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

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Abstract. Agriculture 4.0 represents a huge opportunity for the transformation of agri-food sectors. However, its adoption (and diffusion) in real-world farming contexts faces multiple challenges. This study focuses on greenhouse farming within the Mediterranean basin. It aims to assess the needs of actors involved in the uptake of Agriculture 4.0 and define enabling conditions to support achieving these needs, focusing on the introduction of an innovative decision support system in real-world greenhouses for tomato production. A qualitative and comparative approach is implemented, using participatory data collection methods with cross-disciplinary experts from four case studies across the Mediterranean Basin. Data are collected through one-to-one open discussions, supported using context and SWOT analyses to stimulate reflection and recall. The findings highlight the need to improve digital literacy among farmers and advisors, build trust through tailored education conditions and mentorship, and support young farmers with financial incentives and training. Market dynamics are relevant as well, pinpointing the need for stronger product images and increasing consumer awareness through certification and labelling. Great interest and technology potential emerges from the possibility to enable (partial) remote work thereby benefiting a work-life balance. Simplifying bureaucratic processes and enhancing policy support for cooperation and farmer unions are also essential for encouraging farmers to adopt digital technology.

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Keywords: Decision Support System (DSS), agricultural digitalisation, qualitative research, multi-actor engagement, actor needs, enabling.

1. INTRODUCTION

Agriculture 4.0, or digital agriculture, is widely recognised as a promising pathway to enhance the sustainability and competitiveness of agri-food systems through data-driven technologies such as the Internet of Things, data analytics and artificial intelligence (Wolfert et al., 2017; Mondejar et al., 2021; Maffezzoli et al., 2022). These technologies are particularly relevant for intensive production systems such as greenhouse farming, where input optimisation and monitoring can generate significant efficiency gains (Maffezzoli et al., 2022). However, a growing body of literature cautions that digital solutions risk limited effectiveness if they are not developed and implemented according to the actual needs of actors directly involved in adoption and diffusion processes (Rose et al., 2021; Klerkx et al., 2019).

Empirical research highlights multiple and interrelated needs shaping the uptake of Agriculture 4.0, ranging from usability and affordability to digital skills, advisory support and enabling policy frameworks (Klerkx et al., 2019; McFadden et al., 2022; Yuan and Sun, 2024). Addressing these needs requires the creation of enabling conditions, understood as the institutional, social and economic settings that allow innovations and policies to operate effectively in practice (Huber-Stearns et al., 2017). From a policy perspective, enabling conditions are increasingly framed in terms of coherence between productivity, environmental sustainability and social objectives, especially within European Union's (EU) agricultural policy debates (Coderoni, 2023; Matthews, 2021).

Despite growing investments in digitalisation, evidence on the impacts of Agriculture 4.0, particularly its social implications, remains contested. While several studies emphasise benefits related to efficiency, working conditions and rural wellbeing (MacPherson et al., 2022; Xu et al., 2024), others highlight risks linked to inequality, uneven access and governance challenges (Carolan, 2024; Klerkx et al., 2019). These contrasting findings indicate that there is a need to understand how and under which conditions digital technologies contribute to sustainability, rather than assuming positive outcomes (Ingram et al., 2022; McGrath et al., 2023).

Recent contributions therefore stress the importance of participatory, territorially embedded approaches to bridge the persistent research–practice gap in agricultural digitalisation (McFadden et al., 2022; Matthews, 2021). However, research explicitly centred on actor[1] needs remains limited, particularly when operationalised through Living Labs (LLs) or comparable real-world innovation settings (Mgendi, 2024; Ogunyiola et al., 2024). Moreover, there is a lack of comparative qualitative studies able to generate analytically generalisable insights across diverse socio-economic and institutional contexts beyond single case studies (Klerkx and Rose, 2020; Maffezzoli et al., 2022).

Against this background, this study aims to assess actor needs and identify enabling conditions for fostering the diffusion of Agriculture 4.0 in Mediterranean greenhouse farming through qualitative, actor-centred research. The analysis focuses on the real-world introduction of an innovative decision support system (DSS) and is framed within a Responsible Research and Innovation (RRI) perspective (Owen et al., 2012; Stilgoe et al., 2013). RRI is operationalised through LLs, which are increasingly recognised as suitable environments for inclusive and context-sensitive innovation processes in agriculture (Eastwood et al., 2019; Campos and Marín-González, 2023).

