Innovative Greenhouse Support System in the Mediterranean Region: efficient fertigation and pest management through IoT based climate control — iGUESSMED

Deliverable D4.3 – Feasibility and sustainability assessment document

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Abstract

The "Feasibility and sustainability assessment document" shows the results of the Living lab activities developed in task 4.2, by presenting the environmental and socio-economic impact assessment of the introduction of the DSS in commercial tomato greenhouses (iGUESS-MED demo pilot test sites), and the assessment of Needs, Expectations, and Impacts at the territorial level. The results are firstly presented per each living lab and then they are discussed in a comparative manner, to derive useful implications beyond the case study level. The deliverable provides a wealth of qualitative and quantitative data that can be used as a reference in further research.

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Acronym list

AC: Terrestrial acidification

CC: Climatic change

DSS: decision support system

FE: Freshwater eutrophication

FET: Freshwater ecotoxicity

FU: Functional Unit

HCT: Human carcinogenic toxicity

HnCT: Human not carcinogenic toxicity

LCA: Life Cycle Assessment

LCC: Life Cycle Costing

LL: Living Labs

ME: Marine eutrophication

MET: Marine ecotoxicity

NEI: Need Expectation and Impact

NPV: Net Present Value

PI: Profitability Index

PM: Fine particulate matter formation

SWOT: Strengths, Weaknesses, Opportunities, and Threats

TCOP: Total Cost of Production

TET: Terrestrial ecotoxicity

WC: Water consumption

1. Introduction

The iGUESS-MED project aims to develop a Decision Support System (DSS) able to effectively manage fertigation and prevent plant diseases and pests in tomato crops grown in soil and soilless in commercial greenhouses of the Mediterranean region. This innovative greenhouse DSS will be developed to (i) help greenhouse farmers to improve the management of fertigation in areas with low (saline) quality waters (ii) to reduce the use of chemicals by a sustainable and integrated pest and disease control and (iii) to improve the climatic efficiency in the existent greenhouse by low-cost climate actions. The DSS will allow obtaining healthier and higher quality productions and higher yields, while will reduce the use of water and the losses of nutrients and chemicals to the environment. iGUESS-MED will be able to manage efficient fertigation, to forecast diseases and pests, and to improve the climatic efficiency in tomato greenhouses, using only climate data acquisition and basic information on cropping system. The DSS will provide feedbacks and alerts about crop needs and real time recommendations to the farmers through friendly portable real time data visualization tools as PC, tablets or smartphones. To achieve this objective, new models for calculating crop evapotranspiration will be performed by integrating sensor data from plant, soil and climate, and forecasting models for assessing disease and pest risks will be developed by using the Integrated Pest Management.

The project consortium (research centers, SMEs and end-users of EU and non-EU countries belonging to the Mediterranean basin) will collaborate from the beginning to make the DSS marketable involving, end-users and stakeholders to validate the system in own greenhouses, reducing gaps between research, application developers and farmers. The application of DSS will benefit the workers and the consumers, providing better working conditions, crop healthiness and reduction of environmental impact.

1.1 Summary of the deliverable

The overarching objective of WP4 is to create an enabling environment for the transition towards sustainable, resilient and inclusive greenhouse cropping systems by (i) boosting stakeholders' involvement, empowering a new generation of farmer and overcoming gender barriers; (ii) providing sound evidence-based information about the socio-economic and environmental performance of the innovative solutions proposed in previous WPs, with emphasis on country-specific issues; (iii) supporting farmer investment decisions, while promoting social dialogue, gender equality and inclusion, by removing knowledge barriers. The objective of Deliverable 4.3 is to show the results of the environmental and socio-economic impact assessment of the introduction of the DSS in commercial tomato greenhouses (i.e. the iGUESS MED test sites), as well as the assessment of Needs, Expectations, and Impacts at the territorial level, based on the voice of local actors (as described in D4.2). For iGUESS-MED activities, the territorial level is defined as the NUTS2[1] area where the commercial version of DSS tested in real-world farms (test sites) for EU (Italy, Spain) and EU candidate (Turkey) countries or a comparable area for Tunisia. Additionally, those areas define the geographical boundaries for LL. Test sites are commercial greenhouses that have been monitored before and after DSS adoption to gather detailed primary data for the environmental and economic assessment (Figure 1).

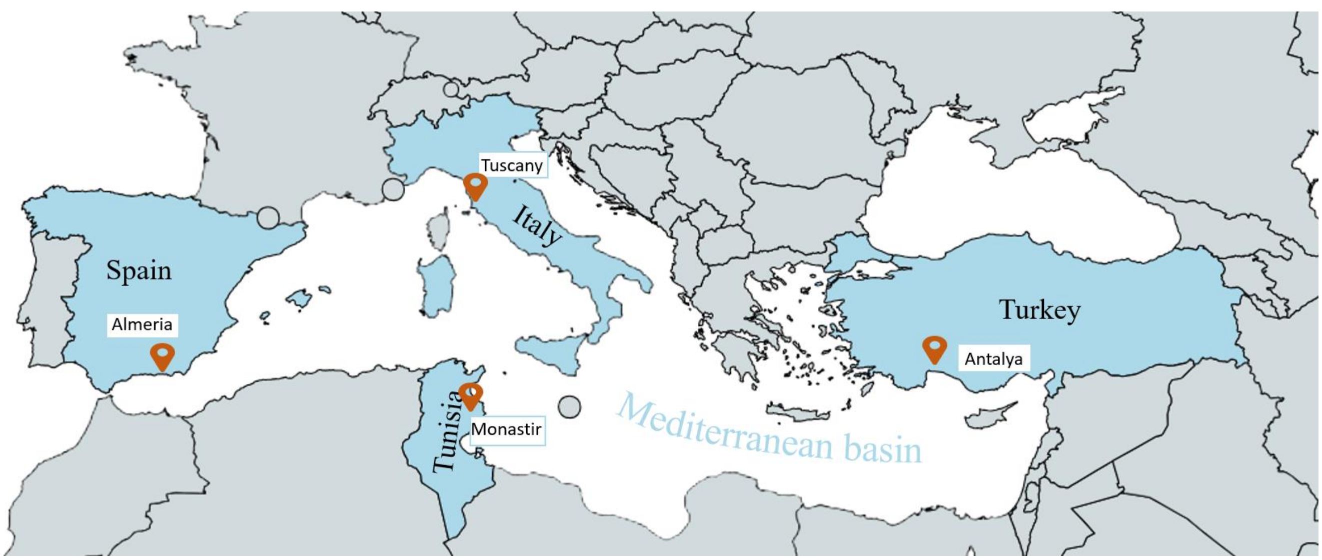

Figure 1 - Location of iGUESS-med test sites (pointers) in partner countries.

[1] NUTS is the Nomenclature of territorial units for statistics of the European Union, which is applied to accession and candidate countries as well.

The test sites share similarities in greenhouse structure, especially galvanised iron frame, concrete foundations, plastic film covering, no heating, drip irrigation, low level of technology, and useful life of about 20 years. However, the test sites have specific characteristics that make them different from each other, especially:

- Italy (Tuscany test site): soilless cultivation, conventional pesticide management, water from private well;
- Spain (Almería test site): soil cultivation, Integrated Pest Management (IPM), water from private well;
- Turkey (Antalya test site): soil cultivation, conventional pesticide management, water from private well;
- Tunisia (Monastir test site): soil cultivation, conventional pesticide management, water from well and surface water from a dam and rain harvest system.

Results are presented on a case-by-case basis to enable a thorough understanding of the specific production systems within their socio-economic contexts. The implications of the findings will be discussed by considering the similarities and differences of the iGUESS MED test sites to derive lessons learnt that are relevant beyond the territorial level. The aim is to draw recommendations for developing and practically implementing sustainable greenhouse cropping in the Mediterranean basin based on a more conscious management of critical production inputs, such as water, fertilisers and pesticides.

Deliverable 4.3 (and its Annexes 1 and 2) collects and systematises all the evidence generated within task 4.2 through LL, especially:

Subtask 4.2.1: Environmental and socio-economic assessment before and after DSS adoption, through a combination of Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and social impact indicators at the test site level;

Subtask 4.2.2: Participatory assessment of Needs, Expectations, and Impact (NEI) after DSS adoption at the territorial level.

2. Essential methodology

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This section provides a succinct overview of the main methodological aspects, to facilitate reading. The complete theoretical framework, analytical methods and data collection processes are available from Deliverables 4.1 (Bartolini et al. 2021) and 4.2 (Sturiale et al., 2022).

2.1. Environmental and economic assessment before and after DSS adoption

The assessment relies on the combination of LCA, LCC and social impact indicators at the test site level. Data were collected via LL.

LCA and LCC are analytical process-based tools that compile an inventory (quantities, costs) of all inputs and outputs of agricultural production that allow quantifying and evaluating impacts from raw material acquisition to disposal. The combination of these methods provides a comprehensive view of the economic and environmental effectiveness of a production system and allows the identification of possible hotspots. LCA and LCC are carried out through a stepwise approach with 4 phases, i.e. goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation.

The selected functional unit (FU) is 1 ha greenhouse. The FU based on area allows for recommendations on the implications for the overall sustainability of greenhouse cultivation. The boundaries of the system where set is a cradle-to-gate. To better identify critical points, the impacts were divided into six production stages: (1) Greenhouse, (2) Fertigation system, (3) Machinery, (4) Fertilizer, (5) Pesticides, and (6) Waste. Considering the differences in the length of production cycles, all data were compared to 1 solar year to allow easier comparison. Primary data were collected through interviews with greenhouse owners. Secondary data, i.e., impacts from industrial production of inputs and extraction of raw materials came from databases Ecoinvent® 3.8 and Agri-footprint® 4.0. The missing processes (some fertilizers and the impact from beneficial insect production) were constructed from scratch by the authors. Finally, emissions to the environment produced directly from greenhouse production were estimated by methods found in the scientific literature. The environmental impact assessment was carried out using the ReCiPe 2016 midpoint (H) method/Word. This impact assessment method was selected to allow comparison with extra-European case studies that are part of the project. Eleven impact categories were selected, considered most relevant to the scope of the project and covering both environmental and human health damage (Table 1).

Impact categories	Acronym	Unit
Climate change	CC	kg CO_2 eq/ha/year
Fine particulate matter formation	PM	kg PM2.5 eq/ha/year
Terrestrial acidification	AC	kg SO_2 eq/ha/year
Freshwater eutrophication	FE	kg P eq/ha/year
Marine eutrophication	ME	kg N eq/ha/year
Terrestrial ecotoxicity	TET	kg 1,4-DCB/ha/year
Freshwater ecotoxicity	FET	kg 1,4-DCB/ha/year
Marine ecotoxicity	MET	kg 1,4-DCB/ha/year
Human carcinogenic toxicity	HCT	kg 1,4-DCB/ha/year
Human non-carcinogenic toxicity	HnCT	kg 1,4-DCB/ha/year
Water consumption	WC	m^3/ha/year

Table 1 - Impact categories of LCA.

For the LCC, we used three economic impact indicators:

- Total Cost of Production (TCOP), calculated on a annular basis;
- Net Present Value (NPV) calculated over the life cycle of the greenhouse, i.e. 20 years, considering 10% interest rate;
- Profitability Index (PI), a dimensionless indicator for the efficiency of the investment over time. PI is calculated as the ratio of NPV to investment costs: profitable case studies have PI > 1.

The LCC inventory does not include the salaries of the owner and family employee, only the pension contribution that is paid annually. The TCOP were divided into the same subcategories used for the LCA analysis, with the addition of "labour and services", which includes workers' wages, consultancies, contributions, and taxes incurred by the owner, and "DSS," which includes costs for the control unit, sensors, and software.

The socio-economic and environmental indicators refer to a list of concerns that have been selected as relevant in each case study area. The selection of these indicators is computed by using an interactive process with local stakeholders. These indicators were initially selected by distilling from the literature, and after a stakeholder interview, a hierarchical structure was developed in D4.1. We use weights to assess their importance in multicriteria, representing the relative importance of different criteria and reflecting the decision maker's preferences and priorities. By assigning weights to each criterion, we can provide a more comprehensive and structured description of stakeholder and area needs, enabling a clearer comparison of the different views and priority of the impact among social, environmental, and economic objectives.

2.2. Needs, Expectations, and Impact assessment

Building of the findings of LCA and LCC, the NEI assessment generates knowledge on the potential sustainability impacts of the DSS at the territorial level. NEI assessments were conducted through a workshop using participatory methods to ensure an inclusive approach to data collection. This activity was combined with sending a questionnaire to local stakeholders to collect individual preferences on the impact domain and assess the relative importance of the proposed criteria. Each LL collected 15-20 completed questionnaires to cover the main stakeholders listed in Table 7 of D4.1. The workshop aims to better understand the main changes in STS due to technological changes and to provide a participatory impact assessment. This exercise aims to generate a broader understanding of the potential sustainability impacts of iGUESS-MED technology deployment at the territorial level. A future perspective is then asked, envisioning a "*what if*" situation in which the technology is adopted by all relevant greenhouse producers in the target area.

The result of the NEI assessment is the creation of logical links between needs expressed at territorial levels and the potential impact of new technologies. NEI assessments are broadly used in participatory exercises.

3. Tuscany, Italy

Focal question of the LL: ***"How to make effective use of the DSS to improve the environmental performance of soilless cropping, while supporting profitability and reduction of workload and health risk for farmers, as well as encouraging new entrants (especially young farmers and women)?"***

3.1 Life cycle assessment and life cycle costing

3.1.1. Description of the test-site

The greenhouse under study is a family greenhouse located in south Tuscany (coordinates: 43°07'30" N; 10°38'24"E). The multi-span greenhouse covers an area of 0.67 ha, of which 0.54 ha is cultivated with tomatoes cv. Pisanello. The greenhouse is made of steel and plastic with a double layer (one layer with diffused light and one with direct light), with opening at the ridge. It has a useful life of 20 years; it is long 112,5 m and wide 48 m, and there are two doors 2.5 m high and 2 m wide. The height at the ridge is 5.6 m, and height at the eaves is 3.3 m. The structure is composed of two spans, consisting of arches of zinc plated steel, with anchorage in concrete and covered in LDPE. The plastic covering is fully replaced every 3 years. The floor is completely covered with PP mulching canvas. There is a roof opening for ventilation, 1 m wide, for each span. Side openings (2 m high and 75 m long) are operated manually. HDPE insect nets cover all openings. Due to the climatic conditions in which the test-site is located and the need for very long production cycles, the greenhouse is equipped with a gasoline-powered emergency heating system, rated at 115 kW. Heating system use was estimated to be about 14 nights during the study period. The temperature is kept under control through whitewashing in summer (potato-starch based product).

Tomatoes are grown on coir pith substrate (growing bags). The bags are replaced every 2 years, and the exhausted coir pith is reused on farm (land spreading). The cultivation density is 3 plants/m^2. The crop is grown for two production cycles per year, for a total of 293 days/year. The first transplanting was done in mid-March and harvest in mid-July; the second transplanting was done in mid-August and harvest in mid-December. One hive is used for pollination in each production cycle, with 1 hive per 1000 m^2. The owner, his wife and 3 other employee work on the farm.

The fertigation system allows nutrient solution to be distributed by drip irrigation. The distribution system consists of PVC pipes, a fertigation unit, and a 0.75 kWh pump that draws water from the farm's well (about 6000 m^3/year). The fertigation unit is in a dedicated farm facility (60 m from the greenhouse). This structure also serves for other farm activities, so its construction is not considered in the LCA. Most materials aren't disposed of to landfill at end of life. Plastics and cardboard are delivered to a recycling plant. Construction materials are delivered to dedicated recycling plants as well. However, the share of materials delivered to recycling plants that are recycled vary based on material quality. In this study, we have assumed a 50% recycling rate for those materials. The rest is landfilled.

Before DSS, the soilless system is open-loop, and chemical pest control is used. To improve agricultural practices, the pre-existing system was modified into a closed-loop system in addition to the DSS. Thus, water drainage channels were inserted, and a system of pipes and water collection tanks was connected to a UV lamp sterilization unit. The DSS was used both to optimize the dosing of fertigation inputs using software based on the SimulHydro model (specifically for soilless) and to support the introduction of IPM control.

3.1.2. Life cycle assessment

The LCA inventory is available from Annex 1.

The table below (Table 2) shows the environmental impacts divided into their respective impact categories before (open-loop, chemical pest management) and after the introduction of the DSS (closed-loop, IPM).

Impact categories	Unit	Before DSS	After DSS	Percent change
CC	kg CO_2 eq/ha/year	34393	32415	- 6%
PM	kg PM2.5 eq/ha/year	76	63	- 17%
AC	kg SO_2 eq/ha/year	257	213	- 17%
FE	kg P eq/ha/year	15	19	+21%
ME	kg N eq/ha/year	36	12	- 67%
TET	kg 1,4-DCB/ha/year	211211	127660	- 40%
FET	kg 1,4-DCB/ha/year	3806	2029	- 47%
MET	kg 1,4-DCB/ha/year	3663	2670	- 27%
HCT	kg 1,4-DCB/ha/year	3589	3292	- 8%
HnCT	kg 1,4-DCB/ha/year	50749	42458	- 16%
WC	m^3/ha/year	8276	8685	+ 5%

Table 2 – Characterised environmental impacts for the test site in Tuscany, Italy.

The table below shows the percentage contributions of each stage for each impact category (Figure 2). To identify hotspots more easily, impacts were divided into six production stages: greenhouse, fertigation system, machinery, fertilizers, pesticides, and waste.

The table below shows the contributions for each impact category.

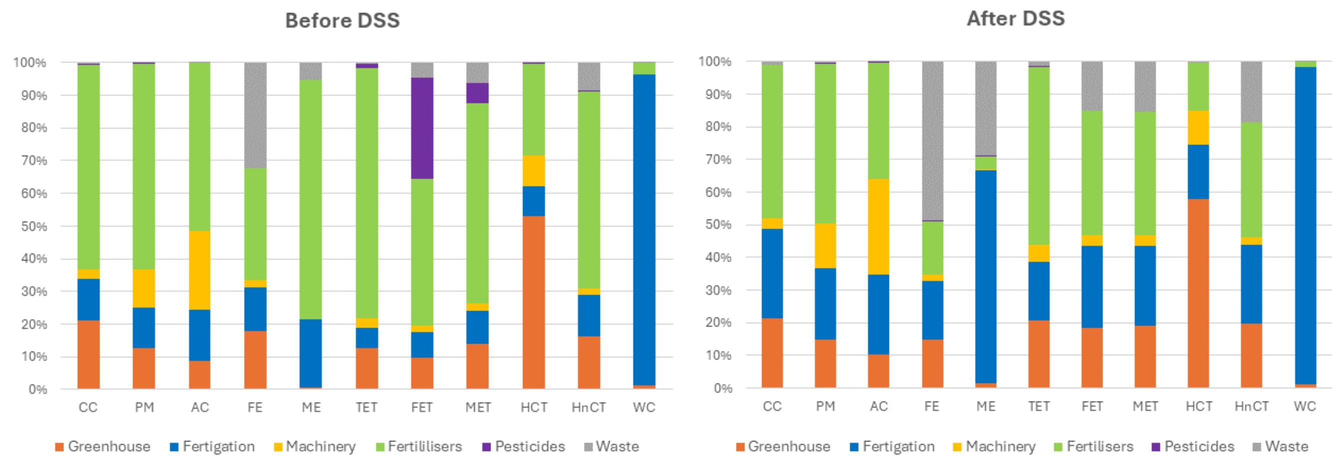

Figure 2 - Contribution analysis of LCA-based environmental impacts for the test site in Tuscany, Italy.

In the Italian case study, fertilizers are clearly a hotspot. Before DSS, fertilizers show high impact values in all selected impact categories (from a max of 77% in TET to a min of 3% in WC). These impacts are mainly due to the extensive use of fertilizers, especially nitrogen- and phosphorus-based ones (e.g. calcium nitrate and potassium sulphate). Transportation of materials and construction of the greenhouse impact several categories, particularly HCT (53%) and CC (21%). Contributing most to these impacts are industrial processes for plastic covers. The use of chemical pesticides predominantly impacts the FET (31%), MET (6%) and TET (1%) categories. The fertigation system is the largest contributor to WC (95%), but it also has impacts on ME (21%) and AC (16%) due to the production of plastic materials (pipes and microtubes, tanks and plant supports), steel structure and substrate. As a soilless crop, it doesn't require tillage machinery, so the impacts of agricultural machinery are limited. Waste contributes most to the FE category (32%), influenced mainly by the disposal of plastics. The production, transportation, and use of the emergency heating system, which is not present in the other case studies and was turned on for about 14 nights in the year analysed, has little influence on the total impacts. In fact, it shows larger contributions in the HCT category (6% of total impacts), and an average of 1% contribution in the other impact categories.

After DSS instead, fertilizers are still a hotspot, although their contribution has greatly decreased (from a high of 69% in ME to a low of 2% in WC). The contribution of impacts on the greenhouse effect is slightly increased as it also includes transport and maintenance of the DSS. The contribution from the fertigation system (mainly in ME, +44%) and waste (mainly in ME and FE, +24% and + 16% respectively) increased due to the increase in plastic material used. The pesticide phase, being based on greater use of biological substances and beneficial insects, showed a near cancellation of the contribution.

3.1.3. Life cycle costing

The LCC inventory is available from Annex 1.

The table 3 shows the results of LCC.

Impact indicators	Unit	Before DSS	After DSS
TCOP	€/ha/year	155,332	159,930
NPV	€/ha/20 years	463,123	406,586
PI	-	1.28	1.09

Table 3 - LCC indicators for test site in Tuscany, Italy.

In general, the use of a soilless fertigation system made annual costs particularly high compared to greenhouses with soil cultivation. Despite the high investment cost, the production of a niche tomato variety allows the grower to extract a higher price (1.44 €) than more common varieties. The yield was equal to 159.3 t before DSS adoption and 158.1 t after DSS adoption. Switching to the closed-loop system allows for a reduction in the use of water and fertilizer, but the use of more complex equipment results in increased expenses that affect the final profit. The figure 3 shows the annual cost distribution.

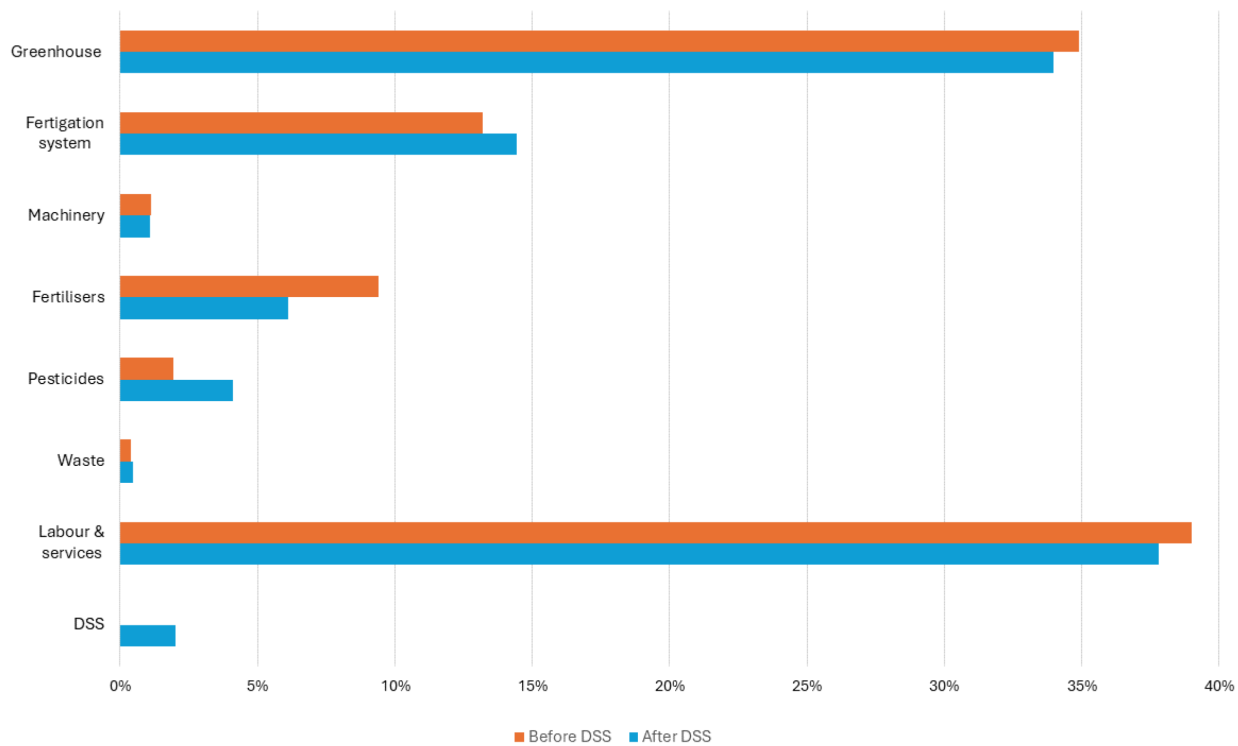

Figure 3 – Contribution analysis to TCOP for the test site in Tuscany, Italy.

