SUPPLEMENTARY MATERIALS

Addressing needs for the diffusion of digital greenhouse farming. Insights from Living Labs in the Mediterranean basin

Oriana Gava[1*], Sara Sturiale[2], Marisa Gallardo[3], Dolores Buendía Guerrero[4], Dursun Buyuktas[5], Gulcin Ece Aslan[5], Asma Laarif[6], Thameur Bouslama[6], Alejandra Navarro[7], Luca Incrocci[2], Fabio Bartolini[8]

1. Research Centre for Agricultural Policies and Bioeconomy, Council for Agricultural Research and Economics, Viale della Toscana 21, 50127 Firenze, Italy (oriana.gava@crea.gov.it)
2. Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto 80, 56124 Pisa, Italy (sara.sturiale@phd.unipi.it, luca.incrocci@unipi.it)
3. Department of Agronomy, University of Almería, Carretera de Sacramento s/n, La Cañada de San Urbano, 04120 Almería, Spain (mgallard@ual.es)
4. Research Station of the Cajamar, Paraje Las Palmerillas 25, 04710 El Ejido, Spain (doloresbuendia@fundacioncajamar.com)
5. Department of Agricultural Structures and Irrigation, Faculty of Agriculture, Akdeniz University, Antalya, Turkey (dbuyuktas@akdeniz.edu.tr, ecebacalan@akdeniz.edu.tr)
6. University of Sousse, LR21AGR03, Regional Research Centre on Horticulture and Organic Agriculture (CRRHAB), 57, Chott Mariem, TN-4042 Sousse, Tunisia (laarif.asma@iresa.agrinet.tn, thameurbouslama@gmail.com)
7. Research Centre for Vegetable and Ornamental Crops, Council for Agricultural Research and Economics, Via Cavalleggeri 51, 84098 Pontecagnano – Faiano, Italy (alejandra.navarrogarcia@crea.gov.it)
8. Department of Chemical, Pharmaceutical and Agricultural Sciences, University of Ferrara, Via L. Borsari 46, 44121 Ferrara, Italy (fabio.bartolini@unife.it)

