared as a step-by-step guide, which is presented in Annex I of the present deliverable. In general, the basic phases that have to be represented in a LCA study include Goal and scope definition, Inventory preparation, Life Cycle Impact Assessment and Results interpretation, as shown in Figure 1.

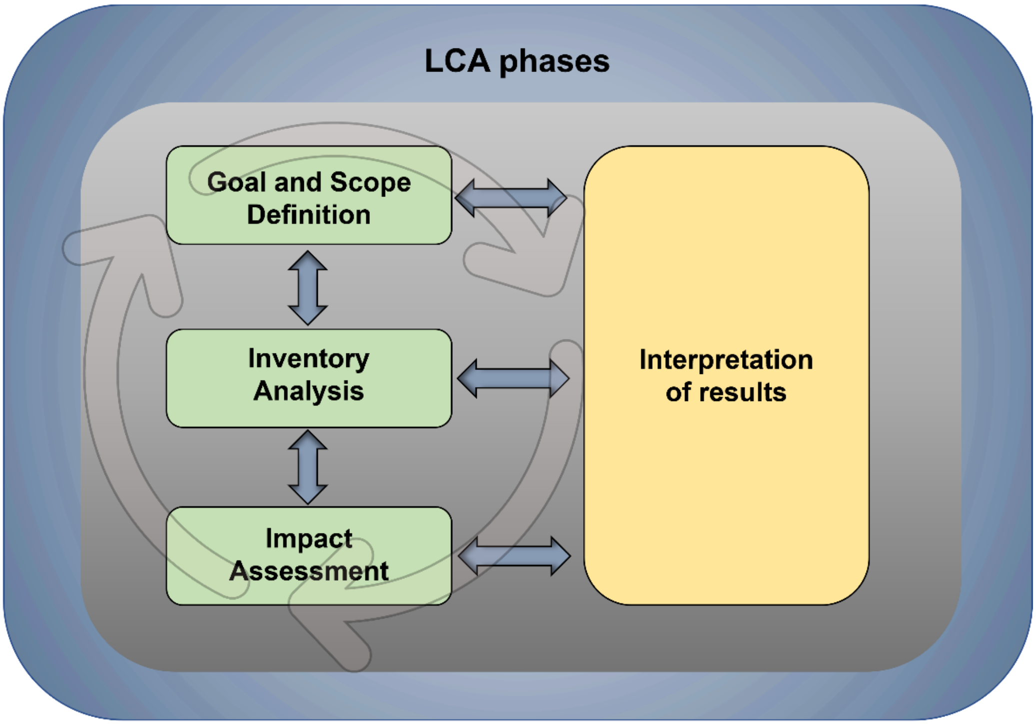

Figure 2.1. LCA phases that will be followed in the LCA LIFE GAIA Sense methodology

Goal and scope definition is the first step in the analysis, in which the main scope of the study is defined. Based on the scope, the system boundaries and the reference unit are selected. In this stage, the main processes that will be examined are also identified, in order to proceed to the inventory preparation. Inventory analysis includes the selection and collection of primary and secondary inputs and outputs of all selected processes. Inputs relate to raw materials and energy required by studied agricultural processes and products at all stages, from acquisition to manufacturing, operation, and finally disposal. All of the aforementioned lifecycle stages may produce atmospheric emissions, waterborne and solid wastes, as the efficiency of material use and energy conversion is never 100%. Assumptions made in regard to the data used are reported for facilitating reproducibility of results. Impact assessment involves the actual impact calculation, based on multiplying the input data with characterization factors, according to the LCIA method used. Finally, the results are produced and processed in informative diagrams to be used for interpretation. In the interpretation phase, data and results from the Inventory analysis and Impact Assessment phases are compared and analyzed to demonstrate the potential benefits of the SF solution in terms of environmental and socio-economic indicators. The phases of the LCA study as used in the LIFE GAIA Sense project will be described in detail in the relevant sections.

2.2. LCA software tool selected

The LCA software tool selected for the LIFE GAIA Sense LCA study is openLCA, version 1.11.0 (current), developed by GreenDelta. The selection was based on the following criteria:

- ISO certification
- Use in relevant studies
- User-friendly
- Access to suitable databases for agricultural products and processes
- Variety in LCIA methods suitable for the scope of the study. The suitability criterion was based on prior analysis and selection of the environmental impacts more relevant to agricultural practices, as reported in the project proposal. These impacts were related to environment (e.g. eutrophication, ecotoxicity, global warming, ozone formation, ozone depletion), human health (e.g. toxicity) and resource depletion (e.g. land use, fossil resource scarcity, mineral resource scarcity).

OpenLCA is an open source and free software for Sustainability and Life Cycle Assessment and the current version can be downloaded through the dedicated web page (URL1). A detailed description of its features as well as learning and support material are also available from the web page. Information and access to the compatible LCA databases is available through openLCA Nexus (URL2).

2.3. Goal and scope definition

The goal of the LCA analysis in LIFE GAIA Sense was to compare the environmental impacts for selected impact categories related to the agricultural sector between the conventional cultivation system and the suggested SF system, in order to highlight the comparative sustainability advantage of the SF solution. For this purpose, field calendar data for reference (conventional practices) and treatment (SF practices) areas for each pilot case were used as primary input data to create the inventory. As the scope of the study was restricted to the evaluation of the impacts of the SF advice, the system boundaries were set from cradle to field-gate, in order to include the agricultural management practices in the field, but also the secondary data related to the market (production, packaging, waste and transport) of the chemicals and machinery used. The system boundaries are demonstrated in Figure 2.2, while the examined flows and the relevant inputs and outputs considered in the study are shown in detail in Figure 2.3.

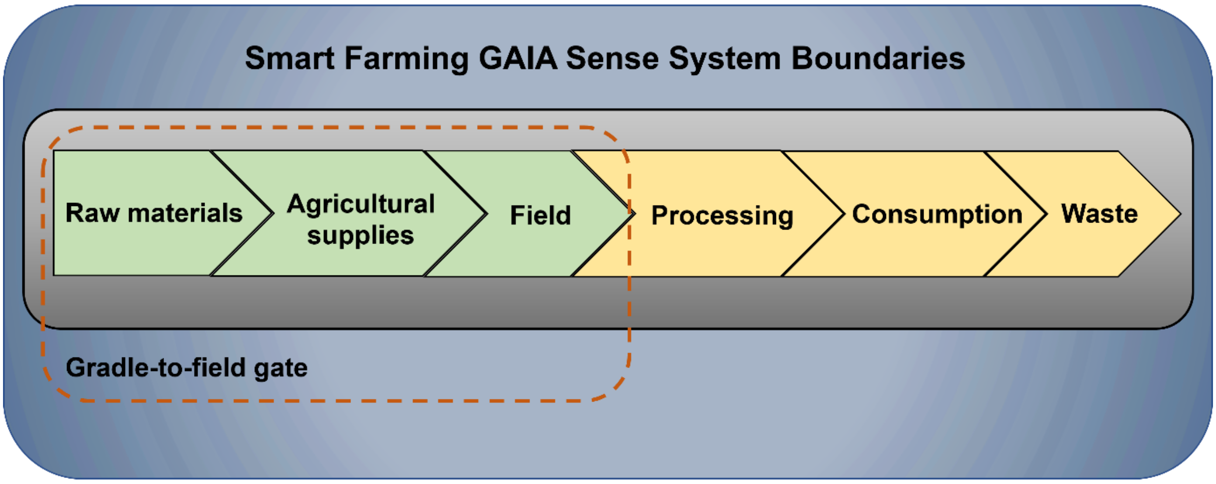

Figure 2.2. SF GAIA Sense LCA system boundaries

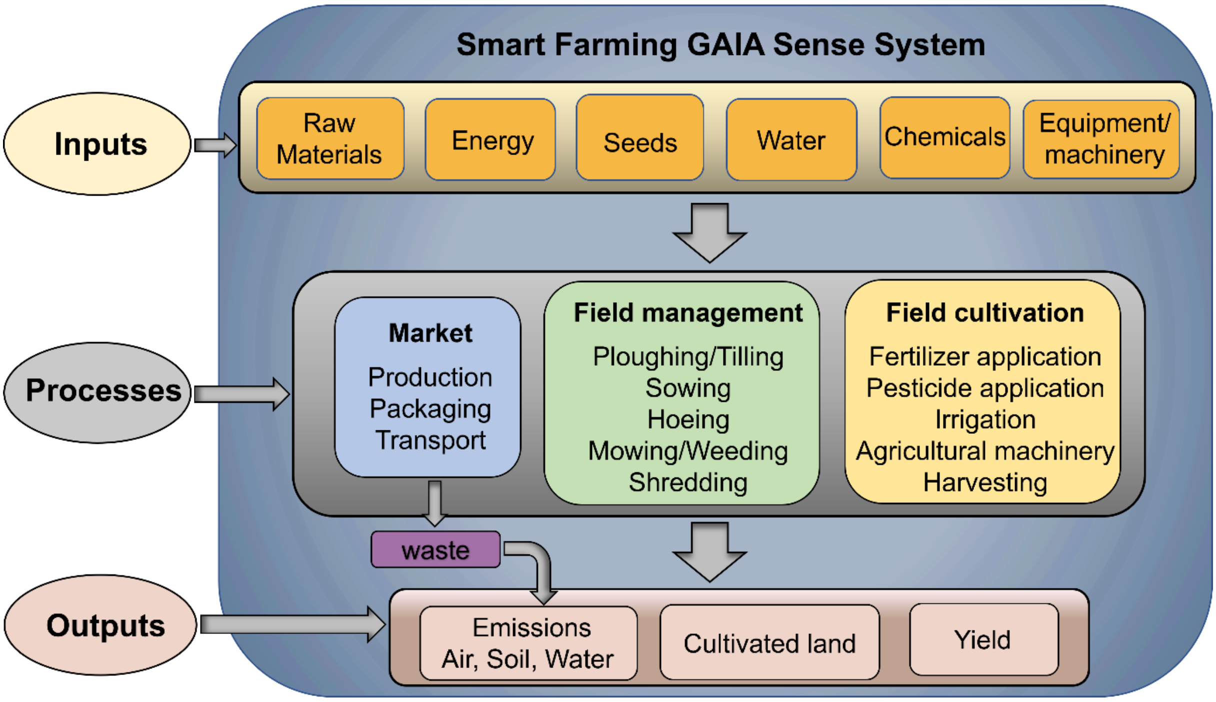

Figure 2.3. SF GAIA Sense LCA system

The functional unit was selected to reveal the environmental impacts on field site resulting from the two different cultivation methods, so it was defined as “cultivated land (ha)”. However, in selected field cases, the influence of including a socio-economic parameter in the analysis, namely the crop yield (kg) as a reference unit, was examined. In this case, the results would be more relevant for the farmers to facilitate decision making. The results of the LCA comparative study are also intended to use for decision making at the farmer level, but also from local authorities and policy makers. This was also taken into account in the “Goal and scope definition” phase by 1. Incorporating a best case scenario in selected field studies, 2. Including both midpoint as well as endpoint impacts in the analysis, as explained in the LCIA methodology section.

2.4. LCA inventory

The preparation of the LCA inventory included identification of the flows and quantification of the relevant inputs and outputs. For this purpose, both primary and secondary data were collected, processed and inserted into the system. The main flows included in the LCA system are reported in Table 2.1 and are related to the processes identified in the “Goal and scope definition” phase (Figure 2.3). The flows included a combination of primary data collected from the field calendars and secondary data provided by the AGRIBALYSEv.3.0.1. database (URL3) that was downloaded free of charge from the openLCA nexus web site. AGRIBALYSE was selected as it is a European-based database for the agriculture and food sector. In particular, it is a French LCI database, provided by the French Agency for Ecological Transition, as the outcome of the Agribalyse® program. Quality control was conducted at two levels, ensuring data quality. As a result, AGRIBALYSE® data meet international quality standards as set by ISO 14044 and ILCD (entry level). In the AGRIBALYSE database, 67% of the data have a DQR judged to be good or very good (1 to 3). The new version 3.0.1 is used in the study, and it has the advantage that ECOINVENT data have been copied in some AGRIBALYSE processes. The database is also compatible with the RECIPE2016 LCIA method which was selected for Impact Analysis in the present study. The processes taken into account for each crop are shown in Table 2.1, while the details of each process are explained in Table 2.2.

Table 2.1. SF GAIA Sense LCA Inventory processes per crop

Processes	Sub-processes	Crops								
		Cotton	**Tomato**	**Potato**	**Walnut**	**Pistachio**	**Olive**	**Kiwi**	**Peach**	**Grape**
Land occupation	Annual crops	**X**	**X**	**X**						
	Permanent crops				**X**	**X**	**X**	**X**	**X**	**X**
Seeds/Seedlings	Market for	**X**	**X**							
Field operations	Ploughing	**X**								
	Harrowing	**X**		**X**						
	Hoeing	**X**								
	Sowing	**X**	**X**	**X**						
	Weeding						**X**	**X**	**X**	
	Crushing wood							**X**	**X**	
	Harvesting	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
N, P & K fertilizers	Production	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Packaging	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Application	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Pesticides	Production	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Packaging	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Application	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Irrigation	Water pumping	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Infrastructure	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**

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Table 2.2. Description of SF GAIA Sense LCA Inventory processes

Seed/Seedlings	
Market for seeds	Cotton
Market for seedlings	Tomato
Field operations (other)	
Ploughing	with 5 or 6 soc plough
Harrowing	with rotary tiller
Hoeing	with 4-6m hoe
Sowing	direct seeding
Weeding	with mower with rotary beater
Crushing wood	with shredder
Harvesting	with combined harvester shaking with shaker assistance with trailer assistance with trailer
N, P & K fertilizers	
Production	average mineral fertilizers, as N, P_2O_5 & K_2O
Packaging	liquid fertilizers solid fertilizers
Application	with spreader, 2500 l with sprayer, 2500 l with spreader/broadcaster, 500 l
Pesticides	
Production	unspecified (mean)
Packaging	solid pesticides
Application	with sprayer, 2500 l with atomiser, 400 l
Irrigation	
Water pumping	electricity powered
Infrastructure	drip irrigation system sprinkler irrigation system

In Table 2.2, the processes are grouped into the main categories, consisting of seed/seedling, field operations, fertilizers, pesticides and irrigation. Quantified data from field calendars are primary data and include all quantities if fertilizers/pesticides applied and quantities of water used for irrigation. Qualitative primary data include information on the method of agricultural practices by farmers, such as the infrastructure used for irrigation (drip or sprinkler), the method used for fertilizer/pesticide application (spreader, sprayer, broadcaster or atomizer), or the method used for field operations. On the other hand, secondary data from AGRIBALYSE were used to cover the life cycle of seeds, chemicals

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and machinery used (from raw material extraction to production and then packaging including waste, as well as transport in the case of “market for” process). In addition, secondary data also involved information on the specific type of machinery or fuel used for the agricultural practices and the time duration required for completion of the agricultural field operations reported by farmers. A number of assumptions were made when structuring the Inventory aiming to increase representativity and reliability of the results produced by the LCA analysis. For reproducibility reasons, these assumptions are reported in detail in ANNEX II.

Primary quantitative and qualitative data were derived from field calendars provided by farmers for reference (conventional farming) and treatment (SF) areas for each pilot field case. Cultivation calendars were available for two subsequent years, 2020, which was the first SF application year and 2021, which was the second SF application year. However, in some cases information from calendars was missing or the same field was used as reference and treatment area, not allowing for the comparison between conventional and SF cultivation impacts. In the pilot cases of Aigina, Portugal and Spain, for which the same area was treated in 2019 using conventional practices, whereas SF practices were applied in the years 2020 and 2021, the data reported for each year were examined and compared, in order to perform LCA for all pilot cases.

2.5. LCIA method

Impact Assessment in LCA is the phase in which inventory inputs and outputs are translated into environmental impact indicators, by using characterization factors which describe the impact per unit of the related stressor (e.g. per kg of emission released). Each Life Cycle Impact Assessment (LCIA) method also applies a set of normalization and weighting criteria, based on current scientific knowledge, in order to categorize the impacts into three Areas of Protection (endpoint impacts categories), namely Human health, Ecosystem quality and Resource scarcity, and indicate the most important impacts caused by the examined processes. This ranking is influenced by socio-economic and political criteria under different future scenarios of technology and economic growth and depends also on the time period considered (e.g. after 20, 100 or 1000 years). Characterization, normalization and weighting factors may vary considerably among different LCIA methods, as they are defined on the basis of different scientific resources.

The LCIA method used in the LIFE GAIA Sense LCA study is ReCiPe2016, developed by the Netherlands National Institute for Public Health and the Environment (RIVM, 2016), which constitutes an updated version of the ReCiPe 2008. ReCiPe 2016 is widely accepted and used in the Netherlands and the rest of Europe. The Hierarchist (H) perspective was selected for value choices, as it is based on scientific consensus with regard to the time frame considered (100 years) and the plausibility of the impact mechanisms. Baseline socio-economic developments are predicted under this scenario, while a controlling adaptation potential to future changes is expected.

The ReCiPe2016 method was selected on the basis of its high ranking score in all five evaluation criteria defined in ILCD Handbook: Recommendations for Life Cycle Impact Assessment in the European context (URL4), namely 1. Completeness of scope; 2. Environmental relevance; 3. Scientific robustness and certainty; 4. Documentation, transparency& reproducibility and 5. Applicability. The ReCiPe2016 method achieved high scores in all criteria for the majority of the environmental impacts that were identified as relevant for the agricultural sector. The method is compatible with the AGRIBALYSE database that was used in the preparation of the LCA Inventory. Another advantage of the ReCiPe2016 LCIA method is that it can be applied both as midpoint, as well as endpoint. This allows for producing midpoint impacts, which are more directly linked to and provide more information on the environmental flows, as well as endpoint results, which reveal the environmental and human health relevance of the flows and are therefore more appropriate for decision making. The 18 midpoint environmental impact indicators considered by ReCiPe2016 and their units are shown in detail in table 2.3.

Table 2.3. Description of the 18 ReCiPe 2016 midpoint impacts

ReCiPe 2016 (H) Midpoint	Unit
Fine particulate matter formation	kg PM2.5 eq
Fossil resource scarcity	kg oil eq
Freshwater ecotoxicity	kg 1,4-DCB
Freshwater eutrophication	kg P eq
Global warming	kg CO2 eq
Human carcinogenic toxicity	kg 1,4-DCB
Human non-carcinogenic toxicity	kg 1,4-DCB
Ionizing radiation	kBq Co-60 eq
Land use	m2a crop eq
Marine ecotoxicity	kg 1,4-DCB
Marine eutrophication	kg N eq
Mineral resource scarcity	kg Cu eq
Ozone formation, Human health	kg NOx eq
Ozone formation, Terrestrial ecosystems	kg NOx eq
Stratospheric ozone depletion	kg CFC11 eq
Terrestrial acidification	kg SO2 eq
Terrestrial ecotoxicity	kg 1,4-DCB
Water consumption	m3

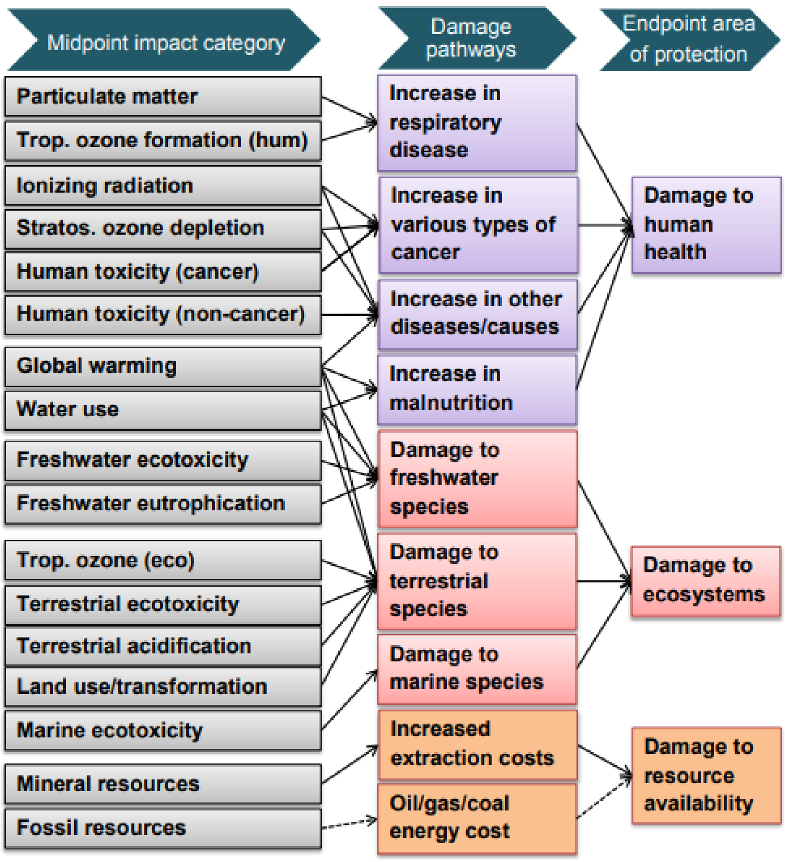

Figure 2.4. ReCiPe 2016 midpoint to endpoint pathways

The damage pathways followed in the ReCiPe2016 method for categorizing midpoint impact categories into endpoint Areas of Protection are displayed in Figure 2.4. The 22 endpoint impacts contributing to the three Areas of Protections and their units are presented in Table 2.4, where the impacts weighted to contribute into the Areas of Protection are colour coded in blue (Human health), orange (Resource scarcity) and red (Ecosystem quality), similarly to the colour coding in Figure 2.4.