Before DSS, the largest annual costs are labour and services (39% of total costs), which include taxes, consulting, and pension contributions. Next are greenhouse design, construction, and maintenance (35%

of total costs). The soilless fertigation system accounted for 13% of the total costs. The purchase of fertilizers and pesticides covers 9% and 2% of total annual costs, respectively. The other cost centres are for the use and maintenance of the farm sprayer (1%) and waste disposal costs (0.4%).

After DSS, switching from chemical control to IPM raised costs in Pesticides (from 2 to 4% of TCOP). This was due to the high price of beneficial insects. The switch to the closed-loop system caused an increase in costs in the Fertigation category due to the purchase and maintenance of drainage channels, tanks, pumps, and sterilization units (14%) and a slight increase in disposal costs for the majority plastic (0.5%). In contrast, the closed-loop system reduced fertiliser consumption, with its associated costs (-3%). The cost of DSS alone accounts for about 2% of the TCOP.

3.2. Needs, Expectations and Impact assessment

3.2.1 Context analysis

Italy is characterized by a Mediterranean climate, with mild, rainy winters and warm, sunny summers. Average temperatures are 15.6°C. Precipitation is mainly concentrated in autumn-winter, with an average rainfall fall of about 769 mm (ISTAT 2023). In Italy about 32’884.84 hectares of protective plots are dedicated to growing vegetables and small fruits, with a total production of 1’546’433 t per year (ISTAT 2022). Statistical data regarding greenhouse management practices are few and fragmented, but through a survey conducted in 2013 we know that most vegetables are grown in soil, while the soilless technique is used in only 10% of the Italian greenhouse area (Incrocci et al. 2020). Of this fraction, about 10% of greenhouses use a closed-loop system. For 93% of soilless cases, vegetables are grown on substrate (mainly peat, coconut fibre, perlite, and pumice); while only 7% use hydroponic techniques. Irrigation is managed 65% with Drip irrigation, 20% with Over-head sprinkler and 10% with Micro sprinkler (Incrocci et al.; 2020). The horticultural sector is increasingly developing but is still not able to meet the domestic needs. About 60% of all Italian greenhouse area is in the South, especially in coastal areas. As for protective structures, the most common are of the pavilion type, used mainly in the southern regions and intended mainly for the cultivation of Solanaceae; and simple and multiple tunnels, found in the other areas and intended for the cultivation of strawberry, melon, etc. Most greenhouses are characterized by lightweight and inexpensive structures covered with simple plastic films, and only 20% of them are heated (usually nursery and floriculture greenhouses). This technology is generally based on the principle of minimizing capital and technology investments, as it is believed that high-tech investments are not justified in these environments (especially in the case of vegetables), due to too high a cost-benefit ratio. In fact, greenhouse units are usually small (less than 0.5 ha) and often family-owned, with a few exceptions (e.g. Ragusa, Sicily). They are not equipped with advanced climate control and fertigation systems due to the high cost of equipment, and mostly use 'open' systems (EIP-AGRI 2019). More information on the greenhouse context at the area level can be found in Annex 2.

The Tuscan region depends heavily on the agriculture. According to the most recent data (RICA 2021), crops made up more than € 3.2 billion, or 61%, of the agricultural sector's total value in 2019. Horticultural and floriculture farms earned the greatest gross earnings among farms, with an average gross income of € 186,000, approximately 40% higher than grain and wine farms. Though Tuscan farms generally employ about 47 kg/ha of phosphorous and 77 kg/ha of nitrogen, horticultural and floricultural farms are among the most intensive users of fertilizers, consuming an annual amount of phosphorous (457 kg/ha) and nitrogen (503 kg/ha) more than average (RICA 2021). With an estimated total added value of € 2.2 billion, the agrifood industry has significantly boosted the regional economy and assisted in the rural areas' economic development (IRPET, 2021).

Additional information is available from Annex 2.

3.2.2 Needs and Expectations

The expansion of the greenhouse sector in Italy, which began in the 1950s, was based on the climatic advantages typical of the Mediterranean, characterized by mild winters and long, hot summers. This has allowed good yields even out of season, with minimal investment: greenhouses are mostly made of steel and plastic, with low or no technology (Castilla 2002). One problem with the typical Mediterranean climate, however, is the general scarcity of water for irrigation. Well water is usually of low quality; in addition, the application of copious amounts of fertilizer can increase water salinization. Therefore, optimal management is needed to ensure maximum yield while minimizing losses to the environment (Fernández et al. 2018).

Agriculture in Italy is widespread, but farms are generally small and family-owned: in fact, according to ISTAT data, about 93% of farms have this characteristic (ISTAT, 2020). The small size makes farms less competitive in the market, resulting in little bargaining power with large-scale retailers on the product price. This characteristic is also a limiting factor for access to new technologies, as they often require major investments that are out of the reach of small farmers. It must be said, however, that the last decade has seen a change in the sector: the number of farms has declined, but at the same time, their size has increased. In addition, the first technological farms are emerging, which can serve as pathfinders (for example, the "Sfera" farm in Tuscany).

In this context, young people and women are still underrepresented. In fact, young people still do not have a solid presence in the sector compared to older people; often due to several obstacles: poor land availability, high start-up costs, low profit potential, and the lack of essential services in rural areas, making them less attractive. However, opening agriculture to the younger generation is one way to invest in the sector's future. First, young people are more aware of the negative effects of climate change and are more committed to combating it than other generations. In addition, young people are more technically and technologically up-to-date and are, therefore, more likely to be involved in innovative practices.

Increasing the presence of young people in rural activities is also an objective recognized by the Common Agricultural Policy (CAP), which aims to facilitate generational change within farms. As a result, several calls for funding in agriculture have been made available in Italy: regional and national RDPs for the development of innovations in the greenhouse sector (e.g., RDP 2014-2020), bonuses for the establishment of young people in agriculture, and support to farmers for tangible investments aimed at improving farm structures, modernizing technological equipment, saving energy, and purchasing agricultural machinery. However, interview results show that few producers use these funds, either because they are unaware of them or because the bureaucratic process is considered too complex and the access parameters too tight. In addition, growing consumer interest in "healthy" and "km0" foods has increased pressure from large-scale retailers on supplier farms, incentivizing best practices.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Favourable climatic conditions • Short value chain • Well-established farming sector	• Burdensome bureaucracy to access public incentives • Low bargaining power of farmers in the value chain • Lack of cooperation • Lack of generational turnover • Reduced propensity to innovate • Water scarcity in summer	• Increased demand for "healthy" and "local food" • Sustainable food strategies of local retailers • Availability of public incentives for sustainable innovation and for young farmers	• Farm exit • Ageing of farmers • Reduced competitiveness on the market

Table 4 - SWOT analysis for the test site in Tuscany, Italy.

The lack of integration between scientific research and agricultural practices and older farmers' reluctance to adopt new technologies hampers sector modernization. Fragmented ownership of small, family-run farms diminishes bargaining power and impedes the adoption of costly innovations. Although public aid programs exist, their effectiveness is hindered by bureaucratic hurdles and poor promotion, exacerbating the need for targeted training on sustainable practices and IoT utilization. Encouraging youth involvement and innovation is vital for revitalizing the sector and addressing the challenges of farmer turnover and rural depopulation.

Needs	Description	Stakeholders
Elimination of the gap academic world - farms	Lack of an appropriate link between scientific research in the sector and business reality. Farms are often run by older producers who are unlikely to be interested in or trust new technologies in agriculture.	Research institutes, universities, farmers, cooperatives, consumers
Aggregation of farms	Most of the companies are small, family-owned and spread across the territory. This division weakens bargaining power over product sales prices and makes the use of new technologies/solutions often too costly for individual farm.	Politics, farmers, cooperatives, consumers
Simplification of bureaucracy	There are many aid and development programmes provided by public authorities, but poor publicity and slow and complex bureaucracy often discourage farmers.	Politics, farmers, cooperatives
Improved technical skills of farmers and advisors	There is a strong need for more targeted training on sustainable production methods and the use of IoT in agriculture, which are still little known and looked upon with distrust.	Research institutes, farmers, cooperatives, consultants
Solving the abandonment of agriculture	Due to low profitability, young people are leaving the countryside, and there is no farmer turnover. it is necessary to entice young people into the sector and encourage their innovation	Farmer

Table 5 - Needs analysis for the test site in Tuscany, Italy.

3.2.3 Participatory impact assessment at the territorial level

During Living Labs, stakeholders were asked to assess the expected impacts of the diffusion of this new technology at the company and territorial levels. The following table (Table 6) shows the answers obtained by stakeholder consultation.

Broad issue	Average weight	Indicator	Average score
Economic	0.35	Increase of farmer competitiveness	7.1
		Creation of rural jobs	5.2
		Greater availability of sustainable technology for greenhouses	6.7
		Risk of misuse of technology	5.4
Social	0.28	Improvement of working conditions	5.3
		Greater equity in the distribution of value added along supply chain actors	4.9
		Greater affordability of food	4.5
		Increased trust among value chain actors	5.3
		Improvement of farmer health	5.5
		Greater food safety	5.8
		Greater job opportunities for women	4.7
		Increase of female entrepreneurship in agriculture	4.9
		Improved farmer education	6.0
		Improved women education (especially in farming)	5.2
		Improved farmer livelihood	5.2
		Condition for vulnerable groups (i.e. minority & migrants)	4.8
Environmental	0.37	Increased protection of ecosystems	6.2
		Cleaner surface water bodies	6.3
		Cleaner underground water	5.8
		Increased availability of water for agricultural uses	6.0
		Increased biodiversity	5.1
		Increased soil quality	6.1
		Reduced climate vulnerability	5.2
		Increased water security	5.5

Table 6 - MCA results for the test site in Tuscany, Italy.

Although all three upper-level criteria are very close each other, the stakeholders agree that economic and environmental criteria have the highest priority. Among the economic criteria, the competitiveness of greenhouses and digital transformation are perceived as the most important in the region. Among the social criteria, improving farmers' health, food safety, and farmer education are the most important. In contrast, the condition of vulnerable groups is perceived as less relevant than the others. Finally, the environmental impacts concern the increased protection of the ecosystem and water management, with a focus on both reducing surface water body pollution and increasing water availability.

3.3 Social impact assessment at the test site and territorial level

The list of social indicators used in the MCA was used to ask stakeholders about the DSS's qualitative economic-social and environmental impacts at the test site and territorial levels. The table below (Table 7) summarises the results.

Indicator	Test site level	Territorial level
Increase of farmer competitiveness	• Helps to make production more sustainable • Facilitates the adoption of standards (e.g., certifications), increasingly requested by large retailers • Reduces the expense for fertilizers and water and therefore the production costs	• Favouring the development of marks of ecological quality at a territorial level, which can allow you to conquer new option markets • Through protected crops the economic development of a region is fostered • By promoting the development of protected crops, the economic development of a region is also promoted (as happened for Almería)
Creation of rural jobs	• Productive cycles in the medium term • By enticement the new generations not to abandon the family business through a more modern approach to agriculture	• Generating interest from new farmers, including women, young people and minorities; • Allowing the sustainable intensification of the production and/or expansion of the structures and productive cycles • Creation of specialized professional/technical figures
Improvement of working conditions	• Simplified nutrient management and pest control and disease control, reducing working hours • Reduce use and exposure to pesticides, increasing safety at work • Improves climate management inside the greenhouse, makes work less stressful • Allows the best management of the internal climate to the greenhouse, making the work less stressful	• increased attractiveness of greenhouse cultivation for new farmers thanks to simplified management • Increased safety at work • Creation of specialized professional/technical figures • Improvement of the often negative image of greenhouse work, guaranteeing greater safety at work

Indicator	Test site level	Territorial level
Greater equity in the distribution of value added along supply chain actors	• The use of DSS allow to increase the sustainability of production (e.g. Certifications), increasing the contractual power of the farmer • No effect	• Favouring collective actions for the development of marks of ecological quality at a territorial level, increasing the contractual power of the community of farmers • Favouring the development of marks of ecological quality • No effect
Greater affordability of food	• The use of the DSS allows you to reduce production costs and therefore allows you to stabilize the sale price • No effect	• The use of the DSS allows to reduce production costs and therefore to stabilize the sale price • No effect
Increased trust among value chain actors	• Facilitates the adoption of standard (e.g. Business-to-business and business-to-consumer certifications) and product traceability • Transparency increases in the management of inputs	• Favouring collective actions for the development of ecological quality brands at a territorial level • No effect
Improvement of farmer health	• Allows better management of the climate inside the greenhouse, making work less stressful • Allows to reduce use and exposure to pesticides • Allows the greenhouse to be monitored remotely, reducing producer stress	• A reduction of chemical risk, including of groundwater • A reduction in chemical greenhouse risk can lead to a lower incidence of diseases and less health expense • Improvement of health in greenhouse areas thanks to the reduction of the pollution of the waterfall waters
Greater food safety	• The reduced use of pesticides involves less residues on the product	• Improved drinking water management • Local products with less residue of pesticides
Greater job opportunities for women	• Reconciling work and family commitments • The DSS allows you to supervise the greenhouse remotely, helping to reconcile work with family commitments • No effect	• Allowing the sustainable intensification of the production and/or expansion of the structures and productive cycles and therefore increasing jobs; • Creation of specialized professional/technical figures

Indicator	Test site level	Territorial level
		• No effect
Increase of female entrepreneurship in agriculture	• The DSS allows you to supervise the greenhouse remotely, helping to reconcile work with family commitments • The DSS can give greater safety in the decision -making process and therefore encourage female entrepreneurship, usually more prudent • No effect	• Creation of specialized professional/technical figures • Increasing attractiveness for entrepreneurship • Allowing the sustainable intensification of production and/or expansion of the structures and productive cycles, increasing attractiveness for entrepreneurship • No effect
Improved farmer education	• Acquisition of more skills • The need to familiarise themselves with technology can encourage farmers to acquire more skills	• Creation of training courses dedicated to digital technologies in agriculture • No effect
Improved women education (especially in farming)	• Acquisition of more skills • The need to familiarise themselves with technology can encourage farmers to acquire more skills	• Creation of training courses dedicated to digital technologies in agriculture • No effect
Improved farmer livelihood	• The DSS allows you to increase the sustainability of production (e.g. Certifications), increasing the contractual power of the farmer • The use of the DSS allows you to reduce production costs and therefore allows you to stabilize the sale price (e.g. In case of market shock)	• The greater profitability can limit the abandonment of agriculture • Favoring collective actions for the development of ecological quality brands at a territorial level
Condition for vulnerable groups (i.e. minority & migrants)	• The DSS makes the know-how of cultivation also accessible to people without experience in the sector (e.g. Migrants) • Better conditions (e.g. Climate, pesticides reduction) inside the greenhouse • No effect	• Creation of training courses dedicated to digital technologies in agriculture • Improvement of health in greenhouse areas, where many immigrants are often used • No effect

Table 7 - Results of the social impact assessment in Tuscany, Italy, at the test site and territorial level.

Adopting the DSS and linking it with sustainable production methods helps reduce the use of fertilizers and water, thereby lowering production costs. Additionally, it facilitates compliance with standards and certifications increasingly demanded by large retailers. DSS can support new generations to continue family businesses by simplifying nutrient and pest management, reducing working hours, and improving safety through reduced pesticide exposure. Enhanced climate control in greenhouses also makes the work environment less stressful. Additionally, using DSS enhances production sustainability and increases farmers' bargaining power through applying sustainable certifications.

DSS standardising the production process can stabilise sale prices and enhance product traceability and transparency. It can also improve climate management in greenhouses and decrease pesticide use and exposure, leading to less residue on products. DSS enables remote supervision of greenhouses, helping to reconcile work. It can also improve the encouragement of female entrepreneurship by providing greater decision-making security. The need to familiarize themselves with technology requires, however, improving digital skills among farmers. Additionally, DSS makes cultivation knowledge accessible to inexperienced individuals, such as migrants.

Improving the environmental quality of greenhouse production can foster regional economic development and open new market opportunities to meet consumers' demand for a more sustainable food choice. This approach attracts new farmers, including women, young people, and minorities, while supporting sustainable production intensification and creating new specialized professional/technical profiles. Simplified management and improved safety make greenhouse cultivation attractive to new farmers and enhance its often-negative image. This would also demand better collaboration among producers to coordinate efforts to improve the ecological quality of production. Consequently, this would lead to an increase in bargaining power for farmers and producers. Reducing chemical risks in greenhouses leads to better groundwater quality, improved health, and lower disease incidence and healthcare costs. This promotes local products with fewer pesticide residues and supports sustainable production intensification, which increases job opportunities and attracts new entrepreneurs. Additionally, the creation of specialized professional roles and training courses in digital agricultural technologies further enhances the sector's development and profitability, helping to prevent the abandonment of agriculture.

4. Almería, Spain

Focal question of the LL: "*How to make effective use of the DSS to improve the environmental performance of soil cropping with IPM, while supporting profitability and reduction of workload and health risk for farmers, as well as encouraging new entrants (especially young farmers and women)?*"

4.1. Life cycle assessment and life cycle costing

4.1.1. Description of the test-site

The greenhouse under study is a greenhouse located in the Almería, (location coordinates: 36°51'46" N, 2°17'04" W). The total area is approximately 800 m^2. The greenhouse has concrete foundation, steel frame and double-layer LDPE roofing. It has ventilation openings in the roof. The greenhouse has manual ventilation openings in the roof, covered by insect-proof net. The height at the ridge is 4.5 m; height at the gutters is 3.0 m. The structure is made up of ten spans, anchored in concrete and covered with LDPE. There are ventilation openings on the roof, operated by an electric motor.

The crop grown is a cluster tomato with Emperador rootstock, grown in soil. The seedlings are planted in a single-row cultivation system, with a row spacing of 1.5 m and a density of 2 plants/m^2. Cultivation is carried out in one season; it is a short-life crop. Transplanting is done at the beginning of March and harvesting at the mid-June, a total of 112 days per year. The gross production is 162 t/ha per year, with a commercial production of 127 t/ha, with a product loss of 20.7 t/ha (about 21% of total production).

The fertiliser supply is distributed by a drip irrigation system and controlled by an automatic system. Fertigation control is by Venturi. Every 3 years, 71% of the greenhouses are supplied with organic matter in the form of sheep manure, at a rate of 157 m^3/ha. Phytosanitary defence is done both through the use of chemical compounds and beneficial insects (IPM method). The farmer also owns a forklift, which is used for harvesting. The distance between the greenhouse and the facility where the waste is stored and recycled is approximately 16 km. The metal is entirely recycled, as are some plastics and part of the cement. The products are transported in 20 kg plastic boxes and sold by the cooperatives. The owner, a family collaborator and 3 other seasonal employee work on the farm.

The data before DSS concern traditional greenhouse management, while after the DSS, management was performed following the IoT-recommended water and fertilizer inputs. This is based on the VegSyst (for predicting crop nutrient requirements) and PrHo (for predicting water requirements) models, validated in semi-commercial/experimental greenhouses in Spain and Italy.

4.1.2 Life cycle assessment

The LCA inventory is available from Annex 1.

Since the greenhouse is only used for about four months for tomato production and the remaining time is used for the cultivation of other crops, the quantities, and costs for the construction materials of the greenhouse and the fertigation system were allocated only to the tomato production activity.

The table shows the environmental impacts divided into their respective impact categories before and after DSS. Using the DSS resulted in a reduction of about 19% in irrigation water and 46% in the amount of fertilizer administered (kg/year). The table below shows the contributions for each impact category (Table 8):

Impact categories	Unit	Before DSS	After DSS	Percent change
CC	kg CO_2 eq/ha/year	28678	24367	- 15%
PM	kg PM2.5 eq/ha/year	74	68	- 9%
AC	kg SO_2 eq/ha/year	136	113	- 17%
FE	kg P eq/ha/year	15	13	- 10%
ME	kg N eq/ha/year	14	10	- 30%
TET	kg 1,4-DCB/ha/year	175547	142668	- 19%
FET	kg 1,4-DCB/ha/year	2169	1822	- 16%
MET	kg 1,4-DCB/ha/year	2901	2446	- 16%
HCT	kg 1,4-DCB/ha/year	7440	7162	- 4%
HnCT	kg 1,4-DCB/ha/year	39999	33924	- 15%
WC	m^3/ha/year	3475	3304	- 5%

Table 8 - Characterised environmental impacts for the test site in Almería, Spain.

The table below shows the percentage contributions of each stage for each impact category (Figure 4):

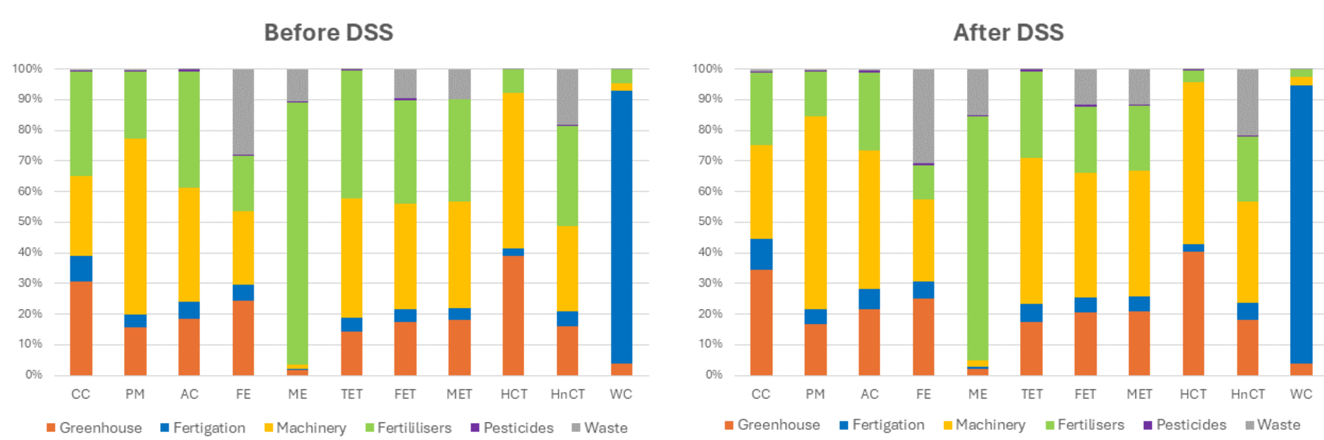

Figure 4 - Contribution analysis of LCA-based environmental impacts for the test site in Almería, Spain.