* Corresponding author at: oriana.gava@crea.gov.it

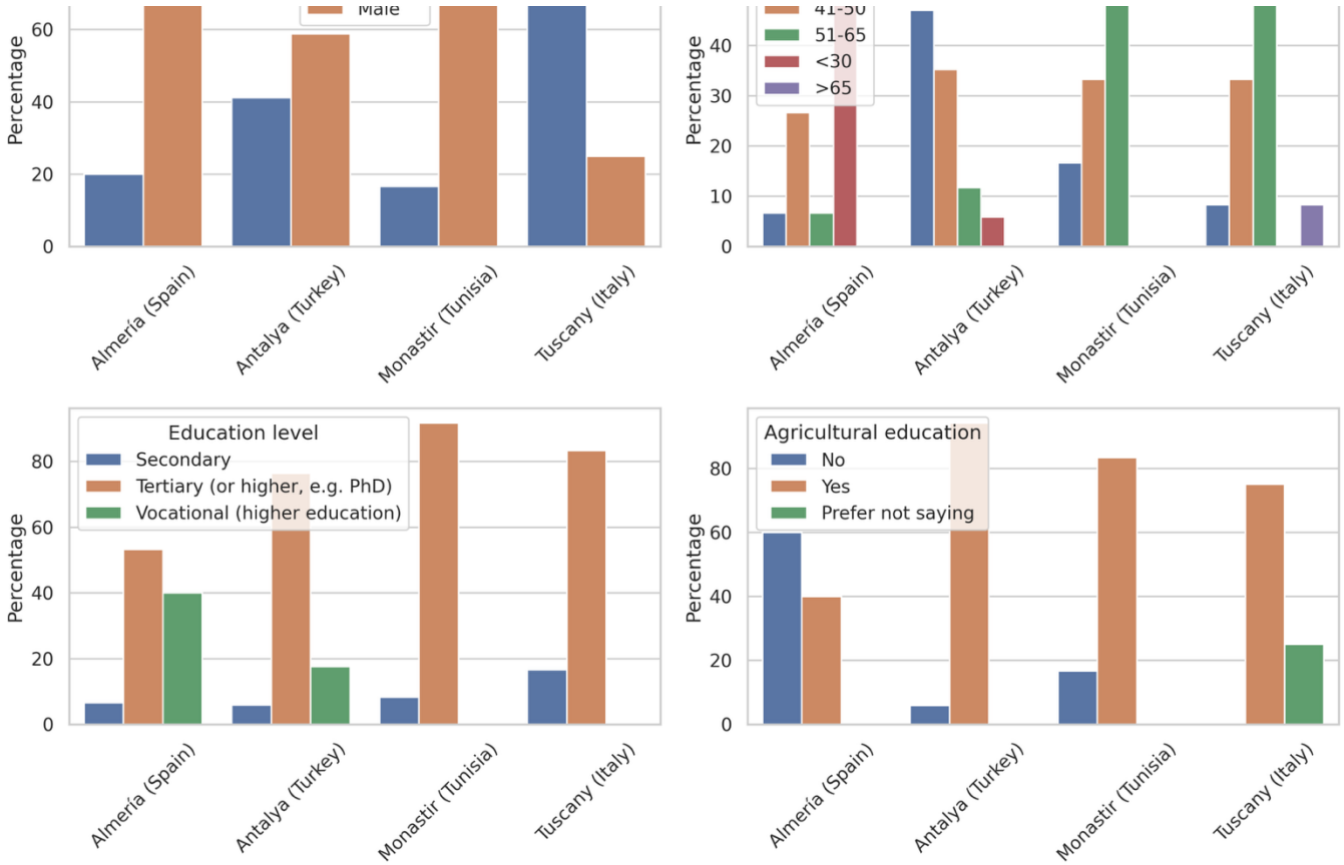
S1 Sample composition across the case studies

Actors participating in each case study Living Lab (LL) constitute the sample for this research (Tabel S1, Figure 1).

Table S 1. Implementation of living labs in the case studies and key case study features.

Case studies	Living lab participants			Decision support system modules	Economic	Social	Environmental	Level of digital technology
	Agribusiness	Knowledge creation/transfer	Policy					
Almería (Spain)	13	8	7	Water, Fertiliser, Pest Management	High labour costs, decreasing margins, competition from other countries	Predominantly immigrant workforce, labour conditions, specialization, contract stability	Limited adoption of advanced techniques (e.g. closed-loop systems), use of biological control and drip irrigation	Moderate
Antalya (Turkey)	16	4	1	Water, Fertiliser	High production costs, insufficient government support	Predominantly immigrant workforce, labour conditions, specialization, contract stability	Limited adoption of advanced techniques, lack of data on sustainable systems	Low to moderate
Monastir (Tunisia)	4	7	3	Water, Fertiliser, Pest Management	Low financing capacity, misuse of inputs, lack of control over costs and prices	National, predominantly unqualified workforce, reluctance of older farmers, fragmented ownership	High chemical use, limited adoption of sustainable practices and advanced techniques	Low
Tuscany (Italy)	5	28	3	Water, Fertiliser, Pest Management	High labour costs, low market power, poor generational turnover	Predominantly immigrant workforce, low confidence in new technologies	Public concerns about food naturalness, taste, and environmental impact	Low to moderate

Figure S 1. Living lab actor demographics. Software: Python libraries matplotlib (Hunter, 2007).



LL actor composition across the case studies shows diversity in terms of gender, age, education level, and agricultural background. However, some cases reveal uneven representation in specific categories, such as a predominance of male participants or limited variation in education levels, reflecting local stakeholder networks, actor availability, and broader socio-institutional dynamics.

LLs were established at the project level as vehicles for embedding RRI principles throughout the innovation process. The established LLs brought together a diverse range of actors operating at both farm and territorial levels. While actor representation differed across case studies, reflecting local technical, social, and cultural contexts, the categorisation of participants aimed to balance inclusivity with operational feasibility, ensuring comparability across cases.