Table 2.4. Description of the 22 ReCiPe 2016 endpoint impacts

ReCiPe 2016 (H) Endpoint	Unit
Fine particulate matter formation	DALY
Fossil resource scarcity	USD2013
Freshwater ecotoxicity	species.yr
Freshwater eutrophication	species.yr
Global warming, Freshwater ecosystems	species.yr
Global warming, Human health	DALY
Global warming, Terrestrial ecosystems	species.yr
Human carcinogenic toxicity	DALY
Human non-carcinogenic toxicity	DALY
Ionizing radiation	DALY
Land use	species.yr
Marine ecotoxicity	species.yr
Marine eutrophication	species.yr
Mineral resource scarcity	USD2013
Ozone formation, Human health	DALY
Ozone formation, Terrestrial ecosystems	species.yr
Stratospheric ozone depletion	DALY
Terrestrial acidification	species.yr
Terrestrial ecotoxicity	species.yr
Water consumption, Aquatic ecosystems	species.yr
Water consumption, Human health	DALY
Water consumption, Terrestrial ecosystem	species.yr

3. Results and Interpretation

In the present section, the LCA results for the two years studied are presented in the form of informative diagrams for each field pilot case comparing reference and treatment areas. Three diagrams are included in each field case, namely 1. Radar plot showing relative percentage differences in the magnitude of the 18 midpoint impacts between the reference and treatment areas (for each impact indicator, the maximum value of each impact of the reference or treatment area is set to 100%, and the results of the other variant is displayed in relation to this result); 2. Bar chart demonstrating the relative percentage change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas. Each Area of Protection is calculated from the relevant of the 22 endpoint impacts (Table 2.4), according to the Damage pathways depicted in Figure 2.4; 3. Bar chart showing average (calculated from reference-treatment areas) percentage contribution of the three main agricultural processes targeted by the SF solution (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts. It should be noted that, the 100% contribution value of each impact in this last diagram is calculated solely on the basis of the life cycle of the aforementioned three processes, and does not include other inventory processes, such as market for seed/seedlings and machinery related contribution from other field operations, e.g. ploughing, harvesting etc.

3.1. Annual crops 2020

3.1.1. Orestiada (Cotton)

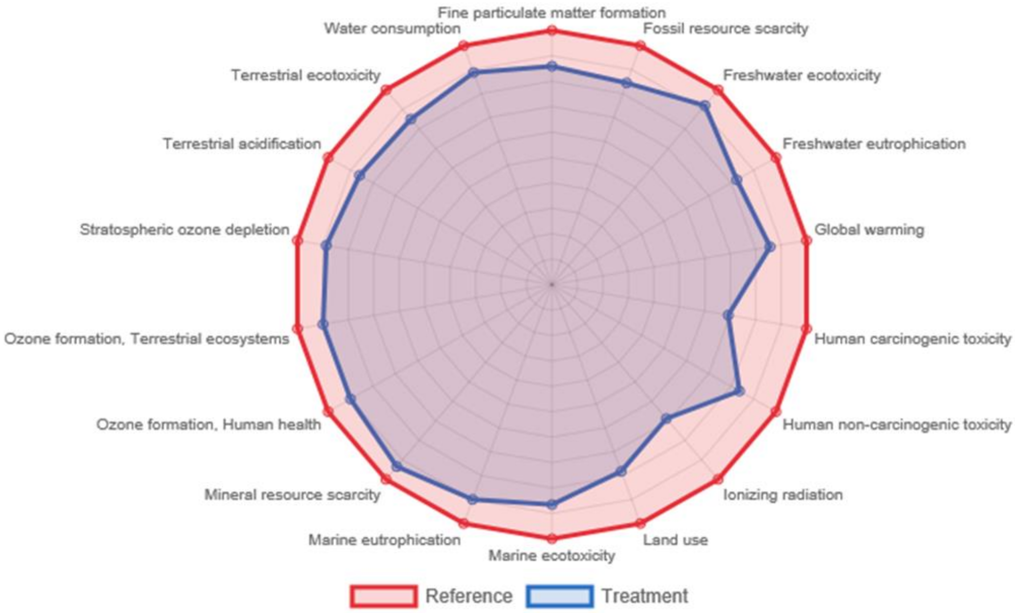

Figure 3.1. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For the Orestiada 2020 field case (cotton crop), the following results in regard to the comparison of the magnitude of impacts between the reference and treatment areas can be noticed that:

- an overall % decrease in all examined midpoint impacts is observed (Fig.3.1). Larger reductions are noted for Ionizing radiation (31.2%), Human carcinogenic toxicity (30.8%) and Land use (21.8%).
- Consequently, reductions in all three endpoint Areas of Protection are achieved as a result of the SF solution, reaching values ranging from 13.54% (Resources) to 15.18% (Human health).
- These reductions in the magnitude of the midpoint and endpoint impacts are attributed to the input reductions reported in the field calendars, as follows: 60% in irrigation, 5.34% in pesticides, 7.1% in fertilizers (11.44% in N, 0% in P2O5 & K2O).

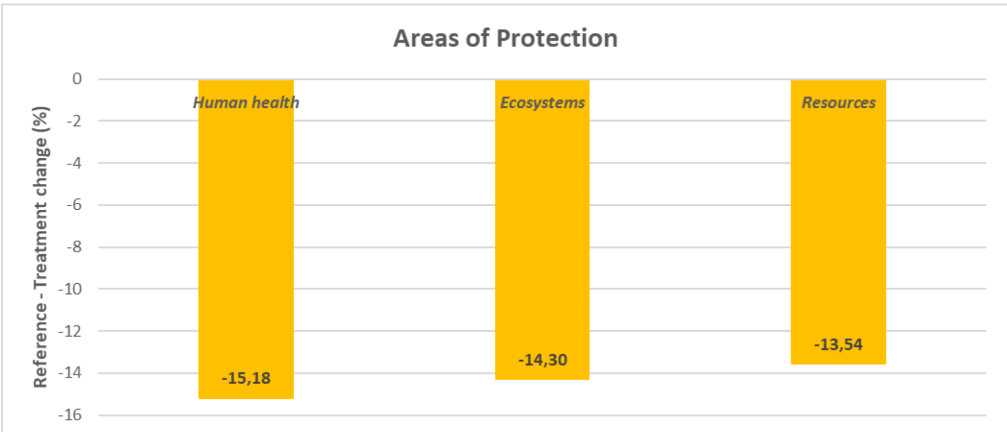

Figure 3.2. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

In the frame of the LCA study, identification of the major process contributors to each impact took place. In the case of Orestiada 2020 (as an average between reference and treatment areas), the results indicate that:

- fertilizers' life cycle is the main contributor in the majority of the impacts, and particularly in Water consumption, Stratospheric ozone depletion, Mineral resource scarcity, Global warming, Freshwater eutrophication, Fossil resource scarcity and Fine particulate matter formation.
- Pesticides play a most important role in the case of Terrestrial, Marine and Freshwater ecotoxicity.
- Irrigation mainly influences Land use and Ionizing radiation.

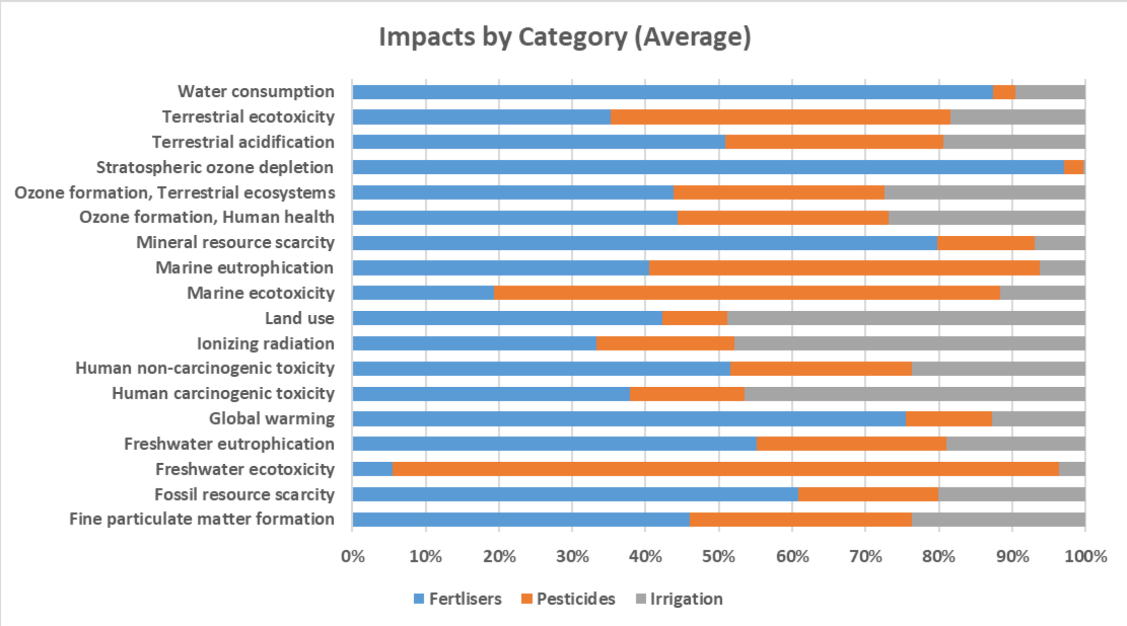

Figure 3.3. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

3.1.2. THESTO (Tomato)

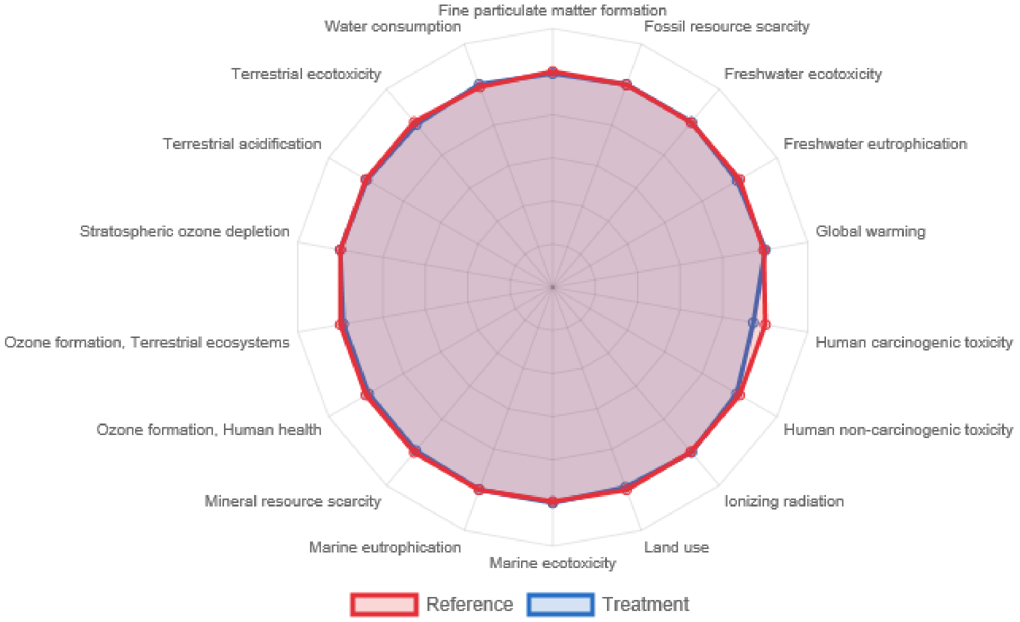

Figure 3.4. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For the THESTO 2020 field case (tomato crop), the following results in regard to the comparison of the magnitude of impacts between the reference and treatment areas can be noticed that:

- no particular changes in all midpoint impacts examined are observed (Fig.3.4), except for Human carcinogenic toxicity which decreased by 5.6%.
- Consequently, changes in all three endpoint Areas of Protection are of very low values, which could be characterized as insignificant. In more detail, there was a small decrease in Human Health (0.36%) and small increases in Ecosystems (0.05%) and Resources (0.3%).
- The increases in the magnitude of the midpoint and endpoint impacts are attributed in a small increase in the volume of irrigation (2.64%), while the reductions from differences in the type of irrigation systems in use. More specifically, 8.79% of the watering in the reference area was applied with a sprinkler irrigation system, while in the treatment area, a drip system was solely used. In other words, the life cycle of a sprinkler irrigation system has a higher impact in total, than that of a drip system.
- No changes in fertilizers and pesticides application was recorded.

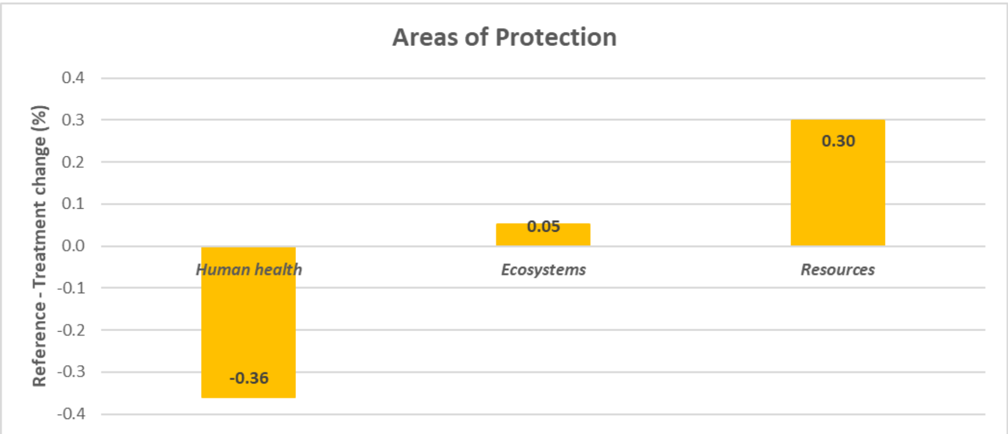

Figure 3.5. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

As for the major process contributors to each impact, in the case of THESTO 2020 (as an average between reference and treatment areas), the results indicate that:

- fertilizers life cycle is the main contributor particularly in Water consumption, Stratospheric ozone depletion and Mineral resource scarcity
- Pesticides play the most important role in the case of Terrestrial, Marine and Freshwater ecotoxicity, as well as Marine eutrophication.
- Irrigation mainly influences Terrestrial acidification, Ozone formation, Land use, Ionizing radiation, Human carcinogenic toxicity, Fossil resource scarcity and Fine particulate matter formation.

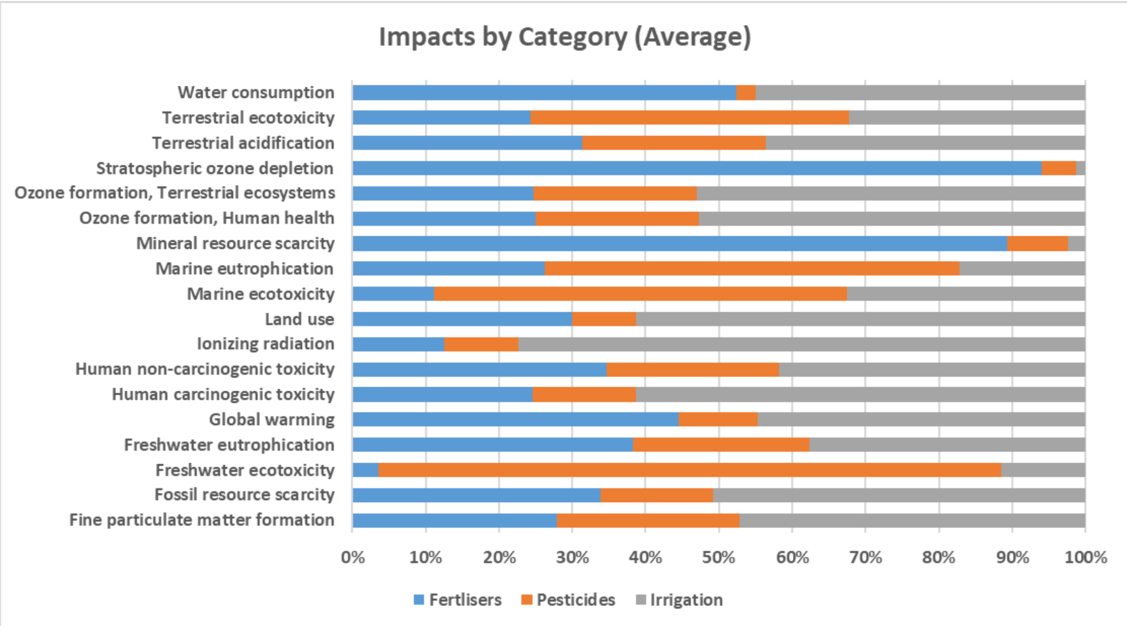

Figure 3.6. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

3.1.3. THESGI (Cotton), Kiato (Tomato) & Lasithi (Potato)

For THESGI (Larisa, cotton crop), Kiato (tomato crop) and Lasithi (potato crop) no differences in fertilizers and pesticides application and irrigation inputs between the reference and treatment areas have been recorded in the field calendars, so no comparative radar and bar charts are displayed.

As for the main process contributors to each impact in the case of THESGI 2020 (averaged between reference and treatment areas), the results show that (Fig.3.7):

- in this case, due to the small amount in fertilizers applied, fertilizers' life cycle influences mainly Stratospheric ozone depletion.
- Pesticides play the most important role exclusively in the case of Freshwater eutrophication.
- Finally, irrigation is the major contributor in all other impacts.

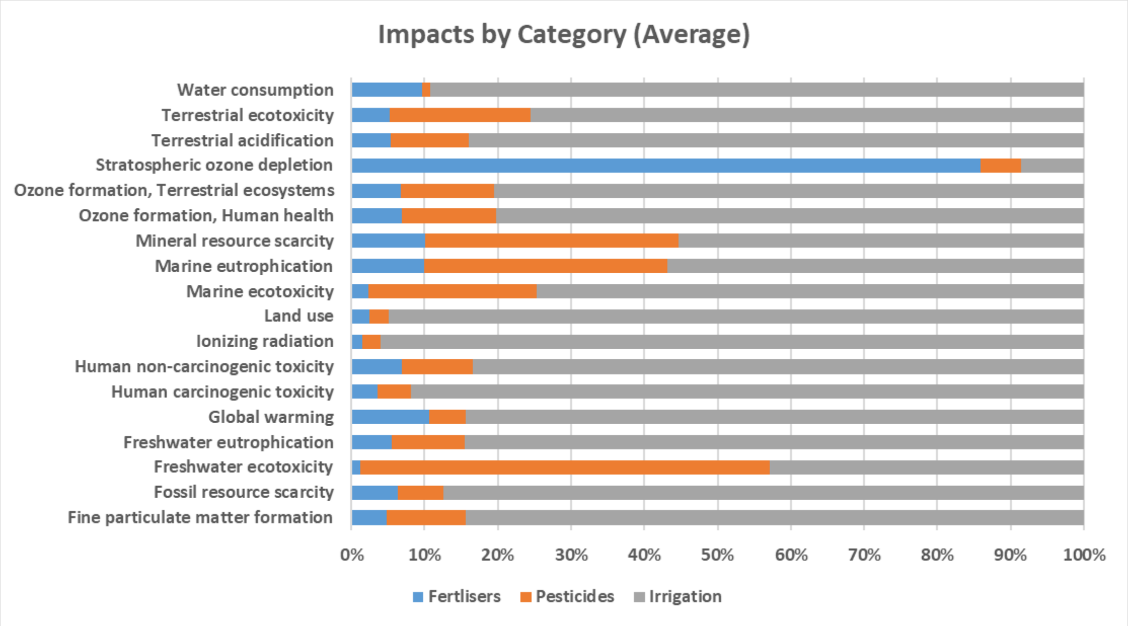

Figure 3.7. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

Moreover, regarding the main process contributors to each impact in the case of Kiato 2020 (averaged between reference and treatment areas), the results show that (Fig.3.8):

- in this case, fertilizers' life cycle influences mainly Stratospheric ozone depletion and Mineral Resource Scarcity.
- Pesticides contribute the most in Freshwater, Marine and Terrestrial ecotoxicity and Marine eutrophication.
- Lastly, irrigation is the major contributor mostly in Water consumption, Ozone formation, Land use, Ionizing radiation, Human carcinogenic toxicity (and non), Global warming, Fossil resource scarcity and Fine particular matter formation.

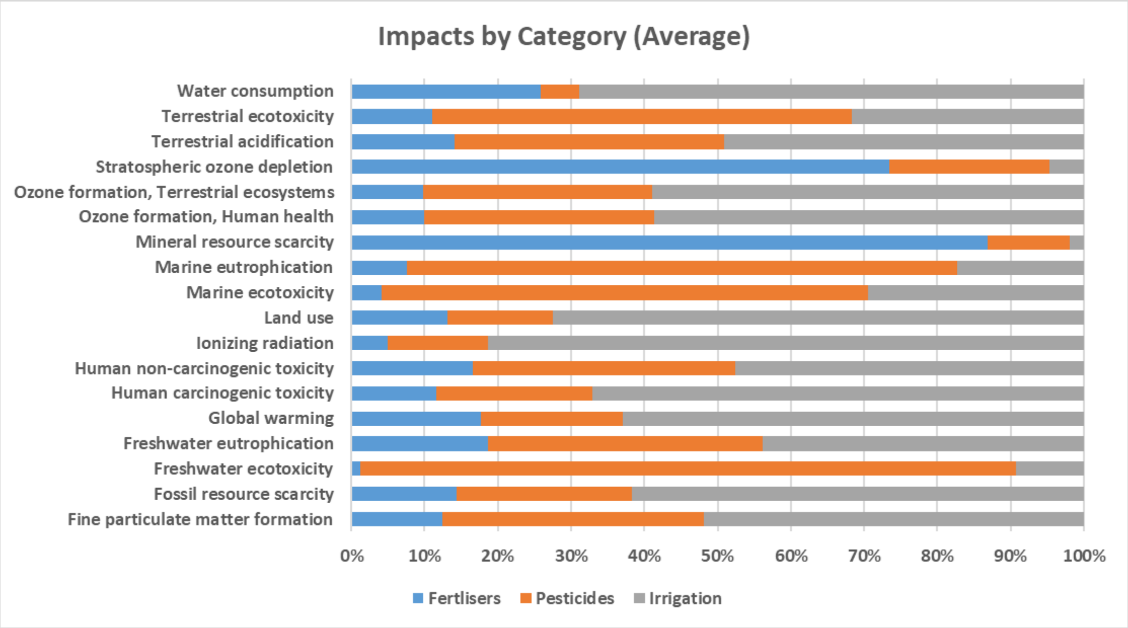

Figure 3.8. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

Lastly, for Lasithi 2020 the results show that (Fig.3.9):

- fertilizers' life cycle is the main contributor in Water consumption, Stratospheric ozone depletion, Mineral resource scarcity, Global warming, Freshwater eutrophication and Fossil resource scarcity.
- Pesticides play a most important role in the case of Marine and Freshwater ecotoxicity and Marine eutrophication
- Irrigation mainly influences Ozone formation, Land use, Ionizing radiation and Human carcinogenic toxicity.