Fertilizers are clearly a hotspot, with high impact values in almost all selected impact categories. Before DSS, fertilizers show high contributions, especially in the ME (86%), TET (42%) and AC (38%) categories. These impacts are mainly due to the extensive use and production of nitrogen fertilizers and manure. Emissions from agricultural machinery are another hotspot, impacting most in the PM (57%) and HCT (51%) categories. Construction and maintenance of greenhouses also involves impacts in most categories, with peaks in HCT (39%) and CC (31%) before DSS. These impacts arise mainly from the transport of materials, as well as from industrial processes for the creation of plastic materials and steel structures. The use of IPM strategies leads to negligible environmental impacts in the pesticide stage. The fertigation system is simple, with few elements, and causes low environmental impacts compared to the other process steps, except for water consumption (WC). Waste contributes to the FE (28%), HnCT (18%), ME (11%) and aquatic ecotoxicity (10%) categories, especially from the disposal treatments of plastic materials. After DSS, the reduction in fertilizers amount impacted mainly in the ecotoxicity categories (-14% in TET and -12% in MET and FET) and HnCT (-11%) categories and with an average of -8% in the other categories. The contributions of the other process steps remained unchanged.

4.1.3. Life cycle costing

The LCC inventory is available from Annex 1.

The table 9 shows the results of LCC.

Impact indicators	Unit	Before DSS	After DSS
TCOP	€/ha/yr	77,436	76,230
NPV	€/ha/20 years	254,007	338,831
PI	-	1.59	2.12

Table 9 LCC indicators for the test site in Almería, Spain.

Since only half of the costs concerning the greenhouse structure and fertigation system are considered in this analysis, the investment for the activity is relatively low. The abundant production of cluster tomatoes, estimated at 127 t of commercial yield before DSS and 131 t after DSS, and sold for an average price of 0.69 €/kg allows a good annual return. The figure 5 show the annual cost distribution.

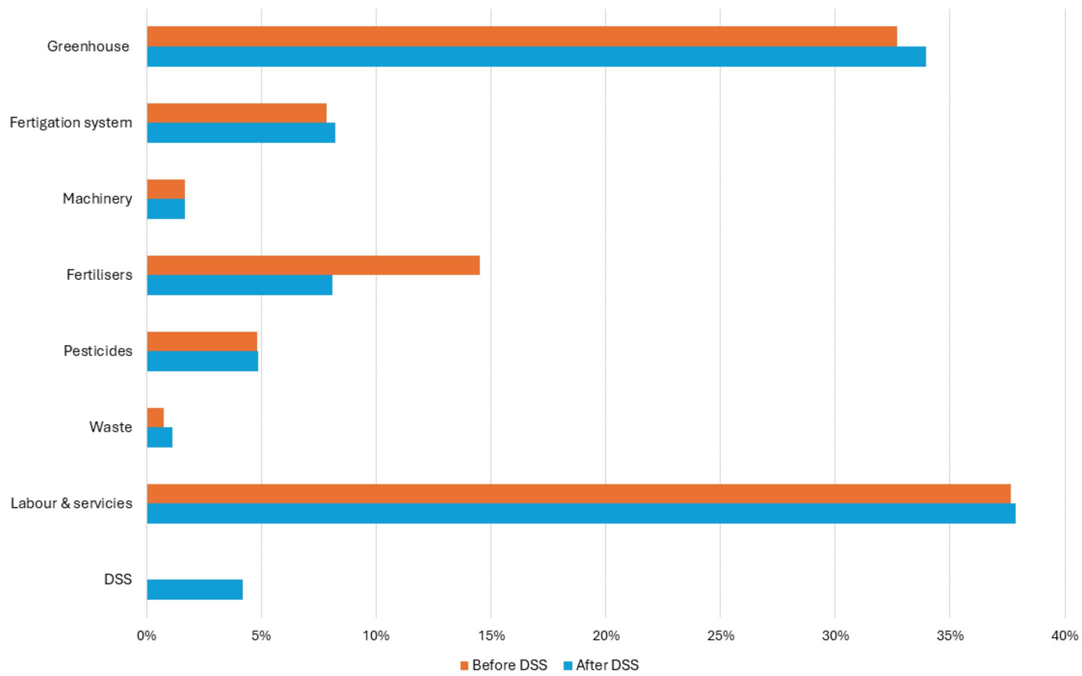

Figure 5 - Contribution analysis to TCOP for the test site in Almería, Spain.

In Almería case study, the largest annual costs are labour and service costs (38%), which include taxes, consulting, and pension contributions; followed by greenhouse construction and maintenance costs (33% of total costs). The significant reduction in the amount of fertilizer led to almost halving its price, from 15% to 8% of TCOP. Simple fertigation system accounted for 8% of annual total costs. Pesticide purchase covered 5% of TCOP, agricultural machinery covered only 2% of TCOP, while waste disposal accounted for 1% before DSS and 0.8% after DSS. Purchase, use and maintenance of DSS influence 4% of total annual costs.

4.2. Needs, Expectations and Impact assessment

4.2.1 Context analysis

In Spain, there is 56.286 ha of permanent greenhouse structures, including the greenhouse surface area, and 13800 ha of non-permanent, mono-span tunnels. The greenhouse area in Spain is approximately 4400 ha (MAPA, 2019).

The main permanent structure greenhouse area is Almería. Agricultural production and its auxiliary industry provide directly almost 45% of local employment. There are three main areas of employment: low-skilled workers involved in field tasks, packaging and delivering (92,000); medium-skilled workers involved in auxiliary industry, transport and other supporting services (12,000); high-skilled professionals related to crop management, quality control, consultancy and marketing (1200); and a small percentage of scientists and technicians, involved in innovation and developments tasks (350).

Almería province is in the southeast of Spain, on the Mediterranean coast. Its landscape corresponds to a warm semiarid climate with an annual average temperature of 22 ºC, ranging between 18 ºC in winter and 29 ºC in summer, with an average annual precipitation of 225 mm. It can be noted that the cropped land constitutes about 3% of the total surface, while the remainder corresponds to forest and scrub. The main economic activity in the Almería region is intensive horticultural cropping, a well-consolidated production system. In less than 50 years, Europe's major horticultural production area has been developed, covering an area of about 32,554 ha (the largest concentration of greenhouses in the Mediterranean Basin), producing almost 3.3 million t of fruit and vegetables annually. The market value of such production is more than 2.2 billion €. About 70% of production is exported, reaching more than 500 million consumers. Commercialisation is based on farmer cooperatives. Gradually a strong commercial infrastructure has been consolidated based on cooperatives, which have incorporated modern post-harvest, logistic and traceable food chain management systems. Today, there are 200 fruit and vegetable marketing companies employing 28450 people.

Greenhouses have very simple structures, plastic covering, poor climate control and, very often, lack heating systems. The original Almería greenhouse is the Parral, an adaptation of the traditional structure of wood and iron-wire used to support grape vines, with a flat roof. This type of greenhouse involves 29% of the greenhouse area and has evolved into a Symmetric multi span greenhouse (63.8 % of the greenhouse area), which has small roof slopes and roof vents (García et al., 2016). Irrigation is managed 100% with Drip irrigation and the 63% of greenhouse are equipped with advanced fertigation systems automatic irrigation control.

The main growing media is “enarenado” soil with of 92.2% of greenhouses area (García et al., 2016). Enarenado is an artificial soil that is prepared as follows: on the original (poor) soil, growers apply, in sequence, a layer (30 cm) of clay soil, a 2-cm deposit of manure and a third layer of sand (10 cm). The soilless technique is used in only 9.8% of the Almería greenhouse area (Perlite 46.6 %, rock wool 21.6 %, coconut fiber 31.8 %, others 2.2 %) (García et al., 2016).

The production is based on family farming; the average size of each holding is 1.5-2.4 ha (García et al., 2016). Usually, there are two cropping seasons per year.

The main economic activity in the Almería region is intensive horticultural cropping, a well-consolidated production system. In less than 50 years, the major horticultural production area in Europe has been developed, covering an area of about 32,554 ha which produces almost 3.3 million t of fruit and vegetables annually. The market value of such production is more than 2.2 billion €. About 70% of production is exported, reaching more than 500 million consumers.

Towards the middle of the 20th century, the Spanish government encouraged a horticultural production system based on family farming, greenhouse structures and irrigation technologies. In less than 50 years, the major horticultural production area in Europe has been developed. Several factors have been critical to the socio-economic development of this agricultural region.

Production is based on family farming as the result of a policy plan for colonising the area. During the first decades (1960–1980), whole families worked on farms. Since the end of the eighties, the increasing intensification of the family farming model has resulted in the need for family labour to be supported by immigrant labour, mainly from different African countries and Central-Eastern Europe. The average size of each holding is 2.6 ha. Today's farmers are the third generation with a significantly higher education than their forebears. From the organisational point of view, farmers are organised in communities focused on water management and infrastructure, including desalination plants, groundwater extraction, conductions, and reservoirs. These communities are in close contact with local and regional policy-makers and public administrations.

Additional information is available from Annex 2.

4.2.2 Needs and Expectations

The local climate allows crops to be grown without heating or cooling the greenhouses, which means massive energy savings. The use of high technology results in higher yields with less input, including natural resources such as water. However, water scarcity is one of the main threats for agricultural productivity, which is based on groundwater extraction

The contribution of knowledge to food safety is remarkable and has been essential to ensuring access to international markets, as most of the production is exported. The current successful agro-industrial production system would have never become a reality without continuous efforts to channel agronomic science while simultaneously developing new technologies to test the newly developed scientific and technological approaches in the terrain. The fact that almost everything concerning S&T had to be built and developed ex novo in the last three decades has favoured the establishment of strong links and alliances between the different stakeholders: farmers, plant breeders, agronomists, industry in general, financial operators and academics, where new ideas and technologies favoured their blossoming and testing.

Training and education are two very important pillars of agriculture. With training, we can achieve a more sustainable and digitised intensive agriculture. Education promotes tolerance between people (social inclusion), and the reconciliation of work and family life. Public and private institutions are working to ensure that people are better educate and that all the information generated in trials reaches all stakeholders. As far as our products are concerned, there is a growing awareness that we need to sell health and that our production system needs to be enhanced. Politicians and associations need must work more closely between contracts and better salaries.

Achieving a competitive and sustainable greenhouse sector requires a robust education, knowledge, and technological transfer foundation. Reaching more demanding consumers is essential, and it requires improving the sector's reputation through transparent production practices. Additionally, efforts must be made to enhance social inclusion, work-life balance, and workers' rights to ensure an inclusive and sustainable agrifood system.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Favourable climatic conditions • Existence of strong organisational structures (cooperatives, irrigation communities, trade unions, etc.) • Excellent marketing logistics • Extensive ancillary industry (you have what you need close at hand). • Great technical advice • A very flexible and dynamic community of farmers and cooperatives, able to absorb changes and promote new strategies in the sector. • Irrigation management and management technification • Continuous research is carried out by public and private institutions in all areas related to agriculture.	• Weak bargaining power of farmers in the value chain • Existence of many middlemen (low prices for the farmer) • Promote socially fair and equitable working conditions (wages, family reconciliation). • Lack of environmental awareness (abandonment of plastics, plant waste, phytosanitary bottles). • Seasonal crop planning could be improved to avoid overproduction and thus low cost of some crops.	• Low-cost technologies developed and evaluated in the greenhouse industry would lead to water savings and a reduction in nitrate leaching. • Ability to adapt quickly to market requirements (sustainability, product taste, special varieties, etc.). • The existence of a market that is increasingly demanding more sustainable production processes (organic farming and Integrated Pest Management). • In Almería, the current rate of young people is enough to facilitate (digital tools) DATS expansion, especially among the advisors. • DATS can be a good opportunity to demonstrate to the consumer that greenhouse production meets the requirements of ecology and sustainability towards which it is tending to.	• Water scarcity • Competition with other markets outside the EU • Lack of waste treatment infrastructure • Very high investment for the purchase and construction of greenhouses. This limits access for young people. • Rising production costs (fertilisers, fuel, seeds, etc.) • Improvement of rural hygiene in the surroundings of the greenhouse area. • The need to raise awareness and inform the international community about the commitment of the agricultural sector to move towards a sustainable model (Consolidating the Spain brand).

Table 10 - SWOT analysis for the test site in Almería, Spain.

Need	Description	Stakeholders
Education, training and transfer.	Achieving an agriculture where there is - Technological implementation - Environmentally sustainable it is necessary to established the education, knowledge and knowledge transfer.	Politics, growers, advisor, society, farmers' association, cooperative owners, public and private centres (schools, universities)
The market is the top priority	Market requirements must be the top priority and we must work on elements that differentiate us from the competition.	Cooperative owners, growers, farmers' association,
Visibility and product awareness	It is necessary to publicize the potential of the produce and improve its image. Publicize and explain the production system.	Cooperative owners, growers, farmers' association,
Employment improvements	Work on social inclusion, work-life balance is needed and workers' rights	Cooperative owners, growers, farmers' association, politics, public and private centres (schools, universities)

Table 11 - Needs analysis for the test site in Almería, Spain.

4.2.3 Participatory impact assessment at the territorial level

During Living Labs, stakeholders were asked to assess the impacts of the diffusion of this new technology at the company and territorial levels. The following table (Table 12) shows the answers obtained in the questionnaire.

Broad issue	Average weight	Indicator	Average score
Economic	0.35	Increase of farmer competitiveness	7.3
		Creation of rural jobs	5.4
		Greater availability of sustainable technology for greenhouses	8.1
		Risk of misuse of technology	5.1
Social	0.30	Improvement of working conditions	5.4
		Greater equity in the distribution of value added along supply chain actors	5.0
		Greater affordability of food	5.0
		Increased trust among value chain actors	6.1
		Improvement of farmer health	5.6
		Greater food safety	6.8
		Greater job opportunities for women	4.3
		Increase of female entrepreneurship in agriculture	4.5
		Improved farmer education	6.4
		Improved women education (especially in farming)	5.8
		Improved farmer livelihood	6.5

		Condition for vulnerable groups (i.e. minority & migrants)	4.3
Environmental	0.35	Increased protection of ecosystems	7.4
		Cleaner surface water bodies	6.9
		Cleaner underground water	7.5
		Increased availability of water for agricultural uses	6.9
		Increased biodiversity	6.5
		Increased soil quality	6.9
		Reduced climate vulnerability	5.4
		Increased water security	6.8

Table 12 - MCA results for the test site in Almería, Spain.

Although all three upper-level criteria are very close each other, the stakeholders agree that economic and environmental criteria have the highest priority. Among the economic criteria, the competitiveness of greenhouses and the availability of sustainable technology largely dominate all others. Among the social criteria, improving livelihood, knowledge, and food safety are the most important. Conversely, the condition of vulnerable groups and female entrepreneurship are perceived as less relevant than the others. Finally, the environmental impacts are concerned with increased ecosystem protection and water management, mainly for groundwater. On the contrary, the reduction of climate vulnerability is perceived as less relevant.

4.3 Social impact assessment at the test site and territorial level

The list of social indicators of the MCA was used to ask stakeholders about the qualitative social impacts of the DSS at the test site and territory level. A summary of the results is shown in the table below (Table 13).

Indicator	**Test site level**	**Territorial level**
Increase of farmer competitiveness	• Reduced fertiliser costs and efficient use of water • Reducing production costs, but also labour costs through task facilitation • Optimisation of input use can contribute to improved competitiveness • Reduction of working hours and time spent in the greenhouse • Obtaining products of equal or better quality by saving water and fertiliser	• More availability of water resources by increase of efficiency • Reduction of drought problems in the region • The use of fewer inputs is beneficial for all links in the agri-food chain and can help improve competitiveness • Decrease in the use of area-limiting resources and reduction of pollution from overuse of fertilizers • Implementation of sustainable production strategies. Improvement of image in the markets.

Indicator	Test site level	Territorial level
	• Saving resources and thus reducing costs.	• Creation of an attractive environment for future farmers • Better quality production • Increased competitiveness with higher profit productions and lower production costs • More availability of water resources by increase of efficiency
Creation of rural jobs	• Creation of new skilled jobs for the use of such tools • Redistribution of tasks, leaving time for other cultural tasks. • Increased need for specialised technicians • Less need for personnel, therefore loss of jobs • No effect	• Sustainability will be a must in the coming years, so qualified personnel trained in the use of effective tools are needed. • Development of additional consulting services, creation of personnel and repair institutions • Creation of jobs related to technology management • Reduction of jobs due to automation of production • Increased competitiveness in relation to other regions, increased attractiveness of the sector • Increased revenue • No effect
Improvement of working conditions	• Reduced working hours and therefore less risk • Healthier environment for workers due to reduced use of chemicals • Simplification of attention-intensive tasks • Increased productivity • Reduction in human error • Increased knowledge of farmers, preparation for more advanced and modern agriculture • Reduction of time needed for nutrient preparation and climate management • No effect	• Improvement at the level of individual companies benefits all workers regionally • Increased consultancy work • Better access to social certifications • Creation of remote jobs for software maintenance and improvement • Reduced need for field visits and less chance of making mistakes • Better trained workers • Reduced working hours and production costs • Less physical or mental effort for producers • No effect
Greater equity in the distribution of value added	• The farmer, by using the DSS, can demonstrate that he is doing good management and can therefore demand fairer prices	• Improved industry image, new quality standards and more competitive prices

Indicator	Test site level	Territorial level
along supply chain actors	• Reducing inspections at downstream stages of the supply chain • Improved profitability, investments to improve production facilities • Same market volume for all companies • Differences in the supply chain will remain despite the farmer improving management • Increased production/product value • Response to consumer demand for more sustainable production, who will be willing to pay more • Higher quality at lower production cost • No effect	• New roles in the supply chain are created for specialised technical advice • Prices may increase because there is more competition between farmers • Reduction in production costs but same sales price • The designation of a certificate for the use of this application would contribute to greater confidence in the product • The use of new technologies can increase the value of the product and thus the selling price. • No effect
Greater affordability of food	• Increased efficiency can lead to more competitive products that can be offered at lower prices • No effect because difficulty of access comes from the distribution platforms, not the farmer • Facilitates control and cost reduction without leading to a decline in farm profitability • Increased demand, stabilized prices • By reducing the cost of fertilizer and water, the farmer will continue to produce and with less economic loss, leading to less abandonment of farming • Optimizing input dosages reduces the risk of disease or plant growth retardation • Savings on inputs • By lowering production costs, the farmer has a higher profit margin even without raising product prices	• Increased efficiency can lead to more competitive products that can be offered at lower prices • No difference because difficulty of access comes from the distribution platforms, not the farmer • Reduced costs mean lower end prices • Redistribution of wealth, improved image of the industry, healthier food. • Many companies will be interested in this DSS because it increases contracting with large-scale retailers • More or equal production with less input use • By reducing the cost of production, the farmer will be able to produce with less economic loss, leading to less abandonment of agriculture • Greater competitiveness with other regions due to the profit margin obtained • No effect

Indicator	Test site level	Territorial level
	• No effect	
Increased trust among value chain actors	• More controlled products enable quality assurance, increasing consumer confidence • Greater control and expert advice • More stable price dynamics, production planning • Reduced risk of human error • Ability to access sustainability and good management certifications	• Production will be more aligned with EU guidelines, framed in the farm-to-fork strategy. • Improved product image, because more sustainable crop management is ensured through the use of DSS. Gaining confidence in the European market compared to products from other areas • Cost reduction with the same yield is beneficial to all and provides added value as it shows an image of sustainable production • Data availability facilitates monitoring by intermediaries and consumers • Ability to access sustainability and good management certifications • Use of DSS can generate an image of good resource use in the region • Reduction of human error • Will improve trust among supply chain actors due to increased traceability and control of production
Improvement of farmer health	• Increased monitoring of working conditions • Reduced use of pesticides ensures less exposure of workers to potentially toxic substances and thus a reduction in the occurrence of work-related illnesses • Better health for farmers and thus better quality of life • Reduction in mental problems resulting from stress or other occupational diseases due to overwork. • Preventive alerts can allow treatments to be minimized and thus reduce worker exposure • Reduction in time spent in the greenhouse • No effect	• Increased monitoring of working conditions • Reduced use of pesticides ensures less exposure of workers to potentially toxic substances and thus a reduction in the occurrence of work-related illnesses • Better health for farmers and thus better quality of life • Reduction in mental problems resulting from stress or other occupational diseases due to overwork. • Preventive alerts can allow treatments to be minimized and thus reduce worker exposure • No effect

Indicator	Test site level	Territorial level
Greater food safety	• Reduction of chemical residues on food products • May help reduce nitrate concentrations in vegetables • Greater assurance of product healthiness • No effect	• Reduction of chemical residues on food products • Allow a better image of sustainability and circularity in production. • It gives you greater security, whether from diseases, pathogens or toxic waste • Less risk of poisoning due to the excessive use of phytosanitary products • May help reduce nitrate concentrations in vegetables • No effect
Greater job opportunities for women	• Creating new opportunities for qualified young people, including women • No effect	• Creating new opportunities for qualified young people, including women • Use of DSS could provide more opportunities for women and lower their unemployment rate • No effect
Increase of female entrepreneurship in agriculture	• Access to digital solutions can significantly increase opportunities for women entrepreneurs • Increased opportunities for flexible work, which can make the sector more attractive • Facilitation of production management, increased accessibility to the sector • No effect	• Digital platforms often have lower barriers to entry compared to traditional businesses. This means that female entrepreneurs can start their businesses with less initial capital and overhead costs, making entrepreneurship more accessible. • Remote management can provide more time to invest in complementary business activities • No effect
Improved farmer education	• Digital solutions allow farmers to access a wide range of information about farming practices. • The use of innovative technologies can push farmers to inform themselves and take training courses to increase their knowledge • Increased awareness of gaps and mistakes resulting from management based on experience alone	• Digital solutions enable farmers to access a wide range of information related to agricultural practices • A more technologically educated production sector is more open to innovations and more dynamic in the face of possible market changes • Increased supply of centres with specific training • Improved functioning of the value chain, establishment of partnerships

Indicator	Test site level	Territorial level
	• Need for continuous improvement and adaptation through training • Greater attractiveness of the sector to young people, increased turnover and farm modernization • No change due to distrust of technology, considered too complicated for many older farmers • No effect	• Improved knowledge of farmers will enable more sustainable management and higher quality productivity • Increased attractiveness of the sector for young people, new investment and modernization • No effect
Improved women education (especially in farming)	• Digital solutions enable farmers to access a wide range of information related to farming practices • Need to increase their training to make the most of new technologies in the sector • No effect	• A manufacturing sector with more education makes it more dynamic and assertive in the face of possible market changes. • As with male education, new female generations will be more attracted to new technologies and improvements in the industry. • No effect
Improved farmer livelihood	• Digital platforms enable farmers to access wider markets beyond their local area, increasing business opportunities • Remote control and automation of water and fertilizer dosage calculations reduces time in the greenhouse and overall labour hours • Creating a more comfortable and safe environment • Reduced unnecessary costs, increased income and purchasing power • Improved overall profitability • Increased productivity and efficiency • Reduced human risk in management, which makes work less stressful and enables better management of one's time (improved quality of life) • No effect	• Digital platforms enable farmers to access wider markets beyond their local area, increasing business opportunities • By improving livelihoods, agriculture becomes a more attractive industry for young people. • Increased overall standard of living, better work-life balance • Improved image of the sector • Better working conditions for hired staff • Greater agricultural profitability, resulting in improved quality of life for farmers • Less time spent in the greenhouse • Livelihoods for farmers improve and activities diversify, thus improving the region's economy • No effect

Indicator	Test site level	Territorial level
Condition for vulnerable groups (i.e. minority & migrants)	• Although digital solutions in agriculture have great potential for empowering minorities and vulnerable groups, there are indeed barriers that need to be addressed to ensure equitable access and benefits. • General improvement of the entire society involved in the production chain • Reducing the number of workers, less place for illegal labourers • Facilitates job placement for anyone with competencies in these types of technologies • No effect	• Although digital solutions in agriculture have great potential for empowering minorities and vulnerable groups, there are indeed barriers that need to be addressed to ensure equitable access and benefits. • Improving the integration of minorities and immigrants • Reduces the marginalization of the area by facilitating job placement. • A region with less illegal immigration by issuing software electronically • Can be an important barrera, because immigrants in most cases lack adequate training, which can lead to poorer or more precarious contracts • Facilitates job placement for anyone with competencies in these types of technologies • No effect

Table 13 - Results of the social impact assessment in Almería, Spain, at the test site and territorial level.