S2 SWOT analysis on the adoption and diffusion of the decision support system in Mediterranean greenhouse farming areas.

SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis is a tool used for strategic planning in various fields like management, education, marketing, healthcare, and agriculture (Benzaghta et al., 2021). SWOT analysis can also be used at a larger, territorial level, where external factors for companies might become internal factors for the region. Here, the SWOT matrix (Table S1) was filled to highlight favourable conditions for greenhouse farming (S), persistent problems (W), external factors that can provide potential solutions (O), or that can worsen problems (T).

Table S 2. Output of the SWOT exercise in the case studies.

Strengths	**Weaknesses**	**Opportunities**	**Threats**
Almeria, Spain			
Favourable climatic conditions: Ideal climate for diverse crop cultivation Strong organizational structures: Presence of cooperatives, irrigation communities, and trade unions Excellent marketing logistics: Efficient systems for product distribution Extensive ancillary industry: Availability of necessary agricultural inputs and services Technical advice: Access to great technical support and advice Dynamic farming community: Flexible and adaptive farmers and cooperatives Irrigation management: Advanced irrigation techniques and management	Weak bargaining power: Farmers have low bargaining power in the value chain Many middlemen: The presence of intermediaries reduces farmers' profits Workload: During the campaign, there are periods of intense activity followed by quieter ones with varying workloads Work-life balance: difficult to find a balance between farming and family, especially for women Environmental awareness: Lack of information leading to improper disposal of some waste Seasonal crop planning: Inefficient planning leading to overproduction and low prices High production costs: Rising costs for fertilisers, fuel, and seeds	Low-cost technologies: Development and evaluation of affordable technologies for water savings and reduced nitrate leaching Market adaptation: Ability to quickly adapt to market demands for sustainability and product quality. Sustainable production: Increasing market demand for organic farming and integrated pest management Youth engagement: Sufficient young population to facilitate digital tool expansion Consumer trust: opportunity to demonstrate ecological and sustainable greenhouse production to consumers.	Water scarcity: Risk of water shortages affecting production Market competition: Competition with non-EU markets Waste treatment: Lack of infrastructure for the treatment of a few types of waste. High investment costs: Significant investment required for greenhouse construction Rising production costs: Increasing costs for inputs and energy Rural hygiene: Need to improve compliance with hygiene standards in greenhouse areas Public awareness: Need to raise international awareness about sustainable agricultural practices in Spain

Strengths	Weaknesses	Opportunities	Threats
Continuous research: Ongoing research by public and private institutions	Investment barriers: High costs for greenhouse construction limit access for young farmers Unskilled labour: most workforce do not hold specific skills, especially in digital tools	Export potential: Strong potential for exporting produce to international markets Work-life balance: Greater awareness about the need to ensure proper work-life balance, with special attention to women Support for young farmers: there are incentives by the local government for starting a farming enterprise by young farmers	
Antalya, Turkey			
Optimised agricultural inputs: Efficient use of water, fertilisers, pesticides, and labour Environmental protection: Reduced environmental damage through prevention of over-irrigation and fertiliser leaching	Limited technology access: Reduced effectiveness in regions with limited access to advanced technology Low level of knowledge: Challenges in finding qualified personnel High costs: Significant development and	Technological advancements: Potential for further improvement with advancing technology Adaptation to diverse regions: Ability to broaden usage across different agricultural regions	Funding and support: Insufficient funding or support may hinder technology adoption Misuse of technology: Potential negative outcomes from improper use of technology Technological infrastructure: Lack of

