ANALYSIS OF DIGITAL ECOSYSTEMS

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D3.1 ANALYSIS OF DIGITAL ECOSYSTEMS

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Part 1: Foundations

1 Introduction

The objective of this Deliverable 3.1 *Report of Digital Ecosystems* (D3.1) within WP3 *Analysis of Digital Ecosystems* is to provide a description of **Digital Ecosystems (DEs)** within the framework of the CODECS project (*Maximising the CO-benefits of agricultural Digitalisation through conducive digital ECoSystems*). This D3.1 relates to three tasks within WP3: T3.1 *Development of Guidelines and training models*; T3.2 *Mapping the Socio-Ecological Context*; and T3.3 *Farm Socio-technical modelling of Use Cases*. The initial version of this D3.1, delivered in M24 of the CODECS project, synthesises main elements gathered from the extensive research results gathered during the first period of CODECs from 19 **Living Labs (LLs).** LLs analysed their problem statements using a methodology useful to explore and analyse complex and layered systems. Such process requires a phased approach to fully reflect research findings. An updated D3.1 will be delivered on M36 and will include a more detailed description and more formal analysis of findings of the agricultural DEs in such LL as well as the relationships, interactions and complexities found within the socio-ecological systems context. The D3.1 delivered on M36 will also have been able to be validated by the LLs, which is an important inclusive step in such process.

A **DE is defined as a dynamic system where digital, socio-economic, organisational, knowledge, and physical components converge to support the production, storage, communication, and utilisation of digital technologies and data.** The data collected and work underpinning this D3.1 is an important output of CODECS Work package 3 (WP3) in which we build the base to describe and explore the DEs of a broad range of LLs within the context of socio-ecological systems framework utilised herein. This base, updated and further analysed in M36, as well as future work in WP3, will serve as the foundation for D3.2 *Comparative assessment of Digital Ecosystems* (due M44) which will include a typology of DEs and a comparison of farm digital readiness, scaling readiness, and digital ecosystems conduciveness across Europe.

Specifically, this Deliverable 3.1 (M24) aims to describe the DEs of 19 LLs which have been set up within the CODECS project, all centred around the digitalisation of agricultural and the specific challenges identified by each LL. **A LL is understood as a network of farmers, knowledge intermediaries, stakeholders, policymakers, technology providers, and other concerned actors, constituted around an emerging problem within a given application scenario, and willing to develop solutions through collaboration.**

To achieve the project objectives and those of this D3.1, the analysis of LL DEs is described through **Mapping the socio-ecological context (Section 4.1), along with defining Agricultural Knowledge and Innovation Systems (AKIS) (Section 4.2) and modelling the socio-technical process of use cases (Section 5)**. These activities have been carried out under Tasks 3.1, 3.2 and 3.3 of the WP3. We explain below in Section 2 how these related activities fit together within the socio-ecological systems framework.

To this end, we rely on and adapt Elinor Ostrom's **Socio-Ecological System Framework (SESF)** (McGinnis and Ostrom, 2014; Ostrom, 2009; supplemented by Ostrom, 1990; and Hess and Ostrom, 2007) to characterise the DEs. This framework serves as a "scaffolding" for the assessment of the context or overall complex environment in which digitalisation takes place, including the socio-ecological-technical SESF, DE, AKIS and process modelling. This **SESF** is a conceptual tool to analyse complex interactions between ecological and social systems. It **divides ecosystems into four subsystems: Actors, Governance systems, Resource units, and Resource systems. Additionally, a "mediating" layer based on Resources, Capabilities, Collaborations and Innovations (RCCIs) is utilised so that LLs can identify and explore the influence of the SESF on their Focal Action situation** (defined below). The **analysis of AKIS as a "layered over" related system, sheds light on knowledge flows between actors** within the DE. (All terms and concepts in this paragraph are further described and explained in "Theoretical Framework" Section 2 below).

Section 4.1, *Mapping of the socio-ecological context*, describes how DEs are structured through the four subsystems of SESF. To facilitate the LLs in their exploration of DE and SESF, data gathering was organised around the identification of RCCIs in each LL. We explore how the SESF subsystems enable the provision of RCCIs necessary for the LLs to carry out their digitalisation initiatives and to address their problem situation. By focusing on the RCCIs

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in the initial analysis of LL and the focal action situation as described below (FAS), the LLs are able to make more concrete the concepts of DE and SESF, facilitating meaningful data collection and linking SES and DE to their digitalisation processes and Focal Action Situations (FAS), defined below. As well, by using RCCIs within our SESF analysis, we will be able to understand "the role of context in relation to whether, and for whom, digitalisation can support the development of capabilities, as well as the role of digitalisation in shaping context" (CODECS proposal 1.2.2 *Beyond the cost benefit analysis*).

At the core of our theoretical and methodological approach is the intent to support and explore the overall CODECS emphasis on "capabilities" and sustainable digitalisation, more specifically, the potential of digitalisation as an enabler of a transition at individual, socio-economic, technical, institutional and governmental levels. Rather than just focusing on "means" (financial assets, digital technologies and other goods, for example) we reframe our research of sustainable digitalisation to also include the "ends". What this means simply in the context of CODECS is that the digital technologies, in and of themselves, do not determine or provide the opportunity to achieve **sustainable and equitable digitalisation of agriculture**.

"Sustainability implies that digitalisation should help maintain or, better, increase, the capacity of socio-ecological systems to respond to external threats (e.g. climate change), and support the livelihood, wellbeing and resilience of individuals, groups and rural communities situated in various contexts across the EU." (CODECS Proposal)

This stage of the Deliverable 3.1 (M24) for Task 3.2 *Mapping the Socio-ecological context*, uses a four-step methodology that is detailed in Section 3.2 within the Methodological approach, and it seeks to give a response to the following general research objective:

> How do the four subsystems of the SESF enable and set the conditions for RCCIs that the LLs need to address their problem statement (thus allowing exploration and definition ultimately of conducive digital ecocsytems)

The methodology established for mapping the socio-ecological context (Task 3.2) begins with each LL identifying a clear problem statement within the **Focal Action Situation (FAS), which is defined as a scenario where subsystems interact to provide an outcome to the problem statement**. In Step 1, LLs focus on their immediate digitalisation contexts and identify their current (what they have) and necessary (what they need) RCCIs to address the FAS problem statement. The RCCIs approach can be considered as an analysis that connects the SESF subsystems with the DEs and the FAS. When LLs identify RCCIs related to each subsystem, they are exploring the SES (including AKIS), but also the DE in relation to the FAS. Step 2 involves describing how the four SESF subsystems, enable, foster, or set conditions for the RCCIs needed to solve the FAS. The identification of RCCIs will allow the assessment of digital ecosystem conduciveness and farmer digital readiness, and subsequently the identification and development of both general and specific LL indicators that can be compared, analysed, and evaluated (Steps 3 and 4, Figure 12 below). In doing so, we will be able to analyse the relationships between subsystems within the SESF and their complexity and how the SES support digitalisation processes. Although LLs´ or farmers' RCCIs may be unique to each farming context, classifying RCCIs and identifying indicators facilitates the comparison of conduciveness and readiness across DEs and allows us to further explore SES.

Digital ecosystem conduciveness refers to the extent to which the environment supports the growth, success, and adoption of digital activities, such as the development of new technologies, the creation of new businesses, and the adoption of digital solutions (UNCTAD, 2019; European Commission, 2018; World Bank, 2016). In contrast, the **Digital readiness of farmers is understood as the individual or organisation's ability to adapt and effectively utilise digital technologies and tools in order to achieve their goals and objectives.**

[For consideration of sustainable and equitable digitalisation see above]

Within Task 3.2, the AKIS will be analysed as a subjacent system within the SESF framework. AKIS assesses agricultural knowledge flows and how agricultural knowledge, and innovations are produced, disseminated, and utilised in the agricultural sector, which supports farmers and other actors in implementing digital technologies and which fosters an environment conducive to digital transformation in agriculture. Within D3.1, the scope of the AKIS analysis is limited to Actors and the Governance subsystems, linking the DE and the FAS. An "infrastructural" AKIS approach will be used herein (see section 2.1.2 for description). This analysis can be situated between the actors (those who are located in the LL's and FAS' environment) and governance, meaning that at the governance level, AKIS is considered as the interplay of many knowledge and innovation related corporate actors as well as governing

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institutions and structures. Resource units and resource systems are not considered in the infrastructural analysis of AKIS. All subsystems of SESF in this D3.1 feed into the SES, RCCIs and DE.

It is important to note that the development of indicators (Steps 3 and 4 in **Errore. L'origine riferimento non è stata trovata.** below) will be carried out in a future stage of the project and will be detailed in forthcoming updates of this Deliverable 3.1 (due M36) and in Deliverable 3.2 (M44), with the corresponding update of Guidelines under Task 3.1 as necessary. This D3.1 (M24) sets the basis for this future work by extracting observations about DEs from which indicators can be determined at a specific LL and general subsystem/SESF level. Therefore, while we are not creating specific indicators for each LL or indicators for each subsystem in this deliverable, we are laying the groundwork for their future development.

Focusing on the FAS level of analysis, Process Modelling (Section 5) is applied in CODECS in the Task 3.3 *Farm Socio-technical Process Modelling of Use Cases* for supporting the analysis of the transformation occurring to business processes after the introduction of digital solutions in the context of the problems statements within FASs addressed by the LLs. The processes of "before and after" of the introduction of digital technologies envisioned by each LL are studied and the expected outcome consists of easy-to-read graphical representations of such before and after processes. To provide an overview of the process relevant to the definition of the social-ecological system, processes are mapped over the entities and relationships of Ostrom's SES framework, thus considering the information required by the SESF methodology on subsystems and process modelling specifically, e.g., Actors, Resource units, Inputs, Inclusion, and participation relationships. To ensure completeness, a set of standard notations for graphical representation has been identified and three types of diagrams will be developed by each LL focusing on three complementary dimensions: structure of the process, actor's goals and strategic relationships and process flow.

This deliverable will contribute to the Policy Briefs 2, and 3, namely *Policy Brief 2: Digital ecosystems for sustainable digitalisation of farming*, *Policy Brief 3: The role of AKIS in digital ecosystems*.

2 Theoretical framework

2.1 Mapping of the socio-ecological context

Overall, the purpose of CODECS is to enhance the motivation and capacity of European farmers to adopt digitalisation as a catalyst for sustainable change. An important consideration in such transition is the ecosystems in which these processes take place and how ecosystems may serve to strengthen the capacities of farmers, farm businesses, farm advisors, and other AKIS actors, in the field of digital technologies and digital systems. To this end, D3.1 contributes to CODECS goals by analysing, and understanding the implications and of the role of different contexts in the generation of costs and benefits (in the wide sense of these terms) of digitalisation through the analysis of DEs. This evaluation places the DE within the SESF and its four subsystems.

This D3.1 evaluates and analyses DEs across 19 LLs in order to explore and assess how a wide range of DEs in different contexts enable or hinder digitalisation and the integration of digital tools and processes. Herein, we provide an initial summary description and analysis of these 19 DEs. As mentioned above, for the purposes of this project, **Digital Ecosystems (DEs)** are defined **as dynamic systems where digital, socio-economic, organisational, knowledge, and physical components converge to support the production, storage, communication, and utilisation of digital technologies and data**. The term 'ecosystem' was first introduced by Arthur Roy Clapham in the 1930s to highlight the material transfers between organisms and their environment (Willis, 1997). Today, it refers to complex, interconnected systems used in various fields such as software development, innovation, and business strategies (Wolfert et al., 2021). This dynamic nature of ecosystems means they are not static but constantly evolving. This concept is significant in the context of CODECs for understanding processes of change, cost-benefit analysis, lifecycle analysis, and process modelling, all of which focus on before-and-after scenarios, transitions, or process evolutions, as well as dynamic interactions.

According to the literature, we have found that DEs may be considered socio-technical systems that emphasise the interplay between software, stakeholders, and their relationships (Falcão, 2023). They bridge social science, computer science, and natural science (Amritesh, 2010) and are enabled by the convergence of ICT, social, and

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knowledge networks (EU, 2007). Additionally, DEs are described as ecosystems where digital technologies mediate and affect the relationships among entities to perform a vast array of functionalities (Metta, 2018). As well, DEs may be seen as a social system which needs to deal with heterogeneity and variations in actors' abilities and resources (Rajagopalan, 2008).

With respect to constraints, costs, and benefits, DEs have been found to involve interconnected and intra-dependant digital platforms that help break down barriers to both horizontal and vertical knowledge sharing (Sarkar, 2007). In the context of knowledge transfer, Amritesh, (2010) view a DE as a socio-technical system which supports knowledge creation, diffusion, absorption, and exchanges of social innovation dynamics related to digital technologies. These “digital” ecosystems cover four key disciplines: social, economic, engineering/computer, and natural sciences (Koch, 2022) and include informal institutional or organisational elements like unwritten rules that influence social interactions and trust (Wolfert, 2023).

To locate this WP3 in the CODECs project, it is useful to note the multi-layered analytical framework that has been used throughout the CODECs project to understand and upgrade the digitalisation of agricultural systems. In WP3 the socio-ecological systems are represented in Figure 2 below and are comprised of 4 subsystems. The incorporations of socio-ecological considerations ensures that digital solutions are not only technically effective but also socially acceptable and environmentally sustainable. Figure 1 illustrates the three interconnected levels of analysis: Focal Action Situation (FAS), Digital Ecosystem (DE), and Socio-Ecological Systems (SES), as well as the subjacent AKIS. The FAS is at the core of the framework and represents the situation where components of a SES interact to provide an outcome, that is, the specific, localised challenges and opportunities faced by farmers and stakeholders in their immediate agricultural environment. This level focuses on practical, actionable aspects such as resource management, decision-making processes, and day-to-day operations within farms. This is where process modelling (T3.3) is closely studied. The outermost layer is the SES, which provides the overarching context in which DEs and FAS operate (T3.2). This level considers the broader socio-economic, cultural, environmental, and institutional factors that influence agricultural systems. The AKIS represents a part within the SES that partly overlaps with the DE and influences the FAS.

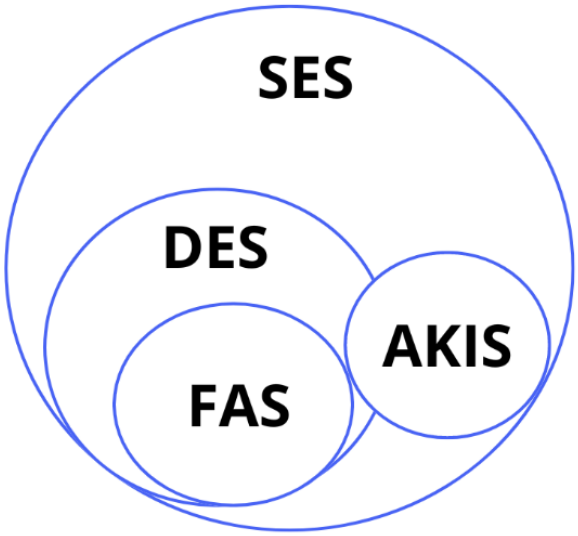

Figure 1. Scheme of nested and combined systems impacting on the FAS

The general concepts above are further conceptualised and operationalised by resorting to the SESF (Figure 2), where **FAS are the LL situations where subsystems of the SES** (actors, resource units, resource systems, and governance systems) **interact to provide an outcome**, understanding the outcome as a solution for the LL problem statement. In CODECS and in this deliverable, Ostrom's SESF is fundamental for mapping, modelling and evaluating the context of which digitalisation take place. This framework's importance lies in its multidisciplinary applicability, encompassing diverse academic fields and multiple actors and roles. It provides a common language to compare LLs and develop theories across cases (LLs) (Ostrom, 2009). The SESF derived from institutional analysis and

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Ostrom's original framework (Ostrom, 2009, and supplemented by McGinnis and Ostrom, 2014; 1990; and Hess and Ostrom, 2007), enables the analysis of multi-tier, complex phenomena by disentangling legal, economic, technological, political, social, and psychological factors. For the purpose of D3.1, the use of the SESF helps identify relevant variables for studying DE, FASs and AKIS. While it has been proven effective in understanding systems related to common-pool resources and traditionally used for natural resources, its application to other systems has been common, including specifically to knowledge in a digital form as a common pool or shared resource (Hess and Ostrom, eds. 2007). We extend the SESF to understand the digitalisation of agricultural and the characteristics of DEs.

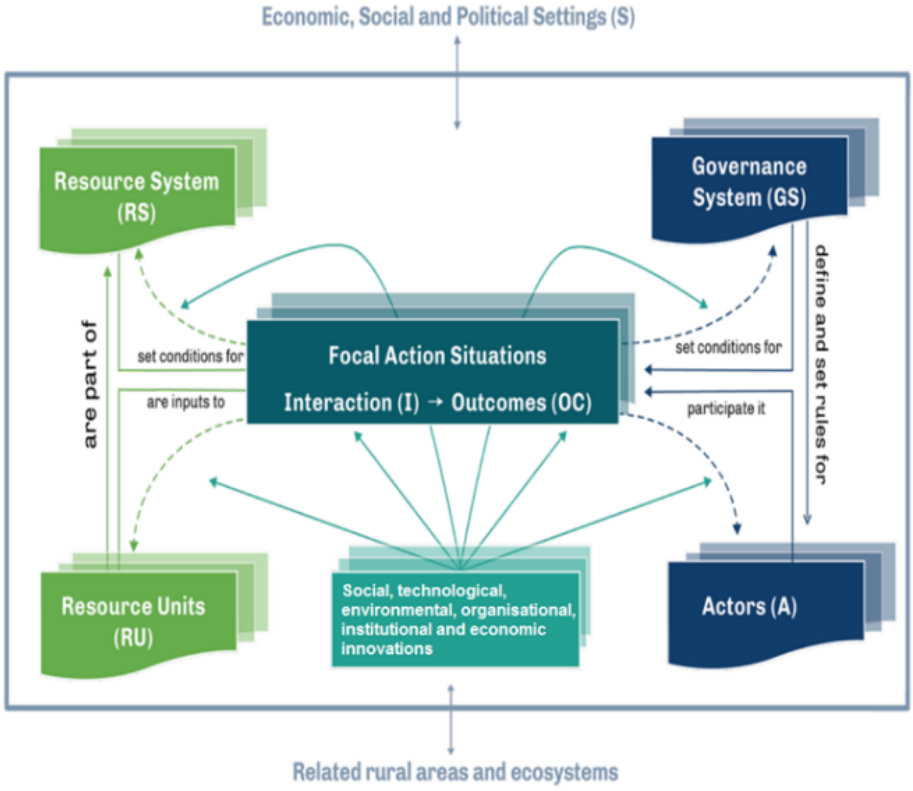

Figure 2. Diagram applying Ostrom's SES framework, showing the interactions between resource systems, governance systems, resource units, and actors, with focal action situations at the core

The concept of knowledge as a common and as a common pool resource is evident in our analysis of resource units and resource subsystems, as well as governance subsystems, and its implications for actors in the SES, including AKIS, and will be further explored in the next iteration of this Deliverable 3.1 (M36). Briefly, the role of knowledge and information as part of complex systems has been researched using systems analysis. Knowledge and information can be analysed within the SESF because it considers both knowledge and information as a commons and a common pool resource. The study of knowledge flows (both in AKIS and in the SES in general) could be therefore analysed as a system which is shared by actors that are addressing social dilemmas (Hess and Ostrom, 2007). In Hess´ words "The complexity of the issues is enormous for many reasons: the vast number of players, multiple conflicting interests, rapid changes of technology, the general lack of understanding of digital technologies, local versus global arenas, and a chronic lack of precision about the information resource at hand" (Hess and Ostrom 2003). Using the SESF described herein, the nature of knowledge and information flows in complex systems will be explored. It is important to recognise that digitalisation introduces a fundamental change in the governance of knowledge, resources, property, etc. The physical and virtual characteristics of distributed digital information have created completely new type of resources, which has implications for resource systems and governance. Hess and Ostrom (2003 and 2007) write that property rights play an important role in the rules for access, extraction, management, exclusion and alienation of resource units and resource systems. Such developments imply significant changes for the SES, DEs and implicitly for AKIS given the way different types of knowledge, data, information are integrated.

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In addition, the SESF offers shared concepts and variables that facilitate comparisons and knowledge gathering across various situations, use cases, and LLs. Initially, the SESF breaks down systems into subsystems: resource systems, resource units, governance systems, and actors (as seen in Figure 2). It also involves interactions, outcomes, and innovations (social, technical, organisational, economic, and environmental). Inside the **Actors Subsystem**, both individual and collective actors operate within the FAS with distinct interests, ambitions, capabilities, resource access, knowledge levels, and beliefs, using resource units for their processes. The **Resource nits** represent the assets accessible to actors within the agricultural ecosystem, beyond just the LL. Assets may be tangible or intangible, material, financial, human or non-human (as set out in Figure 4 below—the R&C classification). The resource units are encompassed by **Resource Subsystems** that outline the management and organisational conditions of these resource units, including social, economic, technological, knowledge/information, and environmental aspects. For the purposes of CODECs data and digital information/knowledge management systems are also relevant. In turn, activities are regulated by rules and norms generated by governance systems. The **Governance Subsystem** comprises formal and informal interactions, rules and self-governance mechanisms, focusing on decision-making processes and their implementation, reform, and reinforcement. Using the Ostrom framework, the analysis of DEs includes various components such as digital resources, which can be exemplified by data, application systems, devices, databases, software, and digital resource systems, such as platforms, infrastructures, clouds, networks, blockchain systems, etc. Additionally, it examines digital governance and resource systems, like data and information/knowledge sharing, regulation mechanisms, cybersecurity policies, and the actors involved in digitalisation.

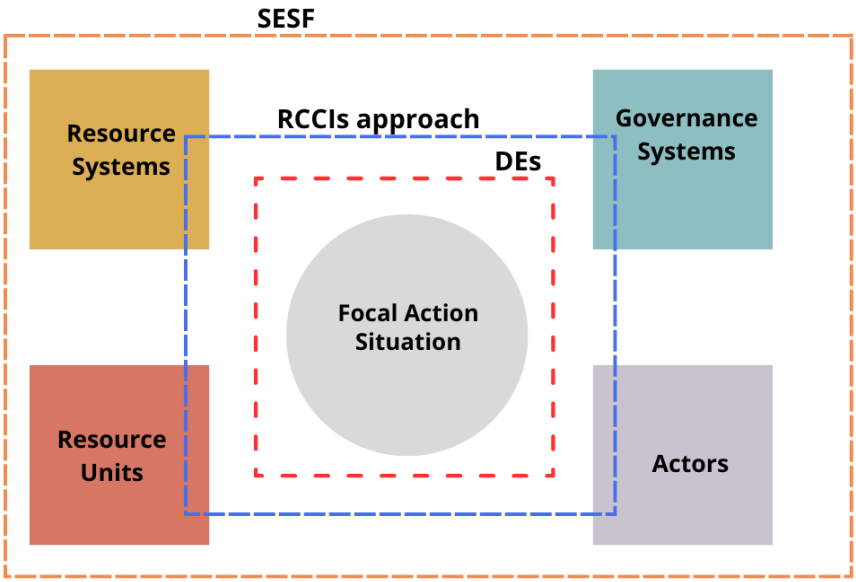

Figure 3. Conceptual diagram integrating SES, DEs, and RCCIs approach within the FAS. The diagram illustrates how the subsystems interact through DEs for describing them, considering process modelling and AKIS

To gain a deeper understanding of the SESF dynamics and its interaction with the DE and FAS (Figure 3) and to facilitate the collection of data from LLs, the identification of resources and capabilities, including collaborations and innovations (RCCIs) has been introduced, relying on resources and capabilities analysis found in business organisation, social sciences and innovation literature (see section 2.1). This analysis helps to understand how actors respond to dynamic and changing environments and how RCCIs within the conditions provided or set by the subsystems influence or can be leveraged or acquired to transition to sustainable digitalisation in agriculture.