Through efficient water use and optimizing input use, DSS can shrink fertilizer costs and labour requirements. This leads to reduced working hours, saving resources, and obtaining high-quality products. However, while adopting new tools may create skilled jobs, it can also reduce the labour demand. This may be in contrast with the creation of a healthier environment for workers, higher increased productivity, reducing the probability of human error, and better preparation for advanced agriculture.

DSS allows farmers to improve their management practices, which can increase prices and reduce downstream inspections while improving profitability and product value. It optimizes input use, reduces costs, and enhances efficiency, leading to higher-quality products at lower production costs and greater consumer confidence in sustainable production. Additionally, it promotes better working conditions and health for farmers by reducing exposure to chemicals and work-related stress, although some areas may experience no significant effect.

Access to digital solutions can significantly increase opportunities for women entrepreneurs and make the agricultural sector more attractive and accessible through flexible work options and production management facilitation. Digital tools enable farmers to access extensive information on farming practices, necessitating continuous improvement, and training, and attracting young people to modernize farms. These solutions also improve profitability, efficiency, and safety, while expanding market reach and reducing working hours, though there are barriers to equitable access and some farmers may resist technology.

5. Monastir, Tunisia

Focal question of the LL: "*How to make effective use of the DSS to improve the environmental performance of soil cropping with chemical pest control and water harvesting system, while supporting profitability and reduction of workload and health risk for farmers, as well as encouraging new entrants (especially young farmers and women)?"*

5.1. Life cycle assessment and life cycle costing

5.1.1. Description of the test-site

The studied greenhouse is an asymmetrical multi-chapel greenhouse located in the centre-east of Tunisia precisely in the governorate of Monastir (location coordinates: 35°45'18" N, 10°49'16" E). The greenhouse is 50 m long and 30 m wide, and has a total protected area of 0.15 ha, 0.14 ha of the area is dedicated for tomato cultivation. The height at the ridge is 6 m; the height at the gutters is 4 m. The structure is made up of three spans, made up of galvanized steel arches, with concrete anchoring and LDPE coating. The plastic coating is completely replaced every 3 years. There is a door 3.2 m high and 3.6 m wide. The floor is completely covered with PP mulch cloth. The ventilation openings (roof, end walls, side walls; for a total of 410 m^2) are operated manually. HDPE insect nets cover all openings.

The crop variety is Pai Pai grafted on winner, was trained on two arms with a total density of 1.6 plants/m^2. The tomato plants are supported by wires and clips, which are replaced every year. The plants are cultivated for 225 days, transplanting being carried out at the beginning of October and harvesting at the beginning of February. 13 pollination hives are used for the production cycle. Fertigation is provided by drip irrigation system. The pumping unit is located at the entrance of the greenhouse. The nutrient solution is pumped from the fertigation unit to the crop by means of a pump that draws water from the well and rainwater harvesting pond in PVC. A hand sprayer transported by a tractor is used for pesticide treatment. The farmer also rents a 23 cv tractor for field operations. The gross production is 166 t/ha, with a salable of 162 t/ha. The tomatoes are sold directly to a local retailer for €484.00/t. The tomatoes are transported in 28 kg LDPE boxes and sold directly to a local retailer. The owner, a family collaborator and 6 other seasonal employee work on the farm.

Before DSS, chemical pest control was carried out; while after DSS installation, this new technology was used to incentivize integrated pest management (IPM) by increasing the use of active ingredients allowed in organic and beneficial insects for pest control.

5.1.2. Life cycle assessment

The LCA inventory is available from Annex 1.

The table shows the environmental impacts divided into their respective categories before and after DSS. The table below shows the contributions for each impact category (Table 14):

Impact categories	Unit	Before DSS	After DSS	Percent change
CC	kg CO_2 eq/ha/year	54,087	53,957	0%
PM	kg PM2.5 eq/ha/year	150	150	0%
AC	kg SO_2 eq/ha/year	390	390	0%
FE	kg P eq/ha/year	37	35	- 3%
ME	kg N eq/ha/year	15	15	- 3%
TET	kg 1,4-DCB/ha/year	167,203	107,732	- 36%
FET	kg 1,4-DCB/ha/year	2453	2258	- 8%
MET	kg 1,4-DCB/ha/year	3077	2976	- 3%
HCT	kg 1,4-DCB/ha/year	8305	8300	0%
HnCT	kg 1,4-DCB/ha/year	53,139	52,069	- 2%
WC	m^3/ha/year	3775	3775	0%

Table 14 - Characterised environmental impacts for the test site in Monastir, Tunisia.

The table below shows the percentage contributions of each stage for each impact category (Figure 6):

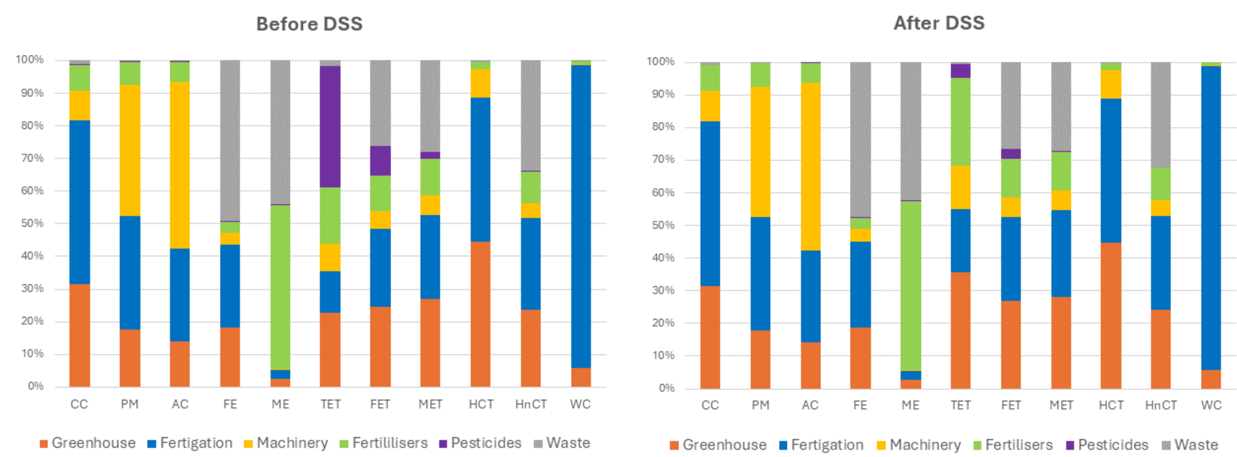

Figure 6 - Contribution analysis of LCA-based environmental impacts for the test site in Monastir, Tunisia.

In the Tunisian case, waste is a hotspot, both because of the large amount of plastic going to landfill and because of the great distance of disposal points from the greenhouse. It particularly affects the ME and FE categories (44 and 49%, respectively), but also HnCT (34%) and aquatic ecotoxicity (about 28% in MET and 26% in FET). The emissions of agricultural machinery are also a hotspot, with a peak in contributions in AC and PM (40 and 51%, respectively). The fertigation system affecting mainly the CC category (50%), due to other plastic production (pipes, rain harvesting systems, etc.), and of course the WC category (93%). The production of greenhouse materials, their transportation and use contribute to most impact categories, with peaks in HCT (45%), FET and MET (both about 27%). Fertilizers mainly impact ME (50%), resulting from the extensive use of manure and potassium sulphate. Chemical pesticides used before DSS showed high contributions to the TET category (37%) and moderate content in the FET and MET categories (9% and 2%, respectively). These impacts are greatly reduced with the introduction of IPM in the DSS, falling to zero in MET and resulting in -33% impact in TET and -6% impact in FET.

5.1.3. Life cycle costing

The LCC inventory is available from Annex 1.

The table 15 shows the results of LCC.

Impact indicators	Unit	Before DSS	After DSS
TCOP	€/ha/year	48,543	51,932
NPV	€/ha/20 years	162,013	151,737
PI	-	1.26	1.18

Table 15 - LCC indicators for test site in Monastir, Tunisia.

The abundant production of tomatoes, amounting to about 153 t/year, is sold at an average price of €0.48/kg, allowing a good annual yield. The TCOP were divided into the same subcategories used for the LCA analysis, with the addition of "labour and services," which includes workers' wages, consultancies, contributions, and taxes incurred by the owner; and "DSS," which includes costs for the control unit, sensors, and software. The figure below shows the annual cost distribution.

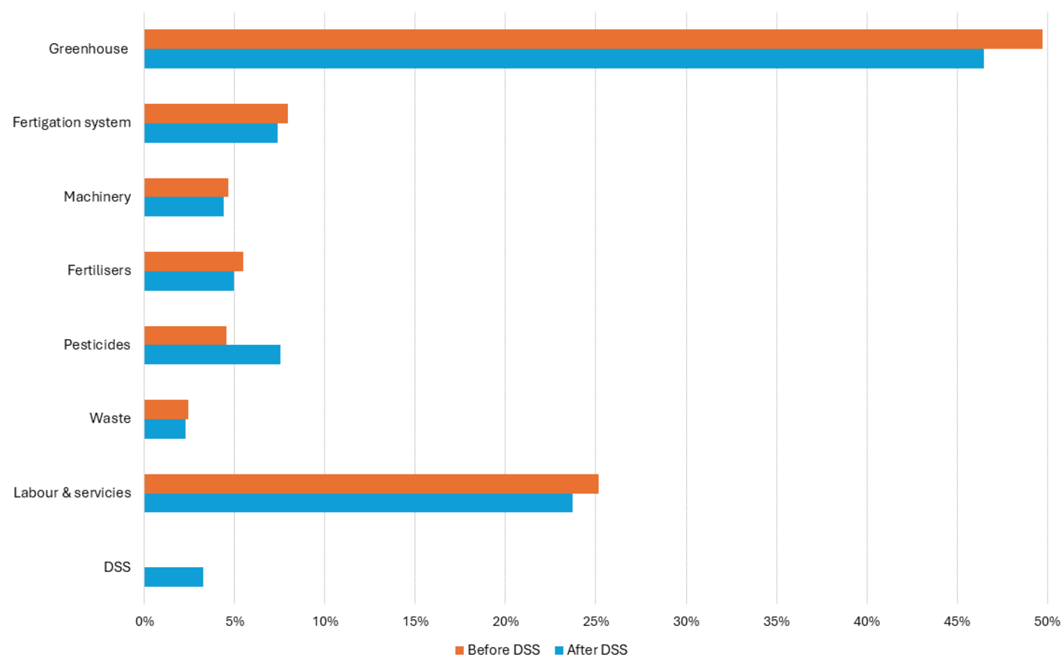

Figure 7 - Contribution analysis to TCOP for the test site in Monastir, Tunisia.

As can be seen from Figure 7, the largest annual costs are greenhouse design, transportation, construction, and maintenance, which cover 50% and 46% of TCOP before and after DSS, respectively. Labour, taxes, consultation, and pension contributions account for the second largest cost item (25% before DSS and 24% of TCOP after DSS). The fertigation system and the artificial plastic pond accounted for 7-8% of total annual costs, respectively, while fertilizer purchase covers 5%. Farm machinery use and maintenance require 5-4% of TCOP, while waste disposal costs are just 2%. Chemical control of pesticides before DSS system occupied a 5% slice of TCOP, which increased to 8% with the introduction of IPM. DSS affects 3% of the TCOP.

5.2. Needs, Expectations and Impact assessment

5.2.1 Context analysis

Tunisia's agricultural sector primarily consists of small-scale family farmers that grow subsistence crops, but larger agricultural companies are becoming more prominent. Vegetable crops cover an area of 150,000 ha. In Tunisia, the development of crops under greenhouses covered with plastic to produce vegetables began in 1974 in the region's coastal areas with warm winter. Non heated greenhouses (mostly tunnels covered with plastic) are in Monastir, Sfax, Mahdia and Sidi Bouzid. grow from December to the end of May. These greenhouses grow from December to the end of May (Soethoudt et al, 2018).

In 1986, the State started using geothermal energy for greenhouse farming in the south by planting an area of 1 ha. The results of this experiment were very encouraging and thus, the areas today have increased to 255 ha. Production is from November till the end of May and are in the regions of Gabes, Tozeur, and Kebili. These off-season vegetables are only used for fresh consumption and mainly exported. These greenhouses are commercial greenhouses with a high technology level compared to the non-heated greenhouses.

Protected crops occupy around 7750 ha, and their production, estimated at 400,000 tons, represents around 14 % of the volume of market vegetables production and 20% of their value. These areas are divided into 6000 ha under small tunnels, 255 ha under heated greenhouses and 1517 ha under unheated greenhouses (ONAGRI, 2022).

The state of Monastir ranks first nationally in terms of production of protected vegetable crops, with an area of 650 ha, representing 42% of national production. Regionally, the early vegetable sector is considered one of the most important pillars of the economic cycle, as the number of greenhouses is approximately 12,000 and provides the equivalent of 67% of the total vegetable production in the region. It also contributes to providing the equivalent of 15,000 direct jobs. The greenhouses are located in irrigated areas through Nabhana system (Apia, 2015).

Monastir is a coastal Mediterranean city located about 150 km from the capital Tunis. It is geographically positioned at 35° 46′ 10″ N and 10° 49′ 10″ E and characterized by the extension of lands with low topography. Monastir region has an average annual rainfall of 328 mm with exceptional rainfall events. The main crops are chili pepper and 91 tomatoes and irrigated with water from the Nebhana dam (77% of irrigation water comes 92 from surface water), surface wells (39% of irrigation water comes from shallow groundwater) 93 and piezometers (7% of irrigation water comes from deep groundwater) (Khaskhoussy and Hachicha, 2020).

These greenhouses are family owned (80% of farmers own between 1 and 2 ha) and their production is marketed on the local market. The most dominant crop is pepper, followed by tomato cultivation. All agricultural inputs are imported (greenhouses, plastic, seeds, fertilizers, pesticides). To control diseases and insects, farmers use chemical pesticides (Jedder et al.,2018).

Additional information is available from Annex 2.

5.2.2 Needs and Expectations

The current potential of Tunisia for greenhouses sector and specially protected tomatoes is based on the climate, infrastructure, and policy incentives. There are many sun hours per day, the humidity is not too high, the soil is suitable for vegetables crops and infrastructure is available in many regions. In addition, certain regions provide the option of geothermal heating for tomato production. Other strengths of greenhouse's sector in Tunisia were cited to be favourable: creation of direct and indirect employment, high added value of crops, efficiently use of irrigation water and various tax incentives for foreign investment. Tunisia is also characterized by low rainfall and limited renewable water resources that affect availability and quality of irrigation water in greenhouses sector. Other weaknesses of the sector were related to small field sizes (mostly 1-2 ha), the little diversity of crops, the high production costs (imported multi-tunnel equipment, plants, fertilisers, pesticides, etc.), low financing capacity and saturated domestic market with little price evolution compared to costs. Low technical level of producers especially regarding disease and insect control and excessive use of pesticides are also weak points in the sector. Work in agriculture is hard and not prestigious, and young people tend to leave rural areas in the search for alternative activities in urban areas.

Demand is increasing for local and foreign markets and particularly for healthy food products. There are vast export opportunities. Regarding little diversity of crops, several other species can be introduced to improve employment and income and increase. To rebalance the forces, institutions should educate producers to organize collectively (eg. through cooperatives). This would improve the exchange of information, to be less dependent financially and encourage investment. Environmental issues are put on the political agenda recently, supported by financial incentives. This opens doors for waste treatment investment etc.

The major issues which can soon turn into serious threats to agriculture and greenhouses sector in Tunisia are the lack of water resources due to climate change, the abandonment of farmers and young people from working in this sector, the increase in the production costs and the deterioration of the livestock producers' profit margins (imported inputs, energy for greenhouses heating.

Improving farmers' knowledge regarding specific greenhouse crop production technologies and effective water, fertigation and pest management methods are recommended through the provision of better crop services. extension and training programs. Providing such information could reduce water variability and reduce the use of fertilizers and pesticide. Better organization of farmers could also improve their working conditions and incomes.

There is a strong need for targeted training in sustainable production methods for greenhouse farming, including technologies, agricultural chemicals, mechanization, and monitoring and controls. The greenhouse sector faces issues such as the abandonment of farming, low generational turnover, and the need for increased liquidity for farmers. Implementing effective agricultural policies to incentivize investment in sustainability technology and increase farmers' income is crucial. Establishing effective farmer organizations like cooperatives and unions is essential to address farmers' low bargaining power.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Most favourable pedoclimatic conditions • Sector creating strong employment • Crops with higher margins and added value / other plant productions • Efficiently use of irrigation water • Efficiently use of soil in terms of income • Existence of tax incentives for foreign investment	• Small field sizes • Production geared to a saturated domestic market, with little price development • Vegetable range poorly diversified • High cost of new multi-tunnel equipment • Low financing capacity • Seasonal production, does not guarantee continuous employment • High production costs • Low technical level of the producer • Poor availability and quality of irrigation water • Lack of control over quality and productivity (soil phytosanitary problems). • Lack of adequate packaging for marketing • Lack of organization among producers (e.g., cooperatives)	• Increasing demand for healthy food products • Wide export opportunities • Improvement of employment and income by the introduction of an autumn catch crop (bean or lettuce), allowing also a diversification of productions. • Potential for the development of the packaging activity, with the preparation of segmented and pre-packed products intended in particular for mass distribution. • Possibility of production for export by developing medium-sized farms (5ha) with mandatory recourse to supplementary heating (olive pomace or natural gas) to ensure the required quality • New financial incentives for environmental issues (e.g. waste treatment)	• Water shortages • Increased cost of energy and fuel (needed to heat the greenhouses) • abandonment of the activity due to low profitability • Lack of intervention by public authorities to renovate old facilities

Table 16 - SWOT analysis for the test site in Monastir, Tunisia

Achieving a competitive and sustainable greenhouse sector requires a robust education, knowledge, and technological transfer foundation. Reaching more demanding consumers is essential, and it requires improving the sector's reputation through transparent production practices. Additionally, efforts must be made to enhance social inclusion, work-life balance, and workers' rights to ensure an inclusive and sustainable agrifood system.

Needs	Description	Stakeholders
Improvement of technical skill of farmer and advisors	there is a strong need for more targeted training for sustainable production methods in greenhouse, for example, providing training to producers on production technologies, use of agricultural chemicals, agricultural mechanization technologies, making necessary inspections...	Farmers, cooperatives, advisors (especially youth and women)
More public support for sustainable technology	There is a problem due to abandonment of farming activities and low generational turn-over. There is also the need for more liquidity for farmers. Then there is a need for the implementation of effective agricultural policies to provide incentives to foster investment in sustainability technology.	Farmers, cooperatives
Better distribution on value added along the value chain	There is a need for increasing the income of greenhouse farmers to foster investment in sustainability technology. However, farmer have low bargaining power. Then effective farmer organizations (for example cooperatives, farmer unions) should be established.	Farmers, cooperatives, market, consumers

Table 17 - Needs analysis for the test site in Monastir, Tunisia

5.2.3 Participatory impact assessment at the territorial level

During Living Labs, stakeholders were asked to assess the impacts, at the company and territorial levels, of the diffusion a of this new technology. The following table (Table 18) shows the answers obtained from the questionnaire.

Broad issue	Average weight	Indicator	Average score
Economic	0.33	Increase of farmer competitiveness	7.0
		Creation of rural jobs	5.5
		Greater availability of sustainable technology for greenhouses	7.0
		Risk of misuse of technology	5.5
Social	0.30	Improvement of working conditions	4.5
		Greater equity in the distribution of value added along supply chain actors	3.5
		Greater affordability of food	4.5

		Increased trust among value chain actors	4.5
		Improvement of farmer health	4.5
		Greater food safety	4.5
		Greater job opportunities for women	4.5
		Increase of female entrepreneurship in agriculture	4.5
		Improved farmer education	4.0
		Improved women education (especially in farming)	4.0
		Improved farmer livelihood	4.5
		Condition for vulnerable groups (i.e. minority & migrants)	4.5
Environmental	0.37	Increased protection of ecosystems	4.5
		Cleaner surface water bodies	4.5
		Cleaner underground water	4.5
		Increased availability of water for agricultural uses	3.5
		Increased biodiversity	4.5
		Increased soil quality	4.5
		Reduced climate vulnerability	4.5
		Increased water security	4.5

Table 18 - MCA results for the test site in Monastir, Tunisia.

Although all three upper-level criteria are very close to each other, the stakeholders agree that environmental criteria have the highest priority. Among the economic criteria, Tunisian greenhouses show similar results to Spain, with quite high preferences for greenhouse competitiveness and the availability of sustainable technology. The social criteria show quite low value, indicating that stakeholders do not perceive them as a priority. Conversely, the condition of vulnerable groups and female entrepreneurship are perceived as less relevant than the others.

5.3 Social impact assessment at the test site and territorial level

The MCA's list of social indicators was used to ask stakeholders about the qualitative social impacts of the DSS at the test site and territory levels. A summary of the results is shown in the table below (Table 19).