Empirically, the study draws on cross-disciplinary experts participating in LLs across four Mediterranean case studies, i.e. Almería (Spain), Antalya (Turkey), Monastir (Tunisia) and Tuscany (Italy), selected to reflect both the relevance of greenhouse production and substantial diversity in socio-economic and institutional conditions (Sturiale et al., 2024). The research follows a stepwise approach combining: (i) identification of priority socio-economic issues shaping adoption and diffusion; (ii) elicitation of corresponding priority actor needs; and (iii) definition of enabling conditions to support the fulfilment of these needs.

The article advances the literature in three main ways. First, it contributes to actor-oriented research on Agriculture 4.0 by translating locally prioritised needs into analytically structured enabling conditions, strengthening transferability beyond individual cases (Soriano et al., 2023). Second, it bridges digital agriculture debates with RRI and LLs approaches, showing how participatory processes can reveal social and institutional dimensions often overlooked in technology-centred analyses (Lajoie-O'Malley et al., 2020; MacPherson et al., 2022). Third, by providing a cross-country Medi-

[1] The term actor is used consistently throughout this study (instead of stakeholder) o better reflect the actor-centred nature of this research.

terranean perspective, the study clarifies which challenges are recurrent across contexts and which are territorially specific, thereby supporting more targeted and context-sensitive policy strategies for sustainable digital transitions in agriculture (Bocean, 2024).

2. METHODOLOGY AND DATA

2.1 Analytical framework

Actor needs are the requirements, expectations, and preferences of those who have an interest or stake in a particular project, process, or system, including a wide range of operational, economic, social, and environmental aspects that are deemed critical for ensuring the successful adoption and implementation of innovations. Identifying and addressing key actor needs is essential for aligning project outcomes with the interests and priorities of all involved parties, thereby enhancing the overall effectiveness and sustainability of the initiative (Feng et al., 2024; Littau et al., 2010). These needs respond to issues experienced not only by farmers but also by other actors, such as e.g., advisors, which are generally context-specific and can negatively affect the uptake and widespread use of digital agriculture in rural areas (Dibbern et al., 2024). Research indicates that real-world issues are barriers to Agriculture 4.0 and can create lock-in situations that hinder the achievement of sustainability goals through digital transformation. Especially, these issues can prevent the full adoption and integration of digital technologies in agriculture, thereby limiting the potential benefits in terms of productivity, profitability, and sustainability (da Silveira et al., 2023a, 2023b).

The literature identifies drivers and barriers of Agriculture 4.0 (da Silveira et al., 2021; Dibbern et al., 2024). Drivers include, e.g., the potential for increased productivity, profitability, and viability of farming through the optimisation of resource use, cost reduction, and enhancement of crop yields (Fragomeli et al., 2024). Other drivers encompass education, age, and farm size; for instance, younger and more educated farmers managing larger, capital-intensive enterprises are more likely to adopt Agriculture 4.0 technologies (Kroupová et al., 2024). Barriers include economic constraints, such as the high initial costs and limited access to capital, which can deter adoption, particularly among small and medium-sized farms (Dibbern et al., 2024). Other examples of barriers are the lack of technical literacy and insufficient information about the benefits and profitability of digital agriculture that hinder farmers' willingness to invest in new technologies (Kroupová et al., 2024). Identifying enabling conditions to support the realisation of actors' needs is of particular relevance to improve the sustainability of farming through digital tools, by removing the barriers and then overcoming lock-in situations (da Silveira et al., 2023b).

Enabling conditions include financial support, technological infrastructure, policy frameworks, and capacity-building initiatives that collectively create a conducive environment to harness the potential of digital tools for enhancing farmers' productivity, resource efficiency, and decision-making capabilities. For instance, financial support through subsidies and incentives can reduce the initial cost burden, making these technologies more accessible to smaller farms (Fragomeli et al., 2024). Public or private support to investment in physical assets in rural areas can address inadequate infrastructure, facilitating the effective and widespread use of Agriculture 4.0 technologies (Derakhti et al., 2023). Implementing training programs to enhance technical expertise among farmers can bridge the knowledge gap and ease the integration of digital tools on farm (Wang et al., 2020). Additionally, creating knowledge-sharing initiatives and fostering a culture of innovation can help overcome resistance to change and build social trust in Agriculture 4.0 (Ganeshkumar et al., 2023).