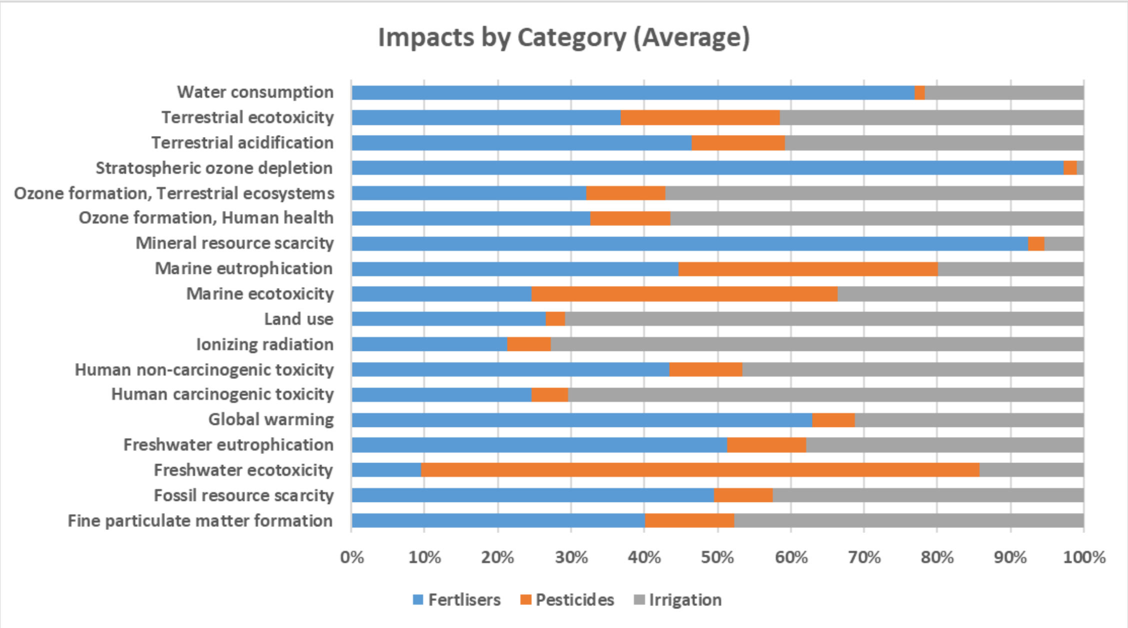

Figure 3.9. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

3.2. Perennial crops 2020

3.2.1. Mirabello (Olive)

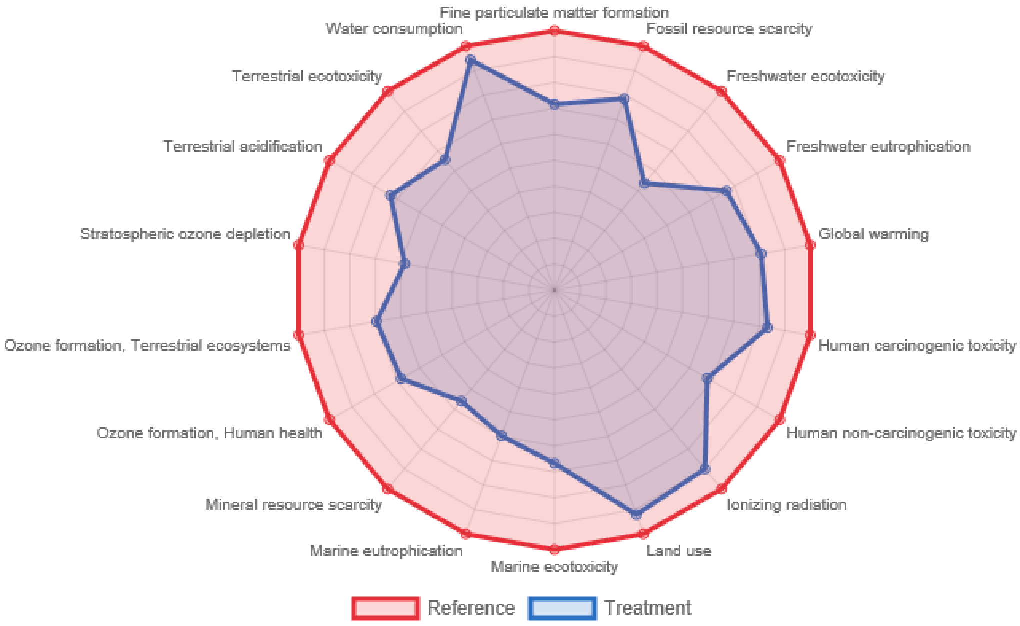

Figure 3.10. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For the Mirabello 2020 field case (olive crop), the following results in regard to the comparison of the magnitude of impacts between the reference and treatment areas can be noticed that:

- an overall % decrease in all examined midpoint impacts is observed. Larger reductions are noted for Mineral resource scarcity (44.2%), Stratospheric ozone depletion (41.4%) and Marine eutrophication (40.2%), while the smallest in Land use (7.9%) and Water consumption (5.6%).
- Consequently, reductions in all three endpoint Areas of Protection are achieved as a result of the SF solution, reaching values ranging from 22.39% (Ecosystems) to 24.68% (Human health).

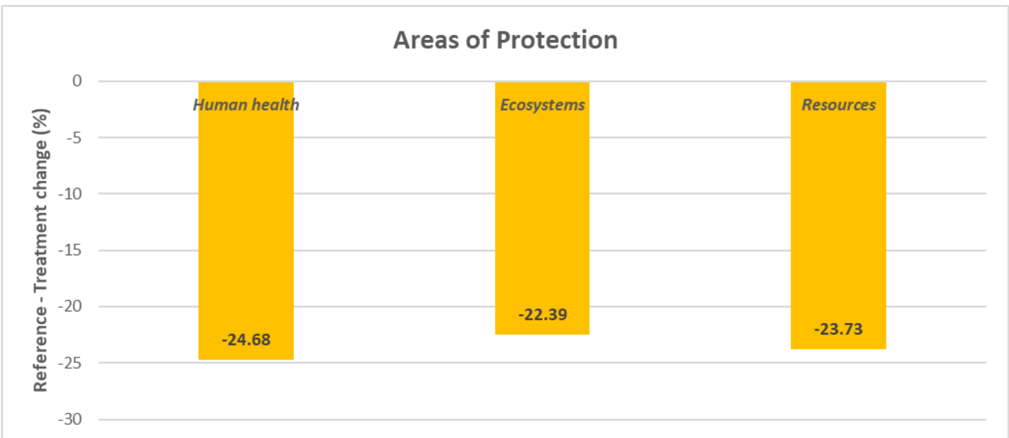

Figure 3.11. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

- These reductions in the magnitude of the midpoint and endpoint impacts are attributed solely to the reduction of pesticides reported, as reported in the field calendars, by a percentage of 53.22%.
- Fertilizers were not applied in the year 2020 in Mirabello, both for reference and treatment areas.

In identifying the major process contributors of each impact in the case of Mirabello 2020 (as an average between reference and treatment areas), the results indicate that:

- pesticides life cycle is the main contributor in Freshwater ecotoxicity, Stratospheric ozone depletion, Mineral resource scarcity, Marine eutrophication.
- Irrigation play the most important role in Water consumption, Terrestrial acidification, Fossil resource scarcity, Freshwater eutrophication, Global warming, Human carcinogenic toxicity, Land use and Ionizing radiation.

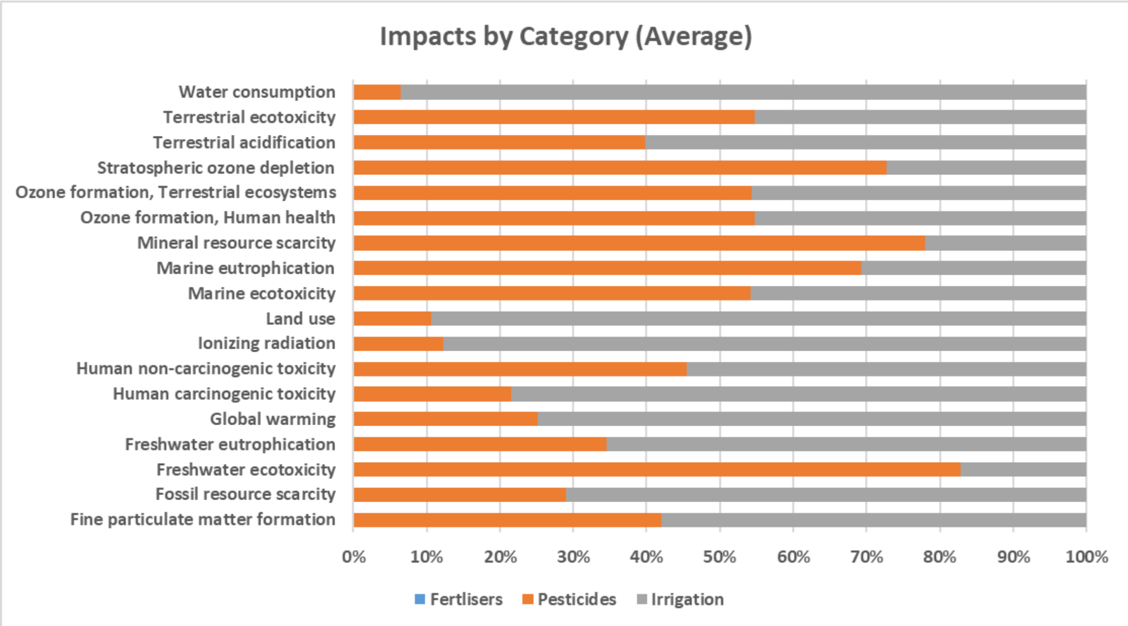

Figure 3.12. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

3.2.2. Pieria (Kiwi)

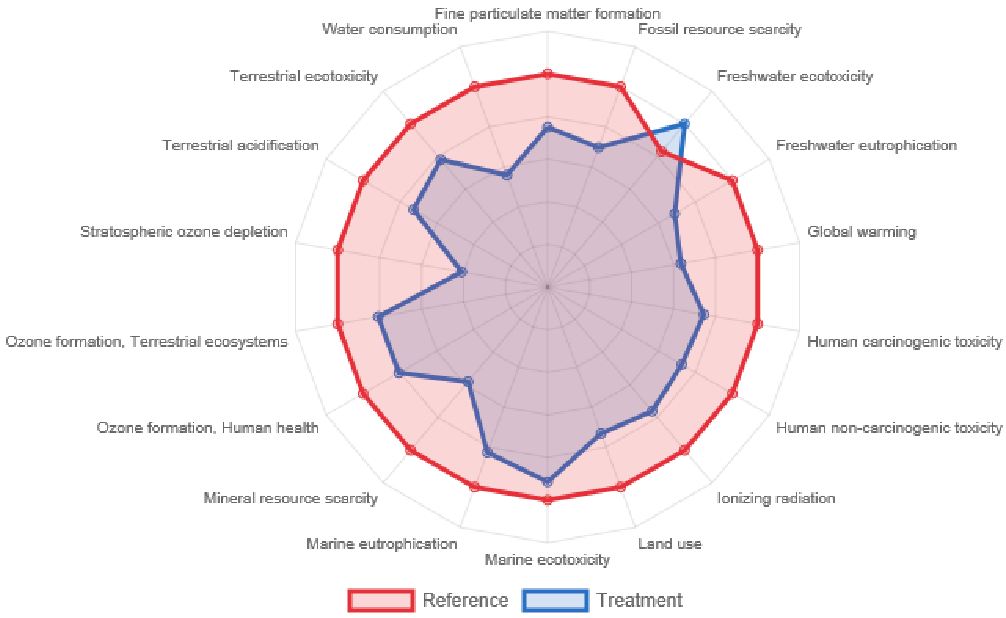

Figure 3.13. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For the Pieria 2020 field case (olive crop), the following results in regard to the comparison of the magnitude of impacts between the reference and treatment areas can be noticed that:

- decreases in almost all midpoint examined impacts are observed, except from Freshwater ecotoxicity which shows a 20.4% increase. The largest reductions are noted for Stratospheric ozone depletion (59%), Water consumption (44.1%) and Mineral resource scarcity (42%).
- Thus, reductions in all three endpoint Areas of Protection are achieved, reaching values ranging from 30.05% (Human health) to 33.37% (Resources).
- These reductions in the magnitude of the midpoint and endpoint impacts are credited to a 20.77% reduction in irrigation and a 49.71% drop in the fertilizers applied (61.93% in N, 48.76% in P2O5 & 43.44% in K2O).
- The increase of pesticides by 48.24% is outlined in the aforementioned increase in Freshwater ecotoxicity.

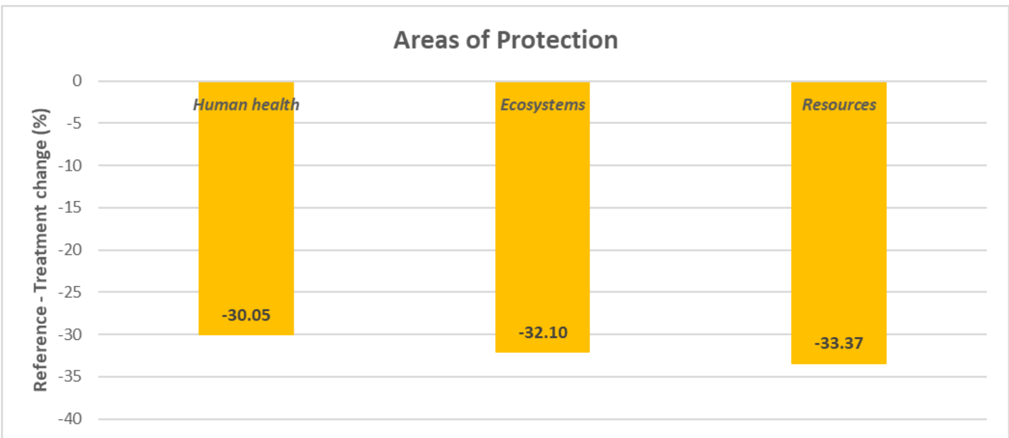

Figure 3.14. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

In identifying the major process contributors of each impact in the case of Pieria 2020 (as an average between reference and treatment areas), the results indicate that:

- fertilizers are the main contributor in Water consumption, Stratospheric ozone depletion and Mineral resource scarcity.
- Pesticides play a most important role in the case of Marine and Freshwater ecotoxicity and Marine eutrophication.
- Irrigation mainly influences Land use and Ionizing radiation, Ozone formation and Human carcinogenic toxicity (and non).

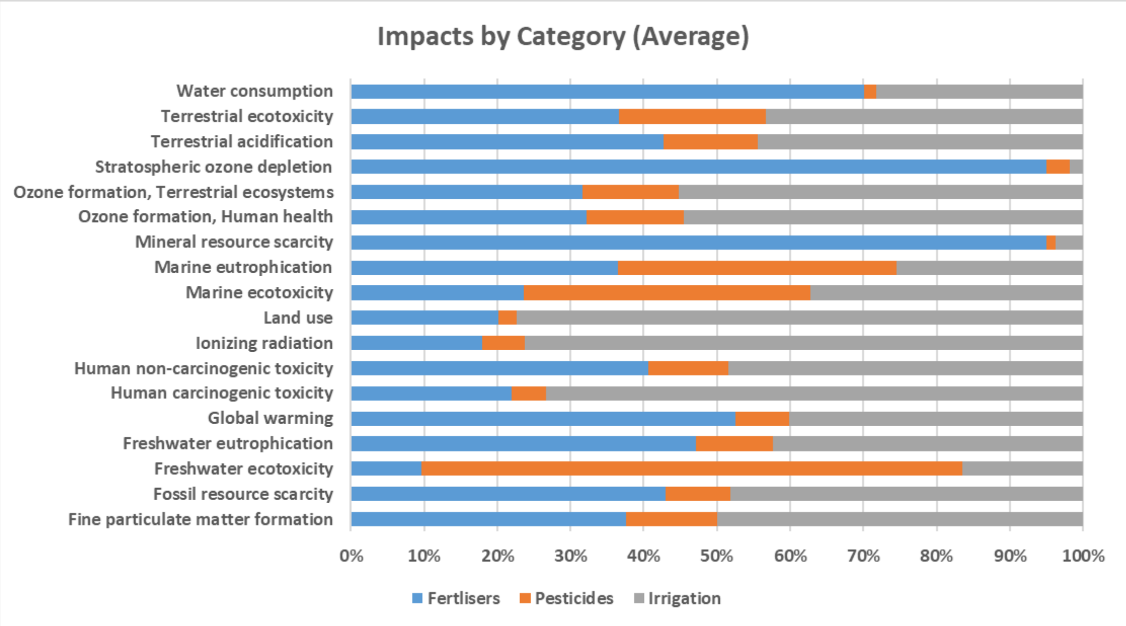

Figure 3.15. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

3.2.3. Stylida (Olive) & Velventos (Peach)

For Stylida (olive crop), no differences in fertilizers and pesticides application and irrigation inputs between the reference and treatment areas have been recorded in the field calendars, so no comparative charts are displayed.

On the other hand, for Stylida 2020 the process contribution results show that (Fig.3.16):

- fertilizers contribute mainly in Water consumption, Stratospheric ozone depletion and Mineral resource scarcity.
- Pesticides mainly influence Marine and Freshwater ecotoxicity and Marine eutrophication.
- Irrigation play the most important role in Terrestrial acidification, Ozone formation, Land use, Ionizing radiation, Human carcinogenic toxicity (and non), Freshwater eutrophication, Fine particular matter formation and Fossil resource scarcity.

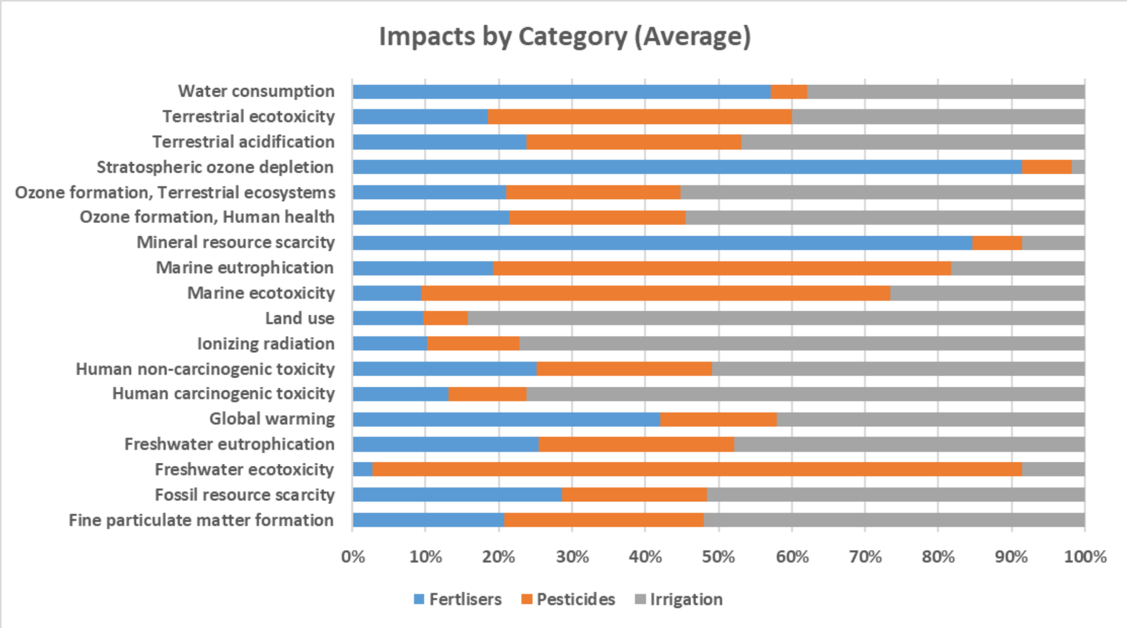

Figure 3.16. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

As for Velventos (peach crop), there have been also no differences in fertilizers and pesticides application and irrigation inputs between the reference and treatment areas recorded in the field calendars, so no comparative charts are displayed.

In identifying the major process contributors of each impact in the case of Velventos 2020 (as an average between reference and treatment areas), the results indicate that (Fig.3.17):

- fertilizers are the main contributor in the majority of the impacts, and particularly in Water consumption, Stratospheric ozone depletion, Mineral resource scarcity and Ozone formation.
- Pesticides play a most important role in the case of Terrestrial, Marine and Freshwater ecotoxicity and Marine eutrophication.
- Irrigation mainly influences Ionizing radiation.

