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LCA of Applying a Smart Farming System – Implementing a Territorial Approach for Recommending Good Agricultural Practices

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Abstract. This study is part of the LIFE GAIA Sense project, aiming to evaluate the environmental efficiency of Smart Farming (SF) through LCA and to produce recommendations for good agricultural practices. Thus, the environmental performance of SF treatment, specifically regarding fertilizers/pesticides application and irrigation, is compared to that of conventional agricultural management, under similar soil and climatic field conditions. According to the goal and scope of the study, a cradle-to-field gate approach was selected, while the inventory was built with data recorded in crop logbooks and questionnaires distributed to farmers, containing details about field activities. The impact analysis results reveal the environmental benefit of the SF-based management approach in relation to resource use, ecosystem and human health protection, in most of the field cases examined. Based on single score calculations with the ReCiPe 2016 (H) impact method, the results strongly suggest fossil and mineral resource scarcity as the most essential impacts to be considered, mainly decreased for the SF fields. Moreover, a territorial approach for introducing regionalization in the application of LCA on agricultural systems is conducted. Finally, good practice recommendations are suggested to facilitate decision making, considering foreground and background system processes.

Keywords: life cycle assessment, air quality management, environmental management, sustainable agriculture, smart farming

1. Introduction

1.1. Sustainable agriculture and smart farming

Nowadays, sustainability in agriculture is a field under development with great challenges, but also considerable opportunities and perspectives. Through the agricultural sector, a range of environmental and socio-economic impact-fields is affected significantly (Figure 1). Among others, air quality (Fragkou et al., 2023), resource scarcity, land degradation, as well as livelihood standards (S. F. Ahmad et al., 2020) are of excessive importance and greatly influenced.

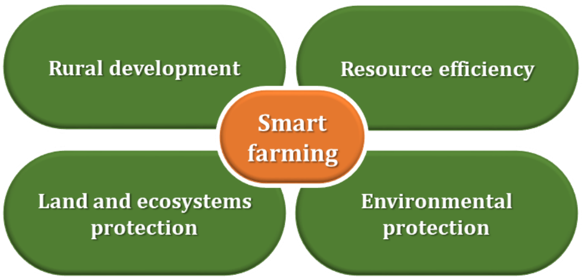

Figure 1. Targets of smart farming

SF is a state-of-the art data-driven practice and as a technological tool, its main target is to lessen all field-inputs (agrochemicals and water) by optimizing their use and thus, support sustainability. More specifically, it can contribute to mitigation of various agriculture related impacts, while promoting the economic prosperity of rural communities through achieving higher yields by accomplishing less expenses for the farmers (Lieder et al., 2021).

1.2. LIFE GAIA SENSE project

In this frame, the LIFE GAIA Sense project (URL1) aims at promoting resource efficiency and moderating environmental impacts, while enchancing yield through the implementation of the respective SF system, which offers precise advice on irrigation and fertilization/pesticides application. Individual farmers, cooperatives and companies across Greece, Spain, and Portugal participated in the project, through a number of demonstration pilot cases.

2. LCA methodology

Life Cycle Assessment (LCA) was used according to the provisions of ISO 14040:2006 [URL2] for assessing the environmental performance of SF, as well as to make suggestions for environment-oriented agricultural practices, based on the study's results.

2.1. LCA phases

Based on the goal and scope of the specific LCA study, a cradle-to-field gate approach was implemented, as seen in Figure 2, indicating that the life cycle does not include any activity beyond the field's exit boundary (field gate).

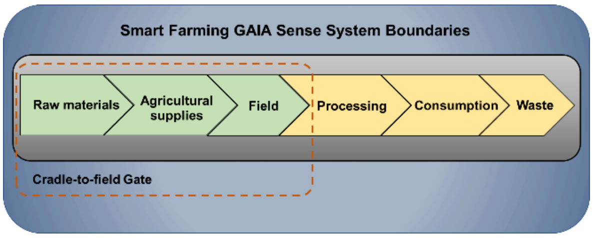

Figure 2. System boundaries

For each field under study, the Life Cycle Inventory (LCI) was based on data recorded in crop logbooks and questionnaires distributed to farmers, containing details about field activities. In Figure 3, a schematic inventory is presented in which the processes taken into account are shown, as well as the kind of inputs and outputs required. One hectare of cultivated land was set as functional unit.