Indicator	Test site level	Territorial level
Increase of farmer competitiveness	• Improved crop management • Targeted and effective interventions in input management • Decreased inputs with increased or maintained yields. • The use of DSS and IoT solutions enables farmers to make informed	• Use of technology can make the greenhouse sector more attractive to new entrepreneurs. • Encourage neighbouring farmers to adopt this

Indicator	Test site level	Territorial level
	decisions and improves almost all aspects of their work, • Reducing production costs • Improved product quality and quantity and reduced use of chemical inputs. It also enables better management of water, which is becoming increasingly scarce in the east-central region of Tunisia • With DSS, farmers can also monitor the conditions of their fields remotely and choose between manual and automated options to take necessary actions. It also allows them to predict and prevent crisis situations, enabling more thoughtful and efficient decision making	technology and related decision-making tools. • Optimization of yield and product quality • Preservation of agroecosystems, which is essential due to the continued reduction of agricultural land and depletion of natural resources • Increased operational efficiency of farms by automating and optimizing production lines. • Decreasing the use and import of chemical inputs, increasing the export of agricultural products.” • Encouraging investment in alternative greenhouse farming practices (e.g., soilless)
Creation of rural jobs	• Reducing the hiring rate of the agricultural labour force • Creation of new skilled workers • Increased opportunities for skilled agricultural labour, engineers, and technicians • No effect	• Use of IoT can attract young people interested in artificial intelligence to work in modern agriculture. • Reducing the hiring rate of the agricultural workforce • Creation of new jobs for computer or digital engineers applied to agriculture for smart farming. • No effect
Improvement of working conditions	• Reduced hours of on-farm presence and the possibility of remote management • Ease and adequacy of intervention • Decreased use of chemical pesticides	• Greater protection of human health and the environment • Reduction of working hours in the greenhouse, especially in case of disease or epidemic (e.g. covid). The farmer has fewer burdens, less stress and more free time.
Greater equity in the distribution of value added along supply chain actors	• More sustainable production system, increased bargaining power of farmers • No effect	• The use of DSS can enable a sustainable supply system • Can lead to greater equity between farmers, but does not guarantee greater equity

Indicator	Test site level	Territorial level
		between different actors in the supply chain • No effect
Greater affordability of food	• Reduction of production costs, which could have consequences on the sales price • Increased productivity and efficiency • Difficult to assess as it is still in the experimental phase • No effect	• Sustainable production system that takes into account the environment and offers healthy products • The use of IoT technologies will lead to an increase in feed costs. • Encourage farmers to come together in structures that enable them to invest in this type of technology to increase production • No effect
Increased trust among value chain actors	• A sustainable production system that minimizes production inputs, has a high yield and offers healthy products allows for increased confidence between suppliers, producers and consumers. • The DSS makes it possible to meet the changing demand of the population, from the downstream of the production chain (processor). • The DSS improves the traceability of chemical interventions, favouring the trust between all actors • No effect	• A sustainable production system that has proven its effectiveness will be preferred by the various actors in the value chain. • It can encourage the networking of farms to optimise activities and interactions along the entire value chain • Increased traceability of products and practices used • Consumers are becoming more and more demanding about pesticide residues and will have more confidence in the products of farmers who apply precision and smart technologies • No effect
Improvement of farmer health	• Reduced exposure of farmers to the risks of side effects of chemicals, with reduced risk of disease	• Farmers and their families (most farms are family-owned) are less exposed to chemicals and consume less polluted products • The DSS is able to change farmers' mindsets and habits in the excessive use of chemical inputs and to educate and

Indicator	Test site level	Territorial level
		encourage the adoption of IPM components. • Reducing farmers' exposure to pesticides would reduce the risk of cancer and other debilitating diseases
Greater food safety	• Use of DSS can reduce production inputs, reducing resudues and ensuring safer and healthier products • Supplying local and international markets with higher quality and controlled agricultural products • Creating a sustainable production system with crop diversification and large and stable yields. • No effect	• Reduction of pesticide residues on the product • Increasing or maintaining production by managing to limit unforeseen events due to the effects of climate change or human error • No effect
Greater job opportunities for women	• Creation of new jobs for consultants and specialized figures • No effect	• DSS, precision and smart agriculture, are attracting more and more women trained in computer science and digital technology to develop decision-making tools for farmers • No effect
Increase of female entrepreneurship in agriculture	• Assistive tools and technology attract female entrepreneurship for the development and improvement of these tools • No effect	• Smart farming and consultancy can attract women to entrepreneurship in agriculture • Women may be more attracted to organization and traceability • No effect
Improved farmer education	• DSS and the technologies used require a higher level of education among farmers, which could encourage them to improve their skills and knowledge • Need to create courses and organize information days	• The need to learn how to exploit technologies to improve production is pushing farmers to inform themselves and improve their knowledge • Greater attractiveness of the sector for young people • Access to information can change the current mentality of agricultural work • Greater interest in sustainable production in the long term • DSS provides farmers with access to in-depth information

Indicator	Test site level	Territorial level
		about their operations, from field mapping to climate analysis.
Improved women education (especially in farming)	• No effect	• No effect
Improved farmer livelihood	• Greater exploitation of agroecosystems in the long term, preserving natural resources and reducing the impact on the environment • Lower consumption of resources (water and soil) and production costs while maintaining yield	• Greater exploitation of agroecosystems in the long term, preserving natural resources and reducing the impact on the environment • A sustainable production system can improve farmers' livelihoods. • Optimize of production system
Condition for vulnerable groups (i.e. minority & migrants)	• No effect	• No effect

Table 19 - Results of the social impact assessment in Monastir, Tunisia, at the test site and territorial level.

The use of DSS and IoT solutions in agriculture improves crop management, reduces production costs, and enhances product quality and quantity while decreasing the use of chemical inputs. These technologies allow farmers to make informed decisions, optimize water management, and remotely monitor and manage their fields, leading to more efficient and sustainable farming practices. They also make the greenhouse sector more attractive to new entrepreneurs and encourage neighboring farmers to adopt similar technologies. Additionally, the adoption of DSS increases operational efficiency, and can create a demand for new skilled jobs, and attracts young people interested in modern agriculture.

DSS enhances traceability, meets changing market demands, and educates farmers on reducing chemical use, thereby increasing consumer trust for greenhouses products. DSS can also network farms to optimize value chain activities, create new job opportunities, and attract women and young people to agriculture. Reducing farmers' pesticide exposure improves their health and safety, while DSS helps maintain production levels amid climate and human challenges. . Overall, these advancements contribute to the preservation of agroecosystems, the protection of human health, and the reduction of working hours and stress for farmers.

The DSS can have neglected impact on social dimension, especially on gender and female entrepreneurship or in the condition of vulnerable groups (migrants).

6. Antalya, Turkey

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Focal question of the LL: "*How to make effective use of the DSS to improve the environmental performance of soil cropping with chemical pest control, while supporting profitability and reduction of workload and health risk for farmers, as well as encouraging new entrants (especially young farmers and women)?*"

6.1. Life cycle assessment and life cycle costing

6.1.1. Description of the test-site

The Turkish greenhouse is part of a family farm located in Abdurahmanlar county (Serik district), about 30 km east of the centre of Antalya (coordinates: 36°58'13"N, 30°56'08"E). The greenhouse covers an area of 4200 m^2. The height at the ridge is 4.5 m; the height at the eaves is 3.0 m. The structure consists of seven bays, consisting of a circular iron profile, with concrete anchorage and LDPE roofing. There is a ventilation opening on the ceiling, operated by an electric motor, and manually operated side openings on the north and south sides (1.2 m high and 50 m long).

The variety cultivated is the cluster tomato. The seedlings are transplanted in a double row cultivation system, with distances between each double row being 1.2 m. The density is 2.5 plants/m^2. Cultivation takes place in two production cycles: from the beginning of September to the end of January for the autumn period; and from the end of February to the end of June for the spring period; for a total of 146 days. Fertilisation is done by means of a Venturi-controlled drip irrigation system. The farmer rents both a turbo atomizer for pesticide distribution and a chisel plow for field operations. The products are transported in 10 kg plastic boxes and sold directly to a local retail company. The owner, a family collaborator and 5-6 other seasonal employee work on the farm.

In this test site, a comparison was made between conventional greenhouse management (before DSS and the use of DSS to improve fertiliser management (after DSS).

6.1.2. Life Cycle Assessment

The LCA inventory is available from Annex 1.

The table shows the environmental impacts divided into their respective impact categories before and after DSS. Using the models resulted in a reduction of about 19% in irrigation water and 46% in the amount of fertilizer administered (kg/year). To identify hotspots more easily, impacts were divided into six production stages: greenhouse, fertigation system, machinery, fertilizers, pesticides and waste. The table below shows the contributions for each impact category (Table 20).

Impact categories	Unit	Before DSS	After DSS	Percent change
CC	kg CO_2 eq/ha/year	53,818	47,143	- 12%
PM	kg PM2.5 eq/ha/year	124	113	- 9%
AC	kg SO_2 eq/ha/year	206	177	- 14%
FE	kg P eq/ha/year	34	32	- 6%
ME	kg N eq/ha/year	35	21	- 42%
TET	kg 1,4-DCB/ha/year	328,531	279,158	- 15%
FET	kg 1,4-DCB/ha/year	3799	3489	- 8%
MET	kg 1,4-DCB/ha/year	5022	4630	- 8%
HCT	kg 1,4-DCB/ha/year	14,617	14,320	- 2%
HnCT	kg 1,4-DCB/ha/year	67,593	67,077	- 1%
WC	m^3/ha/year	11,283	7616	- 32%

Table 20 - Contribution analysis of LCA-based environmental impacts for the test site in Antalya, Turkey.

The table below shows the percentage contributions of each stage for each impact category (Figure 8):

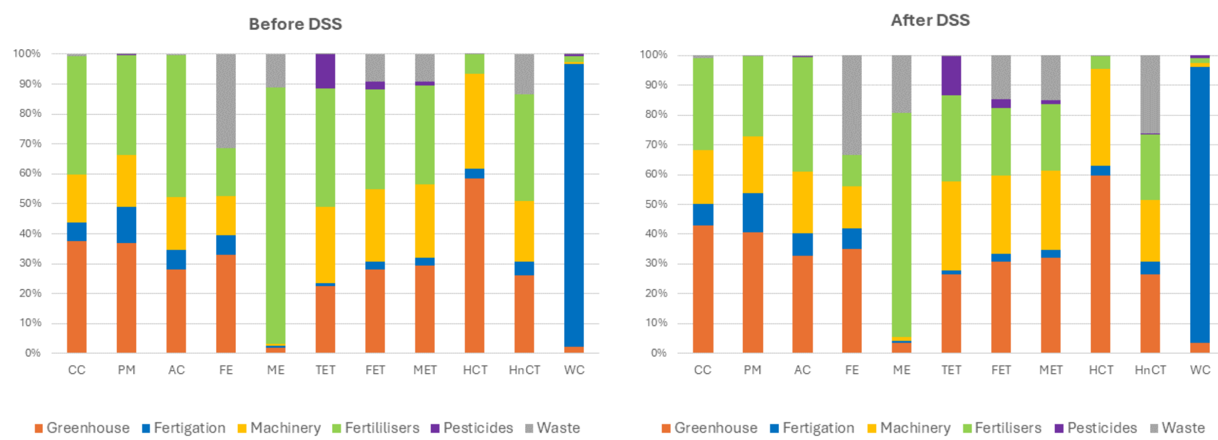

Figure 8 - Contribution analysis of LCA-based environmental impacts for the test site in Antalya, Turkey.

Fertilizers are a hotspot in Turkish case study. Before DSS, fertilisers show high contributions, mainly in the ME (86% of the total impact), AC (47%) and CC (40%) categories, resulting mainly from nitrogen fertiliser production processes. With the introduction of DSS, these are reduced on average by 5% in almost all impact categories (ME -10%, AC and CC -9%). Transportation of materials and greenhouse maintenance is also a hotspot, having high impacts in most categories, with peaks of CC (37% before DSS and 43% after DSS) and PM (37% before DSS and 41% after DSS). Emissions from the use of agricultural machinery also have a fair amount of impact in many categories in this case study, with high values in many impact categories, particularly ecotoxicity (from 24% in FET to 26% in TET before DSS and from 26% to 30% after DSS) and human toxicity (about 32% in HCT). Since there isn't real recycling system, all waste (plastics, concrete, steel etc.) is disposed in landfills, leading to impacts in the FE (31-33% before and after DSS, respectively), ME (11%before DSS and 19% after DSS) and HnCT (13-26% before and after DSS, respectively) categories. The fertigation system is simple, with few elements, and causes low environmental impacts (averaging 5%, peaking at 12-13% in PM before and after DSS, respectively) compared to the other process steps, except for water consumption (WC 94% and 93% before and after DSS respectively). Pesticides show impacts in all categories of ecotoxicity (TET, FET and MET), particularly in TET with 11 and 13% before and after DSS, respectively.

6.1.3. Life Cycle Costing

The LCC inventory is available from Annex 1.

The table 21 shows the results of LCC.

Impact indicators	Unit	Before DSS	After DSS
TCOP	€/ha/year	34,408	31,161
NPV	€/ha/20 years	90,759	114,255
PI	-	1.05	1.32

Table 21 - LCC indicators for test site in Antalya, Turkey.

Tomato production is about 147 t/year, sold at an average price of € 0.33/kg. As can be seen, with the increase in fertilizer prices in recent years, traditional greenhouse (before DSS) production has just enough profitability. The use of DSS allows for greater efficiency in dosage selection and savings of about 43% in annual costs. The TCOP were divided into the same subcategories used for the LCA analysis, with the addition of "labour and services," which includes workers' wages, consultancies, contributions, and taxes incurred by the owner; and "DSS," which includes costs for the control unit, sensors, and software. The figure 9 shows the annual cost distribution.

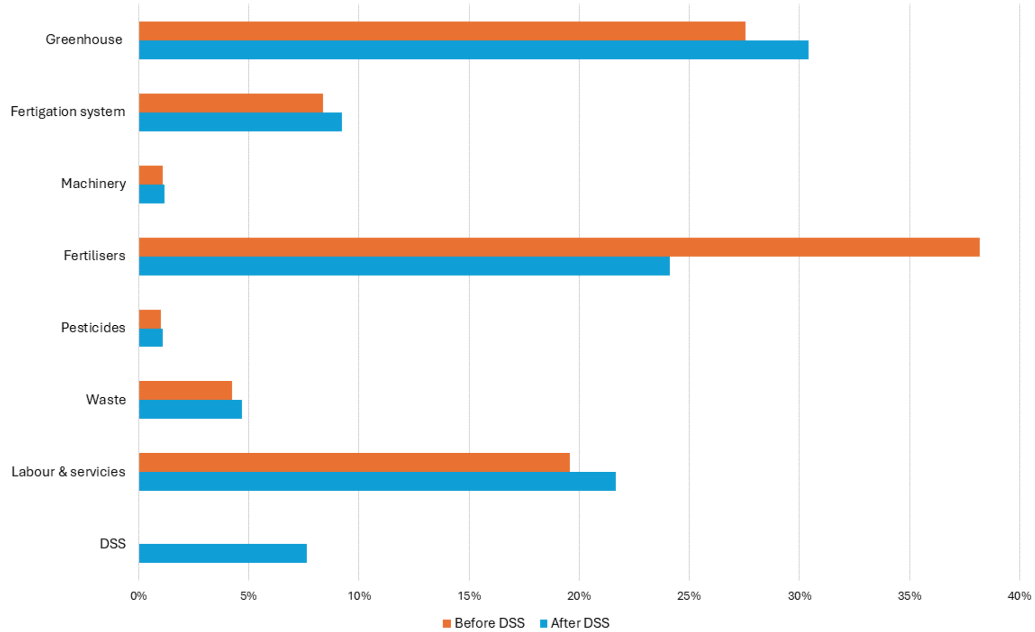

Figure 9 - Contribution analysis to TCOP for the test site in Antalya, Turkey.

The significant reduction in the amount of fertilizer led to almost halving its price, from 38% to 24% of TCOP. As with the other case studies, one of the highest annual costs is greenhouse design, construction, and commissioning (27% of TCOP before DSS and 30% in after DSS). Labour and services (20% and 22% before and after DSS, respectively) also greatly affects the TCOP. The simple fertigation system influences 8-9% of annual expenses. Pesticide purchases covered 1% of expenditures, while agricultural machinery rental covered 2%. The lack of recycling systems results in all waste being disposed of in landfills, at an annual cost of 4% of TCOP. DSS affects 8% of the total annual costs.

6.2 Needs, Expectations and Impact assessment

6.2.1 Context analysis

In Antalya, the low tunnel area has increased by 97.3%, the plastic greenhouse by 52.6%, while the glass greenhouse has decreased by 11.6%, and the high tunnel by 25.3% in the last 10 years. As of 2019, crops mostly grown in the plastic greenhouses in Antalya consists of tomatoes (13259.4 ha), pepper (2943.7 ha), cucumber (2163 ha), and eggplant (660.8 ha), which correspond to 62.7%, 13.9%, 10.2%, and 3.1% of the total areas, respectively. The plastic greenhouse vegetable cultivation area where vegetables are cultivated in Antalya corresponds to 24% of the protected cultivation areas in Turkey, 48.9% of the greenhouse areas in other Turkey's provinces. In 2019, the greenhouse areas in Antalya consist of 91.9% vegetables, 6.2% fruits, and 1.9% cut flower and ornamental plants. Solanaceous crops (tomato, pepper, and eggplant) and cucurbits (melon, zucchini, watermelon) crops account for more than 80% of the protected area. The reasons for the diffusion of these crops are the large market demand, the adaptability to variable climatic conditions of unheated shelters and to long-distance transportation, and the extended cycle that enhances the exploitation of the greenhouse.

The total amount of products provided to the market through the glasshouse in Antalya is 80% of the total amount of product obtained from glasshouse in Turkey. As of 2019, most products from the glasshouses in Antalya were obtained from tomatoes (591326 t), cucumber (241046 t), and peppers (108556 t), which correspond to 55.4%, 22.6%, and 10.2% of the total production, respectively. Although cut flower and ornamental plant potential are low in terms of production area, 5% of the cut flower and ornamental plants obtained from glasshouses in Turkey are grown in glasshouses in Antalya.

The institutions that conduct research on many subjects such as increasing productivity in agriculture by developing new technologies, ensuring the effective use of natural resources, and offering both regional and global solutions to existing problems should play an active role in greenhouse agriculture as the main actor. At the same time, provincial agriculture directorates, which ensure the transfer of research results to farmers, should play a more active role in this regard.

The introduction of plastic in agriculture revolutionized greenhouse agriculture in Turkey, making it a commercially important industry. In regions with favourable ecological conditions, there was a significant increase in greenhouse areas during the 1970s and 1980s. In the 1990s, the resource utilization and support fund incentive for greenhouse investments and cultivation played a crucial role in the substantial increase in the area dedicated to this industry. In these years, modern greenhouses using high technology started to be built and soilless agriculture found a place of use. In the 2000s, sustainable production techniques and certified production became widespread (Tüzel et al. 2020).

Turkey is a country with a dynamic economy due to its favourable ecological conditions, high consumption of fresh vegetables, large youth population, rapid population growth, and high domestic consumption. However, the agricultural sector faces several significant challenges, including structural issues during production, organizational inadequacies, the need for disseminating good agricultural practices, complex marketing channels for vegetables, low producer incomes, high losses from production to consumption, and low foreign trade share despite its high potential. Additionally, food safety concerns have become increasingly important worldwide in recent years. Therefore, it is crucial to not only produce but also ensure the desired quality and standard, while enabling traceability. Turkey has demonstrated the necessary sensitivity to Good Agricultural Practices and food safety by implementing legal arrangements in line with both the EU harmonization process and international developments. However, as with other countries, widespread implementation will require time (Keskin et al. 2007). In this context, the focus is on utilizing technology to promote sustainable agricultural production.

Additional information is available from Annex 2.

6.2.2 Needs and Expectations

As with general agricultural production in Turkey, greenhouse cultivation faces fundamental problems. These are listed below:

- Increase in environmental impacts due to the intensity of energy and water use.
- Land use pressure experienced with the spread of greenhouse areas to urban areas.
- Irregularity of greenhouse production in some regions.
- The presence of many brokers in the process from the producer to the consumer leads to low

earnings for farmers while causing a significant increase in product sales prices,

- High input and energy costs used in agriculture,
- Low level of financial support for agricultural production by the public sector,
- Lack of agricultural support and excessive bureaucratic procedures in this process,
- Emergence of 'cheap labour' with the increase in foreign workers in agricultural production due to intensive foreign migration, especially in recent years.
- Poor working conditions of workers in the greenhouse sector.

It is crucial to provide farmers with financial support and necessary training to encourage the use of good agricultural practices that optimize inputs, rather than relying on traditional methods that involve intensive use of fertilizers, pesticides, and water.

To ensure healthy and cost-effective agricultural production in Turkey, it is important to increase public support. One of the main obstacles to the use of technology in agricultural production is the elderly population's resistance to innovation. Additionally, involving agricultural engineers in every stage of production can lead to an increase in output. Expanding agricultural cooperatives in production can help achieve price stability by reducing the number of brokers in the process from production to the table. The employment of foreign workers in agriculture at low wages and without insurance, due to the increase in foreign migration in recent years, also affects the quality of life and income level of domestic workers. Therefore, addressing the uncontrolled influx of refugees is imperative. Additionally, it is important to utilize skilled female labour in agricultural production.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Optimizes agricultural inputs such water, fertilizer, pesticide use and labour • Reduces environmental damage by preventing over-irrigation and fertilizer leaching • Utilizes sensors and technology for efficient greenhouse management	• Limited technology access may reduce effectiveness in some regions • Concerns about accuracy and reliability may influence decision-making • High development and implementation costs may limit access • The high average age of the agricultural population creates reservations in accepting innovations, • Insufficient support from public institutions for the dissemination of the model • Inadequate demonstration activities	• Opportunities for further improvement with advancing technology • Adaptation to diverse agricultural regions can broaden usage • Educational activities can raise farmer awareness and skills • Healthy and sustainable production • Increased use of technology in agriculture may attract young people to agricultural production • Young labor force with increasing use of technology • Contributes to the use of female labor as skilled workers • Contribute to increasing the number of producers cooperatives	• Insufficient funding or support may hinder adoption • Misuse may lead to negative outcomes. • Lack of technological infrastructure may reduce effectiveness. • Market conditions may impact sustainability

Table 22 - SWOT analysis for the test site in Antalya, Turkey.

Sustainable agricultural production requires comprehensive training for producers on production technologies, chemical use, mechanization, and regulatory compliance. Aligning production with domestic and foreign market demands necessitates a clear orientation to export and with international standards. Addressing the presence of numerous intermediaries in the supply chain requires establishing robust farmer organizations to streamline processes and ensure fair returns for producers.

Need	Description	Stakeholders
Activating agricultural extension studies	For sustainable agricultural production, providing training to producers on production technologies, use of agricultural chemicals, agricultural mechanization technologies, making necessary inspections...	Politics, research institutes, universities, farmers, cooperatives, consumers
Land and Crop Production Planning	Domestic and foreign market needs should be determined clearly, and production is carried out in this direction. Implementation of effective agricultural policies based on production	Politics, farmers, cooperatives
Realization of product distribution from producer to consumer	There are too many middlemen from producer to consumer. Effective farmer organizations should be established.	Farmers, cooperatives, market, consumers

Table 23 - Needs analysis for the test site in Antalya, Turkey.

6.2.3 Participatory impact assessment at the territorial level

During Living Labs, stakeholders were asked to assess the impacts, at the company and territorial levels, of the diffusion a of this new technology. The following table (Table 24) shows the answers obtained in the questionnaire.

Broad issue	Average weight	Indicator	Average score
Economic	0.34	Increase of farmer competitiveness	6.8
		Creation of rural jobs	6.0
		Greater availability of sustainable technology for greenhouses	7.4
		Risk of misuse of technology	2.2
Social	0.28	Improvement of working conditions	7.4
		Greater equity in the distribution of value added along supply chain actors	4.4
		Greater affordability of food	4.5
		Increased trust among value chain actors	6.6
		Improvement of farmer health	6.0
		Greater food safety	7.4
		Greater job opportunities for women	3.8

Broad issue	Average weight	Indicator	Average score
		Increase of female entrepreneurship in agriculture	3.6
		Improved farmer education	5.8
		Improved women education (especially in farming)	4.4
		Improved farmer livelihood	5.6
		Condition for vulnerable groups (i.e. minority & migrants)	2.0
Environmental	0.38	Increased protection of ecosystems	6.6
		Cleaner surface water bodies	6.4
		Cleaner underground water	6.4
		Increased availability of water for agricultural uses	8.2
		Increased biodiversity	5.2
		Increased soil quality	7.4
		Reduced climate vulnerability	5.6
		Increased water security	6.2

Table 24 - MCA results for the test site in Antalya, Turkey.

The stakeholders agree that environmental and economic criteria have the highest priority. Among the economic criteria, greenhouses show similar results to Spain, with quite high preferences for greenhouse competitiveness and the availability of sustainable technology. The social criteria show quite low value, indicating that stakeholders do not perceive them as a priority. Conversely, the condition of vulnerable groups and female entrepreneurship are perceived as less relevant than the others.

6.3 Social impact assessment at the test site and territorial level

The list of social indicators of the MCA was used to ask stakeholders about the qualitative social impacts of the DSS at test site and territory level. A summary of the results is shown in the table below (Table 25).