Strengths	**Weaknesses**	**Opportunities**	**Threats**
Technological utilisation: Use of sensors and technology for efficient greenhouse management Diverse crop production: Cultivation of high-demand crops like tomatoes, cucumbers, peppers, watermelons, bananas, and eggplants Positive public perception: General public belief in the minimal use of pesticides and safe disposal of greenhouse waste	implementation costs for new technologies Low wages: economic conditions compared to the workload are not attractive, especially for the youth Aging agricultural population: The high average age of farmers creates resistance to adopting innovations Insufficient government support: Lack of adequate support from public institutions for model dissemination Low financing capacity: limited access to financial resources Inadequate demonstration activities: Limited activities to demonstrate the benefits of new technologies High input costs: Significant expenses for irrigation systems, pesticides, and fertilisers	Educational activities: Raising farmer awareness and skills through educational programs Sustainable production: Opportunities for healthy and sustainable production practices Youth engagement: Increased use of technology may attract young people to agriculture Female labour: Potential to attract skilled female workers Cooperative development: opportunities to form more producer cooperatives Export market: Strong potential for exporting fresh vegetables to neighbouring countries	infrastructure may reduce the effectiveness of new technologies Market conditions: Economic fluctuations and market conditions may impact sustainability Climate change: Adverse effects on crop yields and farming conditions Rising energy costs: Increased costs for energy and fuel needed for greenhouse operations Low profitability: Risk of farm abandonment due to low profitability Aging infrastructure: Lack of public intervention to renovate old facilities

Strengths	Weaknesses	Opportunities	Threats
	Many working hours: Long and heavy working schedules on farm can generate problems in family management, especially in case on small children		
Monastir, Tunisia			
Employment creation: Source of local employment High-value crops: Cultivation of crops with higher margins and added value Efficient irrigation: Effective use of irrigation water Efficient soil use: High income per unit area Tax incentives: Availability of tax incentives for investments	Small field sizes: Limited land area per farm Saturated domestic market: Limited price development due to market saturation Poor crop diversification: Limited variety of vegetables grown High equipment costs: Expensive new multi-tunnel equipment Low financing capacity: Limited access to financial resources Difficult management of personal life: greenhouse tasks require many working hours and especially women often cannot balance work and family	Growing demand for healthy food: Increasing consumer preference for healthy products Export potential: Opportunities for exporting produce Employment and income improvement: Potential for additional crops and diversified production Packaging development: Opportunities in segmented and pre-packed products for mass distribution Medium-sized farm development: Potential for export-oriented production with supplementary heating	Water shortages: Risk of water scarcity affecting production Rising energy costs: Increased costs for energy and fuel Low profitability: Risk of farm abandonment due to low profitability Aging infrastructure: Lack of public intervention to renovate old facilities Market competitiveness: Difficulty competing with larger, more advanced farms Public perception: Negative views on greenhouse products and environmental impact

Strengths	Weaknesses	Opportunities	Threats
	Seasonal production: Inconsistent employment opportunities High production costs: Significant expenses in production Low level of specialisation: Limited formal knowledge and technical expertise among producers Water scarcity: Poor availability and quality of irrigation water Quality control issues: Lack of control over quality and productivity Inadequate packaging: Poor packaging for marketing Lack of collective organisation: Weak producer cooperatives and associations	Environmental incentives: New financial incentives for environmental sustainability	Climate change: Potential adverse effects on crop yields and farming conditions
Tuscany, Italy			
Favourable climatic conditions: Tuscany's climate supports diverse crop cultivation	Burdensome bureaucracy: Complex processes to access public incentives Low bargaining power: Small, family-owned farms	Increased demand for healthy and local food: Growing consumer preference for fresh, locally-produced food	Farm exit: Risk of abandonment of farm activities, particularly among smaller farms