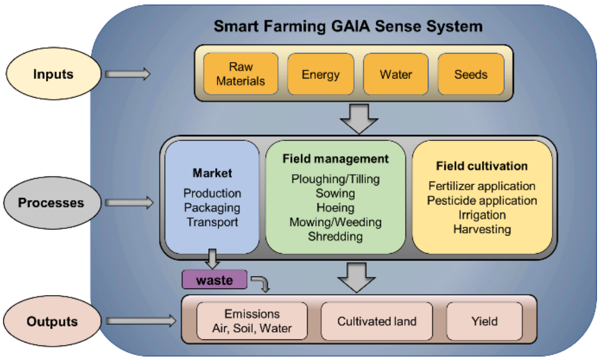

Figure 3. Schematic inventory

For this purpose, AGRIBALYSE dataset (v3.0.1) was used in combination with the openLCA software (v1.11.0), while ReCiPe 2016 (H) impact method (LCIA method) was selected for conducting all related impact calculations and analysis.

2.2. Regionalization in LCA via territotial approach

Moreover, an attempt of incorporating regionalization in the LCA methodology, when applied in Agricultural Crop Systems (ACS), was performed by implementing a territorial approach. It is understood, that although the particular methodological practice needs to be further developed, it is still an appropriate tool for embodying regionalization in all four phases of an LCA study referring to ACS (Wowra et al., 2020).

As implied, the territorial approach involves the split of the inventory (as well as of the other phases) in two main parts, of the foreground and background system. As foreground, all activity processes evolving locally on the cultivated fields are taken into account, while the background system refers to all the related, but not on site, activities, as shown in Table 1. With this distinction and by considering the goal and scope of the current study, making recommendations and decisions for good agricultural practices becomes more targeted, accurate and manageable.

Table 1. Splitted inventory in territorial approach

Background system	**Foreground system**
Inventory processes	
Raw materials extraction, refining, etc. *(Natrural gas, oil, phosphate rock, etc.)*	Field activities *(Fertilizers/pesticides application, water pumping, etc.)*
Chemicals production *(Fertilizers, pesticides, etc.)*	
Transportation *(Lorry, freight train, etc.)*	
Infrastructure *(Tractors, irrigation systems, shelters, etc.)*	
etc.	

3. Results and discussion

The study's results are grouped in four parts. First, the effect of SF on air quality and its related impacts is shown. Secondly, the LCA findings are presented based on 1) the midpoint impacts, 2) the areas of protection analysis and 3) single score calculations. Finally, recommendations for good agricultural practices, stemming mainly from the territorial approach analysis, are displayed.

3.1. Air quality and related impacts

As noted, air quality is influenced considerably by agricultural field activities, while fertilizers are one of the most important factors contributing to nitrogen (N) pollution, which SF also aims to improve (Fragkou et al., 2023). Indicatively, in the case of a field in Velvento area, in 2021 (Table 2), a decrease in the nitrogen amount applied in the treatment field resulted also to lower losses in the form of nitrogen air reactive species (NH_3, NO_x and N_2O air emissions).

Table 2. N-fertilizers and emitted nitrogen air reactive species (Velvento field, 2021)

Velvento (2021)	**N (kg/ha)**	**NH_3 (g/ha)**	**NO_x (g/ha)**	**N_2O (g/ha)**
Reference field	108	7236	4320	1080
Treatment field	84	5628	3360	840
% change	-22.2			

3.2. Life cycle impact assessment

In the LCIA, processes associated with other agricultural activities, such as harvesting, field cultivation, etc., are excluded, because SF does not aim to affect them and thus, they do not satisfy the goal and scope of the study.

In this context, the main processes examined are those of fertilization, pesticides application and irrigation.

3.2.1. Midpoint indicators

Results from the ReCiPe 2016 (H) impact analysis indicate that except for some cases that showed no differences by applying the SF technology, there were mainly reductions in most of the impacts studied, potentially occuring from the implementation of the advices produced by the SF system.

The following radar chart (Figure 4) shows the relative indicator results. For each impact, the maximum value is set to 100% and the results of the other variant are displayed in relation it. As seen, for a pilot case in Pieria in 2020, reductions in SF treatment are noticed for most impacts, except for those which are mainly affected by the pesticides application, as in the treatment field the respective amount was observed to be higher.

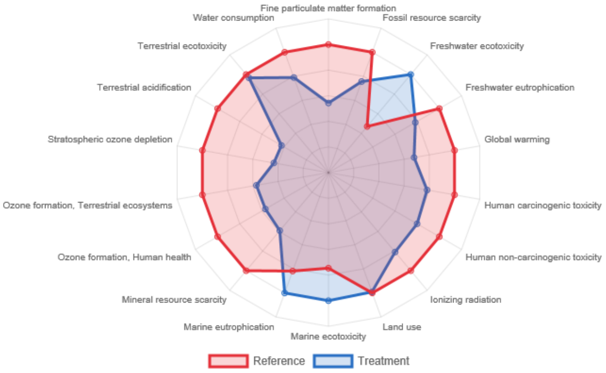

Figure 4. Midpoint impacts - relative % difference between reference (conventional) and treatment (SF) fields (Pieria field, 2020)

3.2.2. Areas of protection analysis

The 18 midpoint indicators of ReCiPe 2016 were characterized into 22 endpoint indicators, according to the damage pathways followed in the method. The endpoint results were categorized into three main areas of protection, which represent the systems' total damage to: a) human health, b) ecosystems and c) resources availability. For the same case of Pieria field (in 2020), Figure 5 states decreases in all three areas, within a range of -17 to -39%.