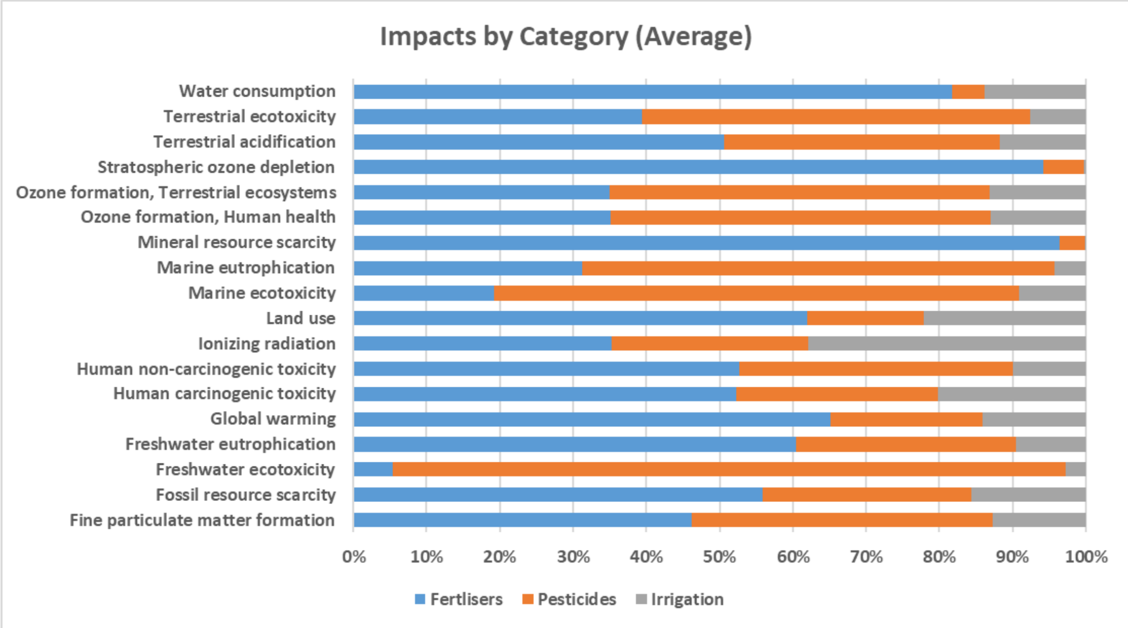

Figure 3.17. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Pesticides, Irrigation) to each of the 18 midpoint impacts

3.3. Annual crops 2021

3.3.1. Kiato (Tomato)

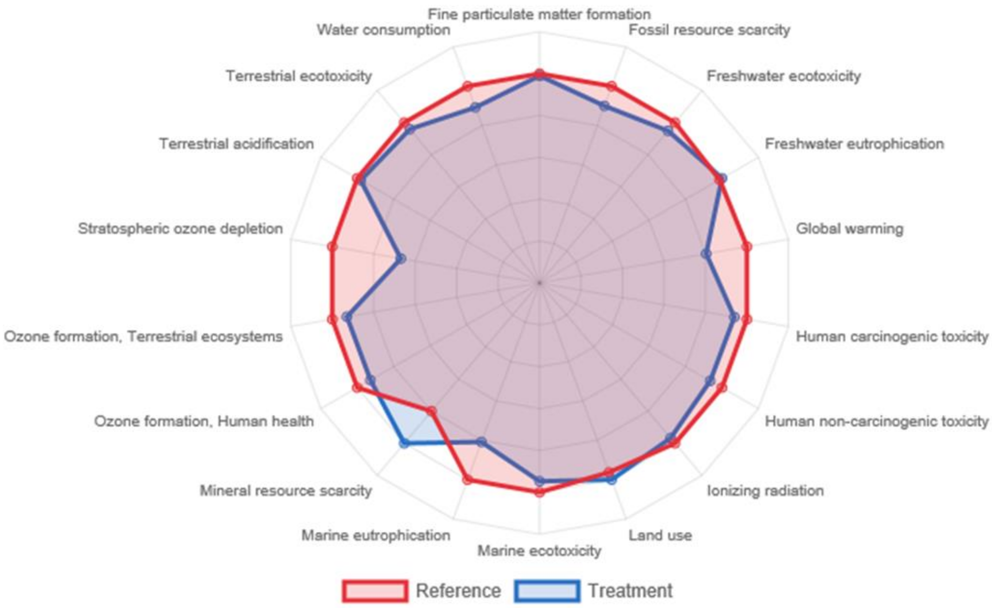

Figure 3.18. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For the Kiato 2021 field case (tomato crop), the following results in regard to the comparison of the magnitude of impacts between the reference and treatment areas can be noticed that:

- an overall % decrease in the majority of midpoint examined impacts is observed, apart from the case of Mineral resource scarcity where an increase is noted (25.09%). A marginal increase can also be seen in the Land use impact (3.87%) (Fig.3.18). Larger reductions are noted for Stratospheric ozone depletion, (33.06%), Global warming (19.68%) and Marine eutrophication (19.18%).
- Consequently, reductions in all three endpoint Areas of Protection are achieved as a result of the SF solution, reaching values ranging from a minimum of 2.03% (Resources) to 14.49% (Ecosystems).
- These reductions in the magnitude of the midpoint and endpoint impacts are attributed to the input reductions reported in the field calendars, as follows: 14.6% reduction in total fertilizers (33.4% in N)
- The increases calculated are a result of respective changes in P2O5 (34.1%) & K2O (25.8%) fertilizers.

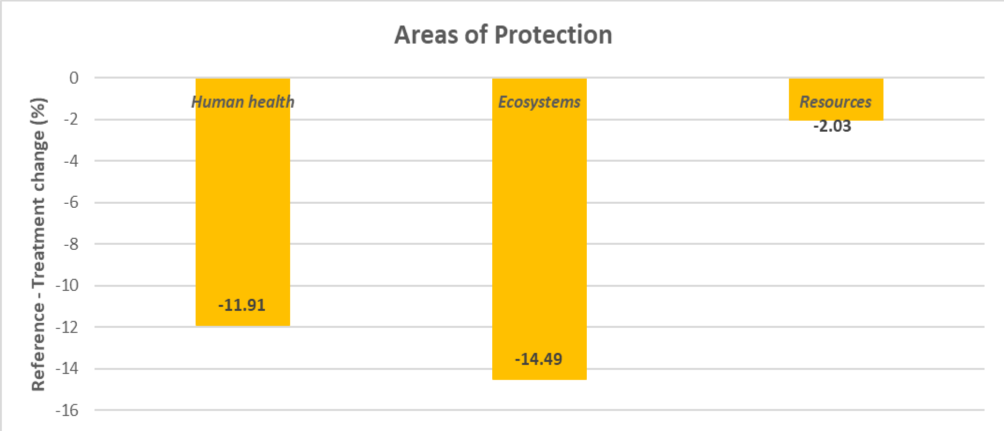

Figure 3.19. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

In regard to the major process contributors to each impact, in the case of Kiato 2021 (as an average between reference and treatment areas), the results indicate that:

- fertilizers' life cycle is the main contributor in all the impacts, with the exception of Ionizing radiation, for which the contribution of irrigation is marginally larger by 2%). In the case of Stratospheric ozone depletion and Mineral resource scarcity, fertilizers' life cycle is almost the only contributor to these impacts.
- Irrigation mainly influences the impacts of Ionizing radiation and Freshwater/Marine ecotoxicity.

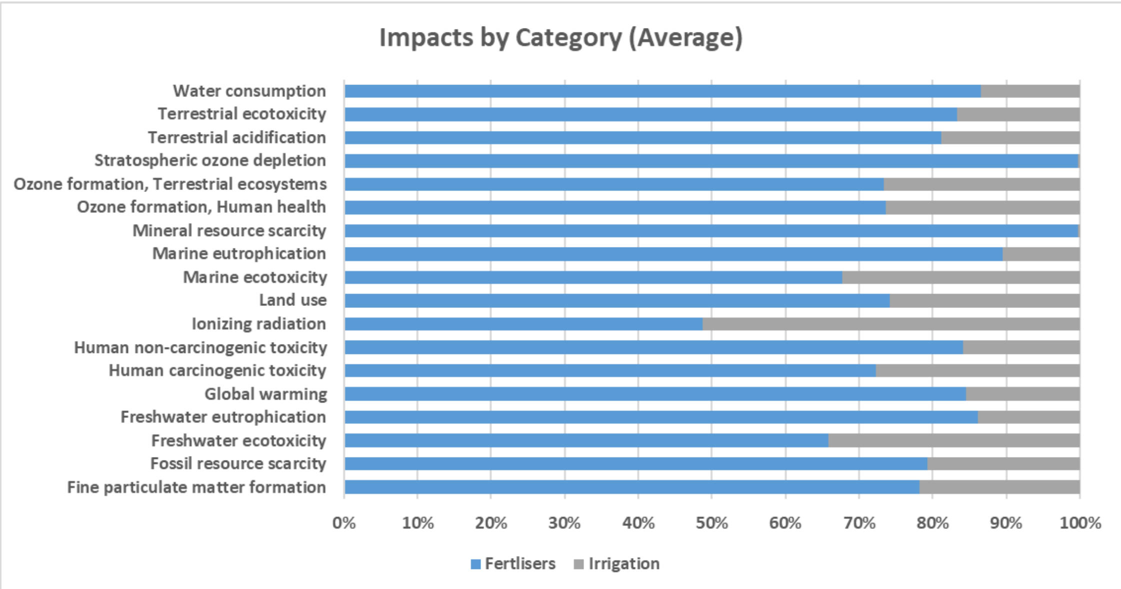

Figure 3.20. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.3.2. Lasithi (Potato)

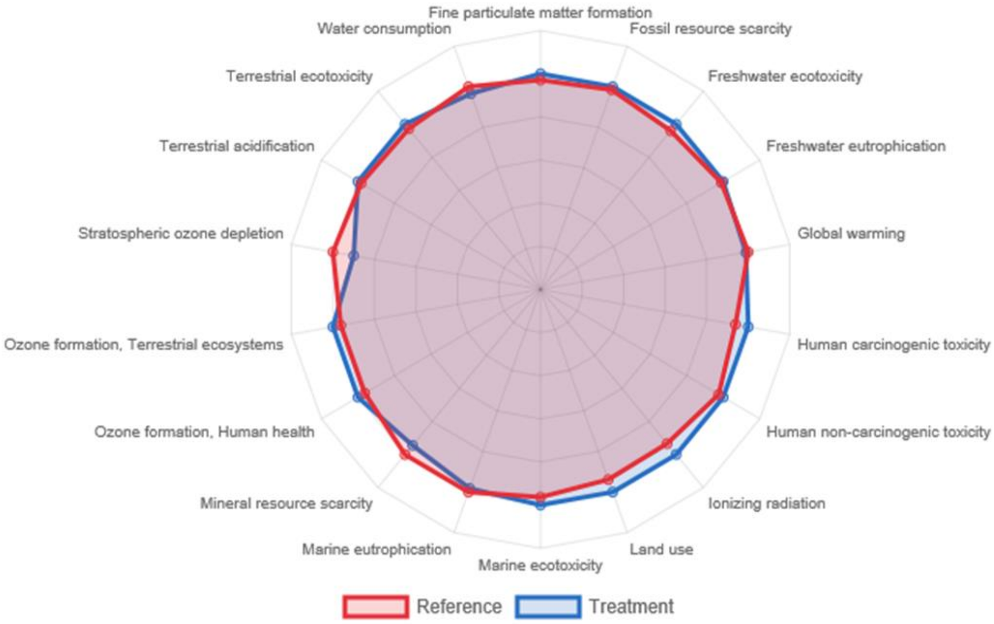

Figure 3.21. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For the Lasithi 2021 field case (potato crop), the following results in regard to the comparison of the magnitude of impacts between the reference and treatment areas can be noticed that:

- the magnitude of the impacts is very similar in the two areas, with a marginal increase caused in some cases and a marginal decrease in other cases, as a result of the application of the SF solution. The most noted decrease can be observed in the Stratospheric ozone depletion impact (10.02%) (Fig.3.21), whereas the biggest increases are noted for Ionizing radiation (37.16%), Human carcinogenic toxicity (6.61%) and Land use (6.57%).
- Consequently, insignificant increases in the range of 0.38% to 1.41% are calculated in the Human health and ecosystems Areas of Protection, whereas a marginal decrease of 0.08% can be seen in the case of the Resources Area of Protection.
- This similarity in the magnitude of the midpoint and endpoint impacts is attributed to the input marginal changes reported in the field calendars. Increases in impacts are a result of increases in irrigation (11.2%), while the decreases are a consequence of the recorded respective decreases in fertilizing (8.9% in the total amount, 10.4% in N and 6.7% in P2O5 and K2O).

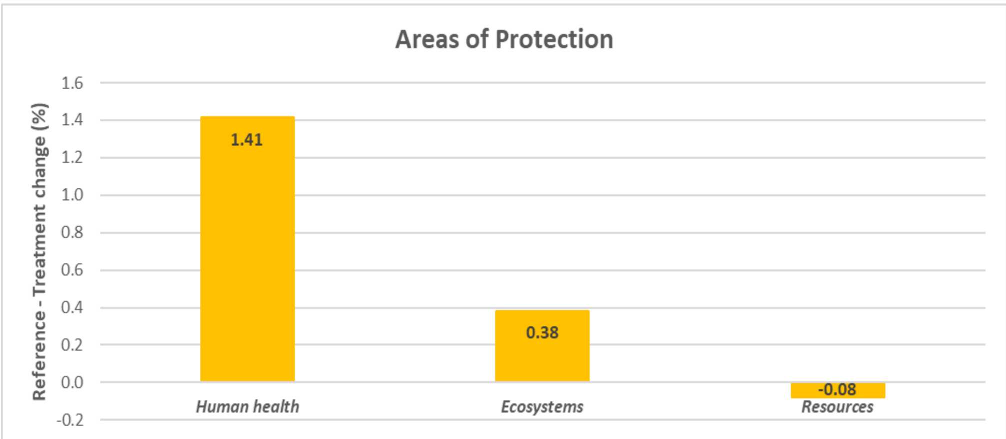

Figure 3.22. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

In regard to the major process contributors to each impact, in the case of Lasithi 2021 (as an average between reference and treatment areas), the results indicate that:

- fertilizers are the main contributor in six out of the 18 midpoint impacts, particularly in the case of Water consumption, Stratospheric ozone depletion and Mineral resource scarcity.
- Irrigation influences the majority of the impacts by contributing to more than 70% in Ozone formation-Terrestrial ecosystems, Ozone formation-Human health, Land use, Ionizing radiation and Human carcinogenic toxicity, and more than 60% to Marine and Freshwater ecotoxicity and Fine particulate matter formation.

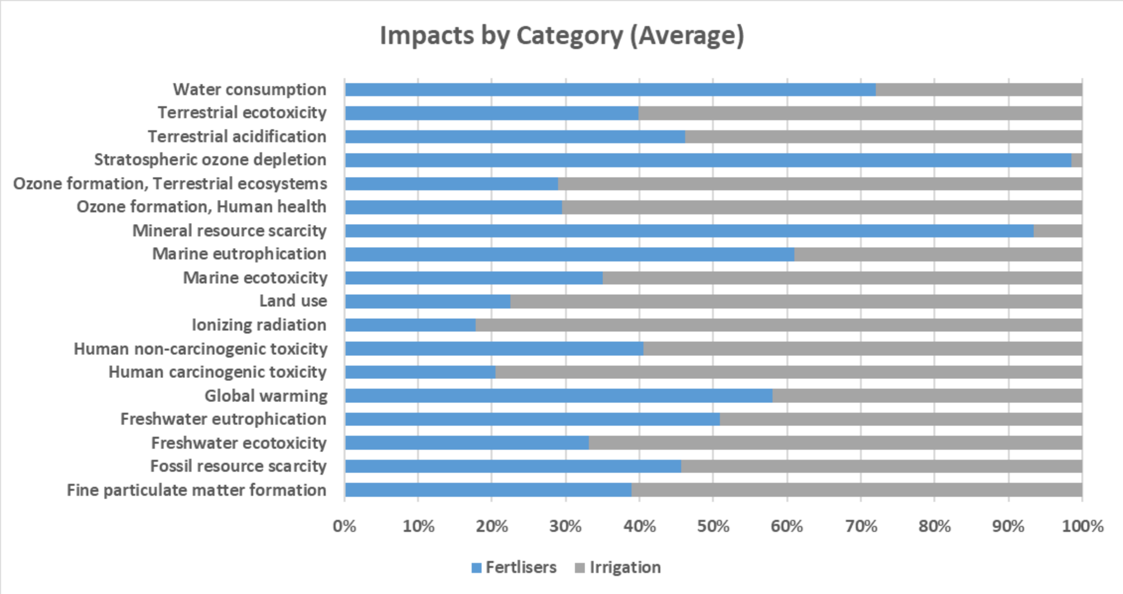

Figure 3.23. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.3.3. Orestiada & THESGI (Cotton), THESTO (Tomato)

Both for Orestiada and THESGI (cotton crop), no differences in fertilizers and pesticides application and irrigation inputs between the reference and treatment areas have been recorded in the field calendars, so no comparative charts are displayed.

Regarding the process contribution in Orestiada, the results show that (Fig.3.24):

- fertilizers contribute mainly in Water consumption, Stratospheric ozone depletion, Marine eutrophication, Global warming and Mineral resource scarcity.
- Irrigation play the most important role in all other impacts, such as Land use, Ionizing radiation, Terrestrial, Marine and Freshwater ecotoxicity, Fossil resource scarcity etc.

As for the process contribution in THESGI, the results show that (Fig.3.25):

- fertilizers contribute mainly in Water consumption and Mineral resource scarcity.
- Irrigation play the most important role in all other impacts.

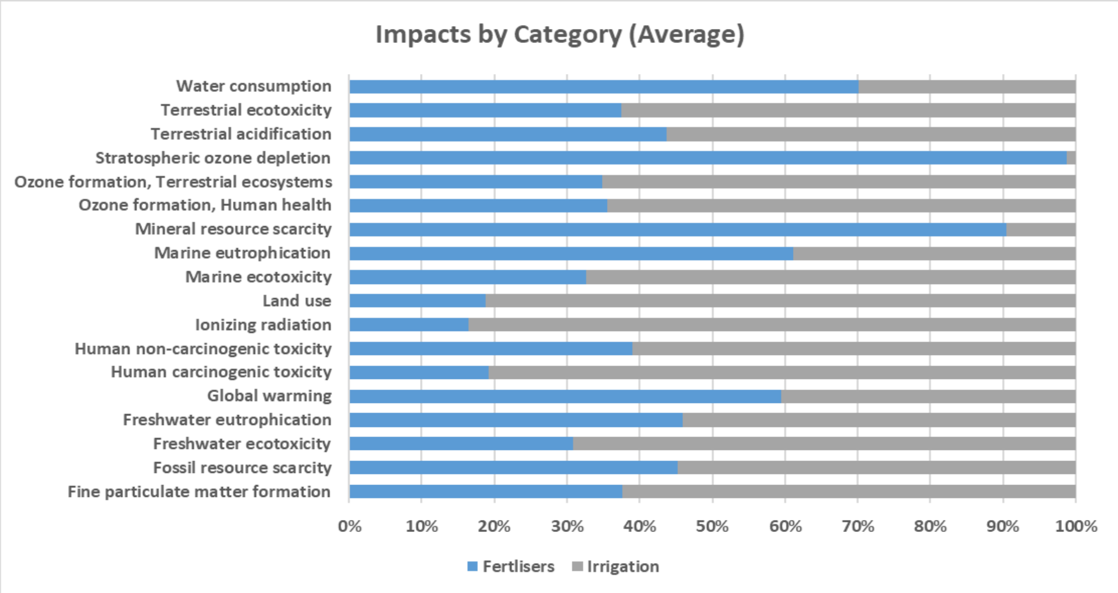

Figure 3.24. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

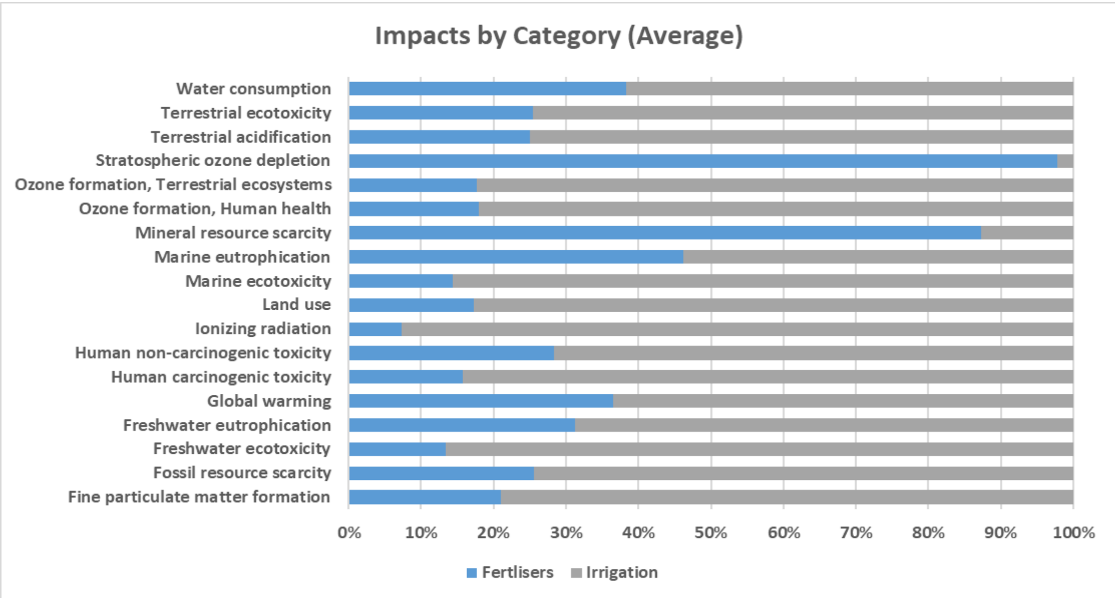

Figure 3.25. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

Moreover, for THESTO (tomato crop), no differences in fertilizers and pesticides application and irrigation inputs between the reference and treatment areas have been recorded in the field calendars, so no comparative charts are displayed.

Regarding the process contribution, the results show that (Fig.3.26):

- fertilizers contribute mainly in Stratospheric ozone depletion, Marine eutrophication and Mineral resource scarcity.
- Irrigation play the most important role in all other impacts, such as Land use, Ionizing radiation, Fossil resource scarcity etc.