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2.1.1 Analysis of Digital Ecosystem, SESF and RCCIs

In order to bridge the SES and the FAS, in the identification of the RCCIs, an important branch of organisational theory based on resources and capabilities, (including innovations and collaborations) has been used, encompassing the resource-based view of the firm (Barney 2001), dynamic capabilities (Teece, Pisano, & Shuen, 1997; Helfat and Peteraf, 2009), the knowledge-based view, (Kogut & Zander, 1992) and the relational view (Dyer & Singh, 1998). The RCCIs approach, compatible with SESF, allows us to better understand the context within the SES and its four core subsystems that interact in the FAS as well as how organisations that carry out agricultural activity response to change and digitalisation processes, and. As in Figure 3 above, the RCCIs approach is "layered over" or used to explore SESF subsystems at play in DEs, LL and their FASs. It is a novel use of both institutional and organisational approaches.

The DEs and the RCCIs available in the digitalisation of agriculture are shaped by the SESF subsystems. For example, a resource subsystem might provide standards for interoperability, thereby enhancing the digital ecosystem for a farmer who uses multiple digital tools on their farm. Another example related to resource systems such as widespread internet in rural areas may contribute to foster the access to specific knowledge, the use of innovative tools, or certain adaptive capabilities. Another example would be knowledge (as a Resource) where knowledge is managed or organised in a system (Resource subsystem) so as to foster innovation capabilities in farmers, technology providers and producer organisations. **The RCCIs approach is used to mediate the analysis of the core SESF subsystems as perceived from FAS level's perspective in LLs (Figure 3).**

Definitions of resources vary and for D3.1 we have adopted the most widely agreed-upon approach defining **resources** as: **tangible and intangible assets owned, controlled or accessed by an entity (e.g., farm enterprise, LL, organisation, etc.), which may be utilised in order to create value, achieve an objective, or solve a problem**. Tangible resources may refer to land, buildings, equipment, and financing, while intangible resources encompass knowledge, motivation, collaborations, etc. (adapted from Barney 1991, Fernández et al. 2000, Galbreath 2005). Intangible resources can be human-dependent (human capital) or independent (non-human) and they are categorised into organisational and technological resources, such as software and AI (Hall, 1993; Fernández et al., 2000). A digital tool, such as a sensor would be considered as a tangible resource because it is material. Tangible resources include those factors related to financial and physical/material assets (Grant, 1991; Galbreath, 2005) (*Figure 4*). In the case of collaborations, resources may include valuable networks and strategic agreements, and in the case of innovation involves novel technologies, or organisational arrangements. It should be noted that the capability to innovate, and having the resources to do so (assets, access to knowledge, enabling institutions, etc.) is included within the RCCIs approach. For example, a capability to innovate can be measured within the subsystem of Actors.

Meanwhile, **capabilities** are defined as the **individual/collective know-how/abilities to achieve or undertake a specific activity or intended goal, which implies a combination of resources and organisational routines or guidelines**. Subcategories of capabilities, such as internal and external, as well as functional and organisational/cultural may be identified (Figure 4) (adapted from Penrose, 1959; Mahoney and Pandian, 1992; Winter, 2003; Grant, 2016; Navas & Guerras, 2018).

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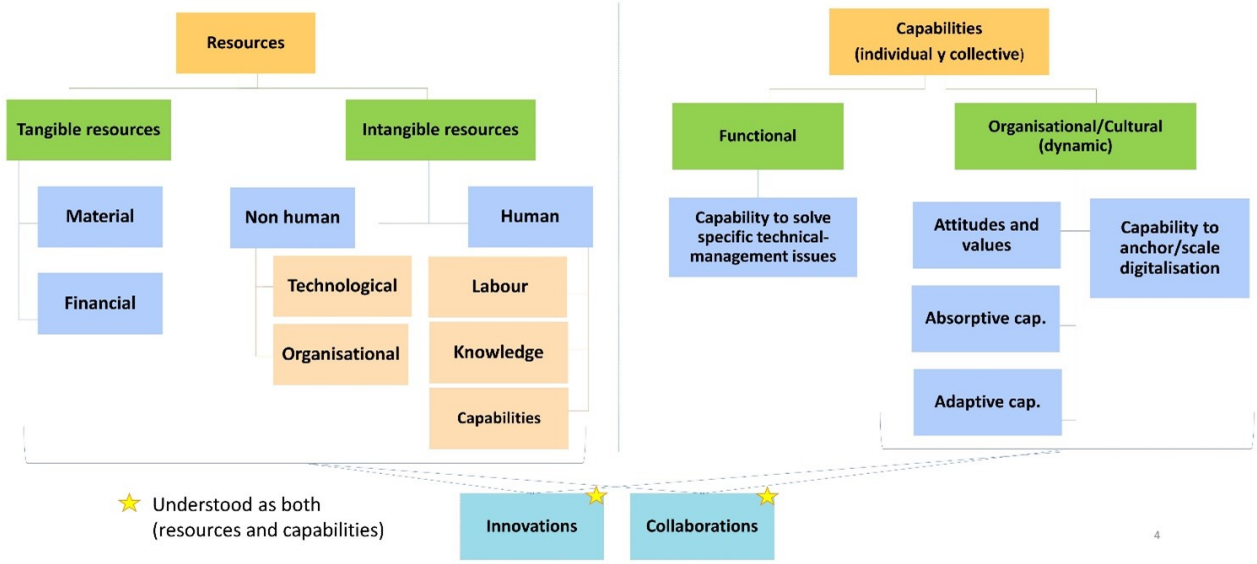

Figure 4. Proposed RCCIs classification for describing DEs, including collaborations and innovations (based on authors´elaboration showed in section 2.1.1)

However, due to the need to tailor the analysis of capabilities to the SESF (including AKIS) and to gauge digital ecosystem conduciveness, as well as farmer digital readiness, definitions and categories of capabilities have been explored and further developed. Capabilities assist to assess the socio-ecological context and the DE. A classic definition of capabilities starts with (Penrose, 1959; Mahoney and Pandian, 1992) wherein “Capabilities are linked to firms´ technological and organisational know-how and represent ways of performing activities and using resources”. Nevertheless, this definition is insufficient when we talk about capabilities within an ecosystem, in which it is necessary to consider the dynamics and the relationships between the components of which it is made. Therefore, there is a need to evaluate capabilities at both individual and collective levels. All this makes it necessary to move to a less static definition and categorisation of capabilities, giving rise to the term "dynamic capability":

In general, **dynamic capabilities** can be understood as **the ability to reorganise the assets** (resources, skills, etc.) **that an individual or collective entity possesses, controls, or has access to, not only to be able to respond to changing environments** (readiness) **but also to increase its capacity for adaptation, survival, and competitiveness** (conduciveness).

The RCCIs approach, particularly the dynamic capabilities, contributes to understand how transitions occur and how RCCIs are utilised to respond to external factors. Nonetheless, dynamic capabilities related to change, differ from operational/functional ones (Winter, 2003). Capabilities are divided into functional and cultural, involving habits, attitudes, beliefs, and values (Hall, 1993) (Figure 4).

We consider **to what extent the SESF and DEs are conducive to fostering the RCCIs that LLs need to solve their FAS problem statements,** so that the 19 DEs could be described and analysed for this D3.1

2.1.2 Agricultural knowledge and innovation systems (AKIS)

Complementary to the study of FAS as embedded in the DES, the AKIS will be analysed, using predominantly the infrastructural perspective, which means the influence of the AKIS actors, institutions, policies and research and innovation related programmes (to name some key elements) that create the environment for the LL to be studied.

Over the last decades, the study of innovations in agriculture has shifted from individual adoption models to more complex approaches where groups of stakeholders and social networks play an important role, recognising the procedural character of innovations, the multiple influencing forces, and the value of different types of knowledge

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and their integration. The concept of the Agricultural, Knowledge and Innovation System (AKIS) has emerged as a way to structure this complexity more systematically (see definition below).

Agricultural Knowledge and Innovation Systems (AKIS) are mental constructs that relate corporate, collective and individual actors with the aim to support voluntary, knowledge-based change and innovation processes. As social entities they may be shaped as multi-actor networks that co-develop solutions tailored to specific contexts. The **AKIS** concept helps analyse knowledge and innovation infrastructures in DEs, and is defined as **knowledge flows between persons, organisations and institutions who use and produce knowledge for agriculture and interrelated fields, and by linking people and institutions, AKIS promotes mutual learning and generate, share, and utilise agriculture related technology, knowledge, and information**.

A very specific dimension of AKIS in the European Union (EU) context is that it recently moved from being solely an academic concept used to describe actors, networks and institutions (Knierim et al., 2015) to a policy instrument, which is supposed to guide Research and Innovation policies of EU Member States (MS) (Knierim and Birke 2023; Sutherland et al. 2023). In the context of the Common Agricultural Policy (CAP), AKIS is defined as the combined organisation and knowledge flows between individuals, organisations, and institutions in agriculture (Reg 2021/2115). In this new policy perspective, the AKIS concept promotes individual, collective and organisational generation, sharing, and utilisation of agriculture-related knowledge and technology and learning among the various actors engaged in the agricultural sector and related spheres (Birke et al, 2022). The concept helps in understanding linkages, interdependencies and interactions dedicated to knowledge and innovation spread and acquisition processes, contributing to the conduciveness of Des. The application of the AKIS concept aims at supporting targeted coordination among a broad range of actors despite national differences, ensuring effective funding mechanisms and research scopes (Moreddu and Poppe, 2013).

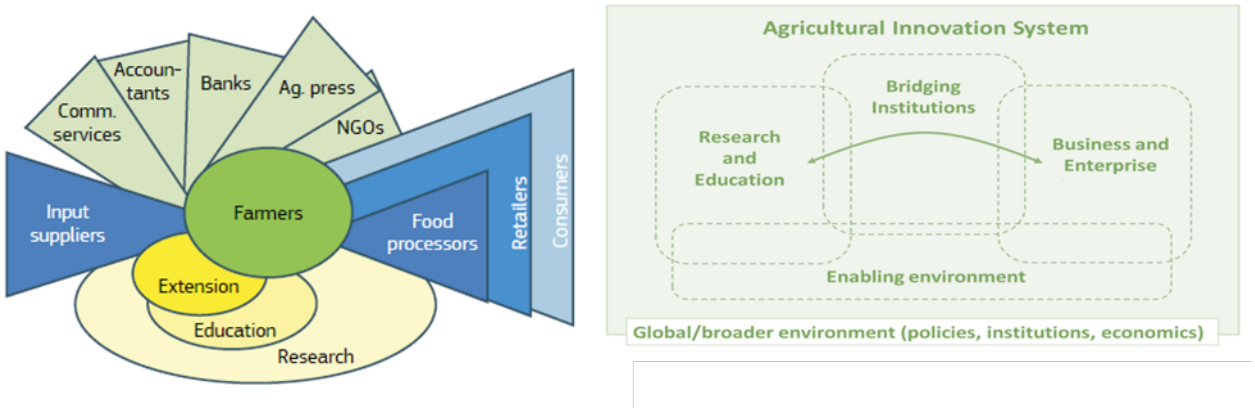

Figure 5. Left AKIS actors (Standing Committee on Agricultural Research (SCAR) Collaborative Working Group AKIS, 2012). Right: Components of Agricultural Innovation Systems (FAO, 2022)

The definition of AKIS has also evolved. According to the Regulation (EU) No 2021/2115 AKIS is "*the combined organisation and knowledge flows between individuals, organisations, and institutions who use and produce knowledge for agriculture and interrelated fields*" (EU, 2021). The EIP-AGRI operating unit (2018) describes the AKIS as "*the whole knowledge exchange system: the ways people and organisations interact within a country or a region. AKIS can include farming practice, businesses, authorities, research, etc., and can vary a lot, depending on the country or sector*". According to EU SCAR (2012), AKIS is a useful concept to describe a system of innovation, with emphasis on the organisations involved, the interactions between them and the institutional infrastructure with its incentives. Some authors highlight that although extension, education and research are key components of the concept, there are many more actors that directly influence the decision making of farmers and their innovations (Figure 5).

The process of digitalisation affects, and it is affected by, knowledge flows e.g. through the emergence of new actors (Klerkx et al, 2019) or through a shift in knowledge relationships (Ingram and Maye, 2020). Digital innovations can

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enable or disrupt knowledge networks, allowing new actors to enter and changing preexisting roles (Ingram and Maye, 2020). In contrast to other types of innovations in agriculture, the adoption of digital technologies requires a transition from *experiential decision-making* to *data-driven decision* processes (Eastwood 2017) causing high uncertainty and requiring support structures to facilitate learning and building of trust in the implementation process (Monteiro Moretti 2023). For a digital transformation that creates value (optimise the potential and creates a fair benefit for the farmer), the knowledge and skills of the actors (beyond the digital domain) need to be strengthened, in order to manage the new demands, relations and tensions (Ingram and Maye, 2020).

There are different analytical perspectives used to study knowledge networks. In AKIS studies, infrastructural, procedural and/or functional perspectives have been used (Klerkx et al., 2012; Knierim et al., 2015). Particularly important for policy recommendations are the infrastructural and process perspectives on AKIS across the EU, reflecting mostly AKIS strategic approaches in EU Member States (EC, 2023).

As a multilayer system, AKIS can be approached from four different perspectives:

- Focusing on infrastructures, identifying present knowledge infrastructures, actors, their links, and institutions
- Focusing on processes or networks, understanding how change occurs through networking, learning, initiating change, and improving practices and products
- Focusing on capacities, assessing individual, organisational, interorganisational, and institutional capacities within the AKIS
- Focusing on normative aspects and expectations, determining the necessary functions for a well-performing AKIS

In addition, on a micro level Sutherland and Labarthe have focused on farmers' micro-scale knowledge and innovation systems in order to understand hidden and gradual changes (Sutherland and Labarthe 2022).

In CODECS, the concept of AKIS will be used to analyse particular features of the DE, as a subjacent subsystem of the SESF. The AKIS perspective underscores the essential knowledge flows for farm digitalisation, emphasising their influence on digital transformation processes. Consequently, AKIS-related interventions can act as both enablers and hindrances to creating a conducive digital environment, aiming to enhance knowledge circulation and innovation. Summarising, the AKIS concept has the potential to further specify the actor and governance subsystems in the SESF, and to highlight knowledge exchange and learning components relevant for the interactions around the development and application of digital technologies as studied with the FAS focus (Knierim, et al. 2023).

To do so, CODECS follows an infrastructure perspective, which has already been applied to describe AKIS systematically and compare situations in various European countries (Knierim et al., 2015).

2.2 Socio-technical process modelling of use cases

The Socio-technical Process Modelling method adopted in Task 3.3 stems from two main areas of the information systems field, namely business process modelling and requirements engineering.

Business Process Modelling (BPM) (Aguilar-Savén, 2004) is a method used to create a visual representation of an organisation's workflows and activities. This technique involves using diagrams and flowcharts, i.e., models, to map out the steps involved in various processes of the organisation. Business process models serve as a common language between stakeholders, as they enable a shared understanding among IT experts, business analysts, social scientists and economy experts, facilitating collaborative analysis, discussions, and decision-making. By modelling and reasoning on their processes, organisations can analyse their workflows to identify bottlenecks, inefficiencies, and areas for improvement. Among the visual languages used in BPM, Business Process Model and Notation (BPMN, 2010) is the most prominent one, having a large diffusion among practitioners. BPMN models are means for information exchange between engineers and business analysts (Corradini et al., 2018). The language supports advanced techniques, even AI-based, for data analysis, such as process mining (Aalst 2011), or change impact analysis (Alam, 2015).

Requirements Engineering (RE) (Loniewski et al.; Horkoff et al., 2019) is a field of software and systems engineering that focuses on understanding and defining what a system must accomplish. It involves capturing the

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expectations and needs of stakeholders, detailing them clearly, and ensuring they are realistic and achievable. The process also includes handling any changes to these requirements over time, ensuring that the system being developed aligns with user needs and business goals. To facilitate communication with stakeholders and reason on their goals, RE also involves graphical modelling activities, similar to BPM. Common visual languages used in RE are iStar (Yu et al., 2011), and KAOS (Dardenne et al., 1993). iStar focuses on representing social relationships between stakeholders that are part of a socio-technical system, i.e., a system composed of human actors and technological elements, and in representing their goals. Instead, KAOS focuses on system's objectives to be achieved, and decomposition of the objectives into lower-level requirements. Another common notation used in RE is the Unified Modelling Language (UML, 2017), which is a comprehensive software engineering language including different types of structural diagrams (e.g., class diagrams) and behavioural ones (e.g., sequence diagrams). UML is widely used in industry for requirements representation, according to the survey by Wagner et al., 2019.

3 Methodological approach

3.1 Activities of WP3 for D3.1

The Guidelines produced under Task 3.1 (Annex A) sets out how the characterisation of DEs occurs in three distinct phases during the life of the CODECS project (Figure 6). Initially, the process involves preparing, reviewing, and utilising existing information. The second phase emphasises engaging with LLs and stakeholders to collaboratively develop and validate the DE characterisation. This D3.1 (M24) presents the outcomes of stage 2 (except for the validation which will occur during the third LL workshop), and the final phase 3 will be dedicated to analysing and synthesising the collective research results. Stakeholders involved in the LL participated in two main activities: 1) Identification of RCCIs and characterising the SESF subsystems for mapping the socio-ecological context, and 2) developing process diagrams using formal notations for the socio-technical process modelling.

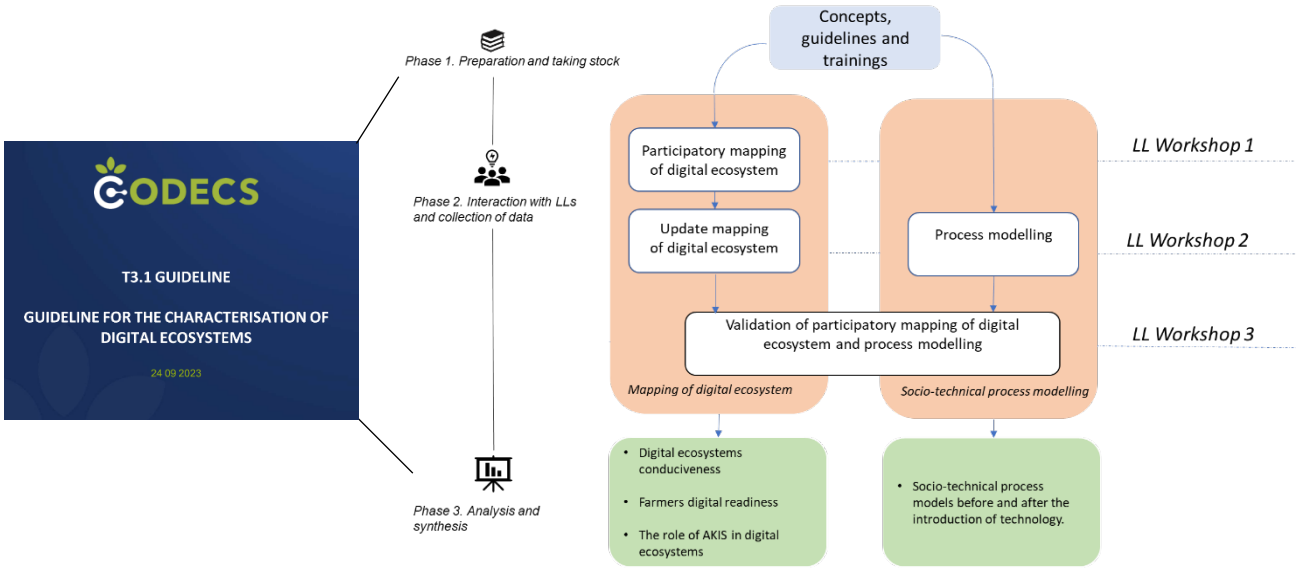

Figure 6. Guidelines for the characterisation of DEs within the CODECS project. It includes three phases: preparation, interaction with LL for data collection, and analysis. The methodology involves participatory mapping and socio-technical process modelling

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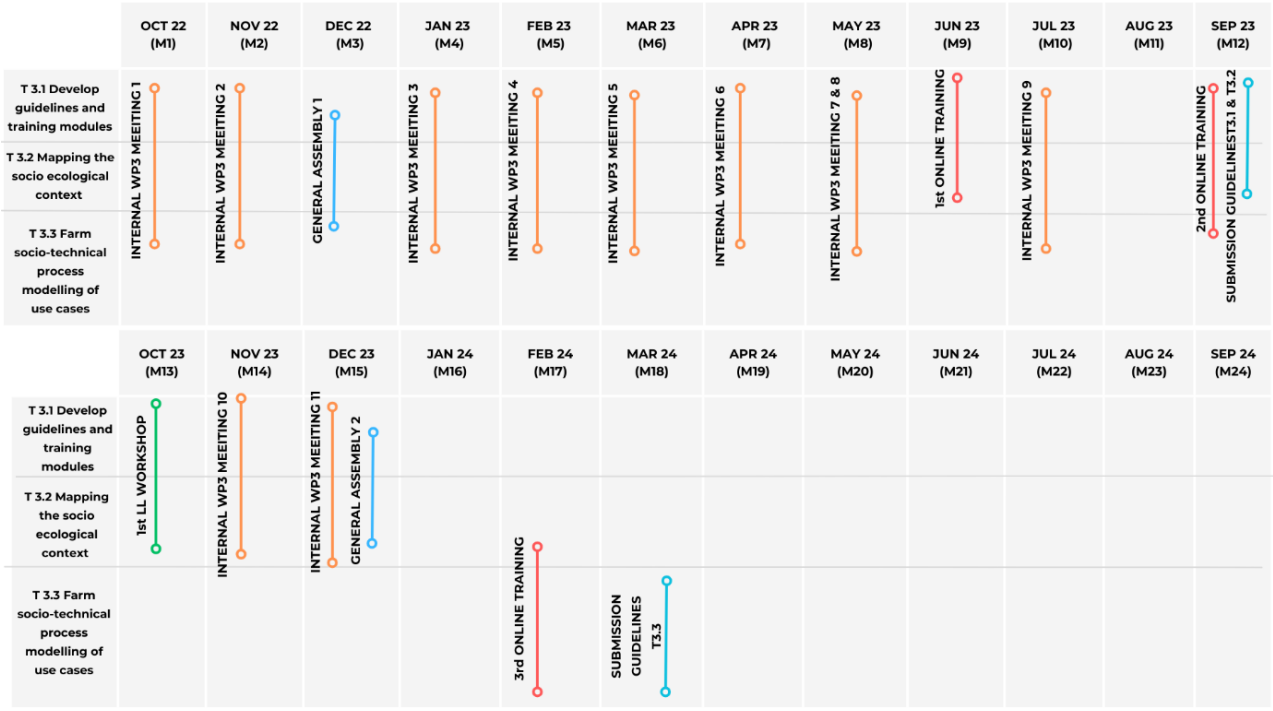

Figure 7. Timeline of key WP3 activities (meetings, workshops, training, and deadlines) from Oct. 2022 to Sep. 2024

Figure 7 outlines the activities undertaken to achieve the objectives of each phase in the DEs characterisation. WP3 internal meetings were held during the initial phases to configure and co-create the theoretical framework to follow[1]. During the first general assembly in December 2022, the initial approach was explained to LLs and other project participants, and feedback was gathered to refine the methodology[2].