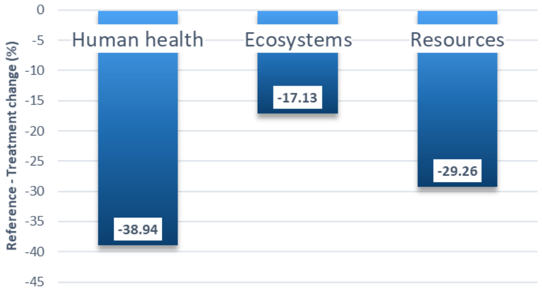

Figure 5. Areas of protection - relative % difference between reference (conventional) and treatment (SF) fields (Pieria field, 2020)

3.2.3. Single score analysis

The next step of the study is the most suitable for decision making, as it embodies single score analysis, thus allowing for system comparison in quantitative terms. So, by normalizing and weighting the endpoint results with the normalization and weighting set of the chosen dataset (World 2010 H/A), single score bar charts were produced in order to create total environmental profiles of the systems representing the conventional and the SF field-treatment practices.

As shown, regarding the same pilot case of Pieria 2020, the results highlight resources (fossil and mineral) depletion as the most important impacts (of several order of magnitude larger than all other calculated impacts), which are mainly decreased for the treatment fields, implying that SF can lead to significant resource efficiency benefits (Figure 6).

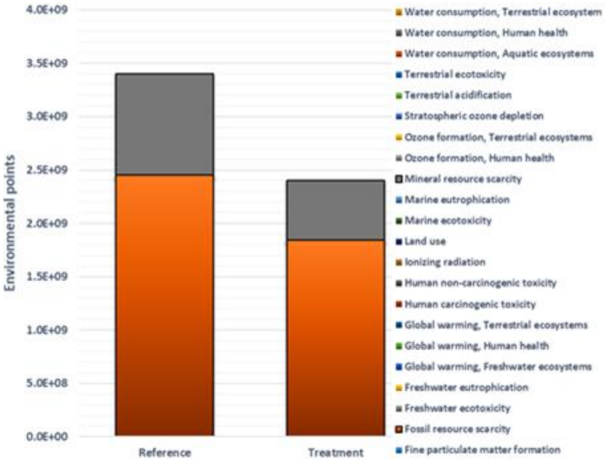

Figure 6. Single score analysis - relative % difference between reference (conventional) and treatment (SF) fields (Pieria field, 2020)

Except for the above-mentioned resource scarcity impacts, fine particulate matter formation, global warming (human health) and human carcinogenic (& non-) toxicity are also impacts with high environmental scores and thus, they should be considered in management practices (Figure 7).

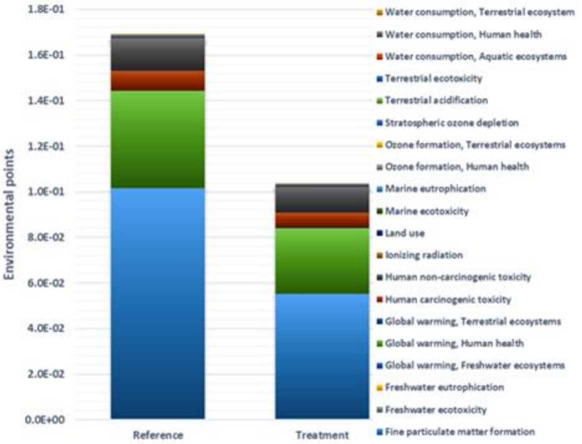

Figure 7. Single score analysis - relative % difference between reference (conventional) and treatment (SF) fields (Pieria field, 2020)

3.3. Territorial approach for recommending good agricultural practices

Recommendations for good practices were generated in order to suggest measures for further mitigation of the environmental impacts studied. For this reason, based on the single score analysis, the focus was directed on the six above-mentioned impacts, estimated to be the most significant. Firstly, as seen in Figure 8, for the example case of Veroia in 2021, the contribution of the basic agricultural activities (fertilizers/pesticides application & irrigation, through their whole life cycle) to each impact was calculated, so as to respectively indicate the most essential ones.