Strengths	**Weaknesses**	**Opportunities**	**Threats**
Well-established farming sector: A long history and tradition in agriculture Short value chain: Direct sales to local wholesalers and cooperatives High crop diversity: Tomatoes, courgettes, lettuce, melons, and strawberries Sustainable practices: Increasing use of rainwater recycling and biomass-fuelled heating	struggle against large-scale retailers Level of cooperation: Limited collaboration among farmers Generational turnover: Aging farmer population with low youth involvement Propensity to innovate: Reluctance to adopt new technologies Water scarcity: Significant issue during summer months, with growing length of drought periods Unskilled labour: Prevalence of unskilled workforce Work-life balance: Difficult to find a work-life balance due to the need to work many hours on-site, which may prevent new entrants, e.g. young parents Environmental impact: Great quantities of plastic waste and toxicity issues due to pesticide use	Public incentives: Availability of funding opportunities for sustainable innovation and young farmers Technological advancements: Potential for adopting digital tools and other farming innovations to improve sustainability Sustainable food strategies: Local retailers' companies focusing on sustainability attributes of food Youth involvement: Encouraging younger generations to enter the sector, especially through secondary school programs Sustainability investments: Opportunities for investments in eco-friendly practices, by	Aging farmers: Increasing average age of farmers may result in lock-in situations Market competitiveness: Challenges in competing with larger, more technologically advanced farms, both domestically and internationally Public perception: Negative views on greenhouse-grown food and their environmental impact Climate change: Potential adverse effects on crop yields and farming conditions, especially given the growth of extreme events Economic viability: High production costs and relatively low profit margins

Strengths	Weaknesses	Opportunities	Threats
		following existing exemplary models	

S3 Supplementary results

S3.1 Improving technical skills of farmers and advisors and knowledge transfer

The widespread deficiency in knowledge and practical skills related to digital tools among agricultural workers presents a significant issue, which can become a barrier to the effective implementation of digital solutions. This was consistently observed across the case studies. Advisors often possess skills in digital technologies, but they lack the time to test or explain them to farmers. This disconnect between research and practice hampers the adoption of Agriculture 4.0 technologies and the DSS under study, potentially leading to suboptimal farm management and productivity.

These findings suggest a pressing need for comprehensive educational reforms and targeted training programs at both national and international levels. Interviewees emphasised the importance of integrating digital skills into agricultural education to ensure that current and future generations of farmers are equipped to use Agriculture 4.0 technologies effectively. They also highlighted the need for robust knowledge transfer mechanisms to bridge the gap between research and practice. This includes fostering partnerships between research institutions and agricultural practitioners to facilitate the dissemination of innovative practices and technologies.

S3.2 Building acceptability and trust

All case studies emphasize the general lack of acceptability and trust in digital technology among farmers. Farmers, particularly older ones, may be reluctant to adopt digital tools due to

resistance to change, perceived risks, and a lack of digital literacy. Those who have relied on traditional methods for decades may be sceptical about the benefits of Agriculture 4.0 and prefer to stick with familiar practices. They may see the initial investment and learning curve associated with digital tools as risky. Providing tailored education and training, including mentorship programs that demonstrate the tangible benefits and offer hands-on sessions with digital tools, can help build trust and encourage adoption.

The reluctance of older generations to adopt digital tools highlights the need for tailored educational initiatives that address specific concerns and barriers. Policymakers should consider implementing mentorship programs that pair experienced farmers with younger, tech-savvy individuals to foster trust and facilitate knowledge exchange. The role of young farmers as change agents in the adoption of digital technologies should be recognised and supported through targeted entrepreneurship programs. Furthermore, cultivating communities of support through collaborative platforms can empower all farmers, including those beyond the greenhouse sector. These platforms encourage peer-to-peer learning, creating a collaborative environment that is also beneficial for enhancing trust and confidence in technology use.

S3.3 Reducing farm exits

In Monastir and Tuscany, a key issue is the gradual abandonment of farming activities, primarily due to low profitability and very limited generational turnover. This trend poses a significant threat to the agricultural sector, as it may hinder the adoption and diffusion of Agriculture 4.0 technologies, which are essential for modernising farming practices and improving productivity. Therefore, there is a need to reduce farm exits. By making farming more attractive to younger generations, the sector can ensure a continuous influx of new entrants and ideas, which is essential for the adoption of innovative practices.