Indicator	Test site level	Territorial level
Increase in farmer competitiveness	• DSS optimizes the use of water and fertilizer, reducing costs and increasing efficiency. This provides a significant advantage in increasing the competitiveness of farmers. • DSS provides farmers with a competitive advantage by giving them the ability to make decisions quickly and flexibly.	• DSS improves the competitiveness of farmers in terms of productivity and use of resources, reducing production costs • With the use of DSS, farmers in the region can adapt to more innovative agricultural practices and increase their competitiveness in the global market

Indicator	Test site level	Territorial level
	• Reduction of production cost and increase farmer's income • The increase in efficiency with DSS will cause a serious increase in competition • Competitiveness increases as it will help save time both in terms of harmful disease control and in other aspects • No effect	• Increased production efficiency for all company sizes • Encouragement to establish associations between farmers to increase production capacity • DSS can support regional development as it will contribute to improving the economic situation of farmers in the region • Efficient and high-quality production at the regional level will make the region more recognisable • Saving time both in terms of controlling harmful diseases and managing other aspects
Creation of rural jobs	• The adoption of more effective and efficient methods in irrigation, fertilization, and other agricultural activities with the use of DSS causes changes in the need for labour. • The use of DSS can create job opportunities to provide agricultural support services (such as sensor installation, data collection and analysis services). • Increase farmer training in rural areas and conscious farming. • Increase recognition and earnings of rural jobs to prevent migration to large cities. • The use of low-cost farming techniques can lead to a reduction in labour costs and labour requirements. • Through remote control, can provide incentives for rural jobs due to accessibility from the city centre • No effect	• DSS can contribute to the development of agricultural technologies in rural areas and the creation of a skilled workforce in this area. • DSS can create new business opportunities in the area of agricultural consulting and technical support • Migration from the city to agricultural areas, could increase due to better incomes. • Increased attractiveness of the sector for young people, reduced abandonment of the agricultural sector
Improvement of working conditions	• Through better planning, more work can be done in less time, increasing profitability • Remote control of the greenhouse's internal conditions can	• DSS offers farmers the opportunity to plan and manage their agricultural activities, achieving more efficient results with less work

Indicator	Test site level	Territorial level
	• save time and fuel for farmers who have more than one greenhouse • Improved working conditions and reduced human error • Reduced labour hours and manpower as it promotes organized and planned work in production • With a more efficient and effective production process, costs for farmers are reduced, which can lead to better financial conditions	• Fuel economy, reduced energy consumption, sustainability of natural resources • DSS optimizes the timing of agricultural work, taking into account climatic conditions and soil fertility, can help farmers plan their work better
Greater equity in the distribution of value added along supply chain actors	• Encouragement in the formation of farmers' unions and cooperatives, with increase and diversification of farmers' incomes • Proliferation of technologies used in production ensures that small farmers and large enterprises have equal opportunities, so that equality can increase • Due to savings in production costs, an increase in product quality and unit earnings can be recorded • No effect	• The dissemination of DSS can contribute to the development of an understanding of cultivation from production to market, highlighting critical points in the value chain • Easier access to higher quality products • Increased profitability would make the agricultural sector more attractive, leading to incentives and investment • Greater bargaining power on the part of the farmer • Value added from field to shelf is negatively reflected on the producer side • Accurate reporting of data on the amount of inputs used in production and the processes applied will increase the confidence of suppliers and trading partners • Due to savings in production costs, an increase in product quality and unit earnings can be recorded • No effect
Greater affordability of food	• Reduced production costs could allow lower prices for direct sales (small-scale impact) • Reduction in input costs, potential lowering of consumer prices	• In the long run there may be a decrease in prices, but this will probably not have much impact on market prices due to the presence of too many middlemen from production to marketing

Indicator	Test site level	Territorial level
	• Reduced dependence on foreign inputs • No effect	• Sustainability is not possible in the foreign-dependent production model • As long as there are no direct sales systems from production to consumer, the producer will continue to earn less and the consumer will continue to buy at high prices • No effect
Increased trust among value chain actors	• Bringing quality products to market increases the likelihood of consumer loyalty • Trust can develop through controlled production, which • guarantees quality standards and sustainability of production • Increased traceability • Clear indication of the methods and technologies used in production gives greater confidence to people throughout the value chain • Preference of supply chain actors for products that are easier to control and have fewer residues	• A long-term effect on production that will continue in the proper use of natural resources • Possible development of a label/certification documenting the increased sustainability of production • More transparent monitoring and recording of the production stage ensures the reliability of operators throughout the supply chain. • By improving the quality and reliability of producers' products, DSS can create a reliable environment for collaboration and trade throughout the value chain.
Improvement of farmer health	• Awareness raising and training on pesticide use with training provided under DSS, can lead to improved health by the farmer • Reduction of pesticide use, minimization of health effects of inhaled harmful substances • Reduces physical workload and time to be spent in the greenhouse, helping to prevent accidents and injuries at work • No effect	• More effective use of inputs will support public health by reducing environmental pollution in its fields of operation (including groundwater and areas around greenhouses) • Products with less residues, thus less health risk • Decreased farmer visits to health institutions as a result of decreased pesticide exposure
Greater food safety	• The DSS supports controlled and sustainable cultivation • Safer food by reducing pesticides residue • Increase traciability and trasparence of production process	• Optimal use of pesticides on a large scale will reduce the risks of pesticide residues on food. • The DSS will contribute to the emergence of quality products at the regional level.

Indicator	Test site level	Territorial level
	• The DSS increases soil fertility and increases the nutritional value of our crops by directing fertilizer use correctly	• The spread of DSS will increase the impact of exports on the economy and ensure a standard and confidence in Turkish products. • Clear indication of chemicals used • Increasing the efficiency of agricultural activities, resulting in increased food production in the region, which contributes to increasing the level of nutrition in the region. • With a better quality product, the profit rate of production in the region will also increase.
Greater job opportunities for women	• It can be an opportunity for the development of women in various fields in business life and increasing their capacity to carry out more than one job. • Women can adapt more easily to innovations. The development of in-greenhouse technologies, such as DSS, could encourage women to be more involved in agricultural production • No effect	• I think that the contribution of women's emotional and managerial sides to management will be positive. The ability to empathize provides positive layers to create perspectives from all sides. • It can contribute to increasing sustainable production by ensuring that women are more involved in agricultural production • No effect
Increase of female entrepreneurship in agriculture	• This technology enables women entrepreneurs to be more effective and confident in the system. • Entrepreneurship can be increased with grants and investment supports • DSS enables remote control and thus facilitates the management of one's time • No effect	• Possible development of projects for women farmers • The fact that women entrepreneurs are more active in agricultural production will also increase regional retention • No effect
Improved farmer education	• With the use of the right tools and equipment, conscious farmer trainings can be provided and the continuity and attractiveness of the system can be created • Supporting conscious production by increasing farmer awareness with workshops and Living Labs • conducted during the project	• Increasing farmer training will contribute to increased regional production efficiency • Possible creation a general standardization of farmers • Organization of training courses in the cooperative • Increased training and advisory services also contribute to more

Indicator	Test site level	Territorial level
	• Education rate could be increased with the reward and incentive system • Creation of training and information courses, perhaps run by cooperatives and farmer associations • Advisory services • The fact that the use of DSS requires technical knowledge will help increase the education level of farmers, who will need regular training	professional agricultural production in the region." • As young people are more inclined to use technology, it will contribute positively to the participation of young people in production and thus to the education of farmers
Improved women education (especially in farming)	• Training courses provided under the DSS could make the manufacturing sector more attractive • Female education is a very important issue in our country and there is already support for it. Increasing education on the use of technology in agricultural production will increase the productivity and efficiency of our women farmers. • Not effect	• Increase of awareness on a large scale with the trainings provided • The producer, who has undergone training and has mastered the knowledge and technique on the subject, will increase the added value of his own production at the point of sustainability • No effect
Improved farmer livelihood	• Increased efficiency provides economic gain as the cost of inputs decreases. • Increasing the yield and quality of the product harvested with the right production practices will increase the farmer's income, improving living conditions. • Increased attractiveness for young entrepreneurs	• Increased regional development • It could initiate a reward system, which will have an impact on insurance, incentives, and the implementation of global models. • Increased bargaining power of producers • May help improve livelihoods through increased product quality and unit prices
Condition for vulnerable groups (i.e. minority & migrants)	• Integration is achieved through co-production, gains and targets • No effect	• Establishing and supervising the rights of registered employees • Since the use of DSS will require technical knowledge, it will be difficult for immigrants and minorities to find a job in greenhouse production. • No effect

Table 25 - Results of the social impact assessment in Antalya, Turkey, at the test site and territorial level.

DSS in agriculture optimizes water and fertilizer usage, reducing costs and enhancing efficiency, thereby can be seen to increase farmers' competitiveness. DSS facilitates quick and flexible decision-making, leading to a reduction in production costs and an increase in farmers' income. This improved efficiency with DSS not only enhances productivity and resource utilization but also encourages the formation of farmer associations to boost production capacity and regional development. Additionally, DSS adoption fosters job creation in agricultural support services, promotes rural job recognition and training, and makes agriculture more attractive to young people, thereby reducing migration from rural areas to urban centers.

Furthermore, the DSS promotes controlled and sustainable cultivation, leading to safer food with reduced pesticide residues and increased transparency in the production process. By optimizing fertilizer use, DSS enhances soil fertility and the nutritional value of crops, contributing to higher food production and profitability at the regional level. DSS adoption also empowers women in agriculture by providing opportunities for entrepreneurship and skill development, ultimately fostering regional development, and increasing the attractiveness of the sector for young entrepreneurs. Moreover, DSS facilitates farmer training, increases productivity and efficiency, and improves livelihoods by enhancing product quality and unit prices, while also strengthening the bargaining power of producers and promoting integration through cooperative efforts.

7. Discussion and conclusions

7.1. Impacts of DSS adoption at the test site level

This section will compare the economic and environmental impacts of the four case studies to assess their sustainability and their eco-efficiency. The graphs below compare the environmental impacts of the four case studies through an internal normalization.

The Figure 11 shows that non-European case studies have larger average impacts than European case studies.

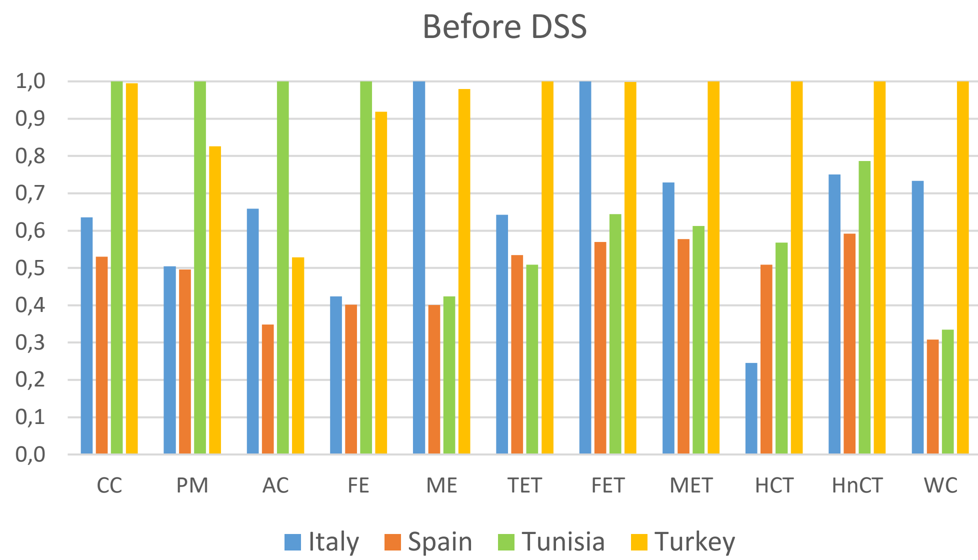

Figure 10– Comparative contribution analysis of LCA results (internal normalisation) before DSS adoption, across test sites.

Except for AC, where it exhibits lesser impacts than both the Italian (by roughly one-fifth) and Tunisian (by roughly half) case studies, the Turkish case study demonstrates above-average affects in practically all areas. The Turkish case in this comparison exhibits the greatest effects in the areas of water consumption, ecotoxicity, and human toxicity. By comparison, the Italian greenhouse has noteworthy effects in FE (almost twice as much as in European examples), PM, AC, and CC (slightly higher than in the Turkish greenhouse). The Italian greenhouse has comparable average values to the Spanish greenhouse, but with significant peaks in ME (more than twice as high as the Spanish and Tunisian cases) and FET (about one-third higher) due to high fertilizer consumption. While the category of HCT has the lowest average value among the instances studied (four times lower than the Spanish greenhouse and around two times lower than the other cases), AC and WC both exhibit high average values in the comparison. Finally, the greenhouse located in Spain demonstrated the least amount of impact in the following categories: FE (half as much as Monastir), AC (about 2.5 times less than Tunisian), ME (equal to the case in Turkey and less than half the impacts of the other two cases), and WC (about 3 times less than Turkey).

Figure 12 shows the impacts following the introduction of DSS.

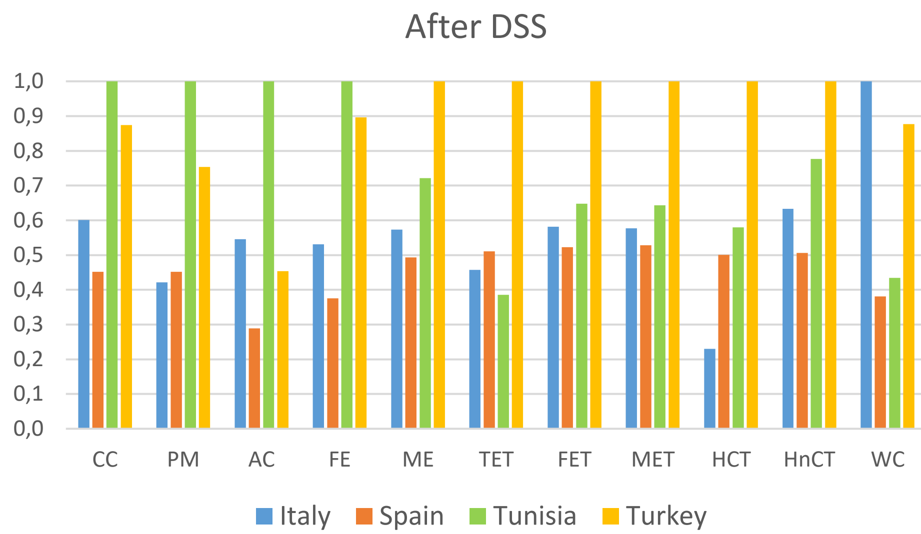

Figure 11 - Comparative contribution analysis of LCA results (internal normalisation) after DSS adoption, across test sites.

As can be seen, the two non-European cases remain the most impactful among the case studies considered. The Tunisian case study, having only made changes in pest control, showed the least variation in this comparison. The switch to an IPM system resulted in a reduction in TET impacts; but also, an increase in ME impacts due to the international transport of DSS and beneficial insects. In the Turkish case, the optimisation of fertigation resulted in a reduction of impacts in the categories CC, PM, AC and FE compared to before DSS; but also, an increase in ME for the transport of after DSS. In the Spanish case study, almost all impact categories experienced reductions except ME and WC. The Italian case study shows decreases in impacts in almost all categories, with a more significant decrease in the ME, TET, and FET categories. However, the increase in the FE and WC categories compared to before DSS. The increase in the WC category is, however, due to the chosen life cycle impact assessment method, estimated through a scarcity model that considers the volume of water withdrawal and replenishment in an area and provides an indicator of water deprivation in an area. In fact, using a closed cycle, all the water withdrawn is reused several times within the cycle and therefore does not return to the same environment as in the open cycle.

7.2. Sustainability implications at the territorial level

The figure below (Figure 13) compares MCA findings across Living labs.

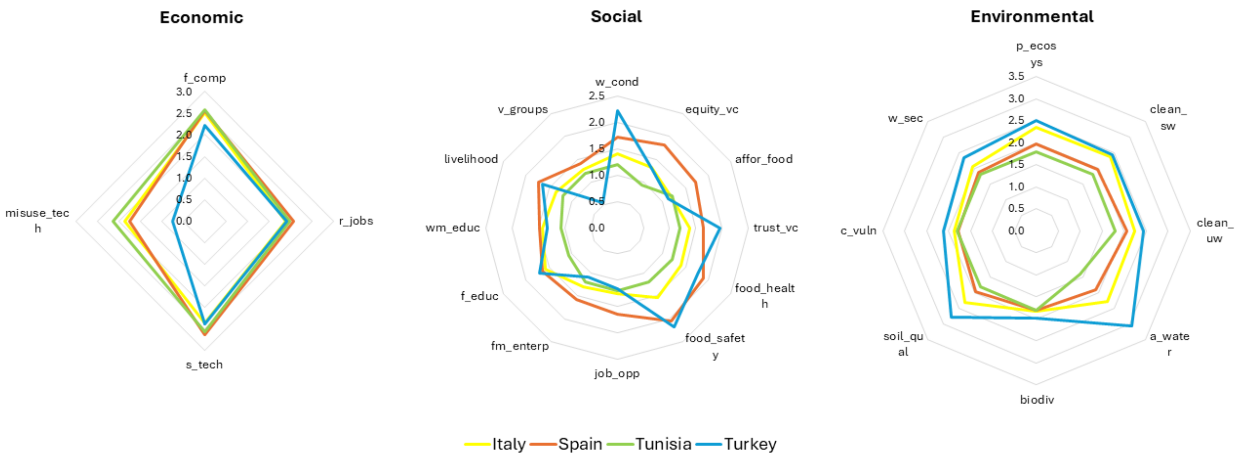

Figure 12 - Results of the MCA across living labs (see Table 26 for the list of codes).

Improving the environmental quality of greenhouse production can stimulate regional economic development and addresses the consumers' demand for sustainable food choices, attracting diverse farmers and supporting sustainable intensification. Collaboration among producers is crucial to enhancing the high environmental quality of agri-food products and improving the bargaining power of farming sectors. This can be pursued by implementing DSS endogenously and strengthening farmers' education and knowledge sharing. DSS plays a pivotal role in optimizing resource use, reducing costs, and improving productivity while also fostering a healthier work environment and attracting new entrants to agriculture. Additionally, it can contribute to job creation, rural development, and women's empowerment in agriculture. On Overall, the adoption of DSS can enhance competitiveness, and foster a positive impact on both economic and social dimensions of agriculture.

Broad sustainability issues	Code	Specific aspects
Economic	f_comp	Increase of farmer competitiveness
	r_jobs	Creation of rural jobs
	s_tech	Greater availability of sustainable technology for greenhouses
	misuse_tech	Risk of misuse of technology
Social	w_cond	Improvement of working conditions
	equity_vc	Greater equity in the distribution of value added along supply chain actors
	affor_food	Greater affordability of food
	trust_vc	Increased trust among value chain actors
	food_health	Improvement of farmer health
	food_safety	Greater food safety
	job_opp	Greater job opportunities for women
	fm_enterp	Increase of female entrepreneurship in agriculture

Broad sustainability issues	Code	Specific aspects
	f_educ	Improved farmer education
	wm_educ	Improved women education (especially in farming)
	livelihood	Improved farmer livelihood
	v_groups	Condition for vulnerable groups (i.e. minority & migrants)
Environmental	p_ecosys	Increased protection of ecosystems
	clean_sw	Cleaner surface water bodies
	clean_uw	Cleaner underground water
	a_water	Increased availability of water for agricultural uses
	biodiv	Increased biodiversity
	soil_qual	Increased soil quality
	c_vuln	Reduced climate vulnerability
	w_sec	Increased water security

Table 26 - List of codes used in Figure 13.

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Annex 1: Life cycle inventories

A1.1 Tuscany, Italy

A1.1.1 Inventory for the LCA

Materials	Unit/ha	Before DSS	After DSS
Water	m^3	10125	8400
Concrete	m^3	5.0	-
Metals	kg	881	-
Plastics	kg	1900	3789
Electricity	kWh	777	3221
Growing substrate	kg	2604	-
Electronic components	kg	9.5	14.5
Agricultural machinery	kg	180	-
Fuel	L	1861	-
Seedlings	pieces	30000	-
Fertilisers			
N	kg	1282	961
K_2O	kg	2072	1657
P_2O_5	kg	484	349
SO_3	kg	851	500
MgO	kg	251	156
Ca	kg	539	224
other microelements	kg	31	14
Pesticides			
chemical p.a.	kg	7.1	6.9
biological p.a.	kg	2.2	3.3
traps	Yes/no	Yes	Yes

Materials	**Unit/ha**	**Before DSS**	**After DSS**
useful insects	Yes/no	No	Yes

Table A1 1 – Material quantities for the test site in Tuscany, Italy.

Direct emissions		**Unit/ha**	**Before DSS**	**After DSS**
Emissions to air				
Fertilisers	N_2O	kg	16.0	12.0
	NH_3	kg	25.6	19.2
	NO_x	kg	3.4	2.52
Pesticides	Copper oxychloride	g	144.3	165.0
	Cyprodinil	g	20.8	7.5
	Fludioxonil	g	13.9	5.0
	Methoxyfenozide	g	25.0	0
	Bacillus thuringiensis var. kurstaki	g	107.5	165.0
	Deltamethrin	g	1.5	0
	Methomyl	g	13.4	0
	Metaflumizone	g	12.2	0
	Sulfoxaflor	g	1.3	0
	Spinosad	g	6.4	3.9
	Emamectin benzoate	g	1.2	0
	Chlorantraniliprole	g	5.8	0
	Indoxacarb	g	3.3	0
	Sulfur	g	0	311.1
Machinery	hydrocarbons	g	1110.0	-
	nitrogen oxide	g	12543.0	-
	carbon monoxide	g	1554.0	-
	carbon dioxide	g	346320.0	-
	sulphur dioxide	g	112.1	-
	methane	g	14.3	-
	ammonia	g	2.2	-

Direct emissions		Unit/ha	Before DSS	After DSS
	particulate matter	g	4555.6	-
Emissions to water				
Fertilisers	NO_3	Kg	384.7	0
	K_2O	kg	2.6	0
Pesticides	Copper oxychloride	g	245.3	0
	Cyprodinil	g	35.4	0
	Fludioxonil	g	23.6	0
	Methoxyfenozide	g	42.5	0
	Bacillus thuringiensis var. kurstaki	g	182.8	0
	Deltamethrin	g	2.5	0
	Methomyl	g	22.8	0
	Metaflumizone	g	20.8	0
	Sulfoxaflor	g	2.2	0
	Spinosad	g	11.0	0
	Emamectin benzoate	g	2.0	0
	Chlorantraniliprole	g	9.9	0
	Indoxacarb	g	5.7	0
Emissions to soil				
Pesticides	Copper oxychloride	g	2208.0	0
	Cyprodinil	g	318.8	0
	Fludioxonil	g	212.5	0
	Methoxyfenozide	g	382.5	0
	Bacillus thuringiensis var. kurstaki	g	1644.8	0
	Deltamethrin	g	22.9	0
	Methomyl	g	205.5	0
	Metaflumizone	g	187.0	0
	Sulfoxaflor	g	20.2	0
	Spinosad	g	98.6	0
	Emamectin benzoate	g	18.2	0

Direct emissions		Unit/ha	Before DSS	After DSS
	Chlorantraniliprole	g	89.3	0
	Indoxacarb	g	51.0	0

Table A1 2 – Estimated direct emissions for the for the test site in Tuscany, Italy.

A1.1.2 Inventory for the LCC

Breakdown of costs	Before DSS (€/year)	After DSS (€/year)
Greenhouse (total)	***54228.17***	**-**
Investment, project design and material transport	14733.11	-
Maintenance	6191.19	-
Consumables, packaging and transport	29733.17	-
Electricity	52.50	-
Heating system + fuel	3518.21	-
Fertigation system (total)	***20526.50***	***23145.14***
Investment	3780.29	5081.42
Growing substrate	15000.00	-
Maintenance	1682.16	2580.52
Electricity	64.05	483.21
Water tax	0.00	-
Machinery (total)	***1757.06***	**-**
Investment	1100.00	-
Fuel and maintenance	657.06	-
Fertilisers (total)	***14592.48***	***9767.52***
Consumables and transport	14592.48	9767.52
Pesticides (total)	***3033.70***	***6296.87***
Chemical consumables	1843.90	807.07
Biocontrol consumables	1189.80	5489.80
Waste (total)	***547.13***	***729.52***
Waste management and demolition cost	547.13	729.52
Labour and services (total)	***60560.00***	**-**

Breakdown of costs	Before DSS (€/year)	After DSS (€/year)
Salary	52060.00	-
Advisory and administration	8500.00	-
DSS (total)	**0**	***3233.33***
Hardware	0	833.33
Software	0	1800.00
Sensors	0	600.00

Table A1 3 – Inventory of costs for the test site in Tuscany, Italy.