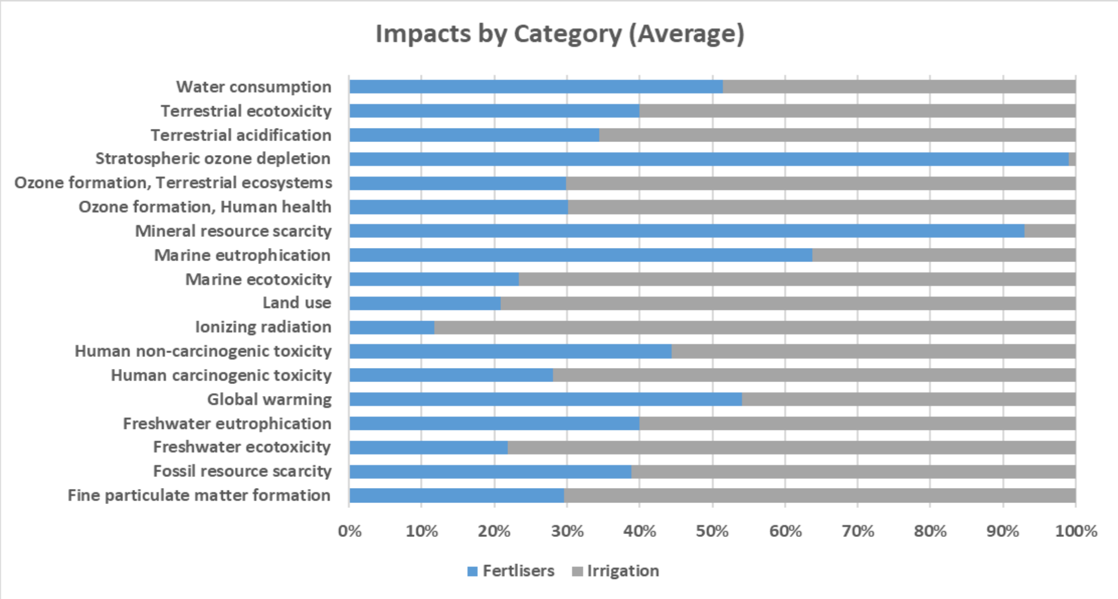

Figure 3.26. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.4. Perennial crops 2021

3.4.1. Mirabello & Stylida (Olive)

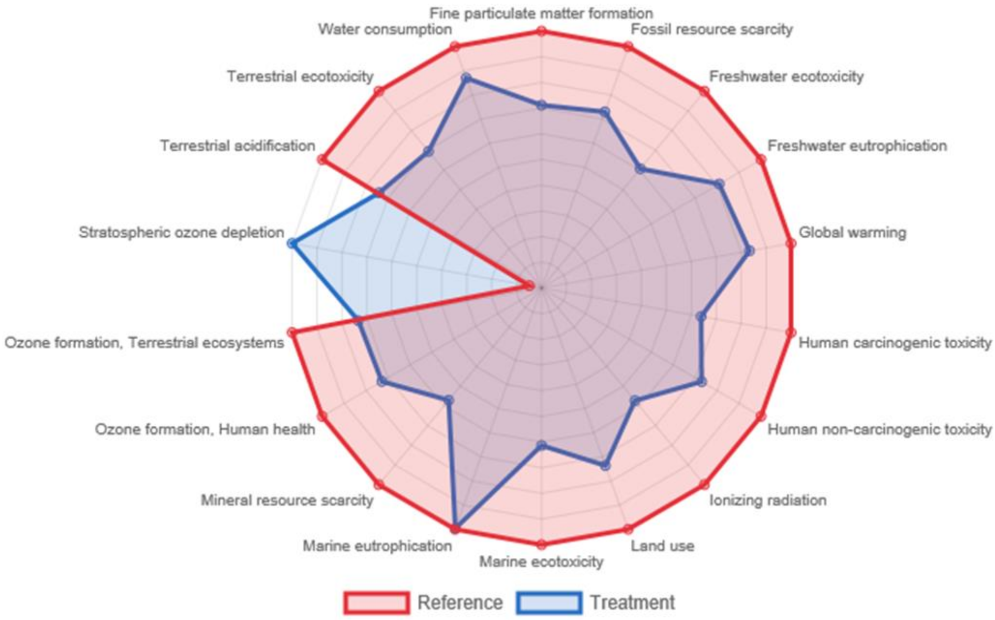

Figure 3.27. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For Mirabello 2021 field case (olive crop), the following results in regard to the comparison of the magnitude of impacts between the reference and treatment areas can be noticed that:

- significant reductions caused by SF application are observed in the majority of the impacts, apart from Stratospheric ozone depletion, in which case the SF solution results to a notably higher impact, and Marine eutrophication, in which case the impact is the same for the reference and treatment area.

- Consequently, significant reductions in all three Areas of Protection endpoint impacts, within a range from 19.66% (Ecosystems) to 23.57% (Human health) and 29.93% (Resources), are calculated.
- These changes in the magnitude of the midpoint and endpoint impacts are attributed to the input data changes reported in the field calendars, as follows: reduction in irrigation by 48.5% and in the total amount of fertilizers applied by 7.1% (5.6% in N). At the same time, P2O5 & K2O fertilizers were applied, meaning that in the reference treatment no such fertilizers were applied.

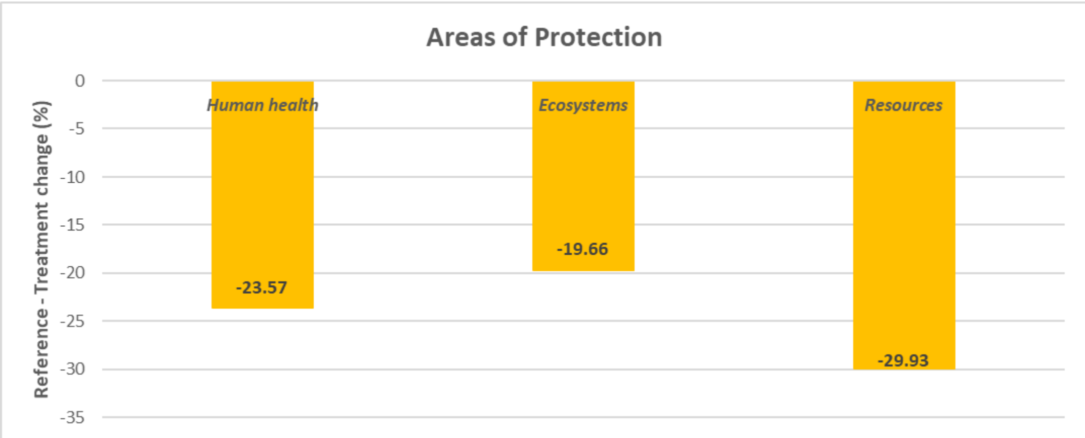

Figure 3.28. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

In regard to the major process contributors to each impact, in the case of Mirabello 2021 (as an average between reference and treatment areas), the results indicate that:

- fertilizers' life cycle is the main contributor in two out of the 18 midpoint impacts, particularly in the case of Stratospheric ozone depletion and Mineral resource scarcity, for which it contributes by more than 90%.
- Irrigation influences all other impacts by contributing to more than 80% in Land use and Ionizing radiation, but also to Marine and Freshwater ecotoxicity.

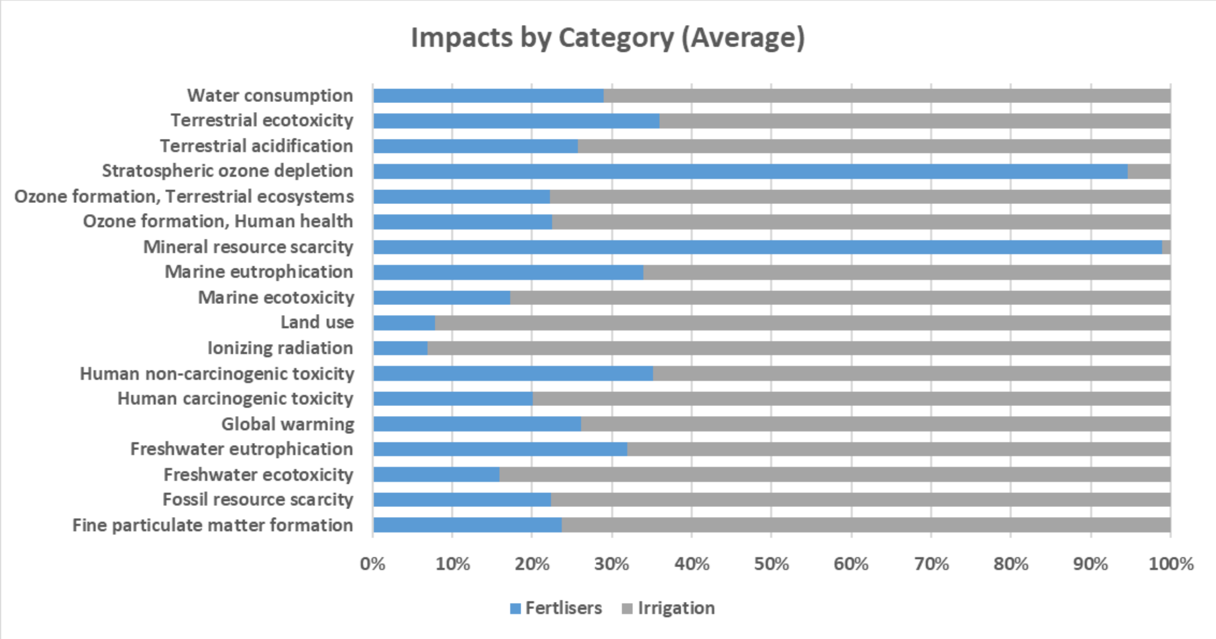

Figure 3.29. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

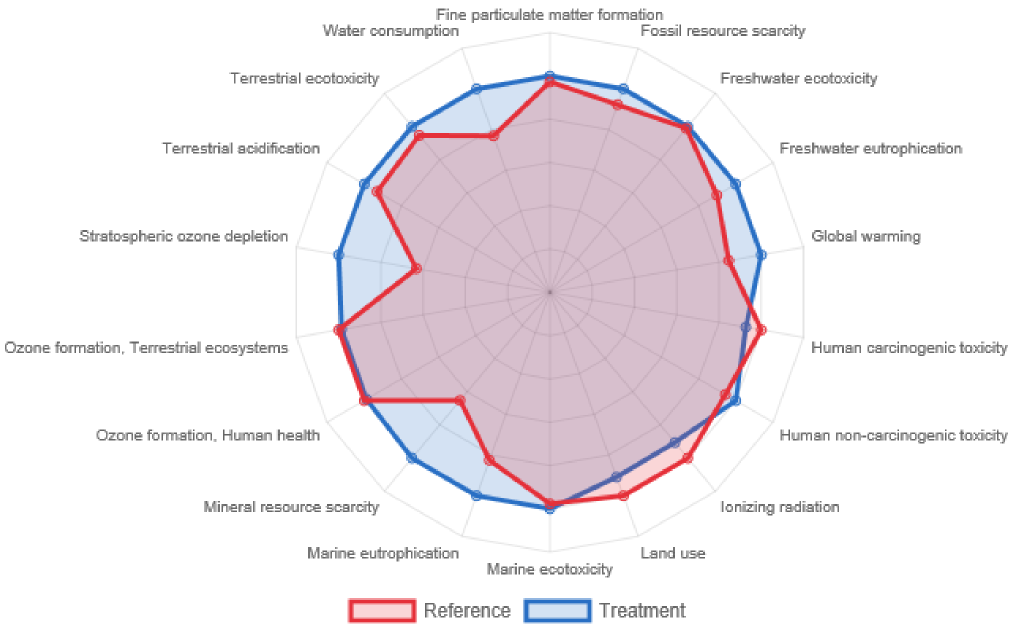

Figure 3.30. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For Stylida 2021 (olive crop), the results regarding the comparison of the magnitude of impacts between the reference and treatment areas indicate that:

- there were decreases in some impacts (e.g., Ionizing radiation (9.4%) and Land use (9.2%)), as well as increases, with the biggest ones to be observed in Stratospheric ozone depletion (58%) and Mineral resource scarcity.
- On the other hand, in all three Areas of Protection endpoint impacts there have been only increases calculated, within a range from 8.65% (Human health) to 16.76% (Resources), despite of observing some decreases in the midpoint level, as mentioned above.
- These changes in the magnitude of the midpoint and endpoint impacts are attributed to the following: a reduction in irrigation by 20% and an increase in fertilizers (60% in the total amount, as well as in N, P2O5 and K2O, respectively).

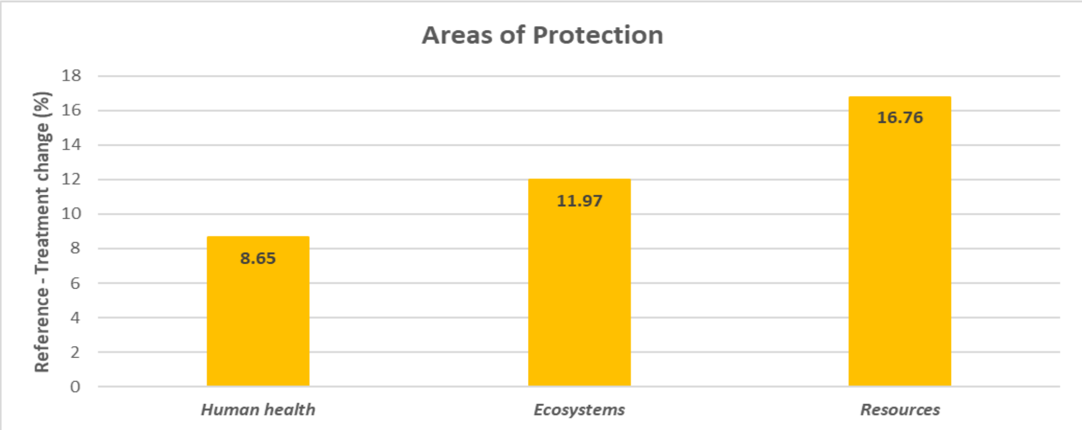

Figure 3.31. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

Regarding the major process contributors to each impact, in the case of Stylida 2021 (as an average between reference and treatment areas), the results show that:

- fertilizers' life cycle is the main contributor particularly in Stratospheric ozone depletion, Mineral resource scarcity, as well as, in a lower level, in Water consumption, Marine eutrophication and Global warming.
- Irrigation influences all other impacts as the major contributor of the two.

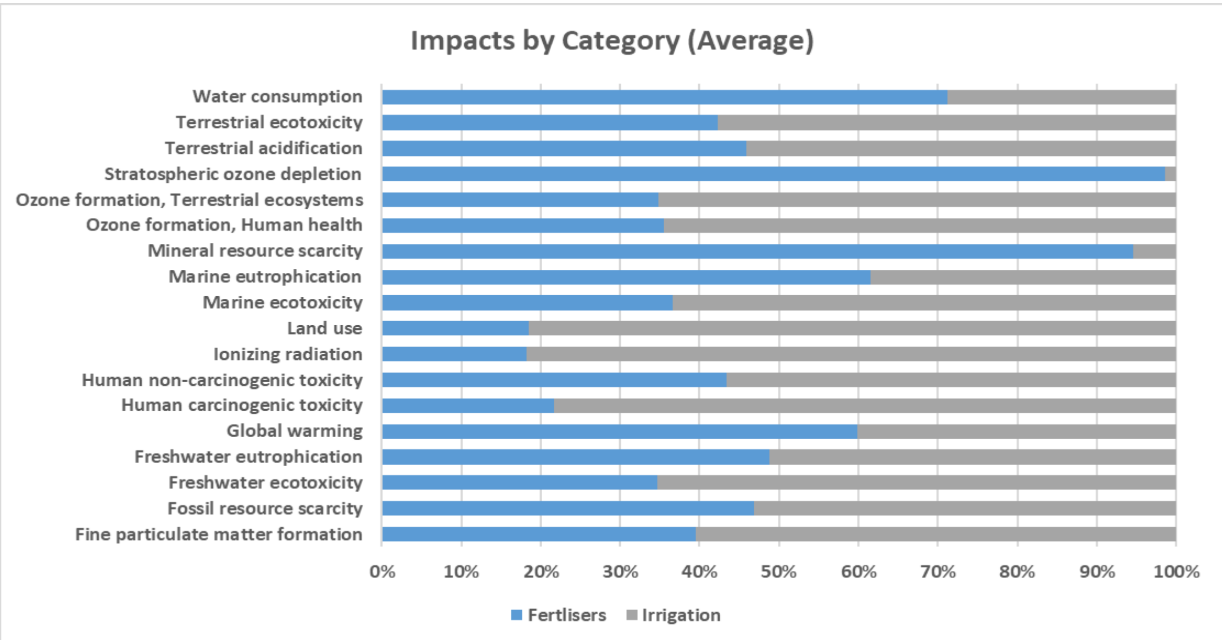

Figure 3.32. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.4.2. Pieria (Kiwi)

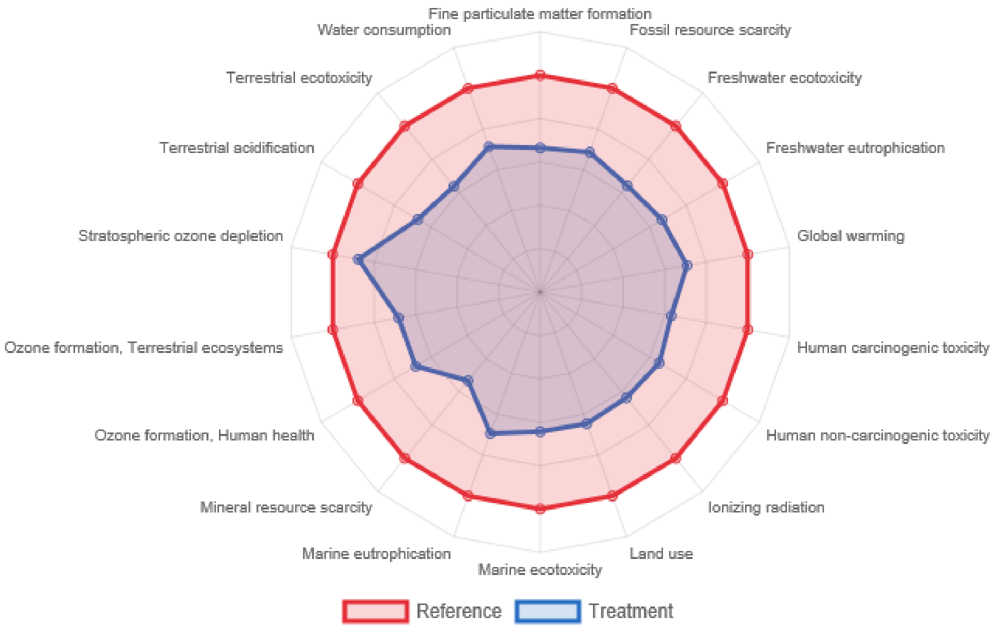

Figure 3.33. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For Pieria 2021 (kiwi crop), the results of comparing the magnitude of impacts between the reference and treatment areas show that:

- significant reductions caused by SF application are observed in all impacts, with the lowest reduction to be observed in Stratospheric ozone depletion (12.3%) and the biggest in Mineral resource scarcity (46.7%).
- Thus, significant reductions in all three Areas of Protection endpoint impacts are observed, within a range from 31.1% in Ecosystems to 33.61% in Resources.
- The reductions in the magnitude of the midpoint and endpoint impacts are attributed to respective reductions in: irrigation by 38.6% and in fertilizers applied (10.1% in the total mass, 10.6% in N, 7.6% in P2O5 & 47.6% in K2O).

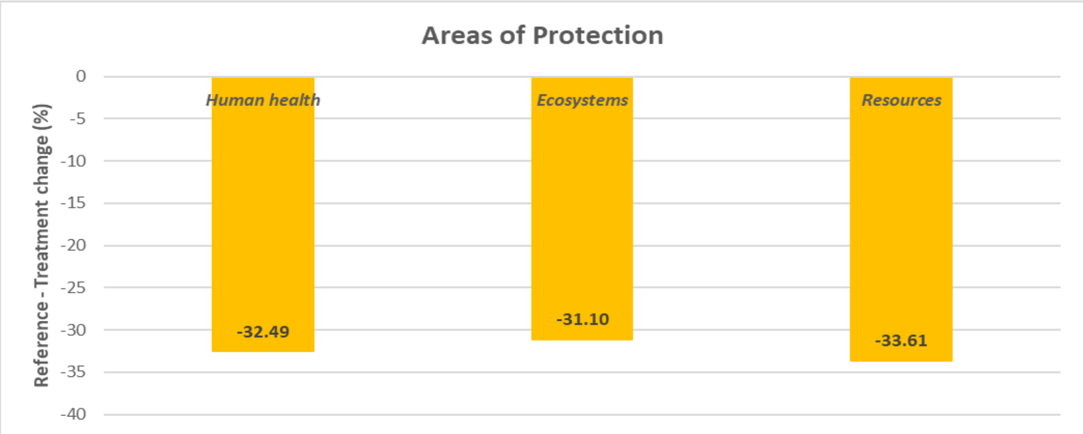

Figure 3.34. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

In regard to the major process contributors to each impact, in the case of Pieria 2021 (as an average between reference and treatment areas), the results indicate that:

- fertilizers contribute the most in two out of the 18 midpoint impacts, particularly in the case of Stratospheric ozone depletion and Mineral resource scarcity, for which it contributes by more than 90%.
- Irrigation influences all other impacts as the major contributor.