2.2 Research methods and data

This study adopts a qualitative and comparative case study design (Yin, 2014) to identify priority socio-economic issues affecting the diffusion of Agriculture 4.0 in Mediterranean greenhouse farming and to derive corresponding actor needs and enabling conditions. The methodological approach builds on the RRI framework operationalised through LLs, following project-level procedures developed and applied consistently across all case studies (Owen et al., 2012; Campos and Marín-González, 2023; Ehlers et al., 2025).

The case studies are four Mediterranean regions, i.e. Almería (Spain), Antalya (Turkey), Monastir (Tunisia), and Tuscany (Italy), selected to combine sectoral relevance (greenhouse vegetable production) with diversity in socio-economic and institutional conditions (Gong and Tan, 2021; Sovacool, 2011). In each case study, a commercial greenhouse hosted a pilot implementation of a DSS for tomato production, which constituted the concrete innovation context anchoring discussions and activities within LLs. A description of the DSS architecture, functionalities and case-specific implementation features is available in related research and project documentation (Sturiale et al., 2024; Sturiale et al., 2025a, 2025b; Gava et al., 2025).

Data were collected from cross-disciplinary experts involved in the LLs, including representatives of agribusiness (38 in total), knowledge creation and transfer (47), and policy (14). Participants were selected through purposive sampling based on their capacity to provide informed insights into barriers, drivers and enabling factors shaping the adoption and diffusion of digital tools in their territorial context (Patton, 2023; Potters et al., 2022). The composition and governance of LLs, as well as their alignment with the four RRI dimensions (anticipation, reflexivity, inclusion and responsiveness) (Ehlers et al., 2025; Stilgoe et al., 2013) are described in detail in Gava et al. (2025).

Actor engagement was facilitated through one-to-one open discussions aimed at prioritising context-specific issues and identifying corresponding needs and enabling conditions. These interviews were conducted via video call, allowing participants to interact with visual materials and texts as they were developed during the conversation.

The discussions were informed by in-depth context analyses conducted at the case study level as part of related research activities. These analyses framed the unique circumstances of each agricultural setting and helped identify the factors influencing the adoption and effectiveness of digital technologies (Rijswijk et al., 2021). They included a broad range of information: physical and technological attributes of greenhouse farming (Klerkx et al., 2019); economic aspects such as financial performance, cost structures, and incentives (Metta et al., 2022); social dimensions including workforce demographics, labour conditions, and public perceptions (Eastwood et al., 2019); and environmental considerations related to sustainability practices and impacts (Rose et al., 2021). Before the interviews, respondents received the context analysis along with a clear explanation of the exercise's aims and procedures. The sessions employed SWOT analysis (see Supplementary materials) as a boundary object, leveraging its accessibility and familiarity to facilitate structured dialogue (Spee and Jarzabkowski, 2009). This approach enabled experts with diverse perspectives to collaboratively identify barriers and drivers of digital technology uptake and to prioritise issues relevant to local contexts (Helms and Nixon, 2010; Pagot and Andrighetto, 2024). Respondents were explicitly invited to elaborate through recall and brainstorming with research team members, following a three-step process:

1) Reflect on priority issues that should be addressed in the greenhouse farming sector at the territorial level to foster agricultural digitalisation, based on their experience in the LL and knowledge of the DSS, but not limited to it;
2) Identify barriers and drivers to solving these issues, derived from SWOT items—specifically, barriers from weaknesses and threats, and drivers from strengths and opportunities (Pagot and Andrighetto, 2024);
3) Highlight priority needs that could help overcome barriers or leverage drivers to address the identified issues.

Enabling conditions for these priority needs were defined through discussion during the final project workshop, which included all scientific partners and LL actors. These conditions were informed by the presentation of project outcomes and refined through collective input.

4. RESULTS AND DISCUSSION

Table 3 provides an overview of the observed priority actor needs and associated enabling conditions, highlighting recurring patterns across all case studies and pointing to common enabling conditions, while also revealing context-specific needs across different territorial settings (detailed qualitative evidence, including illustrative examples for each case study are reported in Supplementary Materials).