A1.2 Almería, Spain

A1.2.1 Inventory for the LCA

Materials	Unit/ha	Before DSS	After DSS
Water	m^3	5142	4179
Concrete	m^3	3.9	-
Metals	kg	1248	-
Plastics	kg	1698	-
Electricity	kWh	431	-
Electronic components	kg	0.1	0.3
Agricultural machinery	kg	2000	-
Fuel	L	127	-
Seedlings	pieces	13300	-
Fertilisers			
N	kg	603	393
K_2O	kg	1057	766
P_2O_5	kg	460	353
SO_3	kg	363	132
MgO	kg	189	132
Ca	kg	619	169
other microelements	kg	7	2
Pesticides			
chemicals p.a.	kg	5.7	-
biological p.a.	kg	3.8	-
traps	Yes/no	Yes	-
useful insects	Yes/no	Yes	-

Table A1 4 – Material quantities for the test site in Almería, Spain.

Direct emissions		Unit/ha^{-1}	Before DSS	After DSS
Emissions to air				
Fertilisers	N_2O	kg	7.53	4.92
	NH_3	kg	12.06	7.87
	NO_x	kg	1.58	1.03
Pesticides	Cimoxanile	g	25.0	-
	Bacillus amyloliquefaciens	g	187.5	-
	Azoxistrobine	g	10.0	-
	Sulfur	g	250.0	-
Machinery	hydrocarbons	g	1110.0	-
	nitrogen oxide	g	12543.0	-
	carbon monoxide	g	1554.0	-
	carbon dioxide	g	346320.0	-
	sulphur dioxide	g	112.1	-
	methane	g	14.3	-
	ammonia	g	2.2	-
	particulate matter	g	4555.6	-
Emissions to water				
Fertilisers	NO_3	Kg	180.8	118.0
	K_2O	kg	0.04	0.02
Pesticides	Cimoxanile	g	42.5	-
	Bacillus amyloliquefaciens	g	318.8	-
	Azoxistrobine	g	17.0	-
	Sulfur	g	425.0	-
Emissions to soil				
Pesticides	Cimoxanile	g	382.5	-
	Bacillus amyloliquefaciens	g	2868.8	-
	Azoxistrobine	g	153.0	-
	Sulfur	g	3825.0	-

Table A 5 - Estimated direct emissions for the test site in Almería, Spain.

A1.2.2 Inventory for the LCC

Breakdown of costs	Before DSS (€/year)	After DSS (€/year)
Greenhouse (total)	***25348.42***	**-**
Investment, project design and material transport	6541.70	-
Maintenance	1041.13	-
Consumables, packaging and transport	17128.74	-
Electricity	636.85	-
Fertigation system (total)	***6070.83***	**-**
Investment	3513.89	-
Maintenance	2206.89	-
Electricity	350.00	-
Water tax	0.00	-
Machinery (total)	***1292.63***	**-**
Investment	1100.00	-
Fuel and maintenance	192.63	-
Fertilisers (total)	***11237.06***	***6237.82***
Consumables	10308.16	5256.57
Manure treatment (3 yr)	928.90	-
Pesticides (total)	***3740.90***	**-**
Chemical consumables	2500.00	-
Biocontrol consumables	1240.90	-
Waste (total)	***585.00***	**-**
Waste management and demolition cost	585.00	-
Labour and services (total)	***29161.26***	**-**
Salary	26892.26	-
Manure treatment (3 yr)	639.00	-
Advisory and administration	1630.00	-
DSS (total)	**0**	***3233.33***
Hardware	0	833.33

Breakdown of costs	Before DSS (€/year)	After DSS (€/year)
Software	0	1800.00
Sensors	0	600.00

Table A1 6 - Inventory of costs for the test site in Almería, Spain.

A1.3 Monastir, Tunisia

A1.3.1 Inventory for the LCA

Materials	Unit/ha	Before DSS	After DSS
Water	m^3	6160	-
Concrete	m^3	2.5	-
Metals	kg	1257	-
Plastics	kg	7459	7036
Electricity	kWh	1800	-
Electronic components	kg	1.2	1.4
Agricultural machinery	kg	1470	-
Fuel	L	1050	-
Seedlings	pieces	16000	-
Fertilisers			
N	kg	377	-
K_2O	kg	707	-
P_2O_5	kg	464	-
SO_3	kg	184	-
MgO	kg	75	-
Ca	kg	52	-
other microelements	kg	1	-
Pesticides			
chemicals p.a.	kg	8.6	7.7
biological p.a.	kg	0.2	-
traps	Yes/no	No	Yes
useful insects/organisms	Yes/no	No	Yes

Table A1 7 – Material quantities for the test site in Monastir, Tunisia.

Direct emissions		Unit/ha	Before DSS	After DSS
Emissions to air				
Fertilisers	N_2O	kg	4.7	-
	NH_3	kg	7.5	-
	NO_x	kg	1	-
Pesticides	Copper	g	40.0	0
	Folpet	g	60.0	20.1
	Sulfur	g	106.7	253.3
	Flubendiamide	g	2.0	0
	Fosetyl- Al	g	80.0	80.4
	Emamectin Benzioate	g	1.3	0.7
	Chlorantraniliprole	g	18.2	3.7
	Orange oil	g	11.8	0
	Spinosad	g	17.7	0
	Copper sulfate	g	26.7	0
	Mancozeb	g	6.7	0
	Abamectin	g	3.6	0
	Flupyradifurone	g	53.4	0
	Metalaxyl- M	g	60.8	2.5
	Methyl thiophanate	g	0	22.51
	Trifloxystrobin	g	0	4.2
Machinery	hydrocarbons	g	3500.0	-
	nitrogen oxide	g	39550.0	-
	carbon monoxide	g	4900.0	-
	carbon dioxide	g	2735460.0	-
	sulphur dioxide	g	885.5	-
	methane	g	113.1	-
	ammonia	g	17.5	-
	particulate matter	g	45933.2	-
Emissions to water				
Fertilisers	NO_3	Kg	113.10	-
	K_2O	kg	0.05	-
Pesticides	Copper	g	68.0	0
	Folpet	g	102.1	34.0

Direct emissions		**Unit/ha**	**Before DSS**	**After DSS**
	Sulfur	g	181.4	430.6
	Flubendiamide	g	3.4	0
	Fosetyl- Al	g	136.1	136.1
	Emamectin Benzioate	g	2.3	1.1
	Chlorantraniliprole	g	31.0	5.2
	Orange oil	g	20.0	0
	Spinosad	g	30.1	0
	Copper sulfate	g	45.4	0
	Mancozeb	g	11.3	0
	Abamectin	g	13.8	0
	Flupyradifurone	g	5.8	0
	Metalaxyl- M	g	103.5	4.3
	Methyl thiophanate	g	0	38.3
	Trifloxystrobin	g	0	7.1
Emissions to soil				
Pesticides	Copper	g	612.3	0
	Folpet	g	918.5	306.2
	Sulfur	g	1632.8	3875.2
	Flubendiamide	g	30.6	0
	Fosetyl- Al	g	1224.6	1224.6
	Emamectin Benzioate	g	20.4	10.2
	Chlorantraniliprole	g	278.6	46.9
	Orange oil	g	180.0	0
	Spinosad	g	270.6	0
	Copper sulfate	g	408.2	0
	Mancozeb	g	102.1	0
	Abamectin	g	124.0	0
	Flupyradifurone	g	52.4	0
	Metalaxyl- M	g	931.2	38.3
	Methyl thiophanate	g	0	344.4
	Trifloxystrobin	g	0	63.8

Table A1 8 - Estimated direct emissions for the test site in Monastir, Tunisia.

A1.3.2 Inventory for the LCA

Breakdown of costs	Before DSS (€/year)	After DSS (€/year)
Greenhouse (total)	***24134.36***	**-**
Investment, project design and material transport	6280.20	-
Maintenance	358.76	-
Consumables, packaging and transport	17495.24	-
Electricity	0.00	-
Fertigation (total)	***3845.68***	**-**
Investment	2728.73	-
Maintenance	468.75	-
Electricity	360.00	-
Water tax	288.29	-
Machinery (total)	***2266.93***	**-**
Investment	1540.85	-
Fuel and maintenance	726.07	-
Fertilisers (total)	***2587.19***	**-**
Consumables	2587.19	-
Pesticides (total)	***2210.44***	***3915.79***
Chemical consumables	1184.64	493.19
Biocontrol consumables	1025.80	3422.60
Waste (total)	***1188.35***	**-**
Waste management and demolition cost	1188.35	-
Labour and services (total)	***12309.98***	**-**
Salary	11325.58	-
Advisory and administration	984.38	-
DSS (total)	**0**	***1683.33***
Hardware	0	583.33
Software	0	600.00
Sensors	0	500.00

Table A1 9 – Inventory of costs for the test site in Monastir, Tunisia.

A1.4 Antalya, Turkey

A1.4.1 Inventory for the LCA

Materials	Unit/ha	Before DSS	After DSS
Water	m^3	13170	10713
Concrete	m^3	5.0	-
Metals	kg	2082	-
Plastics	kg	2095	-
Electricity	kWh	6481	-
Electronic components	kg	0.2	0.4
Agricultural machinery	kg	5053	-
Fuel	L	365	-
Seedlings	pieces	25000	-
Fertilisers			
N	kg	1485	760
K_2O	kg	2525	1736
P_2O_5	kg	853	466
SO_3	kg	168	312
MgO	kg	96	152
Ca	kg	390	481
other microelements	kg	10	10
Pesticides			
chemicals p.a.	kg	1.7	-
biological p.a.	kg	0.3	-
traps	Yes/no	No	-
useful insects	Yes/no	No	-

Table A1 10 – Material quantities for the test site in Antalya, Turkey.

Direct emissions		Unit/ha	Before DSS	After DSS
Emissions to air				
Fertilisers	N_2O	kg	18.6	9.5
	NH_3	kg	29.7	15.2
	NO_x	kg	3.9	2.0
Pesticides	Spirotetramat	g	5.4	-
	Abamectin	g	1.2	-
	Emamectin Benzioate	g	11.9	-
	Ametoctradine	g	32.1	-
	Dimetomorf	g	24.2	-
	Orange oil	g	14.0	-
	Spinetoram	g	0.9	-
	Cyprodinil	g	6.0	-
	Fluidioxonil	g	4.0	-
Machinery	hydrocarbons	g	141.6	-
	nitrogen oxide	g	1600.0	-
	carbon monoxide	g	198.2	-
	carbon dioxide	g	103334.4	-
	sulphur dioxide	g	33.4	-
	methane	g	24.3	-
	ammonia	g	0.6	-
	particulate matter	g	3584.6	-
Emissions to water				
Fertilisers	NO_3	Kg	445.5	227.8
	K_2O	kg	0.9	0.6
Pesticides	Spirotetramat	g	9.2	-
	Abamectin	g	2.0	-
	Emamectin Benzioate	g	20.2	-
	Ametoctradine	g	54.6	-
	Dimetomorf	g	41.1	-

Direct emissions		Unit/ha	Before DSS	After DSS
	Orange oil	g	23.8	-
	Spinetoram	g	1.5	-
	Cyprodinil	g	10.2	-
	Fluidioxonil	g	6.8	-
Emissions to soil				
Pesticides	Spirotetramat	g	82.5	-
	Abamectin	g	18.4	-
	Emamectin Benzioate	g	182.1	-
	Ametoctradine	g	491.8	-
	Dimetomorf	g	269.8	-
	Orange oil	g	214.2	-
	Spinetoram	g	13.1	-
	Cyprodinil	g	92.2	-
	Fluidioxonil	g	61.5	-

Table A1 11 - Estimated direct emissions for the test site in Antalya, Turkey.

A1.4.2 Inventory for the LCC

Breakdown of costs	Before DSS (€/year)	After DSS (€/year)
Greenhouse (total)	***9461.07***	**-**
Investment, project design and material transport	4265.68	-
Maintenance	1765.71	-
Consumables, packaging and transport	3290.31	-
Electricity	139.37	-
Fertigation (total)	***2867.84***	**-**
Investment	1648.00	-
Maintenance	1198.50	-
Electricity	21.34	-
Water tax	0.0	-
Machinery (total)	***568.01***	**-**
Investment (rent)	568.01	-
Fertilisers (total)	***13107.16***	***7495.66***
Consumables	13107.16	7495.66
Pesticides (total)	***342.13***	**-**
Chemical consumables	251.17	-
Biocontrol consumables	90.95	-
Waste (total)	***1336.54***	***1334.31***
Waste management and demolition cost	1336.54	1334.31
Labour and services (total)	***6724.87***	**-**
Salary	6664.87	-
Advisory and administration	60.00	-
DSS (total)	**0**	***2366.66***
Hardware	0	666.66
Software	0	1200.00
Sensors	0	500.00

Table A1 12 - Inventory of costs for the test site in Antalya, Turkey.

Annex 2: Context analysis

A2.1 Tuscany, Italy

Domain	Indicator	Data	References
Diffusion	Total area in hectares (ha)	39159,52 ha	ISTAT, 2020
	Average extension	Mostly family-owned or small size. More than 50% of agricultural holdings have an area of less than 2 hectares of UAA.	Testa et al., 2014
	Distribution (concentrated or dispersed)	Dispersed	Stakeholder interviews
	% entrepreneurs and foreign investments	/	
	Level technology	Mainly medium-low technological level.	De Pascale et al., 2018
	Structure: • type of prevailing structure (high tunnel, classic greenhouse, multi-span etc.) • Average eaves/ridge height • prevailing coverage type (plastic film, glass etc.) • type of opening • % heated greenhouses	Mainly simple or multiple tunnels and pavilion greenhouses (southern Italy). Lightweigh and inexpensive structures, covered by simple plastic films (PE or EVA) and with limited use of microclimate control systems. Only 20% is heated and covered with glass (floriculture).	De Pascale et al., 2018
Performance	Main cultivated crops (up to five)	Tomato, Courgette, Lettuce, Melon and Strawberry	ISTAT, 2022
	% tomato production	47%	ISTAT, 2022
	Average annual production (t)	6’136’383 t/year	ISTAT, 2022
	Average annual profitability (€)	573’380’880.00 € (average price 1.18 €/kg)	ISMEA, 2022
	Annual waste production (plastic, substrates, etc.)	3,7-4,5 t/ha*yr of plastic 14 kg/ha* production cycle of pesticides	De Pascale et al., 2005
Technology	% of soilless culture and main technique used (hydroponic, substrate, etc..)	only 9% of greenhouses use soilless techniques and of these 93% grow on substrate	Incrocci et al., 2020

Domain	Indicator	Data	References
	The main substrate used	Peat, coconut fiber, pumice, perlite	Incrocci et al., 2020
	Irrigation: • main irrigation system in soil and in soilless crops • Irrigation scheduling in soil crops and in soilless crops • % closed or semi-closed cycle systems	The main irrigation systems used in soil greenhouse are drip irrigation (65%), mini-sprinklers (10%), (over-head) irrigation systems (20%) and furrow irrigation systems (5%), while in soilless system drip-irrigation is the most used method. In soil, irrigation scheduling is mostly based on the grower's experience, using manual control or simple timers (75%). The irrigation scheduling in soilless culture is based on the use of timers (65%), on the estimation of Etc or global radiation (20%) and the rest on the use of soil moisture sensors or tensiometers (10%). Only 10% of soilless greenhouses use a closed cycle system. Each irrigation varies between 1 and 1.5 L/ m^2	Incrocci et al., 2020
	Dominant pest control typology (organic, integrated etc.)	At fixed intervals or integrated control (mainly sexually confusing traps)	Stakeholder interviews
	Climate control technique (manual, automatic, temperature sensors etc.)	Due to mild winters, the heating system is auxiliary or absent especially in the South of Italy. In summer, natural ventilation is the main system for controlling the high temperatures.	Pardossi et al., 2004
	Excess humidity control technique (fans, greenhouse opening etc.)	Mainly greenhouse side and roof openings.	Stakeholder interviews
	Low humidity control technique (mini-fog, foliar spraying, etc.)	Mini-fog is rarely used	Stakeholder interviews
	Chemical inputs (Type and number of treatments)	From a minimum of 5 to a maximum of 12 treatments per production cycle	Stakeholder interviews
	Crop protection (chemical, biological, etc.)	Chemical or IPM	Stakeholder interviews
	% sustainable systems (e.g. rainwater storage, Use of renewable energy, etc.)	Rainwater recycling and biomass boilers are quite used and their use are increasing.	Stakeholder interviews
Worker	Level of specialisation (roles and mansions)	Only 7% of foreign workers are skilled or qualified laborers, while in most cases they are unskilled workers: common laborers (76%) or casual laborers (15%).	RICA, 2021
	Level of salary	Part time: 12-15€/day Full time: 25-30€/day	RICA, 2021
	Average working hours	Part time: 5-6 hours/day Full time: 11-12 hours/day	RICA, 2021
	Type of contract (fixed-term or open-ended)	Over the past decade, the predominant type of contract has always been fixed-term contracts (89-90% of the total).	RICA, 2021

Domain	Indicator	Data	References
	Immigrant/national workers ratio	Italian workers in agriculture have been declining over the past decade, particularly Italian women. In 2017 just over 65% of agricultural workers registered with INPS were Italian, while 14.8% of workers were from Eastern Europe, and 4.6% were from North Africa.	RICA, 2021
	Top five country of origin of workers	Romanians (10.4%), Moroccans (3.1%), Indians (3%), Albanians (2.9%), and Polish (1.3%).	RICA, 2021
	Average age immigrant workers	In 2016, about 47% are under-40 years old, while 7% are over 60.	RICA, 2021
	Male/female ratio	Almost 95% of non-EU citizens from Egypt and Bangladesh are men, as well as those from India (85.5%) and Morocco (74.6%). On the contrary, Ukraine (83.3%) and Moldova (69.8%) are the countries from which most of the immigrants are women. Overall, agricultural workers registered with INPS in 2017 were 66.5% male and 33.5% female.	RICA, 2021
Economics	Estimated production costs	20,87 €/m²	
	Higher production cost (labour, transportation, irrigation, etc.)	50% labour and 10% treatments and fertilisers on total annual costs	Stakeholder interviews
	Incentives and facilities for technological and eco-sustainable investments	Little used in Italy due to bureaucratic complexity	Stakeholder interviews
Production chain	Main stakeholders (seed producer, fertiliser and defence systems, technical consultancy, transport, waste disposal, et.)	Consortia and cooperatives for supplying inputs, cultural programs and intermediaries with GDOs; Regions for the administrative issues; GDO for controls, certifications and sale of products.	Stakeholder interviews
	Distribution market (GDO, local market, direct sale, etc.)	Mainly direct sales to local wholesalers and cooperatives, who then resell the products to fruit and vegetable markets and/or large-scale retail trade (LOD).	Stakeholder interviews
	Critical point	Small companies with low power market, lack of an efficient agricultural policy, poor generational turnover and little confidence in new technologies.	Stakeholder interviews
	Public opinion on greenhouse products and environmental impact	Generally negative opinion: greenhouse products are considered less "natural" and tasty than conventionally grown products. In addition, the greenhouse is considered to have a high impact on the environment.	Stakeholder interviews
	Manufacturers’ opinion on manufacturers' confidence in IoT	Low trust in new technologies. Although manufacturers find it useful to rent greenhouse control units, most would not be willing to spend more than 50€ on their monthly rental	Stakeholder interviews

A2.2 Almería, Spain

Domain	Indicator	Data	References
Diffusion	Total area in hectares (ha)	32.368 ha	Cabrera Sánchez et al., 2020
	Average extension	2.63 ha	MAPA, 2019
	Distribution (concentrated or dispersed)	Concentrated	Junta de Andalucía, 2019
	% Entrepreneurs and foreign investments	8-10 %	Stakeholder interviews
	Level technology	Low-technology greenhouses: 40.9 %. Medium-technology greenhouses: 56.3 %. High-technology greenhouses: 2.8 %.	ESYRCE, 2019 Tognoni et al., 1999
	Structure: • type of prevailing structure (high tunnel, classic greenhouse, multi-span etc.) • Average eaves/ridge height • prevailing coverage type (plastic film, glass etc.) • type of opening • % heated greenhouses	Type of structure: • Flat roof: 29 % of greenhouse area • Symmetric Multispan greenhouse: 63.8 %. • Assymetric Multispan greenhouse: 4.9 %. • Multispan tunnels: 2.3 %. Eaves/Ridge height • Flat roof: 2.9 m/ 2.9 m • Symmetric Multispan greenhouse: 3.6m/ 4.3 m • Assymetric Multispan greenhouse: 3.5 m/ 4.3 m • Multispan tunnels: 3.9 m/ 5.5 m Coverage Type: Plastic. Type of Opening: All greenhouse has sidewall vents (88.4 % sliding vents, 8.3 % roll-up) and 56.2 % have roof flap vents. (% greenhouse area) 4.1 % heated greenhouses (% greenhouse area) and Indirect-combustion, hot-air generators are most frequently used (96 %)	García García et al., 2016
Performance	Main cultivated crops (up to five)	Peppers 852,493 t - 12,310 ha Tomatoes 739,363 t - 8,423 ha Watermelons 578,129 t - 12,572 ha Cucumbers 511,542 t - 5,280 ha Zucchini 489,144 t - 8,061 ha	MAPA, 2019
	% Tomato production	21.07%	MAPA, 2019
	Average annual production (t)	3,488.510 t	Cabrera Sánchez et al., 2020
	Average annual profitability (€)	2,291.6 million of €	Cabrera Sánchez et al., 2020

Domain	Indicator	Data	References
	Annual waste production (plastic, substrates, etc.)	Greenhouse vegetable waste: 2,976,100 t Fresh weight Plastic film waste: 47,044 t	Fundación Cajamar,2016 Junta de Andalucía, 2019
Technology	% of soilless culture and main technique used (hydroponic, substrate, aeroponics etc.)	9.8 % soilless culture and the main technique is hydroponic	García García et al., 2016
	The main substrate used	Perlite 46.6%, rock wool 21.6%, coconut fibre 31.8%, others 2.2%	García García et al., 2016
	Irrigation: • main irrigation system in soil and in soilless crops • Irrigation scheduling in soil crops and in soilless crops • % Closed or semi-closed cycle systems	Irrigation system: Drip irrigation 63 % of greenhouse area has automatic irrigation control. Irrigation scheduling is based solely on the grower's own experience (42.4 %), solely on technical advice (3.8 %) and on personal experience together with technical advice (50.8 %). Closed or semi-closed cycle systems are very scarce.	García García et al., 2016
	Dominant pest control typology (organic, integrated etc.)	IPM (26,595 ha)	Cabrera Sánchez et al., 2020
	Climate control technique (manual, automatic, temperature sensors etc.)	Manual ventilation control is present in 96% of greenhouse area and Automated ventilation control system in 4% (control is based on greenhouse temperature, relative humidity, outdoor wind speed and precipitation)	García García et al., 2016
	Excess humidity control technique (fans, greenhouse opening etc.)	**Natural Ventilation system:** 96.1% of greenhouse area. Sidewall ventilation is present in 100% and Sliding sidewalls openings are most often used (88.4%). Roof ventilation is present in 91.7% and Flap Roof vents are the most frequently used (56.2%). **Forced Ventilation System:** 3.9% of greenhouse area and Air extractors are most frequently used (91%).	García García et al., 2016
	Low humidity control technique (mini-fog, foliar spraying, etc.)	Evaporative water-cooling systems are used in 22.8% of greenhouse area and Low-pressure fog systems are the most frequently used (94.7%).	García García et al., 2016
	Chemical inputs (Type and number of treatments)	Acaricides, insecticides 46477.4 t Fungicides 21506.48 t Herbicides 2175.85 t Others 13267.9 t	Stakeholder interviews