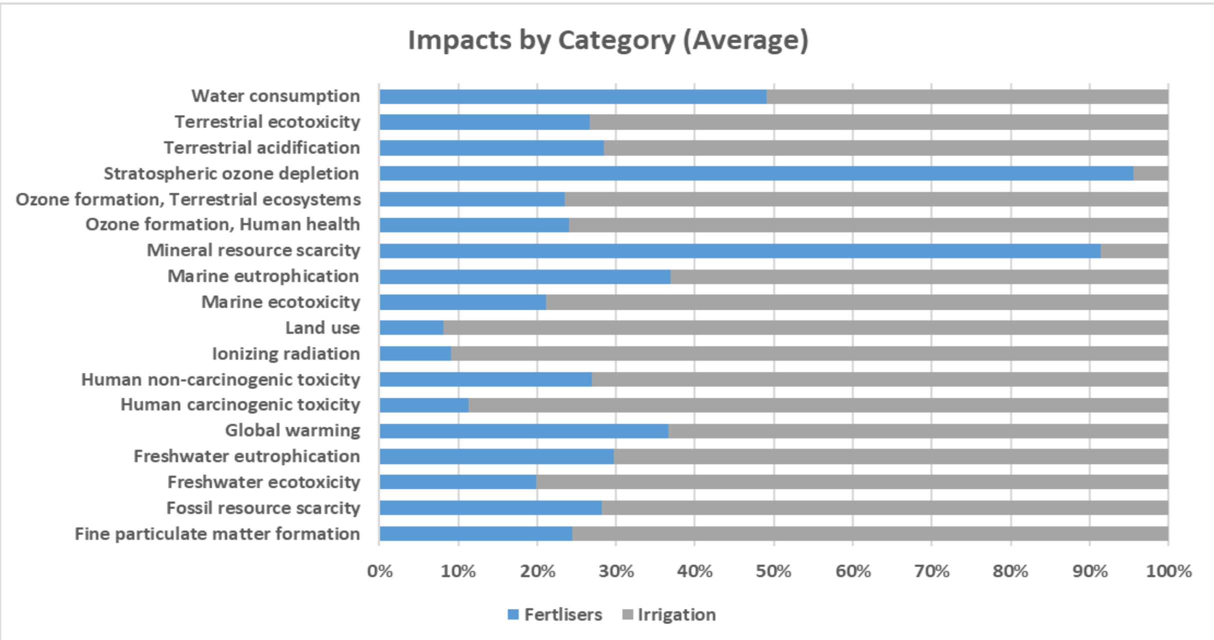

Figure 3.35. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.4.3. Velventos (Peach)

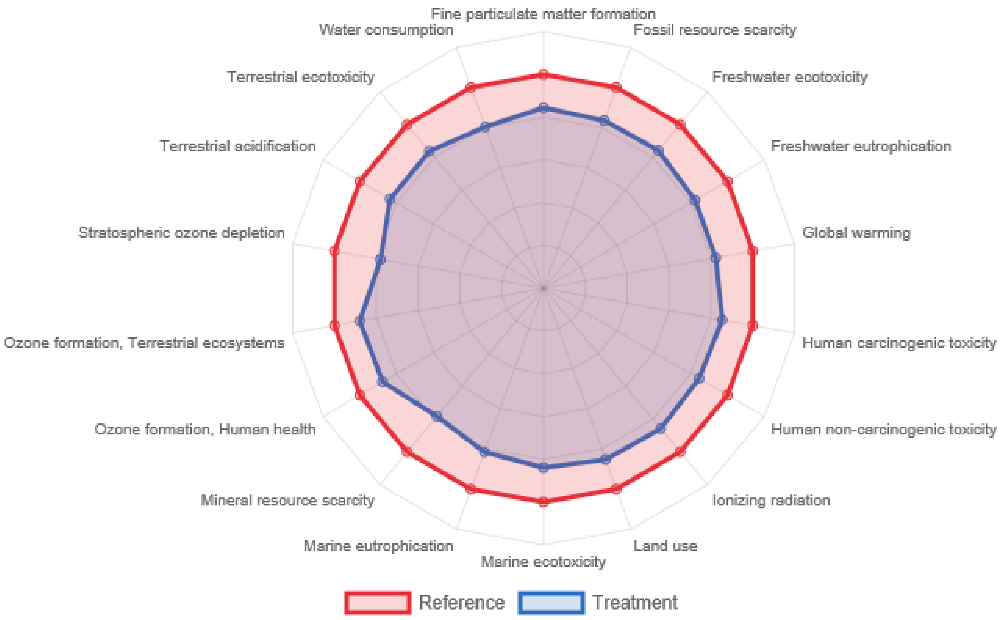

Figure 3.36. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For Velventos 2021 (peach crop), the results regarding the comparison of the magnitude of impacts between the reference and treatment areas indicate that:

- significant reductions are observed in all impacts, with the smallest reduction in Ozone formation (~12%) and the biggest in Stratospheric ozone depletion (22%).
- Thus, significant reductions in all three Areas of Protection endpoint impacts are observed, within a range from 16.37% in Human health to 17.75% in Resources.
- The reductions in the magnitude of the midpoint and endpoint impacts are attributed to respective reductions in: irrigation by 12.5% and in fertilizers applied (22.2% in the total mass, as well as in N, P2O5 & K2O respectively).

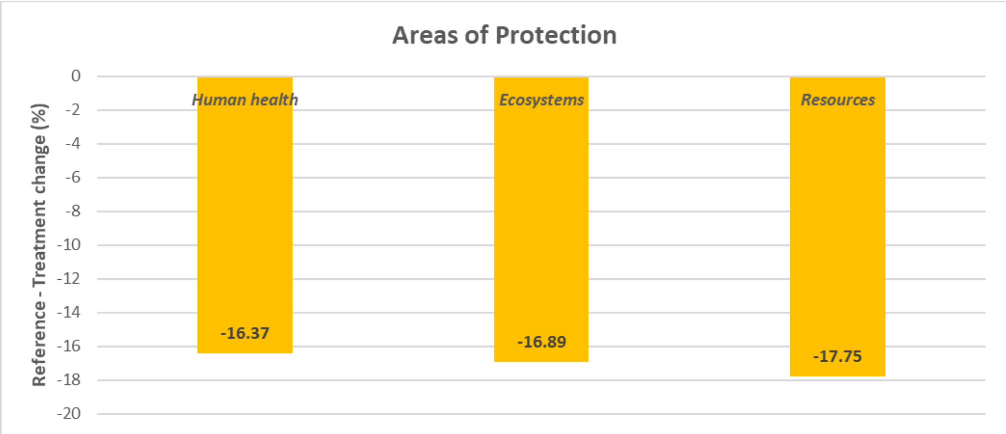

Figure 3.37. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

As for the major process contributors to each impact, in the case of Velventos 2021 (as an average between reference and treatment areas), the results indicate that:

- fertilizers' life cycle is the main contributor particularly in Stratospheric ozone depletion, Mineral resource scarcity, Water consumption, Marine eutrophication, Freshwater eutrophication and Global warming.
- Irrigation influences all other impacts as the major contributor (except Terrestrial acidification, in which fertilizers share the same contribution level).

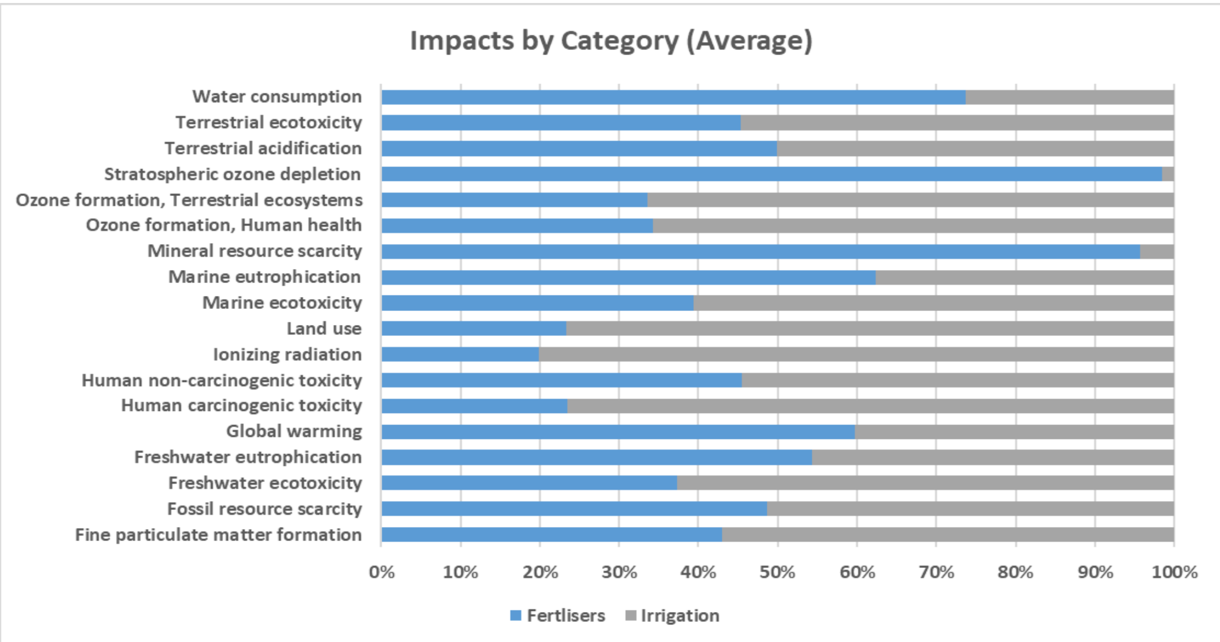

Figure 3.38. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.4.4. Elassona (Walnut)

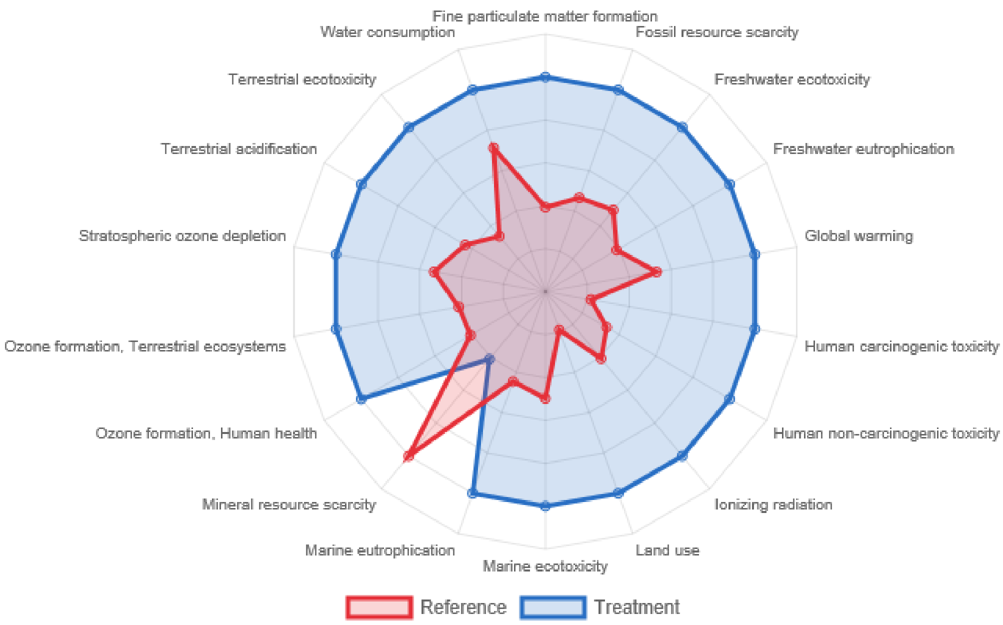

Figure 3.39. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For Elassona 2021 (walnut crop), the results of comparing the magnitude of impacts between the reference and treatment areas indicate that:

- there was only in one impact a noticed decrease (in Mineral resource depletion, by 58.9%). In all other impacts, increases were calculated.

- Thus, in all three Areas of Protection endpoint impacts there have been only increases calculated, as shown in Fig. 3.40.
- These changes in the magnitude of the midpoint and endpoint impacts are attributed to the following: increase in irrigation by 112.4%, decrease in the total amount of fertilizers by 10%, but an increase in N by 87%. Also, no P2O5 and K2O fertilizers were applied in the reference area, however, some quantities were used in the treatment areas.

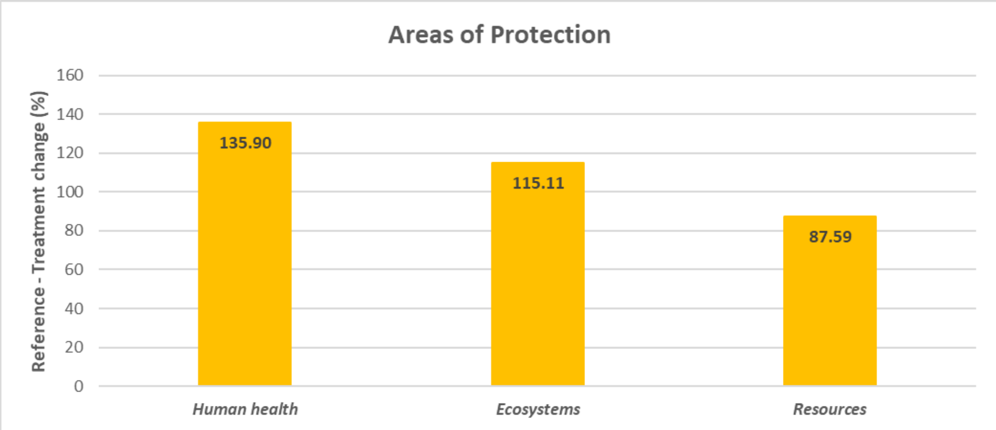

Figure 3.40. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

Regarding the major process contributors to each impact, in the case of Elassona 2021 (as an average between reference and treatment areas), the results show that:

- fertilizers mainly contribute in two out of the 18 midpoint impacts, particularly in Stratospheric ozone depletion (almost 100%) and Mineral resource scarcity.
- Irrigation influences all other impacts as the major contributor. Only in Water consumption, irrigation's and fertilizers' life cycles have almost the same impact share.

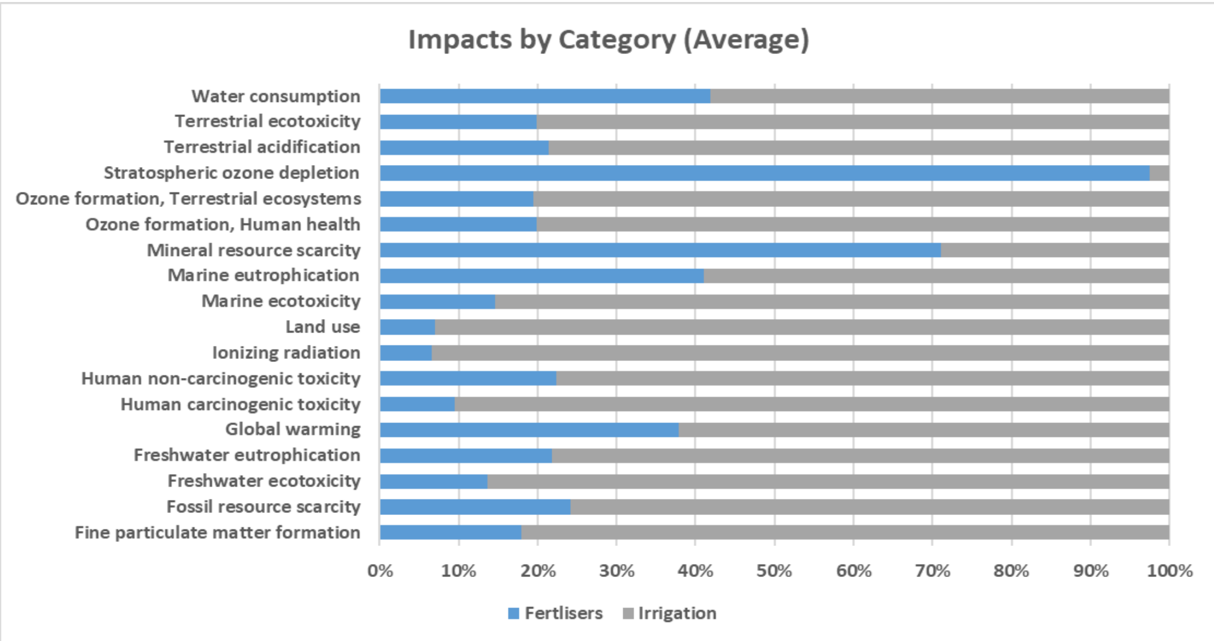

Figure 3.41. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.5. Aigina (Pistachio)

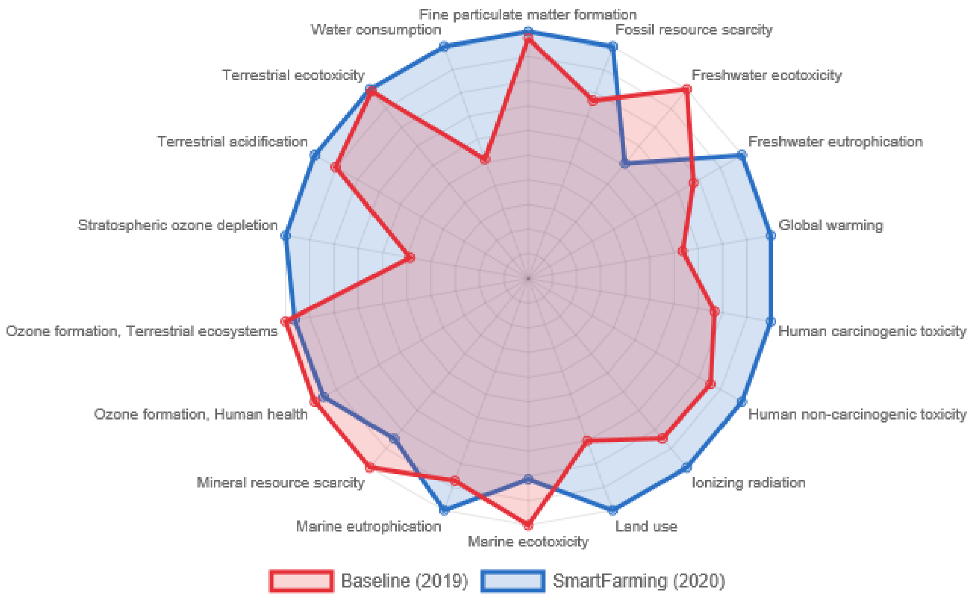

Figure 3.42. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

For a more integrated approach, and in order to conduct an LCA study of comparing also a specific crop field between its baseline and a SF year, one for each country (see also §3.6 & 3.7), one field of Aigina pilot area (pistachio crop) was chosen for this analysis, indicatively for Greece. More particularly, the LCA results of the field were compared for 2019 (baseline year) and 2020 (1^{st} SF year). The results of comparing the magnitude of impacts between the two years indicate that:

- there was a noticed increase in the majority of the impacts between 2019 and 2020, apart from Freshwater/Marine ecotoxicity and Mineral resource scarcity, for which significant reductions are achieved. Ozone formation, Terrestrial ecotoxicity and Fine particulate matter formation remained at similar levels.

- As a result, in all three Areas of Protection endpoint impacts, significant increases were calculated, as shown in Fig. 3.43.
- These changes in the magnitude of the midpoint and endpoint impacts could be attributed to a change in inputs, as follows: decrease in pesticides by 46.7%, increase in the total amount of fertilizers by 76.5%, with an increase in N by 110.7%. The applied amounts of P2O5 and K2O fertilizers have not changed. It should be noted at this point, that input changes in the case of Aigina, Vina Costeira and Confagri (for which the LCA results from two years are compared, instead of results between reference and treatment areas) may not relate to the SF solution, but may have been caused due to other reasons, including different meteorological and soil conditions in the field between the two years.

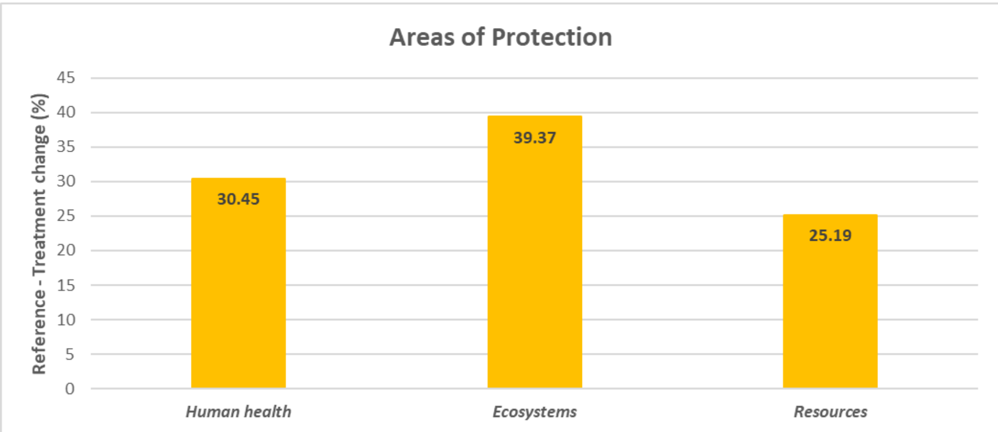

Figure 3.43. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

Regarding the major process contributors to each impact, in the case of Aigina (as an average between 2019 and 2020), the results show that:

- fertilizers appear as the main contributors in the majority of the impacts, particularly in Water consumption, Stratospheric ozone depletion, Land use and Global warming
- pesticides mainly influence Freshwater and Marine ecotoxicity and Mineral resource scarcity
- irrigation does not contribute to the impacts, as the farmer of the studied field in Aigina did not apply irrigation during the two years compared.