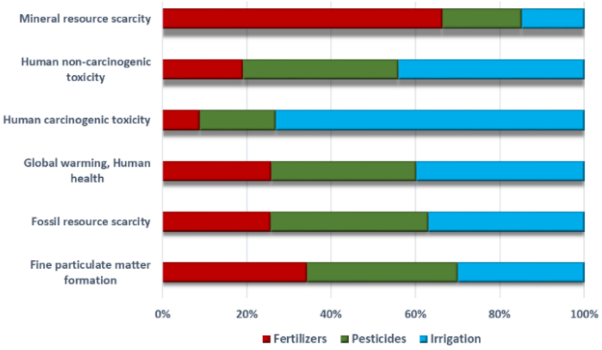

Figure 8. Process contribution of endpoint impacts - relative results (Veroia field, 2021)

Thereupon, the territorial approach was implemented to facilitate targeted recommendations. For instance, considering a strategy for moderating the impact of “mineral resource scarcity”, suggested measures should focus on reducing the amount of fertilizers (of nitrogen, phosphorus, potassium, etc.) used, influencing all related processes of production, transportation, packaging, etc., of the background system.

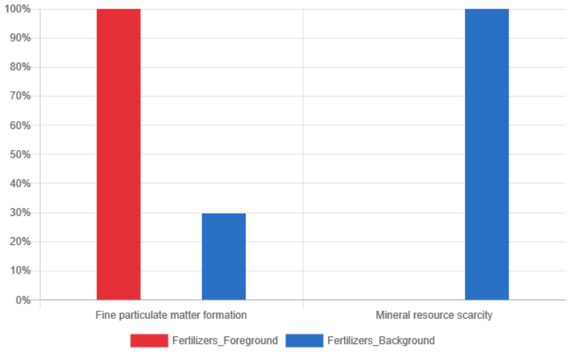

Figure 9. Impact contribution of fertilization foreground and background systems

On the other hand, in order to minimize the “fine particulate matter formation”, an impact which is strongly related to air quality and nitrogen air reactive species due to fertilization, improvement measures should focus on the foreground system (Figure 9). More specifically, the type of fertilizer applied (e.g. Ammonium Nitrate (AN), Urea, etc.) should be taken into account, as a parameter introducing significant variations in the emissions of NH_3, as shown in Figure 10 (EEA, 2019).

For example, in the case of a field in Elassona area in 2021, although increased fertilizer rates by 87% took place in the treatment field, lower NH_3 emissions by 55.8% were calculated due to the change in the fertilizer type, from ammonium sulfate (AS) to an NPK mixture, leading to a respective decrease in all associated impacts (particulates formation, terrestrial acidification).

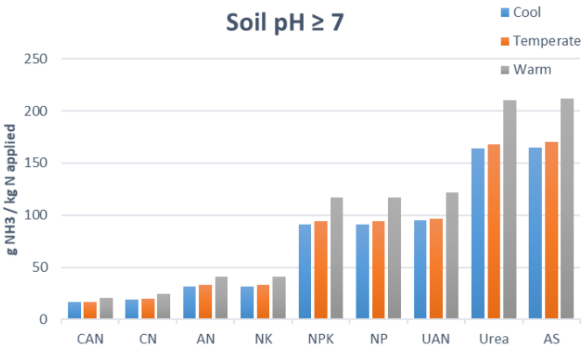

Figure 10. NH_3 air emissions based on different fertilizer types and climatic zones for soil pH≥7

4. Conclusions

In the context of LIFE GAIA Sense project, quantitative evidence of the sustainability of SF technology was produced. Moreover, a territorial approach of LCA applied in ACS was implemented, as a tool to promote regional decision making for good agricultural practices.

References

Ahmad S.F., Dar A.H. (2020), Precision Farming for Resource Use Efficiency, In: Kumar S., Meena R.S., Jhariya M.K. (eds) Resources Use Efficiency in Agriculture, Springer, Singapore, 109-135.

EEA. (2019), EMEP/EEA air pollutant emission inventory guidebook 2019, Technical guidance to prepare national emission inventories, EEA Report No 13/2019.

Fragkou E., Tsegas G., Karagkounis A., Barmpas F. and Moussiopoulos N. (2023), Quantifying the impact of a smart farming system application on local-scale air quality of smallhold farms in Greece, Air Quality, Atmosphere & Health, 16, 1-14.

Lieder S., Schröter-Schlaack C. (2021), Smart Farming Technologies in Arable Farming: Towards a Holistic Assessment of Opportunities and Risks, Sustainability, 13(12), 6783.

Wowra K., Zeller V. and Schebek L. (2021), Nitrogen in Life Cycle Assessment (LCA) of agricultural crop production systems: Comparative analysis of regionalization approaches, Science of The Total Environment, 763, 143009.

URL1: https://lifegaiasense.eu

URL2: https://www.iso.org/standard/37456.html

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