4.1 Recurring patterns: skills, trust, market dynamics, and remote farming

Across all case studies, insufficient digital literacy and practical skills emerges as a central barrier to the diffusion of Agriculture 4.0 tools. This limitation affects both farmers and advisory actors and constrains effective uptake even where technologies are technically available, limiting the capacity to translate digital potential into operational change. The consistency of this finding across diverse territorial contexts reinforces the role of enabling conditions centred on training, education reform and strengthened knowledge-transfer mechanisms, which are widely recognised in the literature as prerequisites for responsible, effective and sustainable digitalisation (Dibbern et al., 2024; Fragomeli et al., 2024; Rose et al., 2021). While the need for skills development is common across all case studies, the underlying mechanisms, institutional arrangements and organisational responsibilities through which skills are built vary substantially across territories (Supplementary Materials).

Particularly among older farmers, perceived risks, limited familiarity with digital tools and resistance to change reduce willingness to adopt new technologies. However, trust does not appear as a purely individual

Table 3. Prioritised needs and enabling conditions related to priority issues and SWOT items in the case studies.

Case studies	Priority issues	SWOT items	Priority needs	Enabling conditions
Almería	Knowledge and practical skills	Unskilled labour	Improving technical skills of farmers and advisors	Create and/or improve education and foster knowledge transfer about digital tools
Tuscany		Unskilled labour		
Antalya		Low level of knowledge		
Monastir		Low level of specialisation		
Tuscany	Reluctance to change	Propensity to innovate; Aging farmers	Building acceptability and trust	Create and/or improve education and foster knowledge transfer about digital tools
Almería		Aging farmers		
Antalya		Aging agricultural population		Support for young farmers' entrepreneurship
Monastir		Low profitability		
Monastir	Abandonment of farming activities	Farm exit; Low profitability	Reducing farm exits	Create and/or improve education and knowledge, and foster knowledge transfer about digital tools; Support for young farmers' entrepreneurship
Tuscany		Farm exit; Economic viability		
Almería	High market competition and low consumer awareness	Market competition	Creating product identity	Product branding
Antalya		Market conditions		
Monastir	Too low margin of product sale	Market competitiveness	Increasing farmer margins	Certification and labelling schemes; Policy support for sustainable products
Almería	Unfair distribution of value added along the value chain	Weak bargaining power; Many middlemen	Increasing farmer bargaining	Promote collective approaches (e.g., cooperatives, unions); Organising demand-driven production
Antalya		Many middlemen		
Monastir		Lack of collective organisation		
Tuscany		Low bargaining power; Level of cooperation		
Tuscany	Slow and complex bureaucracy for public incentives	Burdensome bureaucracy	Simplifying bureaucracy	Simplified paperwork for public incentives
Antalya	Insufficient supply of greenhouse-grown food	Low profitability	Developing land and crop production planning	Production-support policy
Monastir		Water shortages		
Antalya	High production costs	Rising energy costs; High input costs	Increasing liquidity for new technology uptake	Support for investment in digital technology
Monastir		High production costs		
Tuscany	Heavya workload and difficult work-life balance	Work-life balance; Climate change	Facilitating remote farming operations	Education and knowledge transfer; Public/private investment in broadband infrastructure
Almería		Workload; Work-life balance		
Antalya		Many working hours		
Monastir		Difficult management of personal life		

disposition. Rather, it emerges as a socially embedded condition shaped by past experiences with innovation, opportunities for experimentation, access to peer learning, and the presence of credible intermediaries such as advisors, cooperatives or researchers. Enabling conditions therefore extend beyond generic information provision and include tailored training pathways, mentorship schemes and support for young farmers' entrepreneurship as potential change agents. These findings align with the literature on barriers to Agriculture 4.0 implementation and on the importance of targeted, context-sensitive support in overcoming adoption lock-ins (da Silveira et al., 2023a, 2023b; Ganeshkumar et al., 2023; Klerkx and Rose, 2020).

Actors across all case studies also emphasise the role of market dynamics and value distribution in shaping incentives for digital technology uptake. The need for stronger product identity, increased consumer awareness and mechanisms capable of improving farmers' margins and bargaining power is consistently highlighted. Enabling conditions in this domain include branding strategies, certification and labelling schemes and, crucially, collective approaches such as cooperatives and unions. These collective arrangements can reduce fragmentation and strengthen negotiation capacity along the value chain, addressing long-standing imbalances in value distribution that limit farmers' incentives to invest in digital innovations, even when such technologies promise efficiency or sustainability gains (Giagnocavo et al., 2014; Eastwood et al., 2017; Rose et al., 2021).