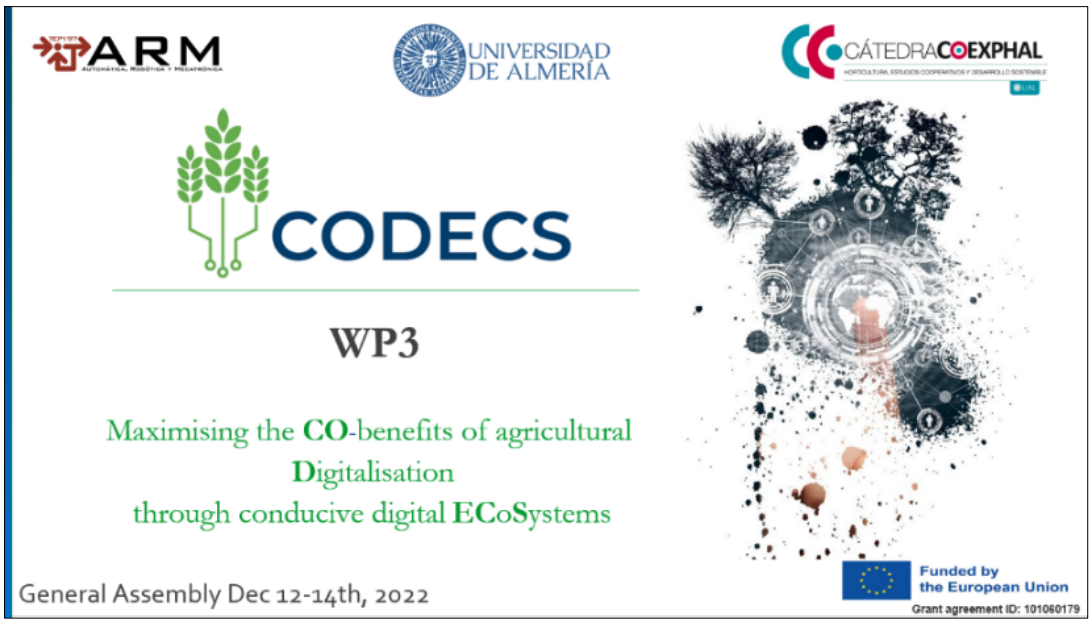

Figure 8. CODECS General Assembly WP3, December 12-14, 2022

[1] WP3 Meeting material
[2] G. ASSEMBLY 2022

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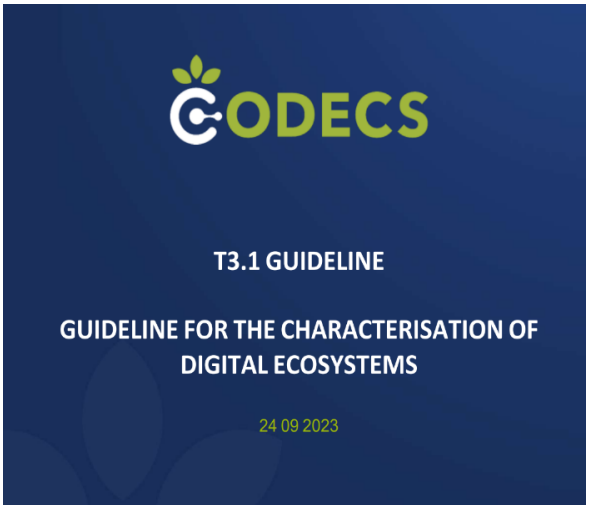
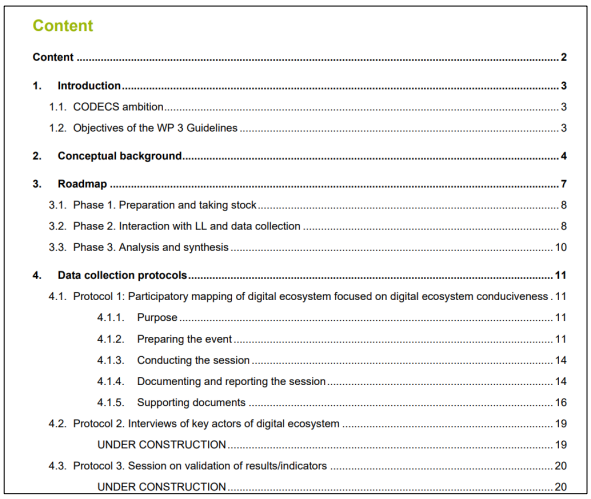
In the following months until M12, work was focused on developing guides (T3.1)[3] and materials for the first workshop (templates, worksheets, PPTs., etc.) dedicated to the socio-ecological context mapping (T3.2), including two online training[4] sessions with LL coordinators for their use in their LL Workshops. Materials for reporting workshop results were provided, thus facilitating and standardising data collection.

a)

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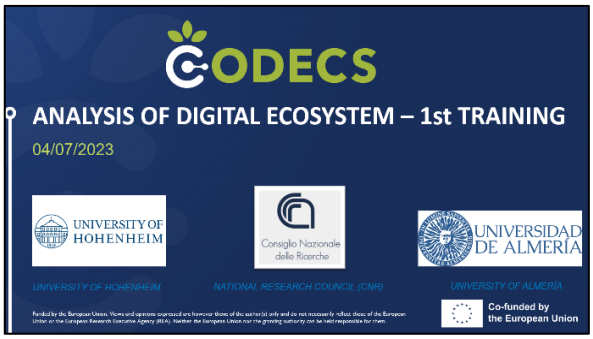
b)



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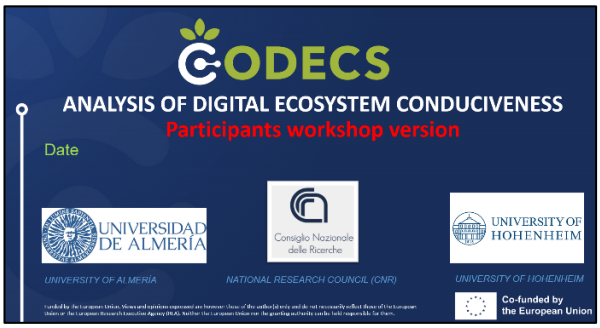

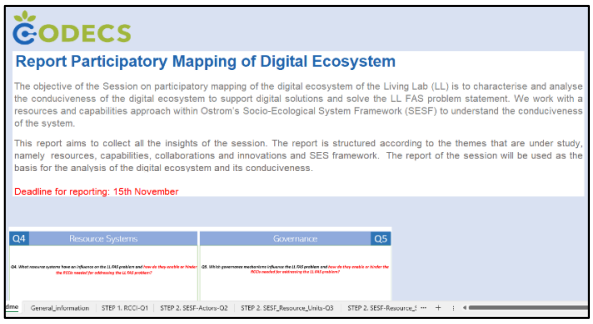

Figure 9. Materials prepared for the participatory mapping of DEs and LLs workshops include a) Guidelines; b) Training sessions presentations and c) PowerPoint for LLs workshops and reporting templates for gathering data to support

In December 2023 M15, the second general assembly took place[5], where an exercise was conducted to gather information on the "ideal DE" (conduciveness and readiness) within the SESF and to identify the characteristics

[3] Task 3.1
[4] WP3 Training
[5] G. ASSEMBLY 2023

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according to subsystems. This exercise was to introduce the concept of indicators which will be carried out at a later stage.

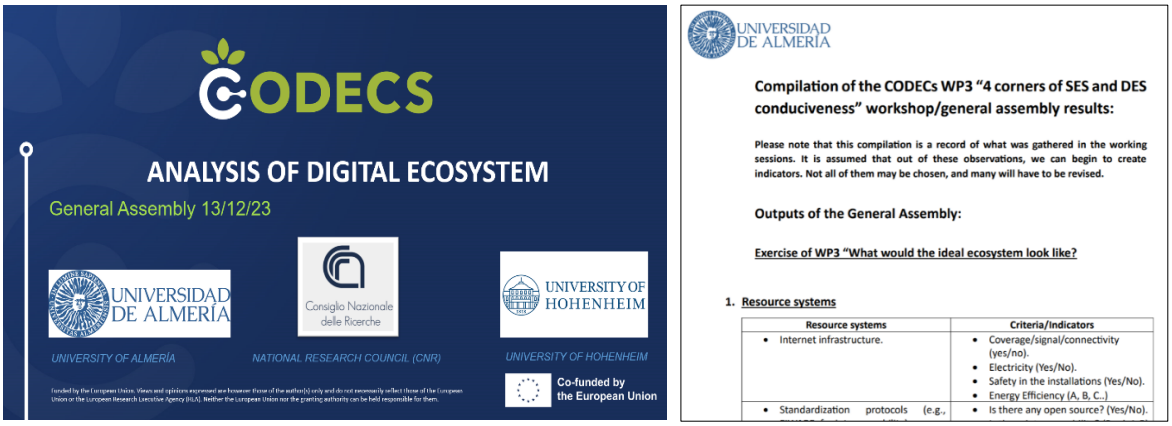

Figure 10. General Assembly materials and results from the "4 corners of SES and DES conduciveness" workshop held on December 13, 2023

Similarly, Guidelines (M18) and online training materials (M17) related to socio-technical process modelling (T3.3)[6] were created and carried out, providing necessary guidance to LL leaders to collect information. A pilot study was carried out and refined with feedback (M9-15) resulting in the consolidation of the methodology and Guidelines (M18). Data collection was performed from M17 to M20.

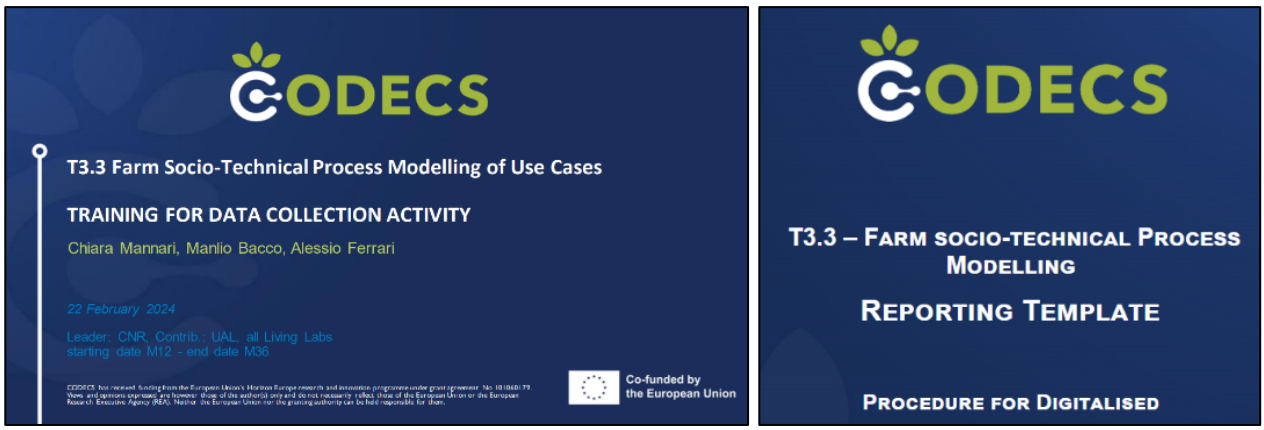

Figure 11. Material prepared for Socio-technical process modelling including Guidelines, Training material for LL coordinators and, Report template for collection of data

[6] Task 3.3

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3.2 Mapping the Socio-ecological context

Referring to **Mapping the Socio-ecological context (T3.2)** a 4 step-methodology was set up (Figure 11) for the LL collaboration and co-creation. This D3.1 involves Step 1 and Step 2. The initial point of the analysis of the participatory mapping of socio-ecological systems is the FAS, where each LL identify a clear problem statement, e.g., lack of interoperability among the technologies in the farm. Then:

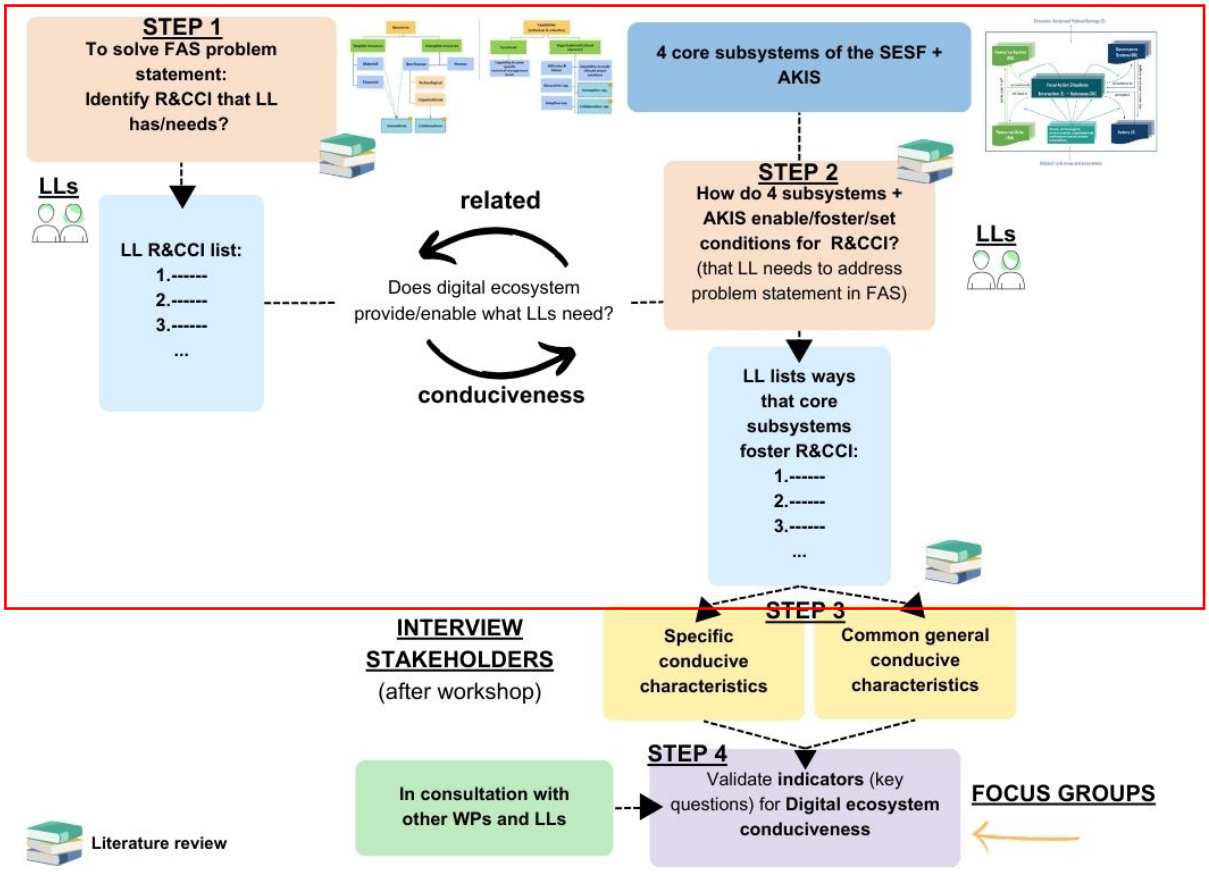

Figure 12. Four-step methodology proposed for mapping the socio-ecological context of DEs

The **first step** involved stakeholders in the LLs **identifying their current and needed RCCIs to address their FAS problem statements**. This implied compiling a comprehensive list of RCCIs that each LL has or requires (Figure 12 - Step 1).

Subsequently in the **second step**, the **four core subsystems of the SESF** (actors, governance, resource units, and resource systems) **are analysed to determine their influence on the FAS and how they enable, foster, or set conditions for the identified RCCIs** (Figure 12 - Step 2). This helped in understanding how these SES subsystems contribute to solving the FAS problem statements.

During the **third step**, stakeholders lead the **identification of specific and common general conducive and readiness characteristics** (Figure 12 - Step 3). These characteristics allow to understand the conducive nature of the DEs in supporting the RCCIs and the farmer digital readiness. The **fourth step** involves **validating the indicators of digital ecosystem conduciveness** and readiness through consultations with other work packages (WPs) and LLs, focus groups, and interviews with stakeholders (Figure 12 - Step 4). This validation ensures that the identified indicators accurately reflect the conduciveness and readiness of the DEs. Throughout that process, continuous interaction with LL coordinators, literature reviews, and stakeholder interviews ensure that the methodology is co-created, validated, and refined for accurate characterisation of the DEs. These last two steps will be carried out at a later stage (before M36 and M44).

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3.2.1 Data collection for Mapping the socio-ecological context

The data for mapping the socio-ecological context and AKIS analysis, was collected as part of the LLs Workshops, which were conducted between October 2023 and March 2024. The participatory workshops were designed to facilitate discussion between participants, with the objective of characterising and analysing the DEs within Ostrom's SESF and using the RCCIs approach. The following questions asked during the workshops guided the mapping of the SESF involving the four "subsystems": actors, resource units, resource systems and governance:

Q1. What resources, capabilities, collaborations and innovations does the LL have and need to address the LL FAS problem statement?

Q2. What are the main actors related to the LL FAS problem statement and how do they enable or hinder the RCCI needed for addressing the LL FAS problem?

Q3. What resource units have an influence on the LL FAS, and how do they enable or hinder the RCCI needed for addressing the LL FAS problem?

Q4. What resource systems have an influence on the LL FAS problem and how do they enable or hinder the RCCI needed for addressing the LL FAS problem?

Q5. Which governance mechanisms influence the LL FAS problem and how do they enable or hinder the RCCI needed for addressing the LL FAS problem?

In total, 19 LLs reported the results of the participatory workshop (Table 1).

*Table 1. Overview of LLs which conducted and reported a workshop. (*Missing LL report)*

ID	Name of LL	Country	Partners
1	Agrifood Technology	Belgium	EV ILVO
2	Automation of orchard management	Czech Republic	CSITA + CZU
3	Grassland Management	Estonia	EMU
4	LIT Ouesterel	France	INRAE
5	Occitanum OL VITI	France	INRAE
6	AgDiBi	Germany	UNI HOHENHEIM + LEL
7	Spraying drones	Greece	AUA
8	Innovative Soil Scanner	Hungary	SZE
9	Cloughjordan Food Hub	Ireland	SUST
10	Pecorino Toscano DOP	Italy	UNIPI + Pec.Toscano
11	Organic table grapes	Italy	CIHEAM-IAMB
12	Local beef cattle farming	Latvia	BSC + ZSA

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ID	Name of LL	Country	Partners
13	RAMAS	North Macedonia	AGFT
14	APPETIT	Poland	ISOTECH
15	Scottish Small Farms and Digital Platforms	Scotland	HUTTON
16	Greenhouse Smart Sensor Laboratory	Serbia	BIOS
17	Artificial irrigation Management	Slovakia	NEWEDU
18	Smart Villages Network	Slovenia	UL
19	Open Lab Sheep*	France	INRAE + IDELE
20	Almería Agroecology	Spain	UAL + COEXPHAL

The overall results of the workshops were compiled by the coordinators of the LL, using the templates provided, and shared for further analysis.

3.2.2 SES subsystems analysis

The data related to the socio-ecological system mapping presented in this D3.1 is derived specifically from Steps 1 and 2 of the proposed methodology for which various materials were prepared[7]. Only synthesis data related to the four subsystems from Step 2 is presented herein, as data from Step 1 is implicit in the Step 2 four core subsystem assessment.

The collected data was analysed qualitatively in two phases. In the initial stage, data corresponding to Step 1 was organised according to the RCCIs classification. Subsequently, the analysis progressed to Step 2, which involved examining how the four subsystems of the SESF (Actors, Resource Units, Resource Systems, and Governance Systems) had an influence on the LL FAS and how they enabled or hindered the RCCIs necessary for the LLs to solve their FAS problem situation.

This analysis was conducted with an end to understand the SES context of, and influence on, the LL and FAS and to gauge the conduciveness of the ecosystem, assessing how the elements identified by each LL facilitate their digitalisation efforts according to data from Steps 1 and 2 and the LL notes and comments. For each LL, the four subsystems have been described, integrating findings from both steps to provide a qualitative characterisation of the DE in which the LLs are situated.

The relationships between actors in the Actor subsystem and the RCCIs identified in Step 1 are detailed, focusing on how they either facilitate or hinder the acquisition of, access to, sharing of, etc. of RCCIs and the role of these actors in the digitalisation process of each LL. Likewise, the subsystems of Resource Units, Resource Systems, and Governance Systems are described in order to understand their relationship with the RCCIs and with Step 1. The extent to which each subsystem facilitates or constrains digitalisation was then described based on the LLs' input. The analysis of data per LL is an overview which will be developed further for M36.

[7] WP3 Training

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3.2.3 Agricultural Knowledge and Innovation System analysis

Within Task 3.2, the analysis of AKIS focused on those aspects of AKIS from the infrastructural analytical perspective, that is, Governance Subsystems and Actors Subsystems, namely the following research questions:

Who are the main actors in and around the Living Lab that have an influence in addressing the LL challenge

What AKIS coordination mechanisms have an influence in addressing the LL Focal Action Situation?

The analysis was conducted by following two cycles of coding, developing a scheme of categories, and subcategories derived from the responses to Q2 and Q5 above. Two coding cycles were done: a) determining salient ideas and b) structuring and comparing with the AKIS analytical framework, refining categories and the coding scheme.

During the first coding cycle, we analysed the answers based on the different themes and facilitating questions of the workshop. During the second coding cycle, we based our analysis on the theoretical grounds. For the *Actor Subsystem* we identified and counted the number of type of actors mentioned. After the first phase of identification, we reclassified the actors considering characterisation of actors in the AKIS literature. The results reflect the type and number of actors mentioned by LL members during the workshops.

During the second coding cycle, for the *Governance Subsystem* we identified and categorised the type of rules, norms that are related to the definition of AKIS governance mechanisms; the results of those reflect norms, rules and regulations related to the coordination of AKIS components, and in some cases, those related with the governance of agricultural knowledge in general.

3.3 Farm Socio-technical process modelling of use cases

The **Farm Socio-technical Process Modelling of Use Cases (T3.3)** analyses the transformation occurring in business processes in the context of the FAS defined by each LL. Process Modelling is a form of **System modelling which consists of an approach used in software engineering to represent and analyse complex systems. Process modelling involves creating abstractions of real-world processes, allowing stakeholders to gain insights into their structure, behaviour, and interactions at a very detailed level.**

In CODECS, a methodology based on process modelling is being developed **to carry out** qualitative analysis of the process transformation envisioned by each LL by describing actors, resources (units and systems), technological innovations, and relations. The objective of the process modelling activity is to create easy-to-read diagrams of processes carried out in a farm *before* and *after* the introduction of digital solutions. The diagrams are used to qualitative evaluate the impact of digitalisation, in terms of additional/removed actors, tasks and components.

To provide a complete overview of the processes relevant to the definition of the social-ecological system, processes are mapped over the entities and relationships of Ostrom's SESF, thus considering the information required by the SESF, e.g., actors, resource units, input, inclusion, and participation relationships. A set of standard notations for graphical representation has been identified and to ensure completeness each LL will develop three types of diagrams focusing on complementary dimensions: the structure of the process, the actors' goals and strategic relationships, and process flow. The analyses will also provide qualitative inputs to the cost-benefit analysis. A step-by-step procedure for carrying out the process modelling in CODECS is being applied. In the definition of the procedure, three major requirements were considered: 1) the process modelling shall be the result of a co-creation activity by LLs and task leaders; 2) the data collection shall be performed in coordination with other tasks, and shall take into account previous project activities that already produced useful data; and 3) The number of iterations with stakeholders in terms of data collection and agreement shall be limited, considering time constraints.