<table>
<tr><th>Domain</th><th>Indicator</th><th>Data</th><th>References</th></tr>
<tr><td></td><td>Crop protection (chemical, biological, etc.)</td><td>Crops using biological pest control 50.5 %. Mechanical defence against pests used in greenhouses -Antipest mesh 99 %. -double doors 77 %</td><td>Cabrera Sánchez et al., 2020
García García et al., 2016</td></tr>
<tr><td></td><td>% sustainable systems (e.g. rainwater storage, Use of renewable energy, etc.)</td><td>Rainwater collection = 57.4% of greenhouse area.
Water storage = 87.3%, farm ponds = 68.1%, farm reservoirs = 17.8%, pond plus reservoir = 1.4%, others 12.7%</td><td>García García et al., 2016</td></tr>
<tr><td>Worker</td><td>Level of specialisation (roles and mansions)</td><td>Medium- High Growers
High technicians</td><td>Stakeholder interviews</td></tr>
<tr><td></td><td>Level of salary</td><td>The agreement includes the new minimum interprofessional salary: 12 payments of 1108.33 €.
For working hours less than 40 hours per week, the basic salary would be calculated proportionally, is at € 6.9 or € 7/h</td><td>Stakeholder interviews</td></tr>
<tr><td></td><td>Average working hours</td><td>8 hours, maximum according to the workers' agreement</td><td>Stakeholder interviews</td></tr>
<tr><td></td><td>Type of contract (fixed-term or open-ended)</td><td>Fixed-term 70%, open-ended 40%</td><td>Stakeholder interviews</td></tr>
<tr><td></td><td>Immigrant/national workers ratio</td><td>64.1 immigrants/ 35.9 national</td><td>MAPA, 2020</td></tr>
<tr><td></td><td>Top five country of origin of workers</td><td>Morocco, Romania, Mali, Senegal, Ecuador</td><td>INE, 2020b</td></tr>
<tr><td></td><td>Average age immigrant workers</td><td>32 years old</td><td>INE, 2020a</td></tr>
<tr><td></td><td>Male/female ratio</td><td>75% men and 25% women</td><td>MAPA, 2020</td></tr>
<tr><td>Economics</td><td>Estimated production costs</td><td>
<table>
<tr><th></th><th>Annual costs (%)</th><th>Euros</th></tr>
<tr><td>Labour</td><td>44.8</td><td>28,904</td></tr>
<tr><td>Seeds and seedlings</td><td>9.2</td><td>5,935</td></tr>
<tr><td>Water</td><td>2.8</td><td>1,807</td></tr>
<tr><td>Fertilizer</td><td>6.1</td><td>3,926</td></tr>
<tr><td>Phytosanitary products</td><td>5.4</td><td>3,510</td></tr>
<tr><td>Chemical control</td><td>3.6</td><td>2,327</td></tr>
<tr><td>Biological control</td><td>1.8</td><td>1,183</td></tr>
<tr><td>Energy</td><td>2.0</td><td>1,284</td></tr>
<tr><td>Services</td><td>6.2</td><td>3,990</td></tr>
<tr><td>Transport</td><td>3.0</td><td>1,908</td></tr>
<tr><td>Communications</td><td>0.6</td><td>411</td></tr>
<tr><td>Financial and insurance costs</td><td>2.6</td><td>1,671</td></tr>
</table>
</td><td>Cabrera Sánchez et al., 2020</td></tr>
</table>

<table>
<tr><th>Domain</th><th>Indicator</th><th>Data</th><th>References</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td>Other expenses</td><td>2.6</td><td>1,665</td></tr>
<tr><td>Total current expenses</td><td>79</td><td>51,020</td></tr>
<tr><td>Substrate / sanded soil</td><td>3.7</td><td>2,373</td></tr>
<tr><td>Greenhouse structure</td><td>8.1</td><td>5,251</td></tr>
<tr><td>Plastic</td><td>5.8</td><td>3,750</td></tr>
<tr><td>Irrigation system</td><td>1.2</td><td>805</td></tr>
<tr><td>Irrigation pond</td><td>0.6</td><td>377</td></tr>
<tr><td>Other</td><td>1.5</td><td>981</td></tr>
<tr><td>Total amortization expenses</td><td>21</td><td>13,537</td></tr>
<tr><td>Total annual expenses</td><td>100</td><td>64,557</td></tr>
</table>
</td><td></td></tr>
<tr><td></td><td>Higher production cost (labour, transportation, irrigation, etc.)</td><td>Labour is the highest production cost</td><td>Cabrera Sánchez et al., 2020</td></tr>
<tr><td></td><td>Incentives and facilities for technological and eco-sustainable investments</td><td>Programs and operational funds. National strategy. Environmental guidelines
Operational group PDR: 4.1, 16 y 19.
Operational programs OPFH.</td><td>FEGA
RedPAC</td></tr>
<tr><td>Production chain</td><td>Main stakeholders (seed producer, fertiliser and defence systems, technical consultancy, transport, waste disposal, et.)</td><td>Companies in: irrigation and climate, seed producers, packaging, biotechnology, plant nutrition and phytosanitary products, greenhouse construction, agricultural machinery, fertilisation, biological control, product handling and transport. Recycling plants.</td><td>Cabrera Sánchez et al., 2020</td></tr>
<tr><td></td><td>Distribution market (GDO, local market, direct sale, etc.)</td><td>
<table>
<tr><th>Countries</th><th>Almería exports by products (t)</th><th>Countries</th><th>Almería exports by products (t)</th><th>Countries</th><th>Almería exports by products (t)</th></tr>
<tr><td>Germany</td><td>826.953</td><td>Bulgaria</td><td>3,412</td><td>Noruega</td><td>7,297</td></tr>
<tr><td>Austria</td><td>34.936</td><td>Cyprus</td><td>1</td><td>Suiza</td><td>34,410</td></tr>
<tr><td>Belgium</td><td>49.038</td><td>Croatia</td><td>2,226</td><td>Canadá</td><td>4,132</td></tr>
<tr><td>Denmark</td><td>42.450</td><td>Slovakia</td><td>29,486</td><td>EEUU</td><td>2,061</td></tr>
<tr><td>Finland</td><td>20.745</td><td>Slovenia</td><td>2,129</td><td>Otros países</td><td>8,382</td></tr>
<tr><td>France</td><td>416.406</td><td>Estonia</td><td>3,201</td><td>Total otros mercados</td><td>56,282</td></tr>
</table>
</td><td>Cabrera Sánchez et al., 2020</td></tr>
</table>

Domain	Indicator	Data	References
		Greece 1.877; Hungary 19,721	
		Holland 279.143; Latvia 8,933	
		Ireland 20.552; Lithuania 13,568	
		Italy 151.914; Malt 93	
		Luxembourg 1.079; Poland 190,340	
		Portugal 46.650; Czech Rep. 62,745	
		UK 361.576; Romania 19.246	
		Sweden 77.193; Enlarged EU 355.101	
		Tot. EU-14+UK* 2.329.512; Tot. EU-27+UK* 2.654.579	
	Critical point	• Increased cultivation costs and therefore lower margins for growers. • The downward trend in tomato production sold abroad continues. • Tomatoes have gone from representing more than 26% of the quantities exported a decade ago to less than 14% today • market competition with other countries	Cabrera Sánchez et al., 2020
	Public opinion on greenhouse products and environmental impact	• 56% of the population consider them safe, healthy and that they have been grown in a way that is environment-friendly. • Almost 50% of the population have a favourable perception of their cultivation methods.	Cute Solar, 2021
	Manufacturer's opinion on manufacturers' confidence in IoT	Feedback is good and positive, and they are looking forward to seeing what comes out.	Stakeholder interviews

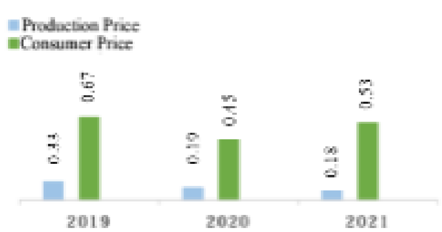
A2.3 Monastir, Tunisia

Domain	Indicator	Data	References
Diffusion	Total area in hectares (ha)	645 ha	APIA, 2015 DGPA, 2020
	Average extension	Family owned. 58.5% of the greenhouse growers have a total area not exceeding 1 hectare, 23.5% have an area between 1 and 2 ha, and 18% have an area of more than 2 ha.	CléProd project Report, 2018 ONAGRI, 2024
	Distribution (concentrated or dispersed)	61% of the greenhouses are concentrated in the delegations of Bkalta and Teboulba. The remaining greenhouses are dispersed on 9 delegations.	CléProd project Report, 2018
	% Entrepreneurs and foreign investments	No foreign investment, only family-owned greenhouses.	CléProd project Report, 2018
	Level technology	Low technology level	CléProd project Report, 2018 APIA, 2015
	Structure: • type of prevailing structure (high tunnel, classic greenhouse, multi-span, etc.) • Average eaves/ridge height • prevailing coverage type (plastic film, glass, etc.) • type of opening • % heated greenhouses	- 4 m mono tunnel: lighter structure than the large tunnel (3 spacers instead of 5), the distance between the hoops remains the same, i.e. 2 m, but the latter is of smaller diameter. - 8 m single tunnel: single tunnel greenhouses made of galvanized metal tubes with manual ventilation by width spacing. Standard units are 64 m long or 500 m2 of covered area. - Canary greenhouses: greenhouses made of wooden posts or galvanized tubes 4 to 5 meters high, which support galvanized steel wires, well anchored to the ground on the sides which in turn keep the plastic film well stretched, are generally built-in units of one hectare - Multi-span and multi-tunnel greenhouses: constituted by three big twin tunnels. Each greenhouse has a surface of 1 500 m2 with a length of 60 m, a width of 27 m, and a height of 5,9 m, automatic or manual ridge aeration can be on one or both sides. All greenhouses are not heated	APIA, 2015 APIA, 2004 Elliseche et al., 1974
Performance	Main cultivated crops (up to five)	Tomatoes, cucumber, chili pepper, melons, eggplants, and zucchini.	APIA, 2015 APIA, 2004 DGPA, 2020
	% Tomato production	24%	DGPA, 2020
	Average annual production (t)	between 120 and 130 t/ha of tomatoes	Interview with stakeholders
	Average annual profitability (€)	6 400 €/Ha for tomatoes	Interview with stakeholders
	Annual waste production (plastic, substrates, etc.)	Green residues: 6 t/ha; Plastic: 0.6 t/Ha; Metals: 1.3 t/ha	Interview with stakeholders
Technology	% of soilless culture and main technique used (hydroponic, substrate, aeroponics, etc.)	100% in-soil cultivation	Interview with stakeholders
	The main substrate used	in-soil cultivation	

Domain	Indicator	Data	References
	Irrigation: • main irrigation system in soil and soilless crops • Irrigation scheduling in soil crops and soilless crops • % Closed or semi-closed cycle systems	Irrigation system: Drip irrigation for in-soil crops Irrigation scheduling is based solely on the grower's own experience	Chebil et al., 2005 Frija et al., 2009 Seed2Feed, 2023
	Dominant pest control typology (organic, integrated, etc.)	IPM strategies are not applied by stakeholders.	Jeder et al., 2018 .
	Climate control technique (manual, automatic, temperature sensors, etc.)	No climate control sensors are used; climate control in the greenhouses is made manually according to the growers' observations (condensation, high temperature...)	Interview with stakeholders
	Excess humidity control technique (fans, greenhouse opening, etc.)	The excess humidity control is made by aerating the greenhouses from the different openings.	Interview with stakeholders
	Low humidity control technique (mini-fog, foliar spraying, etc.)	The low humidity control consists of irrigating and closing the greenhouse openings.	Interview with stakeholders
	Chemical inputs (Type and number of treatments)	From 12 to 27 treatments per production cycle.	Jeder et al., 2018
	Crop protection (chemical, biological, etc.)	Chemical treatments are mostly applied	Toumi et al., 2018
	% sustainable systems (e.g. rainwater storage, Use of renewable energy, etc.)	Farmers don't use renewable energy or rainwater storage for greenhouse cultivation.	Interview with stakeholders
Worker	Level of specialization (roles and mansions)	The manager is a family member since it's a family business. Eight unqualified workers are hired per Ha.	CléProd project Report, 2018
	Level of salary	- For unqualified workers: 1718.75 € per worker and season (10 months). - For the owner: no salary, he has the net revenue.	CléProd project Report, 2018
	Average working hours	8 hours per day	Interview with stakeholders
	Type of contract (fixed-term or open-ended)	Fixed-term contracts	Interview with stakeholders
	Immigrant/national workers ratio	National workers only	Interview with stakeholders
	Top five countries of origin of workers	Not concerned	
	Average-age immigrant workers	Not concerned	
	Male/female ratio	Unqualified workers are mainly females (58%)	FAO, 2021
Economics	Estimated production costs	Production costs are estimated to be about 18750 € per ha.	Interview with stakeholders
	Higher production cost (labour, transportation, irrigation, etc.)	Fertilizers and pesticides are the main production charges.	Interview with stakeholders
	Incentives and facilities for technological and eco-sustainable investments	In agriculture, as in any other field, innovation can relate to one of the following 4 levels. - Organizational innovation - Marketing innovation	APIA, 2022

Domain	Indicator	Data	References
		- Product/service innovation - Technological innovation These levels are encouraged by specific laws mentioned in the guide to agricultural and agri-food entrepreneurship.	
Production chain	Main stakeholders (seed producer, fertilizer and defence systems, technical consultancy, transport, waste disposal, etc.)	- Suppliers of agricultural inputs (plants, fertilizers, pesticides, etc.) - Technical consultants - Transporters for harvested fruits	Soethoudt et al., 2018
	Distribution market (GDO, local market, direct sale, etc.)	Local market	Soethoudt et al., 2018
	Critical point	-Low level of education and high age of operators -Low financing capacity -Low exploited areas -Vulnerability of crops to diseases and pests -Misuse of agricultural inputs -No control over production costs -No control over the sales price (high variability in the sales price). -Low availability of labor -Water scarcity (quality and quantity) -Soil degradation -Aging of greenhouses -Lack of valorization of research findings -Weak outreach and supervision -small farmers are not grouped in a mutual company of agricultural services	Zaibet et Ben Salam, 2005
	Public opinion on greenhouse products and environmental impact	The majority think that products coming from greenhouses contain a lot of chemical residues and don't have a good taste. They also find their price quite expensive compared to seasonal products.	Toumi et al., 2018
	Manufacturer’s opinion on manufacturers' confidence in IoT	Greenhouse owners are not familiar with new technologies and it's quite difficult to convince them about their reliability especially if the cost is high.	Youssef, 2022

A2.4 Antalya, Turkey

Domain	Indicator	Data	References
Diffusion	Total area in hectares (ha)	85,460 ha	TÜİK, 2024
	Average extension	2.64 ha	T.C. Tarım ve Orman Bakanlığı, 2024
	Distribution (concentrated or dispersed)	Partly Concentrated	Stakeholder interviews
	% Entrepreneurs and foreign investments	5 %	Stakeholder interviews
	Level technology		
	Structure: • type of prevailing structure (high tunnel, classic greenhouse, multi-span etc.) • Average eaves/ridge height • prevailing coverage type (plastic film, glass etc.) • type of opening • % heated greenhouses	Type of structure: • 9% Glasshouse, %54 Greenhouse (plastic), %12 high tunnel, Low tunnel • Eaves: Between 3-5.5 m • Ridge height: between 5-8 m • Coverage Type: Plastic and glass. • Almost all greenhouses in the Mediterranean region have roof flap ventilation (%95) • Nearly 95% of the Mediterranean region's commercial greenhouses have no heating systems.	Karaca C., 2020
Performance	Main cultivated crops (up to five)	Tomato 4’406’920 t, 28 364.8 ha Cucumber 1’170’041 t, 8 531.6 ha Pepper 1’129’882 t, 11 111 ha Watermelon 818’350 t, 11956.7 ha Banana 722’703 t, 9448.5 ha Eggplant 388’969 t, 3398.5 ha Total vegetable 8’750 618 t Total fruit 977’958 t	TÜİK, 2023
	% Tomato production	50.36 %	TÜİK, 2023
	Average annual production (t)	9’728’576 t	TÜİK, 2023
	Average annual profitability (€)	Tomato prices (€/kg)  	Eğilmez, 2022

Domain	Indicator	Data	References
	Annual waste production (plastic, substrates, etc.)	Greenhouse vegetable waste: 1’688’572 t Fresh weight (about 204’000 t tomatoes, 35’000 t peppers, 14’000 t eggplants) Plastic waste: 3000 kg/ha	Çerçioğlu M., 2019
Technology	% of soilless culture and main technique used (hydroponic, substrate, aeroponics etc.)	3% Soilless culture the main techniques are substrate and hydroponic	Anonymous, 2016
	The main substrate used	Torf, cocopeat, perlite, rock wool sand, pumice	Anonymous, 2016
	Irrigation: • main irrigation system in soil and in soilless crops • Irrigation scheduling in soil crops and in soilless crops • % Closed or semi-closed cycle systems	Main irrigation system: Drip irrigation 5% of greenhouse area has automatic irrigation control (estimated) Irrigation scheduling is usually performed based on farmer’s experience. In addition, non-scientific technical services are received in return for purchasing goods from agriculture pesticide and fertilizer dealers.	Stakeholder interviews
	Dominant pest control typology (organic, integrated etc.)	2021 2022 IPM 2584 da 2500 da	Stakeholder interviews
	Climate control technique (manual, automatic, temperature sensors etc.)	Manual ventilation control is present in 97% of greenhouse area and Automated ventilation control system in 3%	Karaca C.,2020
	Excess humidity control technique (fans, greenhouse opening etc.)	Greenhouses usually have natural roof ventilation to control the excess humidity control.	Karaca C.,2020
	Low humidity control technique (mini-fog, foliar spraying, etc.)	It is used in mini-fog and foliar spraying seedling producers or in hydroponic cultivation. These processes are not carried out in tomato greenhouses.	Stakeholder interviews
	Chemical inputs (Type and number of treatments)	Fungicides: 20’600 t Herbicides: 13’250 t Insecticides: 12’347 t Acaricides: 2’200 t Rodenticides+Mollucide: 280 t Others: 4’995 t	Stakeholder interviews
	Crop protection (chemical, biological, etc.)	Crops using biological pest control 5%. Chemical protection 95% Mechanical defence against pests used in greenhouses -Antipest mesh 60 %. -double doors 25 %	TÜİK, 2023
	% sustainable systems (e.g. rainwater storage, Use of renewable energy, etc.)	There is no data	
Worker	Level of specialisation (roles and mansions)	Workers' levels of expertise vary depending on their experience, which is associated with work duration.	Stakeholder interviews

Domain	Indicator	Data	References
	Level of salary	The daily salary of agricultural workers varies between 5.57 euro/day and 7.80 euro/day, depending on their work.	Stakeholder interviews TÜİK, 2023
	Average working hours	8 hours	Akçil et al., 2023
	Type of contract (fixed-term or open-ended)	Fixed-term 70 %, open-ended 30 %	Stakeholder interviews
	Immigrant/national workers ratio	70% immigrants/ 30% national (estimate based on conversations with farmers)	Stakeholder interviews
	Top five country of origin of workers	Syria, Afghanistan, Pakistan, Senegal, Sudan	Aksoylu, 2023
	Average age immigrant workers	30 years old	Stakeholder interviews
	Male/female ratio	55% men and 45 % women	TÜİK, 2023
Economics	Estimated production costs	Plastic material (Greenhouse cover material): 417.83 euro/da Soil preparation and tillage: 135.28 euro/da Transport: 222.84 euro/da Animal manure: 167.13 euro/da Seeds and seedlings: 362.12 euro/da Rope: 11.14 euro/da Solid fuel: 557.10 euro/da Electric: 167.13 euro/da Pesticide, fertilizer, labor: 1225.63 euro/da Irrigation system: 781.84 euro/da ** Estimated costs for tomato production in one decare area.	Stakeholder interviews
	Higher production cost (labour, transportation, irrigation, etc.)	Irrigation systems and pesticides, and fertilizer are higher production costs than the others.	Stakeholder interviews
	Incentives and facilities for technological and eco-sustainable investments	**Tomato supports (Ministry of Agric. and Forestry)** **2019 / 2020 / 2021** Organic agriculture(Euro/da): 6.72 / 9.55 / 9.55 Fertilizer support (Euro/da): 0.38 / 0.76 / 0.76 Fuel support (Euro/da): 1.43 / 1.43 / 1.62	Eğilmez, 2022
Production chain	Main stakeholders (seed producer, fertiliser and defence systems, technical consultancy, transport, waste disposal, et.)	Seed producers, seedling companies, input suppliers such as fertilizer, pesticide etc., irrigation companies and transport	Stakeholder interviews

<table>
<tr><th>Domain</th><th>Indicator</th><th>Data</th><th>References</th></tr>
<tr><td></td><td>Distribution market (GDO, local market, direct sale, etc.)</td><td>
<table>
<tr><th colspan="3">The first 5 products are exported of fresh vegetables in Turkiye</th></tr>
<tr><td>Product</td><td colspan="2">January-October 2021</td></tr>
<tr><td></td><td>Quantity (ton)</td><td>Value (euro)</td></tr>
<tr><td>Tomato</td><td>491385,05</td><td>277 194 09</td></tr>
<tr><td>Pepper</td><td>149026,78</td><td>155 330 48</td></tr>
<tr><td>Zucchini</td><td>81178,92</td><td>50 292 38</td></tr>
<tr><td>Cucumber</td><td>60738,32</td><td>45 147 41</td></tr>
</table>
<table>
<tr><th colspan="3">Top 5 countries to export of fresh vegetables</th></tr>
<tr><td>Country</td><td colspan="2">January-October 2021</td></tr>
<tr><td></td><td>Quantity (ton)</td><td>Value (euro)</td></tr>
<tr><td>Syria</td><td>262255,25</td><td>51 799 83</td></tr>
<tr><td>Romania</td><td>117024,06</td><td>90 607 15</td></tr>
<tr><td>Russia</td><td>173957,03</td><td>111 603 74</td></tr>
<tr><td>Ukraine</td><td>103118,14</td><td>47 155 93</td></tr>
<tr><td>Bulgaria</td><td>108142,79</td><td>57 881 78</td></tr>
</table>
Approximately 20-30% of tomato which is produced in Turkey is processed in food industry, residual proportion is used for fresh consumption, 80% of processed tomato is used for paste production, 15% is used for manufacturing of canned food and residual for ketchup and juice etc.</td><td>Eğilmez, 2022</td></tr>
<tr><td></td><td>Critical point</td><td>There are some problems in greenhouse cultivation in Turkey. The first of these is the increase in input costs as a result of currency fluctuations experienced today. High input costs, insufficient government support, difficulties in finding qualified personnel in production, small scale and low-tech greenhouses, and lack of production planning cause low quantity and quality of the products obtained from greenhouse production.
It is a great lack of data obtained in universities and research institutes cannot be transferred to farmer practice due to the lack of coordination between institutions.</td><td>Stakeholder interviews</td></tr>
<tr><td></td><td>Public opinion on greenhouse products and environmental impact</td><td>About 70% of producers claim to use minimal pesticides and chemical fertilizers. They also think that they dispose of the greenhouse waste generated safely. Therefore, they state that they do not have a negative impact on the environment.</td><td>Stakeholder interviews</td></tr>
<tr><td></td><td>Manufacturer’s opinion on manufacturers' confidence in IoT</td><td>There are concerns about cost. However, if the reliability of the system is ensured, the feedback is positive.</td><td>Stakeholder interviews</td></tr>
</table>

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