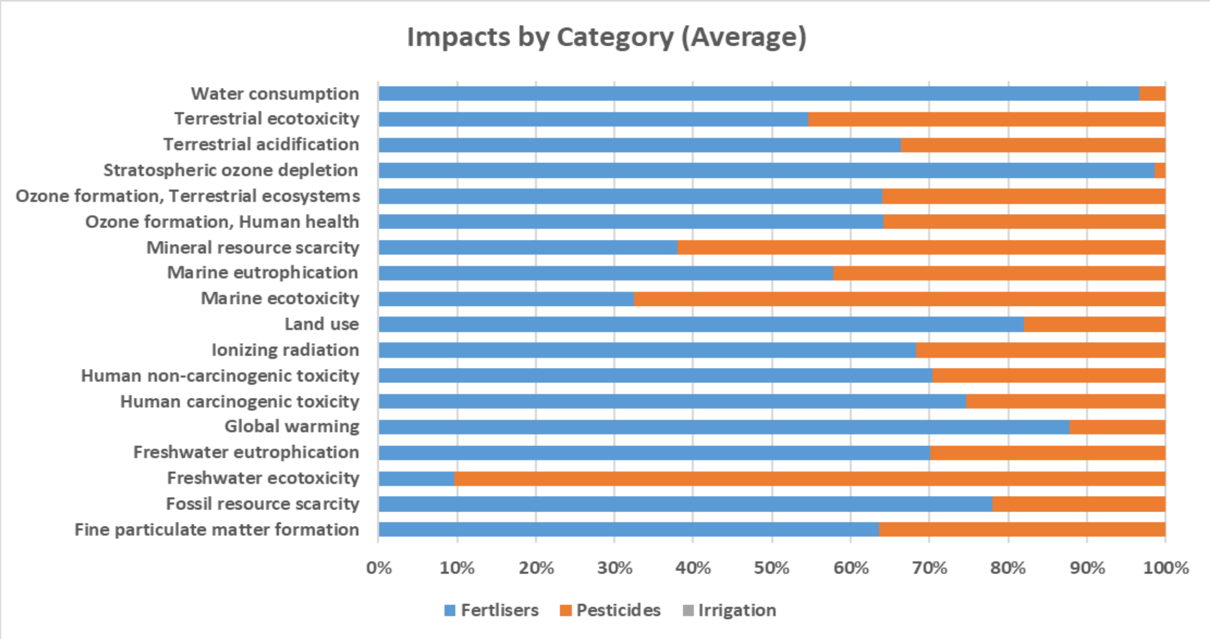

Figure 3.44. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.6. VINA COSTEIRA (Grape)

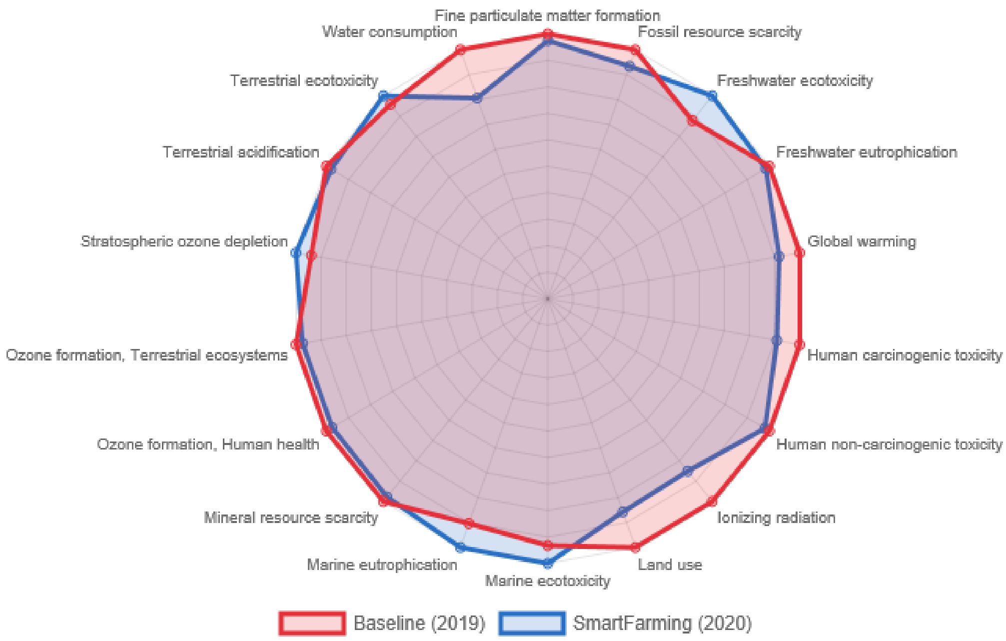

Figure 3.45. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

Similarly to Aigina, for the case of Vina Costeira in Spain (wine grape crop), the comparison between conventional practice and SF was based on results from the same field for 2019, which was the baseline year, and for 2020, which was the SF solution application year (as an indicative SF year). As explained above, for Spain (Vina Costeira), because no field sample analysis and environmental simulation modeling took place, no other LCA study could additionally be carried out (between reference and treatment areas). The results of comparing the magnitude of impacts between the two years indicate that:

- there was a noticed decrease in the majority of the impacts between 2019 and 2020, apart from Freshwater/Marine ecotoxicity and Marine eutrophication, for which small increases were observed. More significant reductions were achieved in the case of Water consumption, Land use and Ionizing radiation.
- As a result, in all three Areas of Protection endpoint impacts, small reductions were calculated, as shown in Fig. 3.46.
- These changes in the magnitude of the midpoint and endpoint impacts could be attributed to a change in inputs, as follows: decrease in irrigation by 25.1%, decrease in pesticides by 16.6%, reduction in the total amount of fertilizers by 15.5%, with a decrease in N by 28.6%, in P2O5 by 35% and in K2Oby 36.2%. It should be noted at this point, that, as explained in the case of Aigina, input changes may not relate to the SF solution, but may have been caused due to other reasons, including different meteorological and soil conditions in the field between the two years.

Figure 3.46. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

Regarding the major process contributors to each impact, in the case of Vina Costeira (as an average between 2019 and 2020), the results show that:

- Pesticides appear as the main contributors in most of the impacts, particularly in Freshwater, Marine and Terrestrial ecotoxicity, Stratospheric ozone depletion and Marine eutrophication
- irrigation mainly influences Water consumption, Land use and Ionizing radiation
- fertilizers play the smallest role in all impacts examined.

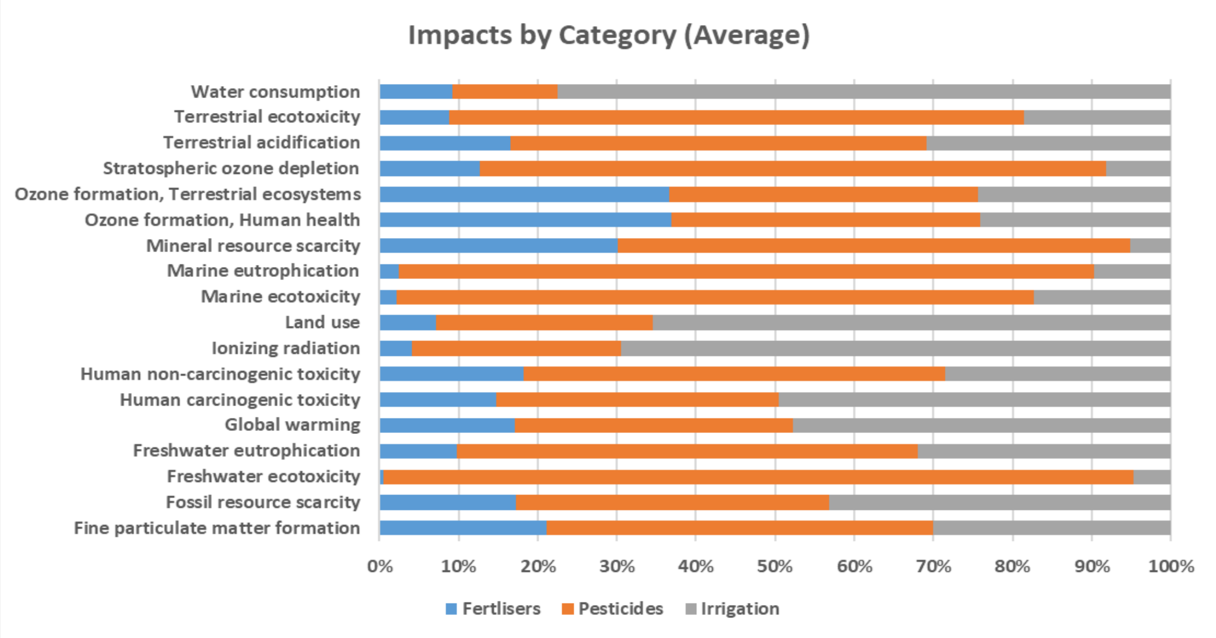

Figure 3.47. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.7. CONFAGRI (Olive)

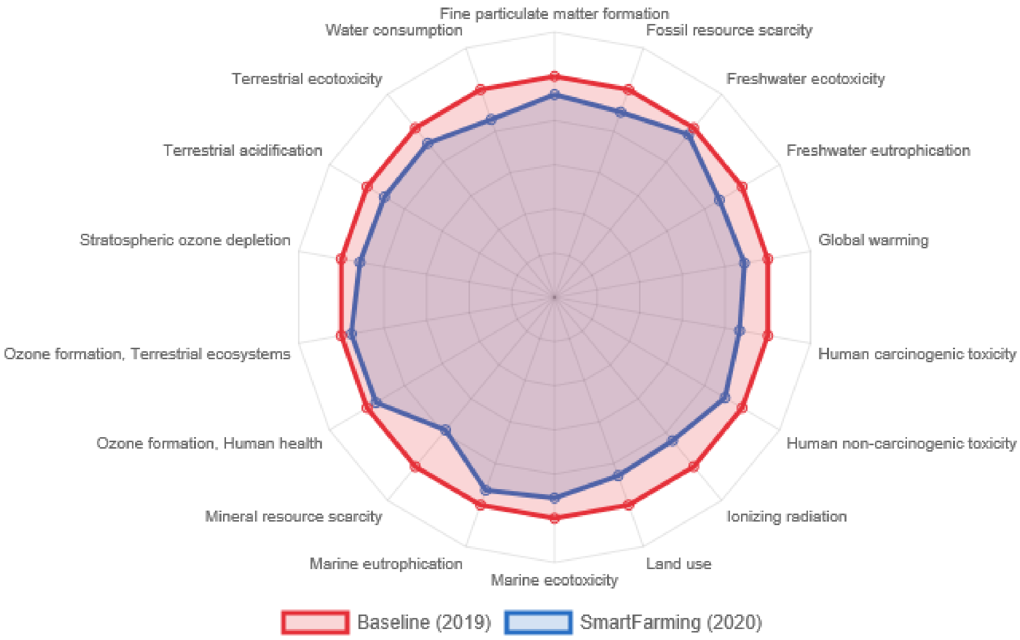

Figure 3.48. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas

Similarly to Aigina and Vina Costeira, for the case of Confagri in Portugal (olive crop), the comparison between conventional practice and SF was based on results from the same field for 2019, which was the baseline year, and for 2020, which was the SF solution application year (as an indicative SF year). As explained above, for Portugal (Confagri), because no field sample analysis and environmental simulation modeling took place, no other LCA study could additionally be carried out (between reference and treatment areas). The results of comparing the magnitude of impacts between the two years indicate that:

- a decrease is shown (Fig. 3.48) in all the impacts between 2019 and 2020. More significant reductions were achieved in the case of Mineral resource scarcity, Ionizing radiation and Water consumption.
- As a result, in all three Areas of Protection endpoint impacts, small reductions ranging from 9.81% (Human health) up to 11.68% (Resources) were calculated, as shown in Fig. 3.49.
- These changes in the magnitude of the midpoint and endpoint impacts could be attributed to the reported reduction in inputs, as follows: decrease in irrigation by 20.2%, reduction in the total amount of fertilizers by 14.5%, with a decrease in N by 8.9% and in K2O by 22.5%. It should be noted at this point, that, as explained in the case of Aigina and Vina Costeira, input changes may not relate to the SF solution, but may have been caused due to other reasons, including different meteorological and soil conditions in the field between the two years.

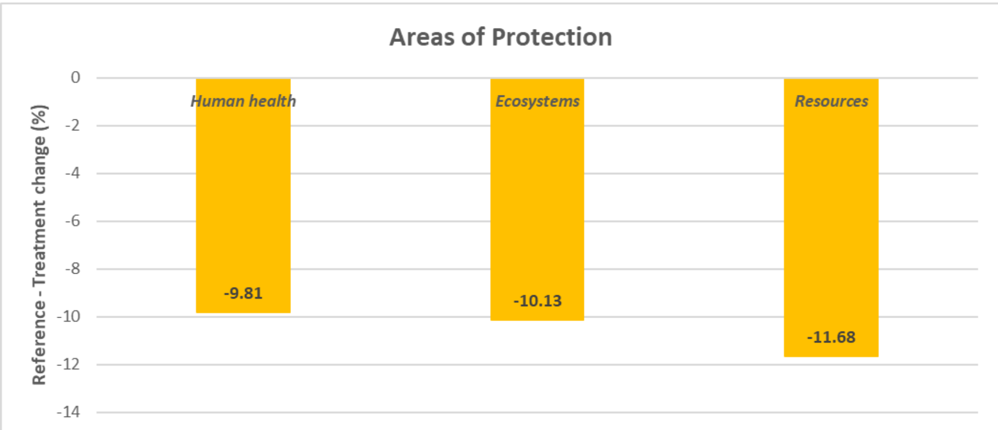

Figure 3.49. Relative % change in the three endpoint Areas of Protection (Human health, Ecosystems, Resources) between the reference and treatment areas

Regarding the major process contributors to each impact, in the case of Confagri (as an average between 2019 and 2020), the results show that:

- fertilizers appear as the main contributors in most of the impacts, particularly in Stratospheric ozone depletion, Mineral resource scarcity and Ozone formation
- irrigation mainly influences Land use and Ionizing radiation
- pesticides are the main contributors in Freshwater ecotoxicity and play an important role in Marine eutrophication and Marine ecotoxicity.

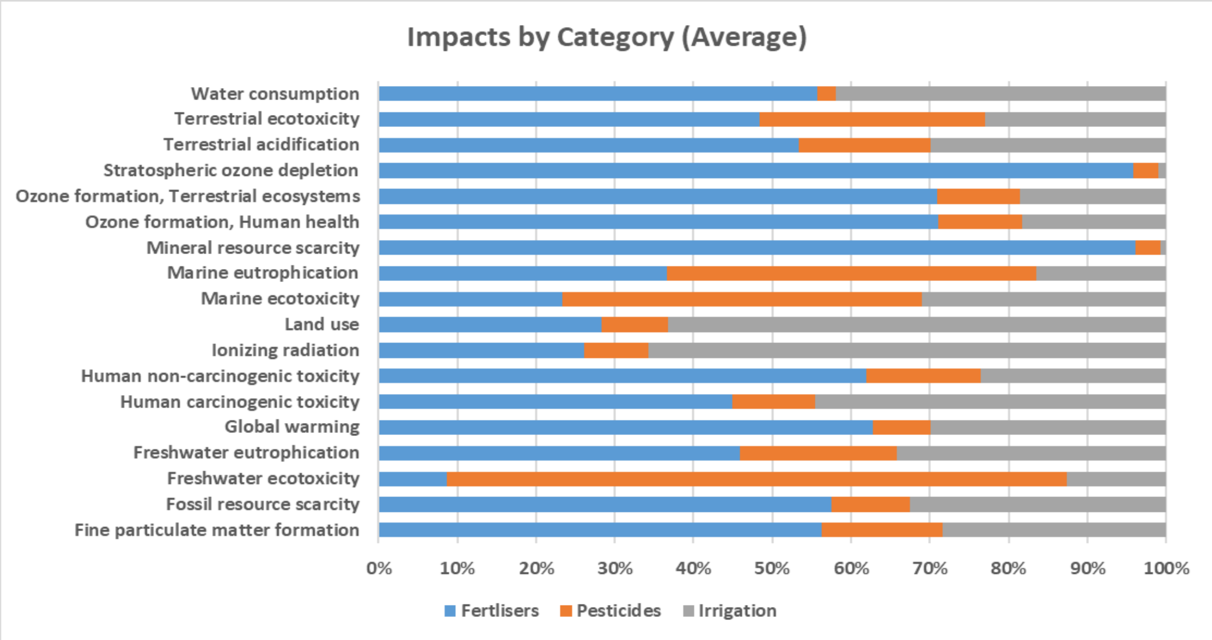

Figure 3.50. Average (reference-treatment) percentage contribution of the three main agricultural processes (life cycle of Fertilizers, Irrigation) to each of the 18 midpoint impacts

3.8. Sensitivity analysis

3.8.1. Best case scenario

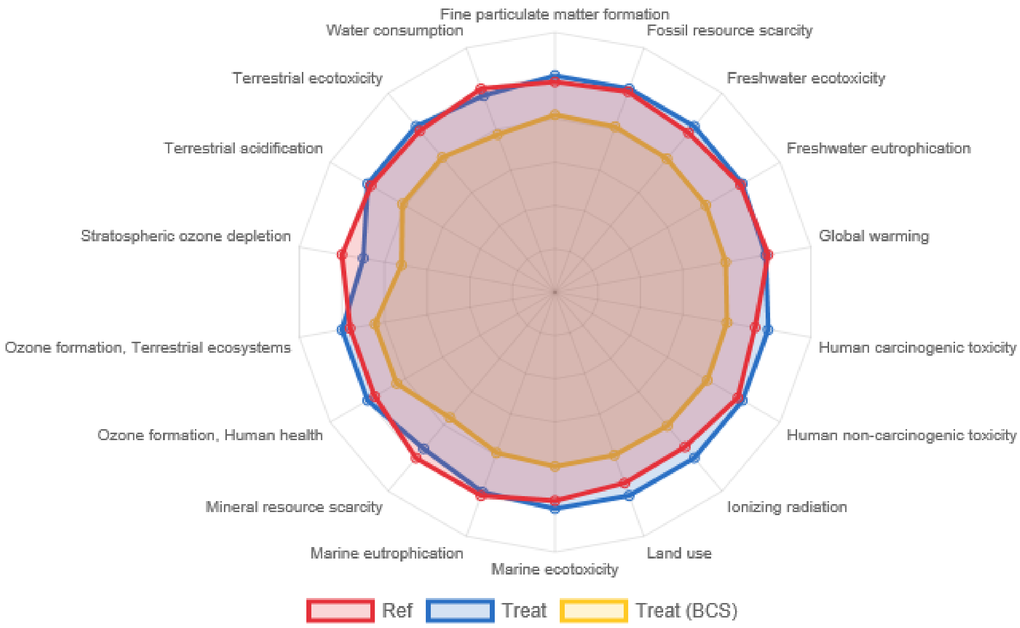

Figure 3.51. Relative % difference in the magnitude of the 18 midpoint impacts between the reference, treatment and treatment (BCS) areas

Additionally, a sensitivity analysis was undertaken, in order to compare the results of the efficiency of the SF solution as applied and the SF solution ideally implemented, according to pre-defined input targets. For this purpose, the results from Lasithi 2021 (as an indicative crop field and year, also considering that no significant changes between reference and treatment areas were recorded) regarding the change in impacts between the reference and treatment areas were examined in relation to the change in impacts between the reference and a best-case scenario (BCS) treatment area, in which the SF advice is ideally followed. In the best-case treatment area, target input reductions are estimated on the basis of the particular characteristics of each field, including the crop type and its geographical location, microclimate and soil conditions. For Lasithi, the targeted reductions for irrigation, as well as fertilizing, were 20% each. The 20% reduction in the total amount of fertilizers applied encompasses a 20% reduction in each of the different fertilizer types, N, P2O5 and K2O.

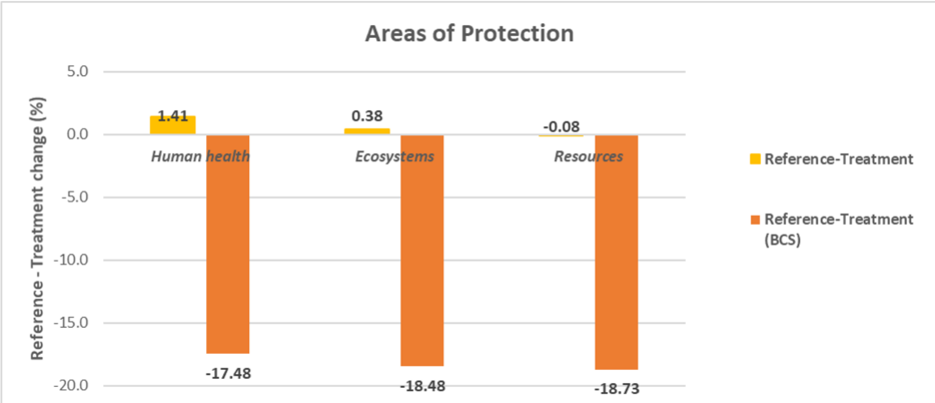

Figure 3.52. Relative % change in the three endpoint Areas of Protection between the reference, treatment and treatment (BCS) areas

As shown in figures 3.51 and 3.52, the application of the BCS in the treatment area resulted in a reduction of both midpoint and endpoint impacts by almost 20%, compared to the case of the treatment area. More particularly,

- significant decreases by almost 20% are shown in all midpoint impacts, while in the real treatment area in 2021, small changes (of no significant magnitude) were noticed, due to the small recorded changes in fertilization (decreases) and irrigation (increase) (see paragraph 3.3.2).
- Subsequently, in all three Areas of Protection, reductions ranging from 18.63% (Human health) up to 18.79% (Ecosystems) were calculated, as shown, while in the real treatment case, insignificant increases in the range of 0.38% to 1.41% were estimated in the Human health and ecosystems Areas of Protection respectively, whereas a slight decrease of 0.08% in Resources was computed.

In the LCA study, it is assumed that changes in impacts between the reference and treatment areas are caused by recorded changes in inputs, as other parameters influencing the crop yield are considered to be the same (meteorological and soil conditions). Therefore, the efficiency of the SF solution in terms of reducing environmental impacts depends exclusively on the degree of adoption of the SF advice by the farmers. In this frame, the sensitivity analysis indicates the sustainability advantage of the SF solution, in case it is adopted by farmers according to the advice offered by the system (BCS).

3.8.2. Yield based Functional Unit

In the frame of the LCA study, a sensitivity analysis based on changing the functional unit (FU) was implemented, in order to present a socio-economic (not strictly environmental) interpretation of the LCA results. In this case, the outcome would be more relevant for the farmers to facilitate decision making. In other words, environmental efficiency of yield (FU: kg of yield) in comparison to farm impact intensity (FU: ha of cultivated land) is studied. For this purpose, the case study of Elassona in 2021 was selected as an indicative crop field and year, taking also into consideration that for the specific field, increases in the environmental impacts were calculated by setting ''1hectare'' as a FU. In the particular pilot case, the yield in the reference area was 650 kg, while the yield in the treatment area was 2000 kg.