The infographic in Figure 13 describes the procedure which is articulated in subsequent phases coordinated with LLs activities:

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Figure 13. Infographic describing the methodology to develop process models

Data Collection: this is conducted by LL coordinators through workshops, focus groups, and interviews with key informants like farmers, advisors, and technology providers, collecting diverse perspectives and insights.

Reporting: following the guidelines, LL coordinators compile and report data using a provided template, ensuring accuracy and completeness, with sections for feedback on data collection challenges and suggestions.

Check: task leaders review reports, seeking additional data from LL coordinators if necessary and validate collected data in plenary workshops with LL stakeholders.

Formalisation: task leaders create multiple diagrams from the textual data, focusing on structure, goals, and processes.

Agreement: in a workshop or focus group, LL representatives validate the diagrams, ensuring their alignment with the focal action situation, fostering a shared understanding and guiding further analysis on the cost and benefits of the introduction of digital technology

The activities for socio-technical process modelling in Task 3.3 are the following. We first identified suitable graphical modelling languages for process representation (M1-M6) and defined a modelling strategy for the agricultural sector (M6-M9). A pilot study tested these languages on the Pecorino Toscano LL (M9-M15), leading to refinements in the modelling method to simplify it for stakeholders (M16-M17). Guidelines and a reporting template were developed and refined through partner meetings (M9-M17). Training was provided to LLs on using these tools (M17), followed by data collection and reporting from LL contact points (M17-M20). Further sub-activities will be defined, based on the needs that will emerge during the projects. More detailed information about the research process followed to define the guidelines and reporting templates is provided in following sections.

The data presented in D3.1 was collected through focus groups and interviews carry out by LL coordinators, for which a training activity was organised to present guidelines (Annex B) for data collection. The following steps include validation activities during plenary workshops and LLs submitting revised reports plus additional iterations for refinement of diagrams, as seen in Figure 13.

3.3.1 Data collection for Socio-technical process modelling

To design the diagrams, process-relevant data need to be collected and reported by the LL contact points. To facilitate the data collection, a set of guidelines were defined together with templates for reporting. The guidelines are available in **Annex B**. In the following, we summarise the content of these documents and provide examples when appropriate.

The guidelines present three alternative procedures for data collection, with associated templates. The procedures are differentiated based on the state of digitalisation of the LL, which will be detailed in the following paragraph. Each procedure contains about 12 questions asking to describe both the process *before* and *after* the introduction of the

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digital solution, as well as other information to design the different models. The templates are editable documents containing the questions explained in the guidelines. Each template corresponds to a data collection procedure.

Three possible states of digitalisation have been identified, with associated data collection procedures and templates. The states are Zero Digital, Digitalising, and Digitalised:

Zero Digital – No digital solution in place, digital solution not identified. This is a state in which the digital solution to solve the problem statement has not been identified yet. Starting from an evaluation of the current process in terms of assets, resources and capabilities available, the LL explores alternative solutions to solve the problem statement based on the adoption of different technologies. LLs are invited to consider that they are in a Zero Digital state also if some technologies are used in their process, but the specific digital solution they are interested in to solve the problem statement has not been identified yet.

Digitalising – Digital solution identified, not yet fully adopted. In this state, a digital solution to solve the problem statement has been identified but not yet adopted. This occurs when the technology is available but not stable yet, or not fully adopted in the LL. For example, the LL could be in the process of introducing the technology within a restricted group (e.g. a demo farm), or a prototype has been developed and tests are being carried out. In this context, the LL is able to compare the process today (i.e., before the introduction of the digital solution) and after the introduction of the digital solution, by trying to envision the process in the future.

Digitalised – Digital solution adopted, to be evaluated. In this state, a digital solution to solve the problem statement has been purchased or developed by the LL. This occurs when, after a first period of in-field testing, the technology has been adopted within the LL. In this context, the LL is able to evaluate the technology and compare the process today (i.e., after the introduction of the digital solution), and before the introduction of the digital solution, by trying to recall the process in the past.

The questions reported in the guidelines can be grouped according to the following sections, which are ordered differently depending on the state of digitalisation of the LL:

Introductory Questions: questions oriented to understand the context of the LL, and in particular the core problem that will or has been addressed through a digital technology. In addition, these questions ask to reflect on the state of digitalisation and guide the LL in the selection of the most appropriate state and associated reporting template. The running example of the Pecorino Toscano LL illustrated in Section 5 can be positioned in the Digitalising case, as a technology has been selected, prototyped, but not introduced yet.

Description of the Digital Technology: questions to provide a description of the digital technology, and the reasons why this has been selected. In our example, the main technology introduced is the FMIS, which aimed at facilitating the exchange of information between actors and improving the monitoring process. In the case of a Zero Digital LL, these questions enable the LL to reflect on the possible alternative digital technologies and guide the LL towards the identification of the most appropriate one for their context.

Process After the Digital Technology: questions aiming to capture how the LL process appears when the digital technology is, or will be, in place. These questions are partitioned into two main groups:

- **Goals, Actors, and Resources:** questions to identify the goals of the actors involved in the LL, and the resources used by the actors to achieve these goals. In our example, the Agronomist actor has the goal of saving time, and to this end it uses the resource of the Pet Scan Bluetooth. This information is particularly useful to design the iStar diagrams and the UML diagrams, as these are oriented to represent objectives, entities, and relations thereof.
- **List of Actions:** questions that list the actions performed by the actors using the available resources, *after* the introduction of the digital technology. These questions ask precise lists of actions, divided by actors, and are mainly useful to design the BPMN diagram for the process

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that has been transformed by the digital technology. In our example, the list of actions for the Agronomist include visiting scheduled farms, requesting animal information, etc.

Process Before the Digital Technology: similar to the previous set of questions, these aim to capture the LL process when the digital technology was, or is, not in place. Again, the questions are partitioned into two main groups:

- **Actors, Resources:** questions to identify actors and resources involved in the process before its transformation. These questions aim to highlight which actors and resources were removed or added with the introduction of the digital technology. In our example, the resource App was introduced, while the sheets to trace the health status of animals were removed. These questions help in the construction of the BPMN diagram before the digitalisation.
- **List of Actions:** questions that list the actions performed by the actors using the available resources, before the introduction of the digital technology. These questions are mainly useful to design the BPMN diagram for the process adopted by the LL when the selected digital technology was not present. In our example, some actions such as the update of the sheet to trace the health status of animals were removed, while other actions such as the update of the FMIS were added.

Training and Preliminary Feedback. The guidelines and templates were released on 20th February 2024 and a two-hour training was organised with LL coordinators on 22nd February 2024. The training consisted of an introduction to the overall Socio-technical Process Modelling activity with the presentation of the case study on Pecorino Toscano LL as an example of an outcome. Then, the procedures for Zero Digital, Digitalising, and Digitalised were explained in detail.

The training was interactive reserving slots for discussion, hints for data-collection, and feedback. Hints were provided in the form of FAQs and questions were related to the management of the documentation, the timeline expected and the data collection activities to be organised. The training was coordinated with the WP4 training that was held immediately afterwards and provided more practical advice regarding interviews with farmers and practitioners. In fact, the strategy suggested to LL contact points was to collect questions for both WPs and to conduct a single interview or focus group asking multiple questions.

A survey on Mentimeter supported the training activity serving as an icebreaker for the meeting and collecting early feedback on the process modelling.

The following questions were asked to the participants in four question survey:

Do you have previous experience with Process Modelling?

How do you feel with respect to the Process Modelling activity in your Living Lab?

Which state of digitalisation would you assign to your Living Lab?

How much information do you already have?

What kind of data collection activities do you plan to organise?

Did this training help to clarify Process Modelling data collection?

3.3.2 Details on the adopted research methodology

This Socio-technical Process Modelling method applied in Task 3.3 is specifically designed to represent and assess technology-driven process transformation within co-design contexts such as LLs, with a focus on the agricultural domain.

The research methodology adopted to define the method is *Design Science* (Wieringa, 2014), a research framework focused on creating and evaluating *artefacts*—such as models, systems, or methods — that solve specific, practical problems. In our case, the produced artefact is a method, i.e., the Socio-technical Process Modelling method. Design

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Science combines creative design with rigorous scientific approaches to develop solutions that are both innovative and effective. The goal of design science is not just to understand reality, but to actively shape it by producing artefacts that can be applied in real-world contexts, e.g., the LLs in our case. The Design Science methodology is based on multiple iterative cycles in which the artefact is incrementally refined and validated. Each cycle is composed of different steps, namely:

Problem Investigation: this phase involves identifying and thoroughly understanding the problem or challenge that needs to be addressed. It includes gathering relevant information, analysing the problem's context, and defining the specific objectives that the solution should meet.

Treatment Design: in this phase, potential artefacts, or "treatments," are conceptualised and designed. This involves developing a framework or model that outlines how the problem will be addressed, often incorporating creative and innovative approaches to meet the defined objectives.

Treatment Validation: the designed artefact is then tested to ensure that it effectively addresses the problem. Validation involves evaluating the solution against the problem's requirements and checking its feasibility, consistency, and potential effectiveness before full-scale implementation.

Treatment Implementation: once validated, the solution is applied in the real-world context. This phase involves the actual deployment of the treatment, where it is integrated into the environment or system where the problem exists.

Treatment Evaluation: after implementation, the solution is monitored and assessed to determine its success in solving the problem. This phase involves collecting feedback, measuring outcomes, and analysing whether the treatment achieved its intended goals, as well as identifying any areas for further improvement.

Table 2 summarises the research activities completed so far, and the artefact being developed, according to the Design Science steps. In the following, we provide details on the different research activities and outcomes.

Two complete design cycles have been performed. The first cycle is dedicated to the preliminary definition of the method, and its implementation and evaluation on the Pilot Study for the Pecorino Toscano LL. The second cycle is dedicated to the definition of the guidelines and templates for data collection, and their evaluation through their application on the LL, which produced the LL reports. Detailed inspection of the reports will trigger possible refinement of the method and will drive the subsequent Design Science cycle. This will be focused on defining and implementing a detailed procedure for the model formalisation and agreement phases.

Table 2. Research activities carried out for T3.3

Cycle	Step	Activity	Outcome
1	Problem investigation	Focus group with agronomists and observation in a pilot LL	Concept of the process modelling methodology
1	Treatment design	Literature review and brainstorming focus group with software engineering experts	Improved concept Modelling languages chosen Procedure draft Requirements definition
1	Treatment validation	Focus groups and plenary presentation	Feedback on concept Requirements refinement
1	Treatment implementation	Case study “Pecorino Toscano” - set of diagrams	Set of diagrams representing the transformation of a cheese production process

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Cycle	Step	Activity	Outcome
1-2	Treatment evaluation / Problem investigation	Case study "Pecorino Toscano" - focus groups with LL stakeholders	Fine-tuning of the set of diagrams New requirements for the method Concept of the guidelines for data collection
2	Treatment design	Brainstorming focus group with software engineering experts	Guidelines and template draft Requirements definition
2	Treatment validation	Validation with agronomists and the WP3 team	Feedback on guidelines and template Requirements refinement Final guidelines for data collection and template
2	Treatment implementation	Application of the guidelines in the CODECS LLs	20 LL Reports
2	Treatment evaluation	Feedback on the guidelines and template	Part of the 20 LL Reports

Cycle 1 – Preliminary Method

The **Problem Investigation** started with a focus group involving the agronomists from the University of Pisa, to understand the context of the research and the needs to be addressed, namely facilitating communication with LL stakeholders and fostering reflections on the impact of digitalisation. The focus group was complemented with a visit to an existing LL, to better understand the context of the research. This phase was carried out before the CODECS proposal was submitted and triggered the definition of the initial concept of the method, with the idea of using graphical models to represent the process transformation.

The **Treatment Design** mainly consisted in identifying the modelling languages to be used, based on a survey of the literature. In this step we also provided a preliminary definition of the procedure to be followed to define and validate the models.

The **Treatment Validation** was based on a set of focus groups with agronomists from the University of Pisa, to understand whether the proposed approach was feasible and useful.

The **Treatment Implementation** consisted in the definition of the models for the Pecorino Toscano LL, based on a set of interviews, observations, and focus groups with the LL stakeholders.

The **Treatment Evaluation** consisted of acquiring feedback from the LL stakeholders about the completeness, usefulness, and understandability of the models, by means of focus groups.

Cycle 2 – Guidelines and Templates

The **Problem Investigation** was based on the focus groups organised in the Treatment Evaluation and led to the identification of further improvements of the method. In particular, it emerged the need to better structure and systematise the procedure for collecting the data to be used to design the models, to avoid an excessive number of iterations with the stakeholders, and limit the effort required by the Task coordinators, also considering the language barriers with the stakeholders of non-English speaking LLs. This triggered the concept of the guidelines for data collection to be used by the LL contact points, which should have facilitated the systematic collection of information.

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The **Treatment Design** consisted of brainstorming among the software engineering experts involved in the Task and led to the definition of a draft of the guidelines and templates.

The **Treatment Validation** involved agronomists from the University of Pisa and from the WP3 Team, which provided feedback on the guidelines and templates. These were finalised based on this feedback.

The **Treatment Implementation** consisted of applying the guidelines to the 20 CODECS LL, and the collection of the LL reports.

Finally, the **Treatment Evaluation** was included as part of the reports, in which the LL contact points were required to provide explicit feedback on the data collection method.

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Part 2: Results

4 Description of the Digital Ecosystems in 19 Living Labs (T 3.2)

4.1 Mapping the Socio-ecological context in 19 LLs

In this section, we present partial summary results focusing on describing each LL and its corresponding DE. We have included as an example, a more extensive description of the subsystems of the Pecorino Toscano LL (Italy) in 4.1.1 to illustrate the depth of narrative analysis to be used for each LL to arrive at a summary of the DE. We have also included in each subsystem for the Pecorino Toscano LL analysis the categorisation of actors (for actors subsystem) and the identification of RCCIs (for Governance, Resource systems and Resource units). This exercise has been carried out for each LL but will be further refined and analysed for M36, with the aim to identify main RCCIs implicated in conducive digital ecosystems. The remainder of the LLs herein include only the summary of the DE. To analyse these ecosystems, we implemented a four-step methodology (Figure 12) designed to capture the characteristics within each LL. This D3.1, specifically includes the findings from Steps 1 and 2 found in Figure 12.

As previously discussed, Step 1 involves identifying the RCCIs necessary for each LL to address its FAS problem statement, and for understanding the socio-ecological-technical factors that enable or hinder digitalisation within the LLs. Step 2 builds upon this foundation by examining how the four core subsystems of Ostrom's SESF (Actors, Resource Units, Resource Systems, and Governance Systems) influence the LL and FAS and enable or hinder the acquisition of RCCIs necessary to solve their problem situation found in the FAS.

To collect the data needed for the participatory mapping of socio-ecological contexts, a variety of materials have been developed, including guidelines, training modules, workshops, and several exercises (Annexes A).

The focus in this Deliverable 3.1 is on the outcomes from Step 2, where we analyse how these four subsystems enable, foster or set the conditions to acquire the necessary RCCIs for the LL´s digital transformation and problem-solving processes. This analysis allows for an improved understanding of how each LL's DE operates within its specific socio-ecological context.

Furthermore, while we primarily focus on the enabling and hindering factors associated with Step 2, it is important to note that the SES analysis and DE will be expanded in D3.1 (M36) through more extensive coding of all four subsystems and the development of indicators. This will ensure a better understanding and allow comparison of the DEs across all LLs, aligning the findings with a unified framework and enhancing the clarity and cohesion of the overall analysis. The relationships between subsystems will be analysed as well as relationships with elements of process modelling and AKIS findings. Further integration of process modelling and AKIS perspectives will be carried out to give a more complete and holistic analysis of complex SES applied to the digitalisation of agriculture.

4.1.1 Pecorino Toscano Living Lab (Italy)

The LL of Pecorino Toscano DOP, located in Tuscany, Italy, focuses on extensive dairy sheep farms. The description of the DE of the Pecorino Toscano LL is carried out to understand how the different elements of the ecosystem enable the digitalisation process, considering the focal action problem statement described as:

"Facilitate farmers in the data collection of data related to farm processes and use such data in order to improve the quality of production, the quality of work and life of farmers, the visibility of the farm and the animal health and welfare."

To achieve this, the LL employs a Farm Management Information System (FMIS) which is currently at Technology Readiness Level 6 (TRL6).

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4.1.1.1. Actors´ system

Table 3. Categorisation of recognised Actors in the Pecorino Toscano LL

Actors	Category of actors	Actors	Category of actors
Sheep farmer	Farmers	Other consultants	Advisor
Agronomist advisors	Advisor	Traders	Value chain
Cooperatives	Supply chain	Farm machineries providers	Supply chain
Dairy Processing Plants	Supply chain	Input providers	Supply chain
Policy makers	Public administration	Large retailers	Value chain
Consortium of Pecorino Toscano PDO	Value chain	Turists	Value chain
Technology developers	IT developers	Public health services veterinarians	Advisor
University of Pisa	Researchers	Other dairy processing plants	Supply chain
Consumers	Value chain	Other farmers	Farmers
Other sheep farmers	Farmers	Banks	Financing institutions
Farmers associations	Farmer associations	Marketing and communication consultants	Value chain
Research entities	Researchers	Commercial consultants that support the information exchange on digital technologies to farmers	Value chain
Farmers unions	Farmer associations	Broadband and Internet connection providers	IT developers
Private veterinarians' advisors	Advisor		

The actor´s mapping has revealed a diverse collaboration structure, with a strong representation of value and supply chain actors and those related to consultancy and advisory services. These include cooperatives, dairies, consumers, traders, input suppliers, technicians, and veterinary services, among others. However, a lower representation is identified in the inclusion of other key actors for scaling up digital solutions and establishing a robust digitalisation ecosystem. This is the case for researchers, public and financial administration, along with farmers and technology providers (Table 2).

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The results obtained in the mapping of actor's categories are aligned with the LL statements on the collaborations needed for the LL´s digitalisation. For example, the representation of research institutions is limited. It has been observed that there is a need for stronger relationships between the university and the PDO consortium, cooperatives and the university, and the university and technology providers. As observed, *"PDO consortium is a very active actor in the ecosystem. Together with the University, it has had the opportunity to have access to financial resources which allows to pay technical assistance".*

The relationship with financial and public institutions is also seen as important for the digitalisation process of the LL. Therefore, connections are sought to bridge this gap through cooperation with producers' organisations or the Pecorino PDO consortium, who play an intermediary role, *"The PDO consortium (…) has an important mediating role with public institutions. Farmers trust the consortium",* and *"Farmers' organisations are important intermediaries between farmers and public institution"* although, *"farmers feel not represented by them.*" The involvement of the public administration facilitates the creation of favourable policies and regulatory frameworks, as well as offering financial and logistical support to digitalisation initiatives.

Regarding the contribution of this landscape of actors to the resources identified as necessary for digitalisation, farmers significantly influence material resources, such as sheep, *"Sheep are considered the key resource of the living lab (…) however, their number is constantly decreasing"*, as well as IT developers have an impact on the supply of sensors, *"some sensors are available in the system, but they are not always the ones needed to create an integrated application of digital technologies",* or could indirectly influence on technological resources such as interoperable databases *"There is a need for interoperable and homogeneous database"* or on the App Poderi, *"the specific technology tested in CODECS is something (…) consider as a resource"*. Similarly, the public administration and financial institutions could contribute most to addressing the lack of financial resources, despite the existing bank loans and CAP funds, *"scarce funds for research and innovation (…) are available (…)"* in addition to *"the need to use [funds] better in order to support digitalisation process".* In terms of human resources, advisors, producers´ associations, farmers, and research institutions could have a determining role in capacity building and training for a more specialised workforce, data elaboration and connecting people in the sector, *"Specialised workers are needed in order to apply digital technologies to sheep farming. Some of them are available, but there is a need to train more people on this."*

Analysing the influence in capabilities, four key actors—advisors, farmers, researchers, and farmers associations—could be recognised for the development and strengthening of most capabilities: functional (e.g., know-how in sheep production, health, data elaboration, and management, among others), absorptive (e.g., integration of traditional and professional knowledge in training, knowledge sharing, awareness of the value of recording and sharing data, etc.), and attitudes and values (e.g., motivation, sharing, proactivity, willingness to change, etc.). Furthermore, the implementation of innovations like the app Poderi improve the quality of life of actors as it allows to "*save time and plan the production in advance*".

In conclusion, the mapping of actors in the Pecorino Toscano LL reveals a well-represented network in the value and supply chains. However, it highlights the need to enhance relationships with key actors such as research institutions, public and financial administrations, technology providers, and farmers' associations. These actors could boost the access for necessary resources for the digitalisation process, such as educational/training, funds, and technological resources, as interoperable databases, and at the same time, strengthening these relationships could also improve the development and building of capabilities, including management skills, know-how in sheep production, and the use of IT software.

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4.1.1.2 Resource units

Table 4. Categorisation of recognised Resource units in the Pecorino Toscano LL

Resource units	Describe how they enable or hinder resources, capabilities, collaborations, and innovations to address the LL FAS problem statement	RCCIs classification
Sheep	(…) key resource for the system. The sheep are also the point of observation of the system for the application of digital technology. The productivity and health of the sheep are the main goals of the FAS problem statement	Material resource
Farms	The main resource in term of agricultural systems are the farms that are aggregated in a wider production system which include the whole cheese food chain: farms, processing plants for cheesemaking and the consortium for the PDO production	Collaboration
Money	The financial resources are always key (…). The main sources identified (…) are the public ones, both CAP policies and research funds (…). However, some of the participants underline that also the private sector should invest in order to allow the digital transition to happen	Financial resource
People which share information and knowledge	The access to information related to the technologies available and their costs and benefits, the possibility to apply existing technologies in the cheese production sector and to other innovations are considered by the stakeholders a key part of the digital ecosystem. The network of people at local and extra local level is considered a relevant part of the system	Human resource Collaboration Informational resource
IT connection points	In order to increase the use of digital technologies and allow different technologies to interact with each other's there is a need to improve the infrastructure for internet connection	Technological resource

The resource units subsystem focuses on the specific resources which might be extracted or used by the actors in the ecosystem. It is explored how each resource unit supports or not the provision and enhancement of the key resources identified for the digitalisation process. This analysis helps to understand the alignment and gaps within the ecosystem that affect the implementation of digital tools. Delving further into the description of resource units, five resource units have been identified as being provided by the LL´s ecosystem.

Firstly, the resource unit "Sheep" is related to one of the major material resources of the LL, *"The sheep have been identified (…) as a key resource for the system (…)"*, and *"The sheep are also the point of observation of the system for the application of digital technology".* Maintaining a healthy sheep population and using digital technologies for its management ensures a constant supply of raw materials and optimises farm operations, facilitating the deployment and integration of sensors and the need for well-structured farms, as "*to apply digital technologies (…) there is a need to have a good farm structure (…) e.g., good shelters (…)*". In addition, the data (technological resource) collected by these technologies/sensors is integrated into a centralised Farm Management Information System (FMIS), allowing for better decision-making and resource allocation (innovations).