To reduce farm exits, especially by attracting and retaining young farmers to ensure a continuous influx of new entrants and ideas, several enabling conditions should be established. Providing financial support through subsidies, grants, and low-interest loans can reduce the initial cost burden for young farmers, making farming more attractive and viable. Implementing training programs that focus on new digital tools and how they can support sustainable practices can enhance the technical skills of young farmers, enabling them to adopt and integrate Agriculture 4.0 technologies effectively. Establishing mentorship programs where experienced farmers guide and support young farmers can facilitate knowledge transfer and build confidence.

The trend of farm abandonment due to low profitability and limited generational turnover is a critical issue that requires urgent attention. Attracting and retaining young farmers is essential for the sustainability of the agricultural sector, including its modernisation through digital tools. Incentives, such as access to affordable land, financial support, and training programs focused on digital tools, can create a conducive environment for youth by making farming more appealing to younger generations. In turn, the agricultural sector can benefit from fresh ideas and innovative practices that are needed for the uptake and widespread use of Agriculture 4.0 technologies.

S3.4 Creating product identity

Meeting market requirements is perceived as a major issue in Almería and Antalya, highlighting the importance of a strong product image to stand out against competitors. The emerging need is for product differentiation in the market and greater consumer awareness, especially by creating a unique identity for greenhouse-grown vegetables, distinguishing them from other horticultural products, e.g. grown elsewhere or using different practices. This involves developing elements that resonate with consumers, such as e.g. product denomination and origin and logo, as well as emphasising the environmental and human health benefits of agricultural

products, while ensuring transparency in the production system. This can be achieved by highlighting unique attributes of the products, especially focusing on eco-friendly practices achieved through DSS use, to attract consumers who are increasingly concerned about environmental sustainability and health. Greater consumer awareness is essential to inform and educate the public about sustainability attributes, thus driving specific demand.

Transparency and sustainability in agricultural practices can be achieved through digital tools like the DSS examined in this study, enhancing consumer trust and demand. Certification and labelling schemes play a critical role in communicating the value of sustainably produced goods, thereby attracting consumers who prioritise environmental and health benefits. Certification provides formal recognition of adherence to specific standards, such as organic farming or sustainable practices, which can enhance the credibility and marketability of the products. Labelling schemes offer a clear and accessible way for consumers to identify and trust these certified products.

The importance of a strong product image in meeting market demands is a key finding that has implications for marketing strategies and consumer education. Farmers should prioritise transparency and sustainability in their practices to enhance consumer trust and demand. This can be achieved through the widespread uptake of effective certification and labelling schemes that communicate the environmental and health benefits of agricultural products. However, initiatives that promote consumer awareness regarding sustainable practices are needed as well to drive or enhance demand for responsibly produced goods.

S3.5 Increasing farmer margins

Actors in Monastir highlight the issue of low profit margins in agricultural sales, which discourages investment in new technology. To address this, there is a critical need to allow for a

price premium on agricultural products. This can be achieved by differentiating products based on their sustainability and quality attributes, such as environmental and health benefits, appealing to consumers willing to pay more for sustainably produced goods.

Enabling conditions for this need include robust certification processes that ensure transparency and trust in the sustainability claims. Certification and labelling schemes can play a crucial role in communicating the value of sustainable products to consumers, justifying the price premium. Effective marketing campaigns are also essential to educate consumers about the benefits of sustainable food and to increase their willingness to pay for it. Additionally, financial mechanisms like subsidies, grants, or other incentives can support farmers in adopting new technologies by offsetting the costs of DSS uptake and related changes in sustainable agricultural practices and inputs, thereby enhancing their economic viability.

The importance of a strong product image in meeting market demands is a key finding that has implications for marketing strategies and consumer education. Farmers should prioritise transparency and sustainability in their practices to enhance consumer trust and demand. This can be achieved through the widespread uptake of effective certification and labelling schemes that communicate the environmental and health benefits of agricultural products. However, initiatives that promote consumer awareness regarding sustainable practices are needed as well to drive or enhance demand for responsibly produced goods.