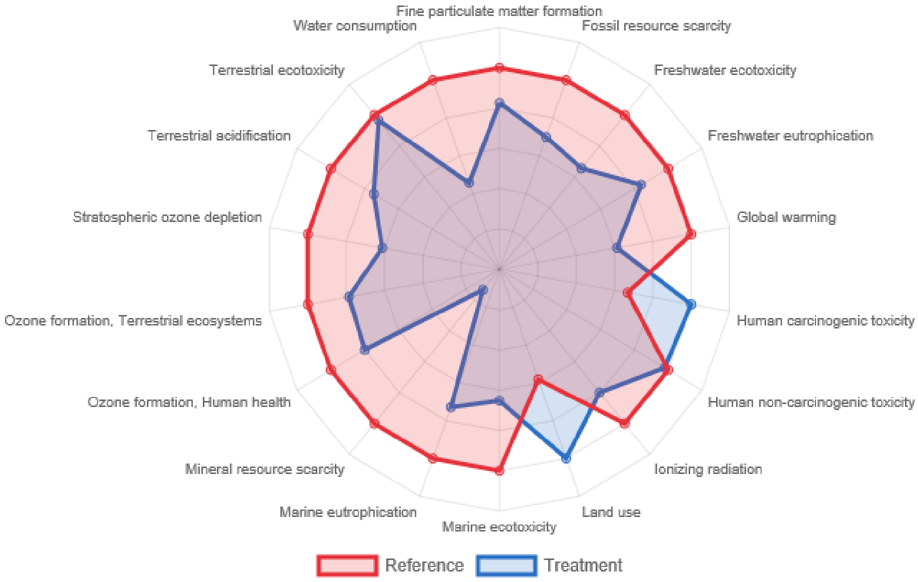

Figure 3.53. Relative % difference in the magnitude of the 18 midpoint impacts between the reference and treatment areas (walnut yield as functional unit)

As observed in Fig. 3.53, changing the FU from land based to yield based resulted in a significant reduction in the majority of the midpoint impacts (except Land use and Human carcinogenic toxicity) for the treatment area, in which the yield was increased (as it can be noted by comparing Figure 3.39 and 3.53).

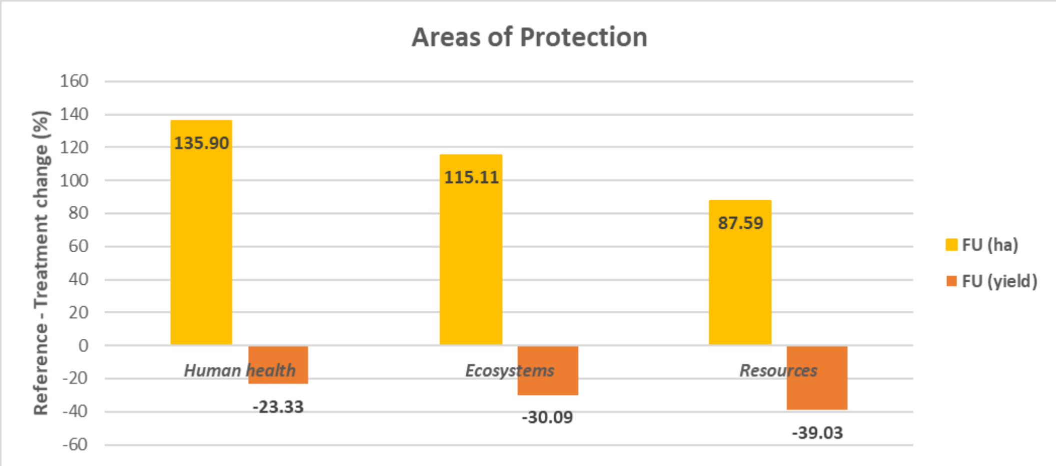

Figure 3.54. Relative % change in the three endpoint Areas of Protection between the reference and treatment areas (comparing ''ha'' and ''yield'' as FUs)

Subsequently, the results of alternating the FU are also expressed in all three endpoint Areas of Protection, for which large increases in the impacts in the range between 87.59% and 135.90% were calculated using the ha of cultivated land as FU, whereas significant reductions in impacts of all three Areas of Protection are achieved (within a range between 23.33% and 39.03%) when the FU is changed to take into account the increase of the yield in the treatment area.

So, by setting yield as FU to which the impacts are referring to, a different decision making context is established, in which the environmental aspects of sustainability are considered in relation to socio-economic indicators.

4 Conclusions

The present "Deliverable C1.3 Reports on Life Cycle Analysis" describes in detail the LCA methodology applied and its results on the impacts caused by Smart Farming agricultural practices compared to the impacts produced from conventional agricultural practices. In this frame, the LCA study aims to demonstrate the comparative advantage of the SF solution in regard to its sustainability potential and facilitate decision making. For this purpose, the openLCA software v.1.11.0 was used, in combination with the AGRIBALYSEv.3.0.1 database on agricultural processes and the ReCiPe20016 Midpoint-Endpoint (H) LCIA method. Primary input data on fertilization, pesticide application, irrigation and field processes were derived from field calendars regarding the pilot areas that a reference-treatment LCA-results comparison was applied.

The results show the potential environmental benefit of the SF solution. In particular, figures 4.1 and 4.2 demonstrate the weighted endpoint impacts for the reference and treatment areas for the years 2020 and 2021, respectively.

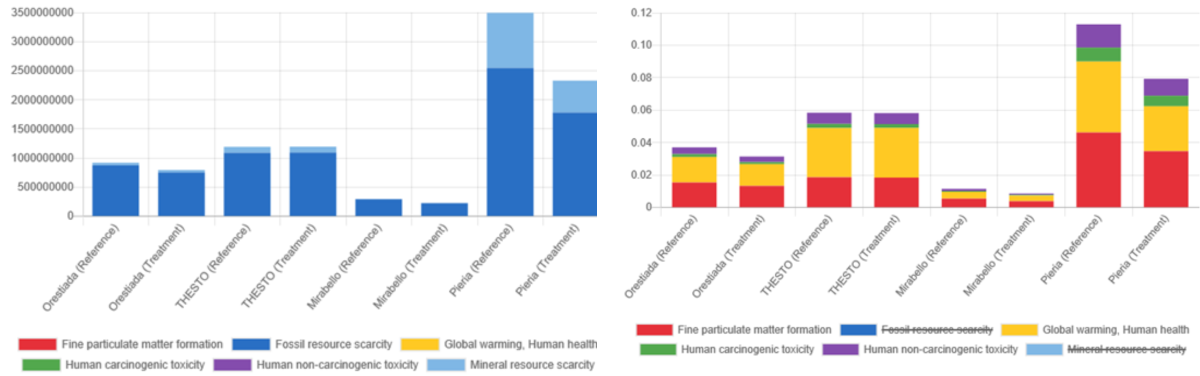

Figure 4.1. Impact assessment comparison between the reference and treatment areas for each pilot case for 2020

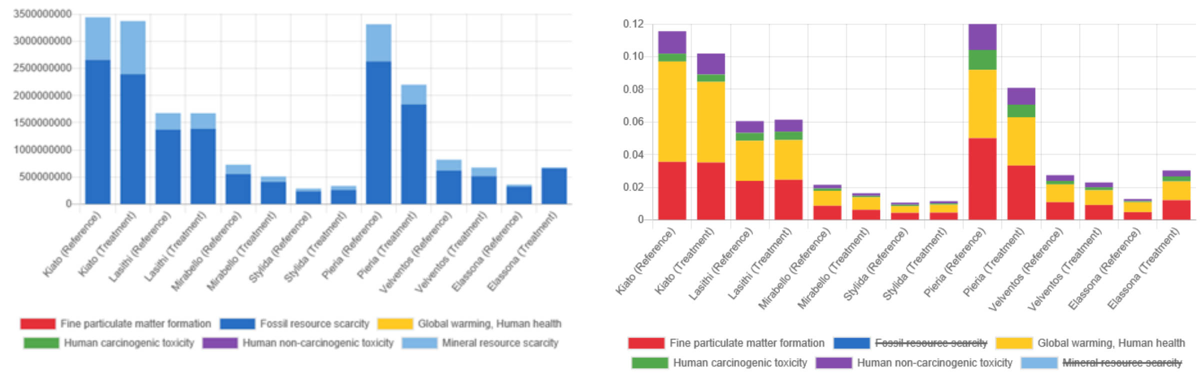

Figure 4.2. Impact assessment comparison between the reference and treatment areas for each pilot case for 2021

The figures include only the pilot areas for which a change in input data between the reference and treatment areas was reported in the calendars, as for some pilot cases, particularly for the year 2020, no differences were reported in the inputs between the reference and treatment areas. In the figures on the left, only the difference in Fossil and Mineral resource scarcity can be observed, as all other impacts are many times of magnitude lower. These two most important impact categories are omitted in the figures on the right, so that the difference between reference and treatment areas in the other impact categories can also be seen.

In the year 2020, impacts are reduced in all four pilot cases as a result of the SF solution application, with Pieria pilot case showing the highest reductions. In the year 2021, a decrease in impacts is achieved in five out of the seven pilot cases, with Pieria demonstrating the most efficient SF application. In the case of Elassona, a noted increase in impacts is noted, while in Stylida, a marginal increase in impacts is observed.

● References

RIVM, 2016. ReCiPe 2016. A harmonized life cycle impact assessment method at midpoint and endpoint level Report I: Characterization. National Institute for Public Health and the Environment, The Netherlands.

URL1: https://www.openlca.org/

URL2: https://nexus.openlca.org/databases

URL3: https://nexus.openlca.org/database/Agribalyse

URL4: https://eplca.jrc.ec.europa.eu/uploads/ILCD-Recommendation-of-methods-for-LCIA-def.pdf

ANNEX I - LCA protocol for the LIFE GAIA Sense project

QA/QC Protocol that will be used as a step-by-step guide for LCA by the Laboratory of Heat Transfer and Environmental Engineering - LHTEE (AUTH)

In order to ensure consistency and quality assurance, the LCA methodology and its individual components will be applied according to the provisions of the International Reference Life Cycle Data System (ILCD) Handbook, as a recommended guide by the European Commission to support the legitimacy of results of an LCA study.

In particular, the following work-flow structure will enable QA/QC in all phases included in LCA, in compliance with ILCD guidelines:

1. Reporting will start from the beginning of the process, and will involve documentation of all steps, decisions and assumptions made, data sources used and calculations performed.

2. Goal definition– the following six aspects will be addressed in the first phase of the LIFE GAIA Sense LCA study:

- Intended application(s) of the deliverables / results
- Limitations due to the method, assumptions, and impact coverage
- Reasons for carrying out the study and decision-context. The decision context will be classified as Situation A, B or C in line with the ILCD Handbook.
- Target audience of the deliverables / results
- Comparative studies to be disclosed to the public, to the Commissioner of the study and other influential actors

3. Scope definition– it is the LCA preparation phase in which the following items will be clearly described:

- The type(s) of the deliverable(s) of the LCA study, in line with the intend application(s)
- The system or process that is studied and its function(s), functional unit, and reference flow(s)
- Life Cycle Inventory (LCI) modelling framework (attributional or consequential modeling and allocation or system expansion / substitution approaches) and handling of multifunctional processes and products
- System boundaries, completeness requirements, and related cut-off rules. In the beginning of the LIFE GAIA Sense LCA study, the system boundaries will be precisely defined (qualitatively and quantitatively) to ensure that all relevant processes are included in the modelled system and that all relevant potential impacts of the SF solution on the environment are appropriately covered. In addition, the levels of cut-off criteria and the maximum permissible uncertainty will be determined as a key measure for the overall quality (i.e. accuracy, completeness, and precision) of the outcomes of the LCI/LCA study.
- Life Cycle Impact Assessment (LCIA) impact categories to be covered and selection of specific LCIA methods (midpoint and/or endpoint level) to be applied as well as -if included - normalization data and weighting set, in order to ensure that their selection is not done interest-driven in view of the initial results and that relevant and matching inventory data is collected. All the defined impact categories will be covered by the combination of selected LCIA methods. The selection of Impact Assessment Models and characterization factors that will be used in the LIFE GAIA Sense LCA study for impact assessment for the calculation of indicators for different impacts (including, but not limited to, climate change, ozone depletion, photochemical ozone formation, respiratory inorganics, ionizing radiation, acidification,

eutrophication, human toxicity, ecotoxicity, land use and resource depletion) will be based on the recommendations of the International Reference Life Cycle Data System (ILCD) Handbook-Recommendations for Life Cycle Impact Assessment in the European context (EUR 24571 EN),in line with ISO 14044:2006 requirements.

- Types, quality and sources of required LCI data and information, and here especially the required precision criteria regarding technological, geographical and time-related representativeness sand appropriateness and maximum permitted uncertainties. At this stage, data quality needs will be defined, and the overall data quality level attained will be documented in the data set as "High quality", "Basic quality", or "Data estimate", in compliance with the ILCD Handbook categories.
- Special requirements for comparisons between systems
- Planning reporting of the results

4. Life Cycle Inventory preparatory work - identify processes within system boundary and planning of data collection

5. Perform a first, rough life cycle inventory system model, its impact assessment calculation, and analysis helps in identifying these "key" processes, parameters, elementary flows, assumptions, LCIA characterization factors, etc. that largely contribute to or influence the environmental impacts of the analyzed process or system.

- Compile initially available LCI data for all processes identified in the LCA preparation stage, on the basis of decisions taken in regard to (a) Foreground system -specific, average, or generic data, (b) Background data for attributional and consequential modelling, (c) Need for multi-annual average data or generic data and (d) Primary and secondary data sources.
- Develop initial life cycle model
- Calculate initial LCI results - the inventory of each process will be scaled in order to relate to the functional unit(s) and/or reference flow(s) of the system, and then the correctly scaled inventories of all processes within the system boundary will be aggregated.
- Calculate initial LCIA results - based on classification and characterization of the individual elementary flows, the LCIA results will be calculated by multiplying the individual inventory data of the LCI results with the characterization factors.
- Significant issues – the results from the first LCA attempt will be analyzed in order to identify significant issues in relation to (a) the main contributors to the LCIA results will be identified via a contribution analysis, i.e. the most relevant life cycle stages, processes and elementary flows, and the most relevant impact categories, as they are important for the overall interpretation of the LCI/LCA study and for eventual recommendations and (b) the main choices (methods, decisions, assumptions, criteria, data) that have the potential to influence the precision of the final results of the LCA will be examined by running the different possible choices as scenarios and comparing the scenario results.
- Sensitivity, completeness and consistency check. A pre-requisite for the completeness check is to define how the 100% value of the "complete" inventory and impact is to be approximated, i.e. what is the 100% of the flows in terms of chemical elements, energy content and costs, and of the inventory's overall environmental impact. In the completeness check, process and elementary flow coverage will be addressed on the basis of operationalization of the cut-off approximation. The sensitivity check will be done by joint scenario analysis and could be accompanied by an uncertainty calculation (e.g. Monte-Carlo Simulation). The influence of data uncertainty for key issues will also be checked by allowing the data and parameters to vary within the limits given by the uncertainty estimates while modelling the system and

comparing the results. The focus point for improvement of data quality via the sensitivity check will be data with both a strong influence on the overall results and a high uncertainty.

6. Second iteration–An iterative approach will be implemented, in order to gradually accomplish the completeness, accuracy and consistency required by the study. The iterative approach is an integral part of ILCD compliance, in line with ISO 14044:2006. The insights of the interpretation / quality checks of the first LCA attempt will be used to increase the overall quality of the LCI model

- Goal and scope revision needed?
- Improve key and other LCI data
- Improve method and assumption related data and information
- Improve LCIA factors
- Calculate LCIA results and perform again a completeness, sensitivity and consistency check

7. Examine the need of more iterations (two – four iterations are recommended)

8. Results interpretation – the interpretation of the results will be closely linked to the goal defined in the very beginning of the study and respect the limitations that the scoping puts on the validity domain of the results.

9. Deliverable including study report and review report

The cross-cutting QA/QC procedures that will be implemented throughout the phases of the LCA study include:

a. Consistency of methods, assumptions, and data -In order to ensure the quality of the results, all assumptions will be made in a consistent way for the different parts of the analyzed system and it will be ensured that the life cycle is modelled applying the same methodological provisions and that the same elementary flow nomenclature is used throughout the whole system model and also across all compared systems in case of comparative studies. The actually achieved consistency will be checked as part of the evaluation step in the interpretation phase and will be considered in drawing conclusions and recommendations of the LCA study.

b. Reproducibility- The achieved reproducibility of a LCI/LCA study provides a qualitative assessment of its credibility and is an important item for review. In order to support a good reproducibility level, a clear guidance for the LCA work performed in the LCA LIFE GAIA Sense study will be prepared in a consistent and transparent way, and by documenting this appropriately in the deliverable report of the study. The ILCD LCA report template and LCI reference data set format will be used for this purpose, in compliance with the ILCD Handbook.

c. Data quality and availability issues - LCI data quality in the LIFE GAIA Sense LCA study will be structured on the basis of representativeness (composed of technological, geographical, and time-related), completeness (regarding impact category coverage in the inventory), precision / uncertainty (of the collected or modelled inventory data), and methodological appropriateness and consistency. During the data collection phase the following issues will be considered to ensure data quality and appropriateness:

- Avoiding black box unit processes by subdivision or virtual subdivision
- Describing what the unit process represents
- Types of input and output flows to collect
- Data and information types for specific, future and generic data sets
- Reference amount of the reference flow

- Representativeness regarding operation conditions
- Checking legal limits
- From raw data to unit process inventory per reference flow
- Solving confidentiality issues
- Interim quality control
- Dealing with missing inventory data: Especially for missing environmental impact data, LCI data sets of similar goods or services will be used in this case or average LCI data sets of the group to which the agricultural products/processes examined belong.

ANNEX II - Assumptions in LCA inventory

1) Fertilizers

- For each fertilizer, only the production of its N, P2O5 & K2O mass-portion was imported in the LCI, as average mineral fertilizers of each kind. Production of other fertilizer components was ignored (see Table 154 in ''AGRIBALYSE: METHODOLOGY Version 1.3'', as an example).
- In packaging processes, the total weight of each fertilizer was taken into account, as well as its type (solid or liquid).
- The application methods of the fertilizers were taken into account. In more detail:
  - Soil fertilization in tomato, potato and cotton (annual crops) was assumed to have been applied by a 2500l spreader, with an operation time of 0.12h/ha per application. On the other hand, fertilizing leaves was assumed to have been applied by a 2500l sprayer (operation time = 0.08h/ha per application).
  - Soil fertilization in olive, kiwi, peach, walnut and pistachio (permanent crops) was assumed to have been applied by a 500l spreader, with an operation time of 0.5h/ha per application. Fertilizing leaves was assumed to have been applied by a 500l broadcaster (operation time = 1h/ha per application).
  - Soil fertilization in vineyards (permanent crop) was assumed to have been applied by a 8-10t spreader, with an operation time of 0.75h/ha per application. On the other hand, fertilizing leaves was assumed to have been applied by a 2000l atomizer/sprayer (operation time = 1h/ha per application).
- Fertilizing organic manure was not imported in the LCI. Only inorganic fertilization was taken into account.

2) Pesticides

- The pesticides production process imported in the LCI from AGRIBALYSE database could not take into account the specific chemicals recorded in the calendars, so it referred to an unspecified, meaning, an average among various pesticides.
- As for packaging, all pesticides were assumed to be of a solid type.
- Regarding application, all emissions from pesticides (not specific to any particular pesticide) were assumed to be 100% to soil, with a 2500l sprayer for annual crops (operation time = 0.08h/ha per application) and with an 400l atomizer for the permanent ones (operation time = 1h/ha per application.

3) Irrigation

- All processes of water pumping (drip or sprinkler irrigation systems) were assumed to be powered by electricity.
- ''Reel/ramp'', ''Reel/sprinklers'', ''Micro-sprinklers'', ''Steady sprinklers'' irrigation methods (as reported in the field calendars) were set as sprinkler irrigation in the LCI.
- ''Drippers (surface)'' irrigation method (as reported in the field calendars) weas set as drip irrigation in the LCI.

4) Machinery (other activities)

- It was assumed that:
  - ploughing was done with a 5 or 6 soc plough (operation time = 1.33h/ha),
  - harrowing was done with a rotary tiller (operation time = 2.5h/ha),
  - hoeing was done with a 4-6m hoe (operation time = 0.33h/ha),
  - the operation time of direct seeding was 0.42h/ha,
  - the operation time of weeding with a mower was 0.9h/ha,

- the operation time of crushing wood with a shredder was 2h/ha,
- harvesting cotton was done with a 4 row harvester (assuming that a harvester is a cotton picker, in this case), having an operation time of 0.875h/ha, considering that a single row harvester makes 3.5h/ha (https://www.fao.org/americas/noticias/ver/en/c/1287985/). In the inventory, 1.75h/ha of harvesting were imported, considering the double operation of the harvester in order to harvest completely one hectare. As for all other crops, all the harvesting operations recorded in the calendars separately were considered as one operation in the LCI, in terms of the total time spent to make a complete harvest of 1hectare,
- lifting potatoes was done with a complete harvester (operation time = 2h/ha),
- harvesting tomatoes (8h/ha), peach (3h/ha), grapes (2.14h/ha), kiwi (assuming the same operation time as peach harvesting), was done by man (not with various harvesting machines), making use of an assistance tractor with trailer,
- harvesting olives, pistachio and walnut was done by a shaker machine, with an operation time of 1h/ha for all 3 crops.

5) Other assumptions:

- The vineyards of VINA COSTEIRA were assumed to be of closely planted vines in the LCI.
- Processes for seeds or seedlings could only imported for cotton and tomato. In more detail, a ‘’market for cotton seed’’ process was included in both Orestiada & THESGI pilot areas for 2020, while a ‘’market for tomato seedlings’’ process was included in both Kiato & THESTO pilot areas for 2020. For 2021, no seed/seedlings processes were included, as sowing processes were not recorded in the calendars.
- Moreover, soil and crop management operations that were recorded in 2020 and not in 2021, but one could easily assume that they would have been implemented, were not imported in the LCI, sticking only to those written in the calendars.