Subsequently, the added value of cooperation and collaboration in the sector was designated under the resource unit "Farms," addressing the deficiency or necessity to bolster existing collaborations or generate new ones, *"The main resource in term of agricultural systems are the farms that are aggregated in a wider production system which*

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include the whole cheese food chain (…)", and, *"Collaborations are key for the transformation of the sheep sector (…) but there is a perceived lack of collaboration with external actors and professionals (…)".* It is important to note that *"knowing how to collaborate and exchange data, (…) have been repeatedly highlighted by all stakeholders".*

Similarly, these partnerships can alleviate the identified need for human resources, particularly in terms of augmenting skilled workforce, "*at the moment it is hard to find workforce for sheep farms in this area".* On the other hand, farms, especially those integrated into a broader system like Pecorino Toscano LL, have access to various informational and knowledge sources, "*several information sources are currently available (…) in particular because the specific cheese processing plant "Caseificio di Manciano" has been involved in several research projects".* This keeps farmers updated on the latest innovations and trends in agricultural technology, in fact, "*advisors and researchers (…) are open to exchange information*" but *"only in the form of technical consulting (…)"*

With regard to the financial resources are one of the main requirements for the LL's digitalisation process, *"The financial resources are always key for the development of innovation and the use of technologies"*, the principal sources of funding accessible by the LL are "*the public ones, (…) However, (…) the private sector should invest in order to allow the digital transition to happen."* Also, *"There is a need to invest from the farmers side (…)".* Moreover, *"those funds (public funds) could be better used and destinated to active agriculture (…)".*

Funding contributes to support the acquisition and implementation of digital technologies, training programs, capacity building, and infrastructure improvements. It enables investments in necessary tools and resources for digitalisation, e.g., educational programs, workshops, dissemination platforms, etc. Furthermore, financial resources could facilitate access to a wide range of information sources, including research databases, subscriptions to agricultural journals, etc.

Some farms together with the consortium act as hubs for interaction and collaboration among farmers, technicians, and advisors, where exchange of knowledge and experiences take place for fostering capabilities, innovations and adopting digital technologies. In relation to the resource unit "People who share information and knowledge," specifically *"The access to information related to the technologies available and their costs and benefits, the possibility to apply existing technologies in the cheese production sector and to other innovations are considered a key part of the digital ecosystem.".* It is observed that despite the availability of information sources, there is indeed a necessity to explore alternative sources, *"New information sources are always welcome (…)".* People who share information and knowledge provide insights into the latest sensors and farm technologies available. By disseminating information about the cost, and benefits of various technologies, they help farmers make informed decisions about which tools to invest in, *"The network of people at local and extra local level is considered a relevant part of the system."*

Additionally, knowledge-sharing initiatives often include training programs, workshops, and seminars that equip farmers and workers with the necessary skills and capabilities to operate and maintain digital technologies. This continuous education develops a skilled workforce capable of leveraging digital tools to improve farm productivity, *"Sheep farmers should integrate the use of traditional knowledge with the use of professional knowledge… skills and capabilities were passed down from generation to generation, should now be transferred into formal training formats."*

To conclude with the resource units available in the LL ecosystem and their contribution to the RCCIs required for digital transformation, the discussion shifts to the resource unit "IT connection points". The LL possesses certain technological resources such as databases. Nonetheless, additional elements (applications, interoperable systems), alongside an enhanced connection infrastructure, are still required, *"In order to increase the use of digital technologies and allow different technologies to interact with each other's there is a need to improve the infrastructure for internet connection."* And *"There is a need for a broad band infrastructure as often internet connection is not good in rural areas, and this create problems in the application of digital technologies in sheep farms."*

The resource units analysis of the Pecorino LL highlights several enablers and obstacles for its digitalisation initiatives. The availability of public funds and the importance of the sheep, identified as a key resource, mainly for the integration of the technologies. The network of farms sets a solid base for information and knowledge sharing, and the challenges with existing technological infrastructure (broadband connectivity).

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4.1.1.3 Resource system

Table 5. Categorisation of recognised Resource systems in the Pecorino Toscano LL

Resource systems	Describe how they enable or hinder resources, capabilities, collaborations, and innovations to address the LL FAS problem statement	RCCIs classification
The Agricultural subsystem	This system includes the activity related to agricultural production, the food chain, the other farms, the technical advice related to agricultural production, the workforce for agriculture, the public funds for agriculture (CAP funds), the public entities controlling the agricultural sector, the associations of producers, etc.	Organisational resource Human resource Collaboration Financial resource
The Financial subsystem	The banks that are connected to local farms giving them loans and that could support private investments in the technology development process Principally public sources of money (e.g. local administration and European Policies)	Financial resource
The Natural resource subsystem	The specific extensive animal production and their interaction with the local environment, including predators and crops that support the sheep production. The extensive sheep farmers have a key role as land managers and environmental protectors	Material resource Human resource
The Social subsystem	The network of people that exchange information on the specific problem related to the FAS and that are interested to share their perspective with others in the same context. This system also includes tourists and potential consumers of the specific production PDO	Human resource Absorptive cap. Functional cap.
IT subsystem	There is a need to have a technological infrastructure that support the digital transition in different institutions and contexts so that the application of digital technologies in a part of the system can be integrated with the one of another part of the system. If one step of the food chain uses digital tools but the others do not, the system is less efficient, and the benefits are not maximised	Technological resource Material resource

The resource system refers to the various interrelated systems that provide and organise the elements required for any activity or process. In the context of the Pecorino Toscano LL, this analysis focuses on identifying and understanding how different resource systems, such as agricultural, financial, natural, social, and IT systems, contribute to providing or hindering the key RCCIs necessary for the digitalisation process.

First, the Natural resource subsystem, related to the "Sheep" resource unit and to the material resources, provides the natural environment for sheep farming and data collection and analysis, "*This refers to the specific extensive animal production and their interaction with the local environment, including predators and crops that support the*

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sheep production". The quality of the natural environment influences the health and productivity of sheep and being able to monitor environmental factors provides data for farm management and allows the deployment of digital innovation for saving time and production planning. Addressing the human capital of the agricultural sector, "*The extensive sheep farmers have a key role as land managers and environmental protectors.",* as noted, *"The local farmers that carry on extensive sheep farming, have a strong link with nature and the environment and they are culturally motivated to maintain nature",* this deals with the attitudes and values of the actors involved. In consequence, this system supports material resources like sheep and contributes to human resources and values by fostering environmental stewardship among farmers.

To continue with the Agricultural resource subsystem, it includes advisors, farmers, farm workers, associations of producers, and public entities that help to coordinate and manage digital initiatives across the sector. It provides the infrastructure (material resources), human capital, and access to information and knowledge (informational resources) needed to implement and manage digital initiatives, *"The main resource in terms of agricultural systems are the farms that are aggregated in a wider production system".* This system is closely related to the resource units 'Sheep' and 'Farm', encompassing material, human, and organisational resources, as well as capabilities such as functional (know-how in sheep production, health, and management), and collaboration "*to maintain the network among people (…) all actors (…) should have a systemic thinking (…)*".

The Financial resource subsystem involves the "*banks that are connected to local farms giving them loans and that could support private investments in the technology development process"*. Banks provide *"them (loans) to farmers"* to invest in digital technologies and farm structures, but then many farmers have to pay many of those loans. This resource system is linked to the resource unit recognised as "Money", promoting the financial resources and functional capabilities for the digitalisation process of the Pecorino Toscano LL, *"in particular, they highlighted how there are various forms of funding, often lost due to a lack of systemic and managerial capabilities in allocating them to the right actors"*. The LL deals "*principally to public sources of money (e.g. local administration and European Policies)"* but *"funds are not well managed (…) so they are needed but (…) better addressed."*

In relation to the Social resource subsystem, it enhances knowledge sharing (absorptive cap.) and access to information (informational resource), "*The network of people that exchange information on the specific problem related to the FAS and that are interested to share their perspective with others in the same context".* In addition, *"This system also includes tourists and potential consumers of the specific production PDO"*. This resource system is related to the resource unit 'People which share information and knowledge' and in turn to the promotion of various human, informational resources ("*New information sources are always welcome* ") and various capabilities (functional ("*(…) able to interact with all the food system and manage it (…)*"), attitudes ("*Sheep farmers knows the value of their production and they are involved in several rural development projects promoting it*"), absorptive ("*Sheep farmers have a good knowledge on how to manage sheep health*"), etc.

Ultimately, the IT resource subsystem focuses on the technological infrastructure supporting digital transition across different institutions and contexts, "*There is a need to have a technological infrastructure that supports the digital transition in different institutions and contexts so that the application of digital technologies in a part of the system can be integrated with the one of another part of the system"*. It is directly related to the previously identified resource unit, "IT connection points", and it fosters the scalability of digitalisation, adaptive capabilities, and various technological resources of the LL. It deals with the lack of infrastructure for integrating digital tools across the food chain, ensuring seamless connectivity and data integration. Furthermore, it supports the coordination of digital initiatives, ensuring all parts of the food chain benefit from technological advancements, *"If one step of the food chain uses digital tools but the others do not, the system is less efficient, and the benefits are not maximised."*

The analysis of the resource systems in the Pecorino Toscano LL notes strong natural and agricultural foundations, including the farm network and a motivated farming community. Additionally, the social resource system is effective in knowledge sharing, supporting both material and human resources. Simultaneously, financial systems offer support through loans and public funds for investments. However, weaknesses include inefficient financial management and allocation of financial resources and significant IT infrastructure gaps, particularly in broadband connectivity and data integration, which hinder digitalisation.

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4.1.1.4 Governance systems

Table 6. Categorisation of recognised Governance systems in the Pecorino Toscano LL

Governance	Describe how they enable or hinder resources, capabilities, collaborations, and innovations to address the LL FAS problem statement	RCCIs classification
CAP rules	Political rules that influence the choices of individual farmers	Financial resource
	Funds from the CAP are key for this system however the rules that implement CAP measures are not always going in the interest of farmers	
	Procedures of management and communication of data are complex and need to be simplified	Organisational resource
	Procedures of access to CAP resources should also be simplified in order to facilitate the access to farmers	
	The current measure of having the set aside in the farms is not considered proper by the actors of the living lab	Functional cap.
	First pillar of the CAP is the same for everyone, this is not a good rule to support active farmers	
Conservation rules: "it has always been like this"	Social rules that could block the innovation	Attitudes and values
	Improve the transformative potential of the living lab actors	Human resources
Lack of collaboration	Farmers with other farmers: Farmers tend to see other farmers as competitors. They don't share information	Collaboration
	Collaboration among public entities is not always easy (ARTEA + APP): The developer needs farm related data that are available in the payment agency and in the national livestock registry. However, having access to these data has been very hard	Informational resource
Negative vision of the sheep farmers in the public opinion	Shepherds are seen (according to farmers) enemies of the environment. There is a strong negative attitude towards 'the environmentalists'	Attitudes and values
	Communication to increase environmental awareness and communication on the social function of sheep farmers	Informational resource
	Storytelling to improve farmers' visibility	Human resources

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Governance	Describe how they enable or hinder resources, capabilities, collaborations, and innovations to address the LL FAS problem statement	RCCIs classification
Rules to manage the predator system sheep-wolf are needed	Wolves are one of the most important threats to the activity of farmers	Organisational resource Material resource
Health and safety regulations	Require to farmers and advisors the data that the Living Lab is working to collect with the app tested in the FAS	Technological resource Functional cap.
PDO scheme	Require data from individual farms in order to improve the quality of the production	Technological resource
Tax and fiscal legislation	Influence the choices of individual farmers	Organisational resource Adaptive cap.
Financial rules	Influence the conditions to give loan to individuals in order to allow them to make choices for the investments at farm level	Financial resource
CAP rules	Farmers must collect several data to get access to CAP funds. Often the keeping of these data are delegated to farmers' associations	Organisational resource Technological resource
National Livestock registry	To comply with safety rules, farmers have to register all movements of animals in and out of the farm. This task can be delegated to Product Associations	Organisational resource Functional cap.

The governance subsystem in the Pecorino Toscano LL encompasses a range of political, social, and regulatory rules that impact the digitalisation process and the acquisition of essential RCCIs.

On the one hand, CAP funds are crucial for farmers, nonetheless *"the rules that implement CAP measures are not always going in the interest of farmers".* The complexity of data management, and communication procedures do not fit to the specific needs of active farmers, hindering the financial resource allocation and the motivation to adopt digital innovations, "*procedures of management and communication of data are complex and need to be simplified".* Simplifying these processes and tailoring measures to support active farmers could enhance the governance system's ability to facilitate digitalisation. For instance, *"procedures of access to CAP resources should also be simplified in order to facilitate the access to farmers",* and *"first pillar of the CAP is the same for everyone, this is not a good rule to support active farmers".*

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In brief, related to the fund access and actor´s capabilities *“policymakers should facilitate and streamline access to funds (…) they should be able to raise awareness (…) that there are reasonable funds available that can be utilised and can be functional to the needs of the territory.”*

Social rules, such as the traditional *"it has always been like this"* mindset, often block innovation by discouraging transformative changes. The LL actors have the potential to overcome and transform these social barriers (attitudes and adaptive cap.). Similarly, a lack of collaboration among farmers, who *"tend to see other farmers as competitors,"* and between public entities, which struggle not to share necessary farm data, hinders information and knowledge sharing (informational resources) and collaborative capabilities. The developer needs *"farm-related data that are available in the payment agency and in the national livestock registry. However, having access to these data has been very hard."*

Public perception also plays a role in governance. Negative views of shepherds as environmental adversaries create a challenging atmosphere for promoting sustainable practices and environmental awareness (values). This is why, having a clear *“storytelling could ameliorate farmer´s visibility”* and the communication about the environmental and social functions of sheep farming could improve public opinion and support for digital initiatives (informational res.; absorptive cap.). Currently, *"shepherds are seen (according to farmers) enemies of the environment. There is a strong negative attitude towards 'the environmentalists.'"*

Regulatory rules, including health and safety regulations, the PDO scheme, tax and fiscal legislation, and financial rules, directly influence farmers' choices and adaptive and functional capabilities. These regulations require extensive data collection and management, often placing additional burdens on farmers. Streamlining these processes and providing clear guidelines can improve compliance and encourage the use of digital tools. For instance, *"health and safety regulations require to farmers and advisors the data that the Living Lab is working to collect with the app tested in the FAS.",* data is also asked *“from individual farms in order to improve the quality of the production”.* At the same time*, “rules to manage the predator system sheep-wolf are needed”* as *“wolves are one of the most important threats to the activity of farmers”.*

Lastly, the National Livestock Registry and CAP rules requiring detailed animal movement records and data collection for funding access further complicate administrative tasks for farmers. Delegating these tasks to associations could alleviate the difficulties and promote better data management and resource distribution, *"to comply with safety rules, farmers have to register all movements of animals in and out of the farm. This task can be delegated to Product Associations."*

The governance subsystem in the Pecorino Toscano LL shows both strengths and weaknesses affecting its digitalisation process. The availability of CAP funds is an advantage, but due to complex procedures they are underutilised. Besides, the potential for overcoming traditional social barriers and promoting change among LL actors can foster innovation and adaptive capabilities. Nevertheless, weaknesses include social rules, negative public perception of shepherds and lack of collaboration among farmers and public entities, which poses obstacles for information sharing. Complex regulatory requirements for health, safety, and financial compliance add burdens on farmers. Lastly, detailed animal movement records required by the National Livestock Registry and CAP rules complicate administrative tasks.

4.1.1.5 Digital Ecosystem of the Pecorino Toscano Living Lab

Focal action problem statement: *"Facilitate farmers in the collection of data related to farm processes and use such data to improve the quality of production, the quality of work and life of farmers, the visibility of the farm, and the health and welfare of the animals".*

The DE of the Pecorino Toscano LL in Italy presents several enablers and hindrances that shape its digital transformation. A well-established network of stakeholders, including cooperatives, dairies, consumers, traders, input suppliers, technicians, and veterinary services, creates a strong collaborative environment that supports the acquisition of resources for digitalisation. This diverse set of actors facilitates resource sharing and knowledge exchange, enabling more efficient collaboration throughout the food chain. Such networks are particularly important for addressing the scarcity of specialised human resources and ensuring that knowledge about sheep farming practices is integrated with digital technologies. Furthermore, the availability of public funds, through the Common Agricultural Policy (CAP), influence in promoting the adoption of digital initiatives across the LL.

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A motivated farming community and an extensive network of farms offer a conducive environment for digitalisation. In addition, this ecosystem comprises strong natural resource management. Farmers, who has a role in environmental stewardship, benefit from participating in cooperative structures that promote the adoption of digital solutions. This collaborative environment ensures that elements like infrastructure, human capital, and access to technological information are available to facilitate digitalisation. The sheep themselves, as a material resource, act as the focal point for many digital applications, supporting the use of sensors and Farm Management Information Systems (FMIS) that aid in decision-making and resource optimisation.

However, the DE also faces hindrances that must be addressed. One barrier is the rigidity of the political framework, particularly regarding regulatory issues tied to the management of CAP funds. While these funds are supportive, the complexity of accessing them often prevent farmers from utilising these available resources. Furthermore, farmers perceive the CAP rules as overly complex and not always aligned with their specific needs, especially when it comes to active farmers. As a result, this hinders the equitable distribution of financial resources.

Another hindrance lies in the negative public perception of sheep farming. This negative view can stifle initiatives that aim to promote sustainable and digital farming practices. The lack of collaboration between farmers, who often view each other as competitors rather than collaborators, further exacerbates the problem. Similarly, poor collaboration between public entities and the farming sector hinders access to data that could otherwise support digital initiatives. Moreover, the IT infrastructure also presents a challenge to digitalisation. Inadequate broadband connectivity and gaps in technological infrastructure impede data exchange and the use of digital tools across the various stages of production.

In summary, the DE of the Pecorino Toscano LL shows strong enablers in terms of collaborative networks, motivated farming communities, and available financial resources. However, it also faces hindrances such as regulatory complexity, negative public perceptions, poor collaboration in some respects, and insufficient IT infrastructure. research institutions, public and financial administrations, technology providers, and farmers' associations could restrict access to educational and technological support.

In summary, the digital ecosystem of the Pecorino Toscano LL exhibits a solid base and potential for digitalisation. Still, it faces challenges in financial management, IT infrastructure, and collaboration with several stakeholders.

4.1.2 APPETIT Living Lab (Poland)

The APPETIT LL, located in Poland, focuses on short food chains. In Poland, the majority of the 1.3 million farms are small or part-time (less than 10 hectares). These small-scale farms represent a resource and opportunity for local food markets and rural sustainability. There is a need for an interactive and adaptive pathway for engaging small-scale food producers, consumers, and rural development stakeholders in growing local markets for locally produced food. The opportunity is to build collaborative arrangements for IT-enabled sharing economy functionalities to strengthen, replicate, and develop local food markets.

The description of the DE of the APPETIT LL is carried out to understand how the different elements of the ecosystem enable the digitalisation process, considering the focal action problem statement described as:

"Supporting self-organisation, growth and development of local food markets in terms of increasing numbers involved, product offering, and transactions, reducing cost per transaction and focusing on producers and consumers transacting directly with one another".

To achieve this, the LL employs the APPETIT IT-enabled platform for collaborative organisational arrangements, currently at Technology Readiness Level 4 (TRL4).

4.1.2.1 Digital Ecosystem of the APPETIT Living Lab

Focal action problem statement: *"Supporting self-organisation, growth and development of local food markets in terms of increasing numbers involved, product offering, and transactions, reducing cost per transaction and focusing on producers and consumers transacting directly with one another".*

The DE of the APPETIT LL is shaped by a combination of enablers and hindrances that affect the progression of its digitalisation process. The APPETIT platform itself serves as both a governance and resource system, providing a

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technological infrastructure that supports local food markets. The platform facilitates collaboration by creating a virtual marketplace where producers, consumers, and stakeholders interact. The availability of financial grants, alongside the use of branding strategies and high-quality local food products, further contributes to the digitalisation process by offering financial resources and enhancing the visibility of the markets. This is particularly important for engaging small-scale farmers, many of whom operate outside of the formal economy but demonstrate a willingness to collaborate and take on leadership roles within their communities. Thus, the active participation of small farmers and local leaders contribute to the growth and development of local food markets through their knowledge of the marketplace and strong leadership capabilities. Furthermore, the involvement of Local Action Groups (LAGs) and EIP-AGRI operational groups provides additional support.

Despite these enablers, the DE faces several hindrances that impede its digitalisation. One challenge is the lack of representation of key stakeholders, such as technology providers, research institutions, public administration and financial institutions. The absence of these actors limits the ability of the ecosystem to scale up digital solutions and develop the necessary technological infrastructure. Moreover, while financial resources are available in the form of grants and subsidies, these funding mechanisms are often directed at individual farmers rather than supporting collective actions. Another notable hindrance is the regulatory framework, which presents both opportunities and challenges. This problem is compounded by the fact that previous policy frameworks, such as the earlier CAP Plan, primarily favoured industrial farmers and export-led agriculture, leaving small-scale farmers underrepresented.

In conclusion, the DE of the APPETIT LL is driven by engaged stakeholders, financial and branding resources, and the APPETIT platform itself, which serves as a hub for collaboration and technological innovation. However, the ecosystem's progress is hindered by gaps in stakeholder representation, regulatory challenges, technological limitations, and fragmented financial support. Moving towards more collective actions and resource allocation.

4.1.3 Orchard management and digitisation Living Lab (Czech Republic)

The LL in the Czech Republic focuses on the use of digital technologies for orchard management to increase the volume and efficiency of fruit harvesting. It also focuses on production management overall and on facilitating reporting obligations. Farmers, members of non-profit organisations, policymakers, and agricultural advisors are working with technology suppliers and researchers to test technologies that will enable automation of irrigation and monitoring of climatic conditions in the orchard. This initiative aims to reduce water and pesticide use, mitigate the impact of adverse weather on crops, and simplify reporting obligations.

The description of the digital ecosystem of the Orchard management and digitisation LL is carried out considering the focal action problem statement described as:

"To reduce impact of adverse weather on crops, reduce water and pesticide use, automation of irrigation and facilitate reporting obligations."

To achieve this, the LL employs a new sensor-based orchard management system for crop protection, remote control of the irrigation system, frost and pollination monitoring, and an end-user application for the farmer, which is currently at Technology Readiness Level 6 (TRL 6).

4.1.3.1 Digital Ecosystem of the Orchard management and digitisation Living Lab

Focal action problem statement: *"To reduce impact of adverse weather on crops, reduce water and pesticide use, automation of irrigation and facilitate reporting obligations".*

The DE of the Czech Republic LL for orchard management possess various enablers and hindrances, such as the availability of financial support through the Common Agricultural Policy (CAP), which provides opportunities for investment in digital tools and technologies. Additionally, the collaborative spirit among farmers and their associations supports the sharing of knowledge and information, fostering collective action that helps in the implementation of new technologies. Research and educational institutions, like the Research and Breeding Institute of Pomology Holovousy Ltd., also have a role in raising awareness and providing training. Likewise, the growing openness of data platforms enable better data integration across different agricultural technologies.

However, the DE also faces hindrances that slow down the transformation process. A challenge is the underrepresentation of technology providers, advisors, and financial institutions, which limits the availability of

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tailored digital solutions specific to orchard management and the exchange of data. For example, the absence of local advisory services forces farmers to rely on costly foreign consultants, further increasing the financial burden and limiting access to context-specific advice that would be more applicable to the Czech environment.

Another hindrance is the misalignment between educational outcomes and industry needs. Vocational and higher education institutions are not adequately preparing individuals for the specialised skills required for digital orchard management, creating a gap in the availability of trained human resources. This gap is further exacerbated by the aging demographic of current farmers, with limited interest from younger generations in entering the horticultural sector. The supply chain also presents challenges for farmers. While it provides necessary inputs, retail chains exert financial pressure by demanding low margins, which weakens farmers' ability to invest in technologies.

The CAP provides a financial enabler, offering funding opportunities that support investments in digital tools. However, the complexity of the subsidy process and bureaucratic obstacles created by national institutions often hinder the allocation of these resources. Therefore, national policies are perceived as unsupportive of horticulture, further complicating efforts to secure investments for digitalisation in the sector.