The potential for remote farming operations emerges as a socially relevant opportunity across all case studies. Actors associate remote management with workload reduction, greater flexibility and improved work–life balance, with particular relevance for women and young parents. Importantly, remote farming does not emerge as an isolated technological feature, but as a cross-cutting outcome closely intertwined with observed needs for skills development, trust in digital systems and adequate infrastructural conditions. Enabling conditions include investments in broadband connectivity and collaborative learning platforms, as echoed in the literature on digital divides and the social dimensions of digital innovation in agriculture (Finger, 2023; Gabriel and Gandorfer, 2023; Rose et al., 2021).

4.2 Context specific needs: structural constraints and enabling environments

Several observed needs and enabling conditions for digitalisation mirror territorial diversity, depending on how structural constraints, institutional arrangements and market conditions interact locally.

In Monastir and Tuscany, actors highlight risks of farm exits linked to low profitability and limited generational turnover. These dynamics point to enabling conditions that combine targeted training with financial incentives and broader support for new entrants, reflecting evidence that long-term farm viability and digital innovation uptake depend on complementary socio-economic conditions (Eastwood et al., 2019; MacPherson et al., 2022; Petraki et al., 2025).

In Antalya and Monastir, actors stress constraints related to production planning and liquidity for new technology uptake, particularly under conditions of high input costs and limited financing capacity. In these contexts, digital technologies are perceived as potentially beneficial but financially risky in the absence of adequate support. Enabling conditions include production-support policies and public–private investment schemes that reduce upfront costs, improve access to capital and mitigate financial uncertainty, supporting the central role of economic and financial barriers in shaping Agriculture 4.0 adoption pathways (Dibbern et al., 2024; Derakhti et al., 2023; Klerkx and Rose, 2020).

The Tuscany case study complements this picture by highlighting bureaucratic complexity in accessing public incentives as a particularly salient constraint affecting digital technology uptake. Lengthy and burdensome administrative procedures required to benefit from available support measures are perceived as discouraging farmers from investing in digital tools and sustainable production upgrades. Then, enabling conditions include not only the availability of financial support, but also streamlined administrative processes and targeted technical assistance throughout application phases. These findings align with broader governance debates on how policy design and institutional capacity can either enable or hinder digital transitions in agriculture (McFadden et al., 2022; Martens and Zscheischler, 2022).

5. IMPLICATIONS FOR RESEARCH, PRACTICE AND POLICY

5.1 Critical assessment and recommendations for further research

The research is geographically limited to four case studies in the Mediterranean basin. Although these regions represent significant players in the global greenhouse vegetable market, the findings may not be fully generalisable to other regions worldwide. LL actor selection aimed to ensure representation across the agricultural value chain, however the number of participants per category varied by case study. For instance, in Antalya, only one policy representative was involved, which may have constrained the diversity of policy perspectives relevant to both the local territorial context and Turkey more broadly. The study relies on qualitative data collected through participatory methods involving a diverse group of actors with interdisciplinary expertise. The sample size and composition of engaged actors may not capture the full diversity of views within each region, and the findings might be influenced by the perspectives and biases of the participants. Data collection and reporting is based on internally developed procedures and protocols, tailored to the LL approach and the relatively small sample size. In contexts where such internal management is not feasible (e.g., studies involving randomised sampling, large sample sizes, saturation-based sampling) widely recognised tools for reporting qualitative research should be considered. For example, the COREQ checklist (Tong et al., 2007) offers a structured framework for ensuring transparency and rigour in qualitative research. Findings emphasise the importance of technical skills, trust, market dynamics, and policy frameworks in fostering the adoption of digital technologies. However, other potential factors that may also play an important role in technology adoption were not extensively explored, e.g., cultural attitudes, social networks, economic incentives.

5.2 Recommendations for the science-policy-society interface

Findings highlight how technical skills, trust, market dynamics, and policy frameworks interact to shape the adoption of Agriculture 4.0 technologies across Mediterranean regions. These dimensions do not operate in isolation but reinforce each other, influencing both the willingness and the capacity of actors to engage with digital innovations. Focusing on greenhouse farming, where remote management is relatively more feasible, this study suggests that successful implementations may offer scalable models for broader agricultural applications, while remaining dependent on context-specific enabling conditions (Bocean, 2024; Yuan and Sun, 2024). These findings support the generation of recommendations for the science-policy-society interface, emphasising the need for integrated approaches to unlock the full potential of digital tools in agriculture.