S3.6 Increasing farmer bargaining

All case studies highlight the issue of unfair value distribution along the food value chain. This imbalance results in farmers receiving a disproportionately small share of the profits compared to other downstream actors, such as distributors and retailers. In some regions, like e.g. Almería and Antalya, this problem is exacerbated by the relatively high number of intermediaries. Inequity

in value distribution can lead to financial instability for farmers, discouraging the adoption of innovations such as the DSS and sustainable practices, and may result in low market responsiveness. Strengthening farmers' bargaining power is then crucial for achieving sustainability objectives through digitalisation.

Key enabling conditions to address this need involve the promotion of collective approaches, such as cooperation initiatives, including second tier-cooperatives, and fostering stronger farmer unions. Additional benefits can be realised by enhancing efficiency through the organisation of demand-driven production. By organising into cooperatives or unions, farmers can pool their resources, share knowledge, and collectively negotiate better prices and terms with downstream actors. Example cooperation initiatives include marketing cooperatives that help farmers sell their products collectively or supply cooperatives that enable farmers to purchase inputs at lower costs. For example, second-tier cooperatives, i.e. union of smaller, first-tier cooperatives, proved successful especially in Almeria, working together to provide services, support, and resources (including training) to their cooperative members. Also, farmer unions can advocate for policies that support fairer farmer prices, provide legal assistance, and offer entrepreneurial training. These collective actions among farmers can lead to improved market access and enhanced resilience against market fluctuations. The organisation of demand-driven production can be achieved through the adoption of dedicated digital tools, such as predictive technology and analytics. These tools link supply with demand, helping growers mitigate unexpected risks and challenges by predicting market demand and maximising productivity. The DSS developed in this research represents a farm-level step towards organising demand-driven production. It equips greenhouses with sensors and IoT devices that provide on-site information useful for predictive models. However, dedicated tools for market predictions are still needed. Cooperation initiatives may help

distribute the costs of these additional technologies, enabling their widespread adoption at the territorial level.

Strengthening farmers' bargaining power is essential for improving their economic viability and enabling the adoption of Agriculture 4.0 technologies. Promoting collective approaches, such as cooperatives and unions, and organising demand-driven production are key strategies. These approaches empower farmers to negotiate better terms, access markets more effectively, and share the costs and benefits of digital innovation.

S3.7 Simplifying bureaucracy

In Tuscany, stakeholders emphasise that slow and complex bureaucracy often discourages farmers from applying for public incentives, hindering the sustainable upgrade of farm practices, including the adoption of new digital tools. The complexity and lengthy processes involved in paperwork can be particularly daunting, leading to frustration and disengagement among farmers. Complex bureaucratic processes can deter farmers from applying for public incentives. To address these issues, there is a need for simpler bureaucracy.

Enabling conditions for this simplification include implementing streamlined application processes that reduce unnecessary bureaucratic steps and increase assistance to farmers and advisors throughout the application process. Simplified application procedures and targeted support can enhance farmer engagement and participation, making it easier for them to access the support they need for adopting digital tools and sustainable practices.

The complexity of bureaucratic processes can prevent farmers from accessing public incentives. Simplifying these processes is crucial for enhancing farmer engagement and participation in programs aimed at promoting digital agriculture. Policy improvement should prioritise the streamlining of application procedures and the provision of targeted technical support

to farmers throughout the bureaucratic process, thereby facilitating access to the resources needed for adopting new technologies.

S3.8 Developing land and crop production planning

Findings from Antalya indicate that the current supply of greenhouse-grown food is insufficient to meet both domestic and foreign market demand. This production gap challenges the region's agricultural sector, potentially leading to missed economic opportunities and reduced competitiveness in both domestic and international markets. Therefore, strategic land and crop production planning is needed to optimise the use of available agricultural land, ensuring that the right crops are grown in the right quantities to meet market demands. This approach can stabilise the market and ensure a steady supply of greenhouse-grown food.