Also, despite the importance of information sharing, there are limitations in the availability information sources. Farmers need continuous and updated channels of information to stay up to speed on the technological advancements and best practices. There are insufficient communication of farmers' needs to IT developers and other key stakeholders, which hinders the development of tailored digital solutions.

In summary, the DE of the Czech Republic LL for orchard management is shaped by a mix of enablers and hindrances. Financial support through the CAP, strong collaborative efforts among farmers, and the growing openness of data platforms serve as enablers that drive the digitalisation process. However, hindrances such as the underrepresentation of key actors, inadequate state support, bureaucratic complexities, and the lack of generational renewal in the farming sector create substantial obstacles.

4.1.4 Occitanum OL VITI Living Lab (France)

The LL in Occitanum, France, focuses on sustainable vineyard agriculture, specifically the management of fertilisation to preserve the typicality of wines while protecting the environment. Fertilising a vineyard plot is a key stage in the growing cycle. It maintains soil balance and grape yield. Maintaining a good availability of elements in the soil over time is a complex task because soils are rarely structurally homogeneous. The description of the digital ecosystem of the Occitanum Viti LL is carried out considering the focal action problem statement described as:

"To ensure successful fertilisation, it is necessary to understand the sources of heterogeneity of the plot, its history, and the pedoclimatic context. Fertilisation can therefore be managed according to the principles of precision viticulture: measure, decide, act".

To achieve this, the LL employs satellite images, vigour maps, and a user-friendly web interface, which is currently at Technology Readiness Level 7 (TRL 7).

4.1.4.1 Digital Ecosystem of the Occitanum OL VITI Living Lab

Focal action problem statement: "*To ensure successful fertilisation, it is necessary to understand the sources of heterogeneity of the plot, its history, and the pedoclimatic context. Fertilisation can therefore be managed according to the principles of precision viticulture: measure, decide, act".*

The DE of the Occitanum LL for sustainable viticulture, designed to enhance vineyard management through digital technologies displays enablers and hindrances that influence its progress toward precision viticulture. A primary enabler is the collaborative environment fostered by the involvement of diverse actors such as research institutions (INRAE, IFV, Institut Agro), farmer associations (Vinnovalie, Cave de la Bastide, CUMA), and value chain participants (Vivea, ASOI). These actors provide technical knowledge, training, and organisational resources, creating a framework for knowledge sharing and skill development.

Additionally, the LL benefits from collaborations like the Digifermes network, which promotes knowledge exchange and experimentation in digital agriculture. The AMI - Call of Interest process also serves as an important enabler, helping to identify the digital technologies that best meet the specific needs of viticulture. This process, along with

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training programs provided by Vivea and Mobilab, builds the technical skills of stakeholders, ensuring they are well-equipped to handle digital technologies.

However, several hindrances limit the digitalisation of the LL. One of the main challenges is the high average age of farmers, around 55 years old, which presents issues related to motivation and adaptability to new technologies. Moreover, gaps in the representation of technology providers and consultancy services hinder the development of tailored digital solutions. Furthermore, the rigid funding schemes, which only cover 50% of project costs, pose financial challenges for stakeholders.

The governance system led by Occitanum, while structured and resource-rich, suffers from a lack of agility and excessive complexity. This organisational rigidity slows decision-making processes and complicates the execution of projects. In addition, the juridical complexities associated with contractualisation (to address the contribution of partners to the innovation, mainly farmers) make it difficult to formalise the involvement of farmers and other partners in the innovation process.

In summary, the DE of the Occitanum LL has a collaborative framework, extensive training resources, and processes that support knowledge sharing and the development of digital solutions. However, several hindrances, including the aging farming population, financial rigidity, and governance complexities, impede the LL's ability to realise its digital transformation goals.

4.1.5 AgDiBi Living Lab (Germany)

The German LL Agri-digital Building (AgDiBi) focuses on knowledge transfer related to digital technologies to enhance the application of digital and precision farming technologies in crop production. Researchers, demo farms, agricultural teachers, and an agricultural state institute collaborate with students and farmers to develop an educational format centred on digital and precision farming technologies. This initiative aims to support knowledge building on digitalisation in a sustainable and long-term manner. The LL is dedicated to social and organisational innovation, working towards creating a digitally literate agricultural community. The description of the digital ecosystem of the Agri-digital Building LL is carried out considering the focal action problem statement described as:

"AgDiBi in Germany works on knowledge transfer on digital technologies to increase the application of digital and precision farming technologies in crop production".

The LL's primary objective is to support knowledge building on digitalisation in vocational education for prospective farmers and agricultural educators. This is achieved through a collaborative approach that integrates the expertise of researchers, demo farms, agricultural teachers, and state institutes, ensuring that the educational format developed is both practical and sustainable in the long term.

4.1.5.1 Digital Ecosystem of the AgDiBi Living Lab

Focal action problem statement: *"AgDiBi in Germany works on knowledge transfer on digital technologies to increase the application of digital and precision farming technologies in crop production".*

The DE of the AgDiBi LL in Germany is centred on knowledge transfer in digital and precision farming technologies, supported by a collaborative network of educational, research, and public administration entities. Enablers in this ecosystem include the strong involvement of vocational training farms, educational institutions such as the vocational schools of Herrenberg and Ludwigsburg, and the University of Hohenheim. These actors ensure that both practical and theoretical knowledge is transferred effectively, providing students, teachers, and farmers with the necessary skills and insights into digital technologies for precision farming. The integration of research institutions like the University of Hohenheim and demo farms, such as Ihinger Hof, provides valuable practical experience and technical infrastructure, strengthening the link between education, research, and on-farm application of digital tools.

Public administration entities, including the Ministry of Agriculture, Ministry of Education, and Landratsamt Böblingen, are also enablers. These institutions supervise vocational training programs and provide a supportive framework for digital transformation in agriculture. Their involvement builds trust in the digitalisation process and fosters the creation of synergies within the ecosystem.

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Key resources such as the infrastructure on demo farms, technical equipment, and trial fields provide a practical environment for hands-on training and experimentation with digital farming technologies. These material resources are complemented by financial support through investment subsidies and Common Agricultural Policy (CAP) measures, which facilitate the adoption of digital technologies by offering funding opportunities.

However, hindrances as the gap that exists in the involvement of technology providers and advisors, constrains the ecosystem's access to cutting-edge digital tools.

In summary, the AgDiBi LL's DE is bolstered by enablers such as strong educational and research collaborations, administrative support, and practical resources for digital experimentation. However, hindrance includes gaps in technological expertise as a result of missing collaboration with technology providers and advisors.

4.1.6 Spraying drones Living Lab (Greece)

The Greek LL focuses on vineyard spraying and crop protection, leveraging advanced digital technologies to enhance the productivity, profitability, and sustainability. It aims to assess and analyse the best drone spraying configurations for field use, comparing them with conventional spraying machinery like terrestrial boom and mist sprayers to evaluate their spraying quality. The description of the DE of the Greek LL is carried out considering the focal action situation described as:

"The Greek LL is working on vineyard spraying and crop protection, utilising advanced digital technologies to enhance the productivity, profitability, and sustainability of European agriculture".

To achieve this, the LL employs spraying UAVs (drones), GIS, sensors, IoT stations, LiDAR for altitude adjustment, and vision systems, which are currently at Technology Readiness Level 9 (TRL 9).

4.1.6.1 Digital Ecosystem of the Spraying drones Living Lab

Focal action problem statement: *"The Greek LL is working on vineyard spraying and crop protection, utilising advanced digital technologies to enhance the productivity, profitability, and sustainability of European*

The DE of the Spraying drones LL for vineyard spraying and crop protection integrates advanced technologies, such as UAVs (drones), GIS, sensors, IoT stations, and LiDAR, and demonstrates both enablers and hindrances that shape its digitalisation process.

Enablers are evident in the well-established network of actors within the ecosystem, including agricultural supply stores, technology companies, research institutions, and farmers, which provide substantial material, technological, and knowledge resources. These resources empower the LL to access the latest agricultural inputs, advanced equipment, and industry best practices.

Collaborations with universities and research institutes enhance the LL's absorptive capabilities by facilitating knowledge transfer and practical experience. These collaborations create an environment conducive to experimentation and real-world application of advanced spraying technologies. The participation of certification bodies ensures adherence to strict standards regarding safety, and environmental impact of the technologies used. This promotes trust among stakeholders and encourages the broader adoption of these innovations. Furthermore, the inclusion of farmers in the decision-making process ensures that digital solutions are aligned with practical needs, which strengthens cooperation and encourages innovation.

Moreover, the availability of funding through grant systems allows the LL to acquire the necessary resources and technology for experimentation. The financial support, though limited, provides a base for the development of advanced spraying technologies. Additionally, systems for data storage and processing facilitate the collection and analysis of data, enabling data-driven decision-making that optimises spraying practices.

However, the DE also addresses hindrances. One of them is the limited education and technical knowledge of farmers, which impedes their ability to understand and adopt new technologies. There is also a need for better communication and dissemination of research findings, as many farmers are unaware of the innovative spraying solutions being developed within the LL. The weak presence of consultancy services further exacerbates this issue, as farmers lack access to specialised advice on adopting and maintaining new technologies.

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Additionally, data accessibility poses a challenge. While some data is available, the lack of open data systems and the complexity of accessing certain data sets hinder the LL's ability to fully optimise spraying practices. On the governance front, regulatory barriers, such as the lack of specific legislation for drone spraying, introduce uncertainty and slow down the integration of these technologies into agricultural practices.

In summary, the DE of the Greek LL is characterised by strong enablers in the form of actor involvement, collaborations, and resource availability, which support the implementation and testing of digital technologies. However, hindrances such as limited technical knowledge, insufficient financial support, data accessibility issues, and regulatory gaps impede the complete potential of digitalisation.

4.1.7 Innovative Soil Scanner technology for sustainable farming Living Lab (Hungary)

The Hungarian LL focuses on optimising fertilisation and reducing environmental impact through the use of innovative soil scanner systems in arable crop farming. The aim of the LL is to change the 'we've always done it this way' approach to nutrient management by using an innovative, easy to use soil scanner system. The description of the DE of the Innovative Soil Scanner LL is carried out considering the focal action problem statement described as:

"Non-site-specific application of fertilisers on agricultural land can cause environmental stress, inappropriate nutrient distribution in the soil and economic damage to farmers. Older generations of farmers tend to be afraid of new technology."

To achieve it, this involves analysing nutrients in the soil in a fast, affordable, and reliable way, and by way of implication, demonstrating to farmers the benefits of digital solutions. The technological setup includes a soil scanner, NIR sensor, cloud database, soil analysis tools, and mobile phones, currently at Technology Readiness Level 9 (TRL 9).

4.1.7.1 Digital Ecosystem of the Innovative Soil Scanner technology for sustainable farming Living Lab

Focal action problem statement: *"Non-site-specific application of fertilisers on agricultural land can cause environmental stress, inappropriate nutrient distribution in the soil and economic damage to farmers. Older generations of farmers tend to be afraid of new technology".*

The DE of the Innovative Soil Scanner technology for sustainable farming LL for soil scanning and nutrient management in arable crop farming is shaped by a combination of enablers and hindrances that influence its digitalisation process. At its core, the ecosystem relies on advanced technologies, including soil scanners, NIR sensors, cloud databases, and IoT devices. These technologies, alongside the expertise and collaboration within the LL, create an environment that facilitates digital transformation.

One of the primary enablers is the involvement of key actors such as farmers, research institutions, and advisory networks. Farmers bring practical insights and a willingness to cooperate, while research institutions contribute with valuable findings that are integrated into everyday practices, thus enhancing the knowledge base and supporting the professional development of stakeholders. The advisory networks and technology providers (including Agrocares), play a role in facilitating knowledge exchange and providing real-time data collection tools respectively.

Furthermore, the presence of the Digital Academy of Agriculture strengthens communication within the LL ensuring that research findings are disseminated, reducing information overload, and translating complex research into practical applications for farmers. The Szechenyi University demo farm network integrates digital technologies in real-world settings, demonstrating the benefits of digitalisation, helping to improve the efficiency, sustainability, and competitiveness of agriculture.

However, hindrances limit the LL's digitalisation, such as the regulatory framework, which is often poorly conceived. Additionally, weak communication between public administration entities hinders coordination and delays the digitalisation process. Besides, laboratory networks do not always support the LL's efforts. Furthermore, the fragile global situation and industrial expansion into agricultural land present external challenges, threatening the long-term sustainability of digital farming practices.

In summary, the DE of Innovative Soil Scanner technology for sustainable farming LL presents enablers such as the integration of advanced technologies, collaboration among actors, and access to key resources like data-sharing

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platforms. However, its progress is limited by hindrances including inadequate regulatory frameworks, limited technical expertise, and external pressures from global and industrial developments.

4.1.8 Organic table grapes Living Lab (Italy)

The Organic Table Grape LL in Puglia, Italy, focuses on enhancing the quality and quantity of organic table grape production while reducing the environmental impact on soil and water resources. This initiative aims to address the challenges in managing key factors of production such as irrigation, fertilisation patterns, and pest and disease control. By integrating advanced technologies, the LL seeks to create a sustainable model for organic table grape farming. The description of the DE is carried out to understand how the different elements of the ecosystem enable the digitalisation process, considering the focal action problem statement described as:

"How can we increase the quality and quantity of organic table grape production by reducing the qualitative and quantitative pressure on the soil and water resources?"

To achieve this, the application scenario involves the deployment of sensors at the field level within orchards, which monitor soil, environmental, and crop conditions. These sensors are interconnected and communicate with a Decision Support System (DSS) operating at Technology Readiness Level 8 (TRL 8).

4.1.8.1 Digital Ecosystem of the Organic table grapes Living Lab

Focal action problem statement: *"How can we increase the quality and quantity of organic table grape production by reducing the qualitative and quantitative pressure on the soil and water resources?"*

The DE of the Organic Table Grape LL in Italy is designed to leverage advanced digital technologies to enhance both the quality and quantity of organic table grape production while minimising environmental impact on soil and water resources.

Among the key enablers are the proactive involvement of agricultural entrepreneurs, advisors, and technology providers, which collectively drive digitalisation and improve farming practices. In addition, advanced digital technologies, such as Decision Support Systems (DSS), open data platforms, sensors, and software, together facilitate knowledge generation, dissemination, and the adoption of digital technologies.

However, several hindrances limit the digital process of the LL. The insufficient time available to stakeholders, hampers the promotion and dissemination of digitalisation. This lack of time also affects collaboration efforts, as stakeholders are unable to engage in knowledge-sharing activities or participate in the development of new technologies. Moreover, the governance structure, although supported by public institutions, suffers from a lack of coordination between different levels of government and public entities. There is also a need for greater interaction and cooperation between national, regional, and European governance bodies to ensure that the regulatory framework supports both digitalisation and sustainability.

Besides, the of market-driven actors, such as large-scale distributors (GDOs) often impose guidelines based on market logic rather than sustainability, which hinders the introduction of digital tools and environmentally friendly practices. Despite the availability of data through various digital tools, the LL struggles with inadequate data-sharing mechanisms, which restricts the broader adoption of precision agriculture techniques. At the same time, there are gaps in networking between farms, which hinders the exchange of knowledge and best practices. Additionally, while financial resources are technically available through public and private channels, they are often not accessed or distributed effectively, which constrains the ability of farmers to invest in new technologies and sustain long-term digitalisation initiatives. Lastly, skills gaps in specific areas, such as regional irrigation and the technical management of organic viticulture, also pose challenges, underscoring the need for improved functional and adaptive capabilities to ensure that human resources are well-equipped to implement and sustain digital solutions.

In summary, the DE of the Organic Table Grape LL in Italy demonstrates several enablers through the proactive engagement of entrepreneurs, advisors, and technology providers, as well as access to advanced digital tools. However, the LL also faces hindrances, such as time constraints, insufficient collaboration, market pressures from GDOs, limited data-sharing mechanisms, inadequate financial access, and skills gaps.

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4.1.9 Local beef cattle farming Living Lab (Latvia)

The LL in Latvia is focused on enhancing the market position of farmers. The aim of LL is to test digital marketing solutions to provide an effective and easy-to-use marketing tool for farmers who produce products from semi-natural grasslands characterised by high biodiversity (special focus on beef, as cattle are used to graze grasslands and maintain their biodiversity). The description of the DE is carried out to understand how the different elements of the ecosystem enable the digitalisation process, considering the focal action problem statement described as:

"To provide an effective and easy-to-use marketing tool for farmers to inform consumers about their farms and the characteristics of their products, thus strengthening their market position."

To achieve this, the technology employed is the ZSA GEO map environment, accessible at https://app.smartagro.lv, which is currently at Technology Readiness Level (TRL 7).

4.1.9.1 Digital Ecosystem of the Local beef cattle farming Living Lab

Focal action problem statement: *"To provide an effective and easy-to-use marketing tool for farmers to inform consumers about their farms and the characteristics of their products, thus strengthening their market position."*

The DE of the Latvian LL is designed to enhance the market position of farmers by providing digital marketing solutions that highlight the unique value of products from semi-natural grasslands.

Key enablers of the DE include public financial support, which facilitates the development of digital solutions like websites and marketing tools. Institutions such as business incubators not only provide funding but also offer educational resources that empower entrepreneurs to embrace digital tools and new business models. Consultants and advisors, particularly from the Latvian Rural Advisory and Training Centre, play a role in offering practical knowledge and advice. Their involvement enhances the LL's ability to implement high-quality digital solutions, driving the adoption of digital marketing systems. In this sense, digital marketing specialists are another important enabler, these specialists address the need for farmers, especially those from small or older demographic groups, to acquire better digital marketing skills, ensuring that the farmers' products are well-promoted and positioned in the market. Furthermore, educational institutions, such as the Latvia University of Life Sciences and Technologies, also contribute offering training on digital skills and nutrition.

However, several hindrances undermine the DE of the LL. For example, bureaucratic obstacles, particularly in collaboration with public institutions. Moreover, public food data registration systems are often unresponsive, further limiting the ability to innovate through data-driven solutions. Additionally, the limited availability of knowledgeable farm advisors leads to long waiting periods, leaving many farmers without timely support. As well, the digital skills gap among farmers, especially those from smaller or aging farm operations, acts as a hindrance to the adoption of digital tools as online sales platforms. This gap in human resources and digital literacy, combined with the absence of marketing expertise, makes it difficult for farmers to promote their products, particularly in the competitive landscape of online retail. On top of that, misinformation spread through social media and other channels about meat consumption or farming practices further complicates the task of educating consumers about the environmental benefits of biodiversity-friendly products. This lack of accurate information about new products and their benefits hampers the creation of a well-informed consumer base for the success of the LL.

The fragmented nature of cooperation among farmers further exacerbates these issues. While cooperatives and other industry organisations exist to foster collaboration, many farmers still prefer to work individually and see each other as competitors. The absence of strong networking structures prevents the sharing of knowledge and best practices.

Finally, certification systems, while enabling trust and transparency, can also act as hindrances due to their high costs and complexity. Not all consumers or farmers are willing or able to pay for certification, and the multitude of existing certification systems can lead to confusion and reduced engagement.

In conclusion, the Latvian LL's DE is characterised by a mix of enablers and hindrances. Public financial support, skilled advisors, digital marketing specialists, and educational initiatives influence in advancing the digitalisation of marketing tools for farmers. However, bureaucratic challenges, limited digital skills among farmers, misinformation, and consumer habits all act as barriers to full digital adoption.

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4.1.10 Scottish Small Farms and Digital Platforms Living Lab (Scotland)

The Scottish Small Farms and Digital Platforms LL focuses on enhancing the economic activities and resilience of small farmers and crofters (farmers) situated in rural and remote rural settings. These farmers face numerous challenges, including distance to markets, issues with digital connectivity, access to digital skills support, and the first impacts of climate change, such as extreme weather events. The description of the DE is carried out to understand how the different elements of the ecosystem enable the digitalisation process, considering the focal action problem statement described as:

"Farmers can harness the power of digital tools and platforms to support and improve sustainable agricultural practices; enhance diversification activities, reach broader audiences and markets, access mental health support; develop community relations; raise public awareness of farming issues - thereby strengthening their resilience in the face of the challenges they face".

To achieve this, the technological setup includes a digital platform for training and collaboration, online social media, QR coding, 360-degree cameras, and virtual reality demonstrations, currently at Technology Readiness Level 3 (TRL 3).

4.1.10.1 Digital Ecosystem of the Scottish Small Farms and Digital Platforms Living Lab

Focal action problem statement: *"Farmers can harness the power of digital tools and platforms to support and improve sustainable agricultural practices; enhance diversification activities, reach broader audiences and markets, access mental health support; develop community relations; raise public awareness of farming issues - thereby strengthening their resilience in the face of the challenges they face".*

The DE of the Scottish Small Farms and Digital Platforms LL presents as enablers within its ecosystem a strong community and family support networks that have a role in alleviating childcare burdens, allowing farmers to engage more with digital tools and platforms. In addition, relations with community associations like Women in Agriculture and initiatives like the CSA Network UK foster collaboration, knowledge exchange, and innovation.

Furthermore, the Royal Mail collection service improves logistics for online sales, saving time and facilitating inventory management. At the same time, access to quality seeds supports innovative agricultural practices, and digital platforms like Patreon and YouTube offer alternative income streams, contributing to the financial resilience of farmers. Considering public institutions and governance actors also provide regulatory frameworks that, while sometimes restrictive, offer a level of support.

On the other hand, hindrances within the DE create barriers to the digitalisation. Firstly, digital skills gaps among family members and the lack of tailored software for small-scale farms highlight a technological shortfall that limits the use of digital tools. Besides, the high costs of existing digital tools, coupled with the absence of affordable, user-friendly options, make it difficult for small farms to embrace digitalisation.

Another hindrance is the poor broadband connectivity that remains as an obstacle, severely impacting the implementation of digital technologies and overall digitalisation of many farms. There are also logistical challenges. While services like Royal Mail's collection for online sales are helpful, poor road networks and inconsistent courier services, particularly in adverse weather conditions, can disrupt the supply chain.

Moreover, overly restrictive certification schemes impose unnecessary barriers through burdensome record-keeping and registration requirements for certified farm products or livestock monitoring. These demands can further complicate the development and adoption of digital tools. Frequent changes in food legislation, combined with the complexity of compliance, frustrate farmers who invest time and resources in meeting these requirements. Additionally, strict food labelling regulations add to the operational burden, particularly when competitors do not adhere to the same standards, creating an uneven playing field. Likewise, the lack of a centralised, easily accessible source for updated food legislation and compliance information further complicates farmers' efforts to stay informed and under the rules.

Regarding funding opportunities, post-Brexit, funding from programs like the TSI Leader programme has decreased leaving many small farmers without access to the financial resources needed to invest in digital tools. This is further

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complicated by the fact that most grants are geared towards larger farms, making it difficult for smaller to compete for financial support.

Natural capital, while providing long-term sustainability benefits, can also act as a hindrance. For example, restrictions on land use near protected wildlife areas limit the scalability of farming operations, forcing farmers to navigate complex regulations that may conflict with their farming practices, etc. As well, the burden of maintaining assets like tractors, storage facilities, and other farm equipment adds to the operational challenges, as breakdowns and repairs disrupt farm activities and divert financial resources away from digital investments.

In conclusion, the DE of the Scottish LL is characterised by strong community networks, material resources, and key technological tools that support digitalisation efforts. However, challenges remain, including digital skills gaps, poor broadband connectivity, restrictive legislation, and logistical issues, all of which hinder the digitalisation for small farmers in Scotland.