There is a critical need for wider and enhanced collaboration among scientists, policymakers, and agricultural practitioners to foster the successful adoption of Agriculture 4.0 technologies (Matthews, 2021). Encouraging interdisciplinary research that integrates insights from agricultural science, social sciences, and technology studies can address the disconnect between research, advisory services and farm practices that emerged across case studies, by providing a holistic understanding of the challenges and opportunities associated with digital agriculture (Finger, 2023; Rotz et al., 2019). Developing policy frameworks that are informed by empirical research and actor input can ensure that interventions are relevant and effective.

The results also indicate that trust and acceptability are socially embedded and closely linked to institutional and market arrangements. From a science-policy perspective, this implies that digitalisation strategies should move beyond technology promotion and instead support participatory, goal-based governance models that integrate environmental, economic and social objectives. Such coherence is essential to align digitalisation with sustainability and food security goals, as emphasised in EU agricultural policy debates (Coderoni, 2023). Engaging farmers and agricultural advisors in the co-creation of policies and support measures emerges as a key enabling condition for enhancing policy legitimacy and effectiveness (Derakhti et al., 2023; Gabriel and Gandorfer, 2023).

The reported evidence on market dynamics and value distribution highlights the importance of addressing demand-side and value-chain dimensions. Strengthening product identity, improving consumer awareness and supporting collective arrangements can enhance farmers' margins and bargaining power, thereby improving incentives for investment in digital tools. These findings point to the relevance of science–policy–society interactions that also encompass consumers and market actors, particularly through awareness-raising initiatives on sustainability attributes of agricultural products (Gouroubera et al., 2025; Rose et al., 2021).

The successful adoption of digital technologies extends beyond individual farms; it empowers communities and enhances their economic resilience. As these technologies become more widespread, rural areas may experience significant transformations that address long-standing rural-urban disparities. Establishing mechanisms for monitoring and evaluating the impact of digital agriculture initiatives can provide valuable insights into their effectiveness and inform future policy decisions. Continuous feedback loops between research, policy, and practice can enhance the adaptability and responsiveness of agricultural interventions towards digitalisation (Fragomeli et al., 2024; Yang et al., 2024).

As the agricultural landscape evolves, significant potential emerges from the adoption of remote farming technologies. The findings on remote farming underscore that the implications of digitalisation extend beyond productivity and efficiency. Remote management is associated with reduced workload and improved work–life balance, with particular relevance for women and young parents, provided that adequate infrastructural and organisational conditions are in place. These technologies can also foster community support and create new job opportunities, although strategic investment in digital infrastructure is still needed. This appeal can enhance workforce diversity, ensuring that agriculture remains competitive and relevant in the rapidly changing job market. Agricultural digitalisation serves not only ecological sustainability but also uplifts rural communities by fostering a more equitable and diverse agricultural community (Rose et al., 2021; Wolfert et al., 2017).

6. CONCLUSIONS

This study identifies key enabling conditions for the effective implementation of Agriculture 4.0 technologies in Mediterranean greenhouse farming. By following a RRI approach, findings from participatory research across LLs case studies suggest that efforts should focus on improving digital literacy, building trust in technology, leveraging market dynamics, and facilitating remote farming operations. These strategies can support the digital transformation of agriculture while promoting social inclusion, equity, and improved workforce conditions, particularly for women and youth.

To support evidence-based decision-making, the following policy recommendations are proposed:

- Invest in digital literacy and training: Tailored educational programs and knowledge transfer mechanisms are essential to bridge the gap between research and farm-level application;
- Support inclusive technology adoption: Initiatives should consider generational and socio-economic differences to avoid inadvertently excluding older or less digitally literate farmers;
- Strengthen market incentives: Certification schemes, consumer awareness campaigns, and simplified bureaucratic processes can enhance product value and encourage investment in digital tools;
- Promote social equity and cooperation: Policies should reinforce farmer unions and collaborative initiatives to improve bargaining power and ensure fair value distribution;
- Enable remote farming solutions: Digital tools that improve work-life balance and operational efficiency can foster sustainability and attract new entrants to the sector.

Key limitations of this study include its context-specific nature and reliance on the socio-institutional dynamics of each territorial LL, which should be carefully considered when interpreting the findings and assessing their broader applicability. Future research should expand the geographical coverage, integrate quantitative methods, and explore additional factors, such as cultural attitudes and social networks, that influence technology adoption. Also, in the context of LLs, integrating Participatory Action Research principles could offer additional value, particularly in enhancing actor agency and long-term impact, given the strong emphasis placed on collective action and transformation led by participants.

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