Implementing policies that support effective production strategies is crucial for optimising resource use and enhancing market competitiveness. Actors identify production-support policies as crucial enabling conditions as they can provide the necessary framework and resources to assist farmers in implementing effective land and crop production strategies. These policies can encourage farmers to adopt best practices and invest in DSS or other digital tools that enhance productivity and sustainability.

Addressing production gaps through strategic planning is essential for ensuring food system resilience and competitiveness. Policy frameworks that support land and crop planning can help align production with market needs, reduce inefficiencies, and promote the adoption of digital tools that support data-driven decision-making in agriculture.

S3.9 Increasing liquidity for new technology uptake

Farmers in Monastir and Antalya are struggling with rising production costs, making it difficult to sustain their operations. In Tunisia, for instance, this issue arises because equipment like greenhouses and agricultural inputs such as seeds, pesticides, and fertilisers are imported. To overcome this issue, better access to liquidity is needed to invest in new technologies that can enhance efficiency and productivity. Access to liquidity is critical to encourage farmers' uptake of Agriculture 4.0 technologies, such as the DSS, which can help reduce costs and increase yields in greenhouses and other farming systems.

Specific support mechanisms for Agriculture 4.0, including grants and subsidies, can encourage the modernisation of farm production and the adoption of Agriculture 4.0. Support from public and private institutions is an important enabling condition to help farmers adopt new digital technologies alongside more sustainable practices. This financial backing is essential for enabling farmers to transition to more efficient and sustainable practices.

Addressing liquidity constraints is essential for enabling farmers to invest in digital tools and transition toward sustainable agricultural practices. Public and private financial support mechanisms, such as subsidies, grants, and low-interest loans, can reduce the initial cost burden and make digital technologies more accessible, particularly for small and medium-sized farms.

S3.10 Facilitating remote farming operations

The heavy workload and difficulty in achieving a work-life balance for the workforce across the case studies underscore the need for technology that facilitates remote farming operations. These issues are particularly sensitive for women and young parents, who often juggle multiple responsibilities. By reducing the need for constant physical presence on the farm, remote farming operations can significantly alleviate the physical and time burdens on farmers, allowing them to manage their greenhouses more efficiently and effectively from a distance. The DSS under study is

designed to enable remote monitoring of greenhouse conditions, such as climate and soil, and to perform tasks like fertilisation, irrigation, and diseases onset and development. The need to facilitate remote farming operations closely aligns with the overarching objective of the study and is intrinsically linked to other needs, such as improving the technical skills of farmers and advisors, and knowledge transfer and building acceptability and trust. Addressing the need for remote work likely requires most previously mentioned enabling conditions. However, two more specific enabling conditions can be identified that complement those already discussed. First, targeting public and private investments to establish robust digital infrastructure in rural areas to ensure reliable internet connectivity is crucial. While some specialised greenhouse districts in the investigated case studies may already have this infrastructure, a digital divide still exists that must be bridged to enable agricultural digitalisation. Second, collaborative efforts are increasingly recognised as vital for digital transformations in agriculture. Fostering a culture of knowledge sharing and collaboration among farmers can greatly improve their ability and confidence to operate remote farming tasks. Peer-to-peer learning and mentorship programs can play a significant role in enabling farmers to operate remote farming systems confidently. This can be facilitated by developing collaborative platforms that foster a community of support, where farmers can share resources, knowledge, and best practices.

Bridging the gap between urban and rural areas is closely linked to rural improvement: investments in digital infrastructure are expected to offer manifold benefits, by enhancing individual farms and improving the overall quality of life in rural communities. Improved internet connectivity facilitates access to digital tools, which can enrich education, healthcare, and economic opportunities for rural residents. An additional important aspect is the potential to offer partial remote work opportunities through the diffusion of DSS that enable monitoring and operating tasks without the need to be on-site. This aligns the modality of agricultural work with those seen in other

economic sectors, making it more appealing. The flexibility enabled by remote farming tasks reduces the physical toll typically experienced by farmers and prioritises the balance between work and personal life, fostering inclusivity for women and young parents in the agricultural workforce.