4.1.11 Greenhouse smart sensor lab Living Lab (Serbia)

The Greenhouse Smart Sensor LL in Serbia is dedicated to enhancing the efficiency and sustainability of vegetable greenhouse production through the introduction of digital solutions. Currently, the farmers still rely on traditional methods and their experience in making the decision related to the agricultural production. This often results in high consumption of inputs, lower profits and lack in farmer time and welfare. The description of the DE of this LL is carried out considering the focal action problem statement described as:

"Introduction of digitally related solutions aims to achieve optimal, efficient and sustainable agricultural production".

To achieve this, the LL monitors greenhouse conditions such as soil moisture, soil water potential, soil pH, air temperature/humidity, leaf wetness, photosynthetically active radiation, and CO2 levels. The technological setup includes IoT sensor nodes combined with a web platform suitable for PCs, tablets, and smartphones, currently at Technology Readiness Level 7 (TRL 7).

4.1.11.1 Digital Ecosystem of the Greenhouse smart sensor lab Living Lab

Focal action problem statement: *"Introduction of digitally related solutions aims to achieve optimal, efficient and sustainable agricultural production".*

The DE of the Serbian Greenhouse Smart Sensor Lab LL is marked by several enablers that collectively support its digitalisation efforts.

Firstly, the LL benefits from a robust base of material resources, such as land, water, and existing greenhouse infrastructure, which facilitate the practical implementation and scaling of digital technologies. The availability of these resources provides the necessary environment to test and apply smart sensor technologies, thus directly impacting the LL's functional and adaptive capabilities. Additionally, the electric power supply system ensures a stable and affordable energy supply for the operation of digital technologies like sensors and farm management apps. The presence of a reliable road infrastructure further enhances accessibility, supporting the deployment of digital solutions and facilitating collaboration with external stakeholders.

Secondly, a diverse network of actors, including research institutes, agricultural advisors, and technology providers, contributes to the LL's human and informational resources. Institutions such as the BioSens Institute and agricultural faculties provide a variety of experienced and knowledgeable individuals who enhance the absorptive and functional capabilities within the LL. On the other hand, the AgroSense platform, serves as a tool for knowledge dissemination and education on new technologies, enhancing farmers' decision-making processes and supporting adaptive capabilities.

The LL operates within a structured regulatory framework established by various ministries and standards like HACCP and IFS. These governance mechanisms create an environment conducive to the adoption of new technologies by regulating the use of land and water and offering subsidies to support financial and organisational resources. The cooperation between ministries, when effectively managed, promotes a cohesive approach to agricultural digitalisation, aligning strategies and regulatory support to bolster the LL's objectives.

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Despite these enablers, the DE also faces several hindrances that could limit its digitalisation. There is a significant reliance on external technology providers due to a lack of domestic technology producers, which affects the affordability and customisation of technological solutions tailored to local needs. Furthermore, while financial resources are available through various national and international programmes, the LL indicates a need for more stable financial mechanisms to support technological innovation and mitigate the risks farmers face when adopting new technologies.

As well, the ecosystem lacks a strategy for knowledge transfer and a digitised system for evaluating the success of implemented measures for improving agriculture. This gap could hinder the acceptance of new technology and the ability to scale digital tools. Additionally, the lack of knowledge dissemination also affects the LL's capacity to educate farmers and improve digital literacy, which is crucial for the adoption of digital solutions.

Moreover, despite having a structured regulatory framework, there are gaps in inter-ministerial cooperation and inconsistent policies that lead to fragmented governance. This fragmentation can result in regulations that are not well-aligned with technological advancements or the practical needs of farmers. Additionally, there is a noted gap in collaboration with farmer cooperatives, state advisory services, and other farmers. Finally, the LL also lacks digital platforms that encompass all stakeholders, limiting communication and knowledge sharing.

The DE of the Serbian Greenhouse Smart Sensor Lab LL has strong foundations, including material, technological, and human resources, and benefits from a governance framework, which together enable the deployment and scaling of digital technologies. However, challenges persist, such as dependence on external technology providers, insufficient financial stability, and gaps in knowledge transfer and governance.

4.1.12 Almería Agroecology Living Lab (Spain)

The Almería Agroecology LL in Spain focuses on addressing the challenges of data interoperability and resource management in vegetable greenhouse production. The description of the DE of this LL is carried out considering the focal action problem statement described as:

"Lack of data interoperability and difficulty in managing and optimising resources."

To achieve this, the LL employs a technological setup that includes sensors, actuators, and a centralised platform for data management, currently at Technology Readiness Level 5 (TRL 5).

4.1.12.1 Digital Ecosystem of the Almería Agroecology Living Lab

Focal action problem statement: *"Lack of data interoperability and difficulty in managing and optimising resources".*

The DE of the Almería Agroecology LL is characterised by several enablers that facilitate the digitalisation process. Cooperatives and producer associations foster a culture of collaboration and shared decision-making, enhancing the human resources and absorptive capabilities of the ecosystem. These organisations support digitalisation by establishing common understanding for technology adoption, influencing technical requirements. This collective approach not only enhances the interoperability of digital tools but also builds human and organisational resources through active participation and training initiatives.

The ecosystem benefits from a range of technological resources, such as data integration platforms and accessible software, which provide a centralised space for data storage and analysis. These platforms are foundational to the LL's digitalisation process, as they facilitate the integration of technologies by allowing different applications and systems to access and share data in a common way. The availability of affordable and reliable technologies supports the widespread adoption and scalability of digital solutions. Additionally, the presence of standardisation protocols and platforms like FIWARE encourages collaboration and innovation promoting interoperability between diverse systems and technologies.

Access to knowledge systems and training is another significant enabler. This ensures that farmers and other sector actors are well-equipped to use digital technologies. The role of advisors and cooperatives as intermediaries further facilitates the adoption of digital technologies with the provision of technical guidance.

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Despite these strengths, the DE of the Almería Agroecology LL faces several hindrances that impede its digitalisation. One of the most significant barriers is the lack of standardisation among technology providers, which complicates the interoperability of digital tools and reduces the scalability of technologies. The presence of monopolistic market structures exacerbates this issue. Dominant private companies may resist adopting open standards that facilitate data interoperability, leading to a fragmented ecosystem with limited choices for digital tools and services. This lack of competition restricts innovation and creates a closed digital environment, posing a barrier to scaling digital solutions across diverse agricultural contexts.

Additionally, infrastructure disparities, particularly in terms of internet connectivity, also present challenges. Limited network coverage and unreliable internet access limit the functionality of digital capabilities, especially in remote or rural areas. Similarly, the uneven distribution of natural resources, such as water and energy, affects the viability and sustainability of digitalisation. These resource constraints restrict the broader adoption of digital solutions, particularly for smaller farms and communities with fewer resources.

Financial incentives and supportive regulations are also enablers. These incentives lower economic barriers to technology adoption, but there is a need for more consistent access to funds, subsidies, and grants to support the scaling up of digital tools and capacity-building activities. While financial incentives from public institutions are beneficial, they are often insufficient to overcome the high costs associated with the initial setup and ongoing maintenance of digital technologies, especially for smaller farms.

Lastly, the absence of a communication strategy and data management plan within the LL highlights gaps in strategic governance. These gaps impede aligning stakeholder goals and ensuring the integration of digital solutions across the value chain. Regulatory challenges and inconsistent public administration support also create uncertainties around market access and funding.

In conclusion, the DE of the Almería Agroecology LL demonstrates a strong background for supporting digitalisation. However, the ecosystem must address hindrances such as market monopolies, inconsistent standards, infrastructure disparities, and financial constraints, among other to leverage the deployment of digital solution in greenhouses.

4.1.13 Cloughjordan Food Hub Living Lab (Ireland)

The Cloughjordan Food Hub in Ireland is a LL dedicated to enhancing local food systems through digitalisation. This LL focuses on local communities and small farmers, with the goal of shortening supply chains and creating a food system controlled by producers, consumers, and local businesses. The LL aims to develop an online marketplace that allows small-scale food producers in rural areas to access local markets, thereby supporting local economies. The description of the DE of the LL is carried out considering the focal action problem statement described as:

"How can local farmers and suppliers get paid a fair price and ensure that people have the option of better, fairer ways to source their food directly from the producers?"

To achieve this, the Cloughjordan Food Hub employs a Opensource digital platform which is currently at Technology Readiness Level 7 (TRL7).

4.1.13.1 Digital Ecosystem of the Cloughjordan Food Hub LL

Focal action problem statement: *""How can local farmers and suppliers get paid a fair price and ensure that people have the option of better, fairer ways to source their food directly from the producers?"*

The active involvement of farmers and consumers within the Cloughjordan Food Hub LL is central to the ecosystem's success. Firstly, farmers supply products to the digital marketplace, which helps shorten food supply chains and ensures a steady flow of local products. Their participation supports the digital platform's functionality and foster a community-oriented mindset. Moreover, farmers benefit from technological tools and training that enhance their digital skills and confidence. Consumers are equally important enablers, providing demand for local produce and valuable data through their purchasing behaviours. This data on the ease of use and overall user experience, help to ensure that the digital tools remain relevant and user-friendly.

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Another key enabler is the LL's emphasis on knowledge sharing and community engagement. The involvement of advisors, researchers, and volunteers facilitates the transfer of knowledge and skills, helping to bridge the digital skills gap among farmers and other local producers. Training programmes, which must be designed to be easy to follow, empower stakeholders to integrate digital approaches into their daily routines.

Additionally, the technological infrastructure provided by the LL, such as the Open Food Network Platform is a foundational element in the DE. The presence of a cooperative attitude and shared values of sustainability, nature, and community well-being among participants further strengthens the ecosystem.

Despite its enablers, the DE of the Cloughjordan Food Hub LL faces several challenges that limit its digitalisation. One major hindrance is the lack of digital skills and confidence among some farmers, which impede the adoption of digital tools and the integration of the local digital market. Without adequate training and support, farmers may be reluctant or unable to engage with the platform, reducing its overall functionality and reach.

Moreover, there is a notable lack of collaboration with technology providers, which hinders the LL's ability to customise digital solutions to meet local needs. This gap in collaboration affects the innovation capabilities of the LL, as it restricts access to new technologies and the development of user-friendly interfaces that could enhance platform usability.

Furthermore, financial constraints also pose a hindrance, while there is some funding available, it may not be sufficient to cover the costs of maintaining the platform, supporting necessary human resources, and investing in digital infrastructure. The lack of strong relationships with financial institutions further exacerbates this challenge, as it limits access to the necessary investments for scaling up operations and ensuring long-term sustainability.

Lastly, logistical challenges within the distribution systems present another barrier to the LL's ability to expand its digital services. The existing infrastructure may not be capable of supporting a larger scale or more complex distribution needs.

In conclusion, the DE of the Cloughjordan Food Hub LL is built on active community participation, technological infrastructure, and a commitment to knowledge sharing and sustainability. Nonetheless, the LL must address hindrances such as digital skills gaps among farmers, limited collaboration with technology providers, insufficient financial resources, and logistical challenges.

4.1.14 Agrifood Technology Living Lab (Belgium)

The Agrifood Technology LL in Belgium focuses on reducing the use of crop protection products in arable crops through digital innovations. The description of the DE is carried out considering the focal action problem statement described as:

"The LL works on arable production and uses digital technologies to reduce the use of crop protection products through site-specific spraying".

To achieve this, the LL employs ultra-high-resolution RGB imaging on drones, AI models, task map generation, and labelling tools for weed, disease, and pest detection. Utilising technologies at Technology Readiness Level 7 (TRL 7).

4.1.14.1 Digital Ecosystem of the Agrifood Technology LL

Focal action problem statement: *"The LL works on arable production and uses digital technologies to reduce the use of crop protection products through site-specific spraying".*

One of the primary enablers within this ecosystem is the active engagement of farmers and consumers. For instance, farmers play a crucial role in testing and adopting new digital tools, such as drones and precision farming technologies. Their involvement in real-world testing scenarios helps to build confidence in these technologies and encourages wider adoption. Similarly, consumers drive demand for products enhanced through digitalisation, thereby ensuring that these efforts remain economically viable and aligned with market needs.

As well, research institutions, such as universities and research centres like ILVO, are also contributors to the DE. These institutions focus on fundamental research and the development of spin-off companies, which act as

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incubators for new technologies and methodologies. Additionally, the LL benefits from a range of supportive technological and material resources (robust detection AI models, RTK GPS system) which enable data-driven decisions, meanwhile, experimental fields serve as environments for testing and validating new technologies.

However, the DE also faces several hindrances as the lack of integration and standardisation among digital tools and platforms. The presence of multiple data platforms without universal standards creates interoperability issues, making it difficult for different technologies and stakeholders to work together. Moreover, the reliance on foreign companies for models that require licensing fees introduces financial and accessibility barriers, limiting the adaptability of these technologies to local conditions and increasing costs for end-users.

In addition, governance and regulatory frameworks further complicate the ecosystem. For example, restrictive drone and spray drone legislation pose barriers by limiting its use. Furthermore, data ownership laws, further complicate data sharing and analysis. The absence of targeted financial incentives for early adopters, combined with the administrative burden of obtaining grants, serves as a major disincentive for farmers. This lack of direct financial motivation slows down the adoption of digital tools. Also, there is a notable gap in education and digital literacy among farmers, without sufficient training programs, these farmers struggle to engage with digital innovations, limiting their ability to benefit from new technologies and reducing the community's adaptive capabilities.

In conclusion, the DE of the Agrifood Technology LL is strengthened by active farmer and consumer engagement, innovative research institutions, and robust technological and material resources that support testing and adoption of new technologies. However, its progress is hindered by regulatory barriers, financial constraints, a lack of standardisation among digital tools, and insufficient education and incentives for farmers, all of which limit the scalability of digitalisation.

4.1.15 Artificial Irrigation Management System Living Lab (Slovakia)

The Artificial Irrigation Management System LL in Slovakia focuses on enhancing irrigation systems in vegetable greenhouse production through technological innovations. The description of the DE is carried out considering the focal action problem statement described as:

"The LL is focused on optimising irrigation to enhance crop production while conserving water".

To achieve this, the LL is developing and testing a mobile application for agronomists that enables the automatic determination of irrigation doses. This application relies on data from soil sensors, irrigation systems, databases on the physiological water needs of specific plants, and environmental factors, using technologies at Technology Readiness Level 7 (TRL 7).

4.1.15.1 Digital Ecosystem of the Artificial Irrigation Management System LL

Focal action problem statement: *"The LL is focused on optimising irrigation to enhance crop production while conserving water".*

The DE of the Artificial Irrigation Management System LL is characterised by several enablers that support its digitalisation efforts. The active participation of farmers and agronomists is key for providing real-world feedback for refining digital tools and applications. Their involvement ensures that the solutions developed are tailored to the specific needs and conditions of their fields. Additionally, researchers and academic institutions contribute to the development of scientific knowledge, data analysis capabilities, and training. This continuous input from the academic and research community fosters an environment of ongoing digital innovation, where algorithms and models for precision irrigation are constantly refined and improved. The collaboration with technology partners further enhances the ecosystem by supplying advanced technological tools and platforms for data collection and analysis.

The LL also highlighted technological infrastructure as supportive for the collection, analysis, and application of data for precision irrigation. This infrastructure, combined with information-sharing practices among various stakeholders, enables the LL to scale its digitalisation. The availability of financial resources through funding mechanisms such as the Common Agricultural Policy (CAP) and its second pillar provides necessary support for rural development, including investments in innovation and knowledge transfer.

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However, the DE of the Artificial Irrigation Management System LL also faces hindrances. One major challenge is the lack of standardisation among digital tools and platforms, which hinders interoperability and integration. This lack of standardisation creates barriers to the use of data across different stakeholders, limiting the scalability and impact of digital solutions.

The ecosystem's effectiveness is further compromised by inadequate water management systems. Inadequate or outdated infrastructure restricts the availability of water for irrigation, making it difficult to implement advanced irrigation techniques. This limitation directly affects the LL's ability to maintain a consistent water supply, which is essential for the effective deployment of precision irrigation technologies. Additionally, high costs and limited access to modern technology impede the adoption of digital solutions, particularly in regions with limited financial resources or among smallholder farmers. Another significant hindrance is the lack of educational programs and vocational training that offer the hands-on experience and specific skill sets required for implementing advanced agricultural technologies and sustainable practices. Furthermore, restrictive regulatory policies and conflicting regulatory frameworks create additional barriers. While some regulations can support the adoption of innovative irrigation techniques, overly restrictive regulations and a lack of supportive policies for sustainable practices can impede the development and adoption of digital solutions. Inconsistencies between local, regional, and national regulations also generate confusion and uncertainty, complicating investment decisions and commitments to digitalisation.

In conclusion, the DE of the Artificial Irrigation Management System LL is shaped by a combination of enabling factors, such as active stakeholder participation, technological infrastructure, and supportive financial mechanisms, and hindering factors, including inadequate water management systems, insufficient educational programs, high technological costs, and complex regulatory frameworks.

4.1.16 LIT OUESTEREL Living Lab (France)

The LIT Ouesterel LL in Grand Ouest, France, focuses on enhancing pig meat production by integrating digital technologies to improve both animal welfare and working conditions throughout various stages of production. The description of the DE is carried out considering the focal action problem statement described as:

"Use digital technologies to find non-invasive practice methods and technologies to improve pig welfare and workers' conditions at different stages of production".

To achieve this, the LL employs a platform that links farm and equipment data to facilitate data sharing between different equipment and management software. The technologies utilised in this LL are at Technology Readiness Level 6 (TRL 6).

4.1.16.1 Digital Ecosystem of the LIT OUESTEREL LL

Focal action problem statement: *"Use digital technologies to find non-invasive practice methods and technologies to improve pig welfare and workers' conditions at different stages of production".*

In the DE of the LIT OUESTEREL LL in Grand Ouest, France a key enabler of the digitalisation process is the technological resources provided by IT developers such as Dashboard editors and ISAGRI, which enable the use of the platform and offer advisory services and IT solutions. Besides, the data storage and management systems, bolstered by cloud systems, provide infrastructure for collecting, processing, and storing data from various sources.

The IFIP experimental farm also facilitate the testing and refining the digital tools, ensuring they are adapted to real-world conditions. Additionally, the PigLink community acts as a collaborative platform that enables the development and use of the platform. The organisational resources provided by AG Porc/GT Porc for data normalisation and standards definitions are another enabler in the ecosystem which streamline operations and facilitate data sharing. This is further supported by knowledge access, an informational resource that ensures farmers and other stakeholders are well-informed on best practices and regulatory requirements. In this regard, European networks toward data exchange enhance the LL to share and implement best practices from similar international initiatives.

However, the DE also faces several hindrances. A major barrier is the broadband systems, as there is a need to have internet in each building of the farm. The digital platform struggles to integrate with outdoor farming systems that lack reliable internet connectivity, which limits the potential of these tools in rural settings.

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Another challenge lies in farmer and cooperative engagement. The willingness of these actors to adopt and utilise the platform can either enable or hinder the digitalisation process. Without active participation from farmers, cooperatives, and equipment manufacturers, the platform's utility is significantly reduced. This reluctance is a key obstacle, as the success of the DE hinges on the widespread adoption of these tools.

From a governance perspective, data regulation and public policies can enable or hinder the LL's digitalisation efforts, depending on how they are structured. The LL requires political support to drive data compatibility and platform use across different stakeholders. While AG Porc and GT Porc help standardise data processes. Furthermore, restrictive policies could limit flexibility in farm management practices, further complicating digitalisation.

In the DE of LIT OUESTEREL LL the integration of digital tools, coupled with the active role of research institutes and supply chain actors, sets a strong base for improving pig welfare, worker conditions, and farm management. However, key hindrances such as inconsistent connectivity, stakeholder reluctance, and regulatory challenges pose obstacles to the implementation of the LL's digital potential.

4.1.17 Grassland Management Living Lab (Estonia)

Grassland Management LL in Estonia aims to enhance the sustainability of grassland ecosystems by improving the monitoring of both protected and cultivated grasslands used for organic beef production. The description of the DE is carried out considering the focal action problem statement described as:

"To improve monitoring of maintenance regimes of grasslands including both protected grassland and the cultivated ones managed for organic beef production".

To achieve this, the LL employs advanced technologies such as drones for capturing changes in vegetation and tree cover, machine learning for analysing the collected data, and a web application that provides this information in a farmer-friendly format. The technologies utilised in this LL are at Technology Readiness Level 3 (TRL 3).

4.1.17.1 Digital Ecosystem of the Grassland Management LL

Focal action problem statement: "To improve monitoring of maintenance regimes of grasslands including both protected grassland and the cultivated ones managed for organic beef production".

The DE of the Grassland Management LL is driven by a blend of enablers and hindrances that either promote or impede its progress toward digital transformation. At the heart of the DE are beef farmers who hold resources, such as biodiverse wooded meadows, and possess knowledge in habitat management. However, their capacity to engage in the digitalisation process is closely tied to external collaborations with technological actors, such as drone operators. Collaboration is further enhanced by groups like the Blooming Meadows group, which fosters peer-to-peer knowledge exchange among farmers and promotes collective learning.

Despite these enablers, several hindrances limit the ecosystem's digital transformation. One of the major barriers is the lack of digital literacy and technical training among farmers, which slows the adoption of advanced technologies. Although external support from drone operators and other service providers helps, farmers struggle with self-sufficiency in operating these technologies. There is a clear need for simplified tools, such as easy-to-use apps or algorithms for drone operations and self-guided mapping processes, which would make these technologies more accessible to everyday farming operations.

Further hindrances stem from the rigid structures of public administration, particularly through the governance practices of Lauku Atbalsta dienests (LAD), the agency responsible for managing agricultural subsidies. Farmers often perceive LAD's regulatory frameworks as overly rigid and disconnected from the realities of seasonal and ecological challenges. For instance, the compliance metrics used by LAD frequently fail to account for wildlife-related or seasonal fluctuations, leading to penalties and reduced access to financial resources for small farmers. This rigidity is an obstacle to the equitable distribution of subsidies. Another hindrance is related to the Internet connectivity as in rural areas the internet provision is inconsistent. Some regions experience poor signal strength, as in the case of two of the farms in the north of the country and in one case, they have good signal strength but low bandwidth with the availability of internet varying throughout the day.

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Additionally, the ecosystem faces challenges in balancing technological advancements with conservation efforts. While the use of high-resolution maps through LIDAR systems provides data for land management, making this data publicly available, it can lead to unintended consequences, such as the exploitation of natural resources. For example, illegal fishing has become a concern in areas where detailed ecological data has been shared publicly, highlighting a security gap in how these informational resources are managed.

In conclusion, the DE of the Grassland Management LL in Estonia is shaped by a combination of enablers and hindrances. Enablers include strong collaborations between farmers, technological actors like drone operators, and groups such as the Blooming Meadows group, which foster knowledge exchange and collective learning. However, hindrances such as limited digital literacy, rigid public administration frameworks from agencies like LAD, inconsistent internet connectivity, and the challenges of balancing technological advancements with conservation efforts impede the ecosystem's digital transformation.

4.1.18 RAMAS Living Lab (Macedonia)

The RAMAS LL in Macedonia focuses on enhancing decision-making processes in agricultural production through communication between farmers and advisors, supporting data-driven decision-making, and promoting efficiency in farm management, particularly by reducing the use of agrochemicals. The description of the DE is carried out considering the focal action problem statement described as:

"Establishing decision-making processes in agricultural production by providing advisory services in extensive, real-time field data gathered at every stage of the agricultural process".

To achieve this, the LL uses the Remote Agricultural Monitoring and Advisory System (TRL 5) to optimise agricultural inputs and processes.

4.1.18.1 Digital Ecosystem of the RAMAS LL

Focal action problem statement: "Establishing decision-making processes in agricultural production by providing advisory services in extensive, real-time field data gathered at every stage of the agricultural process".

One of the primary enablers within the DE of the RAMAS LL is the strong governance presence. In particular, this governance support is complemented by financial mechanisms like the Common Agricultural Policy (CAP) which provides access to financial resources. Also, programs like the Young Farmer Program and Woman-Farmer Program further enhance the DE by targeting young and female farmers, providing both financial and human resources that empower these groups to adopt digital farming solutions.

In addition, the LL also benefits from informational and technological resources. Researchers and educational institutions provide valuable knowledge and training. As a result, this strengthens decision-making processes and ensures that the latest scientific knowledge is integrated into agricultural practices. Meanwhile, IT companies supply advanced technological tools such as sensors, data analysis platforms, and real-time monitoring systems. The integration of these tools facilitates real-time data collection, enabling farmers to make more informed decisions, optimise water use, and improve crop health.

Likewise, the availability of subsidies, rural payments, and IPARD funding programs support the financial infrastructure of the LL. These financial resources allow farmers to scale their digital initiatives and sustain their operations. Financial systems, such as direct payment systems and farm accountancy data networks, streamline transactions and ensure budgeting and planning. Additionally, record-keeping systems and databases, such as farm registers, further improve the organisational structure by enabling data-driven decision-making.

However, while the RAMAS LL has strong enablers, several hindrances limit its digital potential. Bureaucratic challenges, such as delays in fund disbursement from support programs like the Agency for Financial Support in Agriculture and Rural Development, can create bottlenecks, delaying the implementation of digital solutions. Moreover, the rigidity of regulatory frameworks, while promoting compliance, can sometimes restrict digitalisation.

Another hindrance is the need for more skilled advisors and agronomists who possess both digital literacy and the practical expertise to guide farmers through the adoption of new technologies. The gap in human capital hampers the widespread adoption of digital tools, as many farmers remain hesitant or ill-equipped to integrate these

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technologies into their daily operations. Furthermore, unreliable climate data from monitoring systems can negatively impact decision-making and productivity, further complicating the precision agriculture process. The lack of accurate, real-time data can result in poor planting, harvesting, and pest control decisions, which affect crop outcomes and overall farm productivity.

In conclusion, the RAMAS LL benefits from governance, financial and technological resources that support its digitalisation. Programs like CAP, the Young Farmer Program, and Woman-Farmer Program provide financial and human resources, while researchers and IT companies offer the tools and knowledge needed for informed decision-making. However, challenges such as bureaucratic delays, regulatory rigidity, and gaps in skilled advisors limit the potential of the LL.

4.1.19 Smart villages Network Living Lab (Slovenia)

The Smart Villages Network LL in Slovenia is leveraging digital technologies in viticulture and honey production, striving to enhance sustainability across environmental, economic, and social dimensions, ensuring a holistic impact on agricultural practices. The description of the DE is carried out considering the focal action problem statement described as:

"How to use digital technology in viticulture, in order to affect the environmental, economic, and social aspects of sustainability".

To achieve this, the LL employs IoT and LoRaWAN technology for a resilient infrastructure addressing connectivity issues, rugged terrain, and diverse microclimates in same vineyard. Deploying microclimate, soil moisture, rain, and leaf wetness sensors the system transmits data to a dashboard, ensuring continuous availability and informed decision-making (TRL 7).

4.1.19.1 Digital Ecosystem of the Smart villages Network LL

Focal action problem statement: "How to use digital technology in viticulture, in order to affect the environmental, economic, and social aspects of sustainability".

The DE of the Smart Villages Network LL presents various enablers, such as its strong technological foundation, particularly the use of IoT sensors (for measuring soil moisture, rainfall, and leaves wetness), connectivity (LoRaWaN technology) and data collection and management system (ThingsBoard platform) , These technological resources help in optimising resource use, such as reducing water consumption and pesticide application.

In addition to the technological infrastructure, the ecosystem benefits from the collaborative efforts of various stakeholders. Cooperatives, advisory services, and research institutions play a role in fostering knowledge sharing and collaboration, which enhances informational and human resources. Furthermore, financial resources, such as grants and support from the Agricultural policy measures enable small and medium-sized enterprises (SMEs) to access to different types of investment grants and adopt these costly digital tools, driving innovation and contributing to the economic sustainability of the LL's ecosystem.

However, despite these enablers, the DE of this LL also faces several hindrances that limit its potential. One significant barrier is the absence of specific regulations, for example, the missing rules for drone usage. Without these regulations, the deployment of drones for vineyard operations, such as spraying, is hindered. Similarly, bureaucratic obstacles in the export process slow down the LL's ability to engage in the international market, affecting financial and organisational resources. Moreover, the absence of a clear framework for addressing crises, such as economic downturns or pandemics, further weakens the adaptability of the ecosystem, leaving farmers vulnerable in difficult times.

Another challenge is the lack of open cloud platforms, which hinders technological collaboration, reducing the overall efficiency of the digital transformation process. Additionally, the transparency of supply chains is another area that requires improvement. For instance, the lack of clear and transparent data flow throughout the supply chain diminishes consumer trust, impacting the attitudes and values necessary for promoting sustainable practices within the LL´s ecosystem.

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Nevertheless, the governance structures, such as policies supporting the correct frequencies for IoT sensors and data management through GDPR regulations, provide a framework for the deployment of technological tools.

In conclusion, the DE of the Smart Villages Network LL is marked by its strong technological infrastructure and collaborative networks, which drive innovation and sustainability. However, regulatory gaps, such as missing drone usage rules, and the lack of cloud platforms present barriers to full digital transformation.

4.2 Agricultural Knowledge and Innovation System (AKIS)

The concept of Agricultural Knowledge and Innovation System (AKIS) can be used to guide the analysis of knowledge infrastructures, processes and functions in order to describe and compare characteristics that influence the development and adoption of innovations (e.g., digital innovations).

In this section, we analyse key components of AKIS, which is part of the socio-ecological context around transdisciplinary LLs in CODECS. Using the data gathered on from the LL annual workshop, we conducted an analysis to derive categories and subcategories related with it) the actors and their collaborations and ii) how AKIS knowledge and information is perceived as part of governance. As a result, we describe the configuration of actors present in the LLs. From the governance perspective, workshop participants identified rules and norms in place related with the knowledge flows, including those relevant for AKIS: EU level (CAP); regulations related with the innovation, and normative with regard to education and training.

The objective of the analysis is to present the AKIS components shaping the socio-ecological context and influencing the FAS of the LLs, based on the data collected during the LL Workshops conducted in 2023 and sets out specific objectives:

Analyse the AKIS related results of LL workshops with respect to Actor and Governance subsystems, from an AKIS infrastructural perspective

Contribute to the characterisation and construction of indicators for the conduciveness, farmer readiness, and scaling readiness of CODECS with respect to AKIS.

Identify missing information for the characterisation of AKIS and their influence in DEs.

4.2.1 Actors in Agricultural Knowledge and Innovation System (AKIS)

We identified 18 different types of actors that are recurrently mentioned around the LL, influencing the FAS. When we classify those types into the main categories used in AKIS analysis we identified seven categories (Table 3). According to the degrees of relation stated by the workshop's participants, we separate the actors according to three grades of relation:

i) Level 1 are those actors that are actively participating in the LL
ii) Level 2 are those actors which are not yet part of the LL, but could potentially be reached either to be part or to collaborate in the activities
iii) Level 3 are those actors that that despite having an influence in the FAS, are not considered as potential collaborations at the time of the workshop.

Table 7. Actors mentioned by LL Workshops participants, according to AKIS categories

ID_Type_ actors	Type of actors		Total	Relation with the LL		
				In the LL	Potential collaboration with LL	Far from LL
1 Farmers						

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ID_Type_ actors	Type of actors		Total	Relation with the LL		
				In the LL	Potential collaboration with LL	Far from LL
1	Farmers		28	21	9	5
2	Farmers associations, farmers organisations		32	7	17	8
2 Education and research						
1	Researcher		36	15	19	8
2	Education		20	11	7	2
3 Bridging institutions-knowledge exchange (formal)						
1	Advisors (public, private, NGOs)		43	13	22	11
2	Networks: other LL, hubs, platforms, LAGS		14	2	7	6
3	NGOs		4	3	1	1
4 Public actors, authority						
1	Public/authority		64	9	24	35
2	Funding institution		7		4	3
5 Value chain-Business						
1	Companies (private)		100	32	33	39
2	Companies Agtech		33	18	10	7
3	Companies (supply chain)		39	11	15	16
4	Companies (downstream)		17	2	5	10
5	Certification/audit bodies		6		4	1

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ID_Type_ actors	Type of actors		Total	Relation with the LL		
				In the LL	Potential collaboration with LL	Far from LL
6	Financial/investment institutions		5	1	3	1
6 Non-formal knowledge exchange						
1	Family, friends and neighboors, community, fairs		6	4	2	2
2	Consumers		10	3	2	7
7 Media						
1	Media		2		1	1

From Table 3, we can see that the most predominant actors in the LLs are farmers/farmers associations, and private companies followed by researchers and advisors. Potential actors for collaborations are the same group of actors together with public entities or authorities, companies in the upstream of the supply chain (input suppliers) and innovation platforms or spaces such as other LLs and hubs. In general, some type of public authorities, companies and advisors are perceived as far from the LL despite having some influence in addressing the Focal Action Situation.

Although the nature and interaction of actors is highly contextual and difficult to classify due to the heterogeneity of FASs, we can observe the salience of the private actors. We can identify there agritech/developers, input providers, machinery providers, telecommunication/internet providers, private advisors, certification and audit bodies and finally those related with the general process of production and marketing: retailers and buyers. Those actors play different roles with respect to digitalisation: i) providers of technological innovations, or ii) users or providers of information, data or knowledge generated in the production and selling process.

Bridging institutions for formal knowledge exchange were also mentioned frequently. For example, the presence of advisors is widely given, although varying according to the characteristics of the national AKIS structures. Other relevant institutions are networks (spaces for co-production, if we understand co-production as *the process through which inputs used to produce a good or service are contributed by individuals who are not "in" the same organisation- Ostrom, 1996)* relevant for the interaction between actors and instrumental in facilitating future collaborations.

Other actors important to mention are those that are not traditionally studied into the AKIS literature: communities, household members and peers that play an important role in the non-formal information or knowledge flows and in the process of co-creation, adoption or diffusion of innovations.

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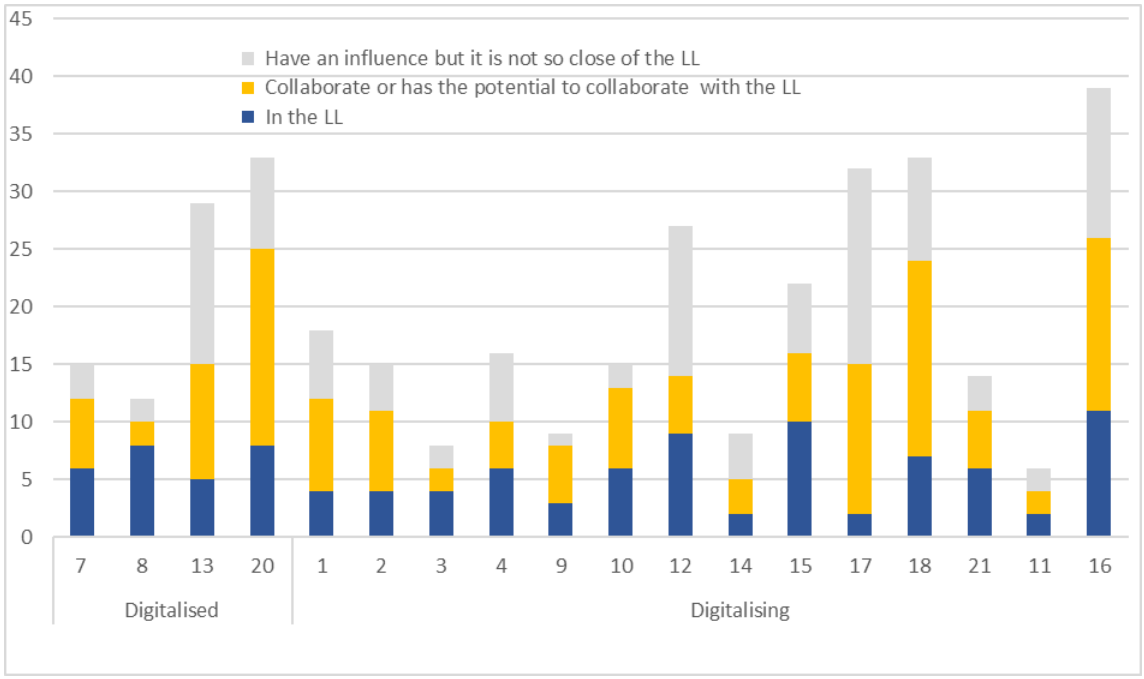

Figure 14. Number of actors by LL according to the closeness to the FAS of the LL and the level of digitalisation

The numbers of actors are very different according to the LLs context specificities and Focal Action Situations (Figure 14). In general, the number of actors were very different in all LLs. The actors *in* the LL show a range between 2 and 10 actors. The variability is higher for those who are far from the FAS. This could be explained by differences in context, the current technological maturity of the innovation or, in some cases, the understanding of the question (e.g., the facilitation of the workshop). The composition of the actors evolves according to the characteristics of the AKIS system. It is expected in the framework of the current CAP policy, new entrants are actors who are experts in the development and support of digitalisation (EU- CAP network, 2023).

The constellation of actors present in the LL is like that configuration observed by Kernecker et al 2021 with the presence of heterogeneous actor groups or networks needed to initiate the innovation processes, as most of the LLs are in a digitalising phase. The important role of new entrants such as tech suppliers or private companies has been also reported to be present according to the stage of adoption of innovation (Sutherland and Labarthe, 2022).

4.2.2 AKIS in Subsystem Governance

We analyse AKIS in the Governance Subsystems based on the answers provided by the participants to the question *Q5. Which governance mechanisms influence the LL FAS problem and how do they enable or hinder the RCCI needed for addressing the LL FAS problem?* After a first coding and identification of main topics, during the second coding cycle, for the Governance Subsystem we identified and categorised the type of rules, norms that are related to the definition of AKIS governance mechanisms.

We categorised the type of rules and norms that are relevant to the definition of AKIS and to those related to the definition of rules for access, extraction, management, exclusion and alienation of knowledge and information resources. The results reflect norms, rules and regulations for the coordination of AKIS components (Table 4). Most of the statements were referring to public policies and regulations, EU level policies, market rules and regulations and association in communities' norms (Table 4). For the AKIS analysis, we looked closer into these categories that reflect formal AKIS coordination mechanisms.

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Table 8. Categories and description found in Governance System

Category	Description of the category	Number of mentions
Local associations norms	Statements describing norms and rules determined by groups of persons, associations) soil, trade, irrigation, GDOS, producers, communities and cooperatives)	11
Private companies and the market rules	This includes markets, farmers consumers and companies involved in the development of rules: some of them are large inputs (seed, planting materials or plant protection products) but also companies which implement rules such as insurance services or in control of geospatial analysis. It also includes norms dictated by certification mechanisms within the value chain, for example Biosert, monitoring social and environmental impact, quality certification bodies, impact certification bodies, food labels, GAP; PDO schemes	23
Public policies and regulations	The participants identified those public actors and policies relevant for the FAS. A long list of regulations and normative were mentioned: accounting, drones, young farmers, exports, environmental protection, fertilisers regulation, food legislation, health and safety regulations, land use, water management, manure management, education, technological innovations, livestock, GDO, nitrates, working time, spray regulatory framework, knowledge transfer strategies, subsidies, taxes and fiscal regulations, phytosanitary regulation. Some other aspects mentioned were the role of regions and municipalities, the participation on the policy making process, and the enforcement of those regulations. Finally, support instruments such funding grants, subsidies for specific innovations (precision agriculture) or entrepreneurs were mentioned	54
EU level public policies and regulations	The coordination mechanisms at EU level such as the CAP; the GDPR; the EU organic regulation, EU guidelines on plant protection products, information systems such as FADN, regulation on frequencies	20
Education related guidelines	Available normative with regard to curricula on digitalisation in technical schools, vocational schools or vocational training farms	3
Farm objectives incentives expectations	This reflects those norms or rules that are seen as pursued by farms, for example improvement on the efficiency in the use of resources, generation renewal (succession) at farm level or those norms that takes into account the farmer as the user of the innovation	5
Social rules or norms	Rules that are present in the community that supports or limit the adoption of innovations. For example, the approach of meetings; the visions on the social system or the availability or lack of collaborations around the FAS	4
Networks rules	Those are groups are networks of producers (AG Porc / GT porc, data providers or users, LLs or activities (tourism or animal production) that have their own norms	6

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Category	Description of the category	Number of mentions
Global macro-trends	Some particular aspects mentioned are the global crises, the interest in the environment and in general the negative perspective about agriculture	5

The governance aspects are closely related to the AKIS concept, in that one of the integral parts of the innovation systems is what is called the *enabling environment and the support system coordination* (FAO, 2022). It is anticipated that national or sectoral arrangements pertaining to knowledge exchange and coordination will be incorporated into the role of AKIS in policymaking.

The enabling environment encompasses the policy instruments and strategies that facilitate innovation support and enhance structural and functional capacities (FAO 2022). Interestingly, data governance mechanisms such as property rights are scarcely mentioned; only one related with the GDPR, but not many aspects arise regarding the access, extraction, management or exclusion of data or information. Some categories were fewer mentioned such as global macrotrends, social rules or education guidelines.

4.2.1 4.2.3 Overview of AKIS results

In this section we have explored from the AKIS perspective which actors are present and most likely to contribute to the final outcomes of the FASs present in CODECS. In this deliverable we have focused on the infrastructural perspective of AKIS (Actors and Governance System) which is part of a larger analysis of AKIS as a complex system.

For the actors, we found that the most predominant actors in the LLs FAS are farmers/farmers associations and private companies followed by researchers and advisors. Private actors, and more specific technology developers are predominant as part of the technology development and testing. Bridging institutions are also important as the local advisory system but also as forms of co-production for knowledge exchange (innovation groups, networks, associations). This condition confirms the importance of spaces to make the best use of complementary types of knowledge and aligns with Eastwood et al (2017) who suggest that complex agricultural innovations require a collaborative approach for successful innovation and diffusion that transcends scales and the public-private traditional functions.

With regard to the governance aspect, it was noted that the majority of the norms and rules identified at the various levels describe coordination mechanisms that are in place, either within the supply chain, in local associations and groups, or in the public policies that are applied. Related to AKIS coordination mechanisms, participants identified the CAP and national strategies for the transference of knowledge. Indirectly, participants identified mechanisms to foster innovation. To a lesser extent, knowledge governance issues such as data protection, property rights, as well as rules for exclusion and accessibility of knowledge were mentioned.

About the methodology for data collection and analysis, we consider that the AKIS studies provides a basis for the identification of actors and their functions; limitations should be addressed in the future such as the role of non-formal knowledge exchange and their importance. With the regard to the use of SES for the analysis of knowledge and information, we consider that the classification of knowledge, information and ideas is useful to make differences on the type of information generated together with the rules of access, relevant for the analysis of digitalisation.

5 Socio-technical process modelling of use cases

This section reports the activity carried out in Task 3.3 - Socio-technical process modelling of use cases. The goal of the task is to enable reasoning about the costs and benefits of digital technology within the CODECS LLs by means of a set of graphical representations called Socio-technical Process Models. These models represent different dimensions of the process transformation, namely:

(a) the goals of the LL that trigger the introduction of a certain technology

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(b) the structure of the LL in terms of actors and resources

(c) the process before and after the introduction of the technology

Altogether, these representations will allow visualising the process transformation entailed by the introduction of a specific digital technology within the LL. In turn, this will enable reasoning about the impact of digital technology on the process, actors, and resources of the LL. These representations are operational descriptions of the farm level, which is part of the DE, with particular focus on the digital transformation of the farm, according to the FAS defined by each LL. Furthermore, the representations will be used as input for the cost-benefit analysis to be carried out in WP4.

The activity of constructing the aforementioned Socio-technical Process Models for each LL is called Socio-technical Process Modelling. This consists of the four different phases outlined in section 3.3, namely: 1) data collection, i.e., gathering information about the process before and after the introduction of a digital technology; 2) reporting, i.e., structuring and writing down this information in a way that it is amenable for graphical modelling; 3) check, i.e., verifying that the information is sufficient for modelling; 4) formalisation, i.e., designing the models; 5) agreement, i.e., using the models to facilitate reasoning with the LL representatives about the impact of digital technology.

The first two phases, i.e., data collection and reporting, are conducted by the contact points of the LLs, based on the guidelines provided by the task leaders. The second two phases, i.e., check and formalisation, are carried out by the task leaders. The last phase is moderated by task leaders and involves LL representatives as participants.

At this stage, we completed the data collection and reporting phases of almost all of the LLs, a few still need to complete their reports. Section 2.2 briefly reports the background required to understand the concepts underlying socio-technical process modelling and section 3.3 provides details about the completed activities and the timeline, highlighting completed and planned ones. Section 3.3.1 describes the guidelines that are used by the LL contact points for data collection and reporting. Section 3.3.2 describes the approach followed to define the guidelines for data collection and reporting, which is based on the Design Science methodology (Wieringa, 2014). Meanwhile, section 5 illustrates the graphical notations that are adopted in CODECS to represent the models. Section 5 summarises the reports provided by the LLs. Pilot case study: Pecorino Toscano LL.

The Socio-technical Process Modelling method introduced in the context of CODECS uses a combination of notations from BPM and RE, namely: the iStar notation (Yu et al., 2011), to represent the goals of the stakeholders, and ultimately the reasons why a certain digital system is introduced; the UML class diagram notation (UML, 2017), to represent the structure of the socio-technical system in terms of actors and resources; the BPMN notation (BPMN, 2010; Corradini et al., 2018; Aalst 2011), to represent the process before and after the introduction of a digital technology. An example of these graphical notations is reported in Figures 13-15. The example refers to the Consorzio Pecorino Toscano case study, which was used also as a pilot study to define the Socio-technical Process Modelling method used in CODECS. In the following, we briefly describe the context of the case study, and then we illustrate the notations “in action”, referring to Figures 15-17.

Example – Context

Consorzio Pecorino Toscano, is an Italian LL based in Manciano, Tuscany and focused on the activity of sheep breeding and pecorino cheese production. The LL is built around the activity of the “Caseificio di Manciano” which is collecting sheep milk from several local farmers and processing it to produce pecorino cheese. Part of this cheese is certified P.D.O. The LL involves the farmers, the processors, the “Consorzio tutela Pecorino Toscano D.O.P.”, and the advisors working with the farmers of the processing plant. Local administration such as the municipality of Manciano and the Tuscany Regional Administration are also participating in some LL activities. A series of technologies aimed at supporting the work at various levels have been developed so far or are currently under development or evaluation. In the context of CODECS, the LL is developing and testing a Farm Management System (FMIS) with an app in use by farmers and advisors to monitor animals’ health status and food ratio optimisation. The FMIS aims to support the work by automating the recording and storage of farm data both through sensors and user input, and to monitor and analyse farm activities with the final objective of predicting the amount and quality of milk produced and to be processed by the cheese-making factory.

Example – Notations

Figures 13-15 report excerpts of the different models for the Consorzio Pecorino Toscano LL.

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The first model, represented in Figure 15, is the **UML class diagram**, where each box represents an entity that is part of the process, i.e., an actor or a resource, while the arrows represent an action occurring between two entities. Inside each box is a list of activities that are carried out by the entity. For example, the Agronomist (box) monitor the animals (arrow) through a Pet Scan Bluetooth (box), and exchange information with a Veterinary (box). The Pet Scan Bluetooth sends data (arrow) to an App (box), which elaborates these data (internal activity).

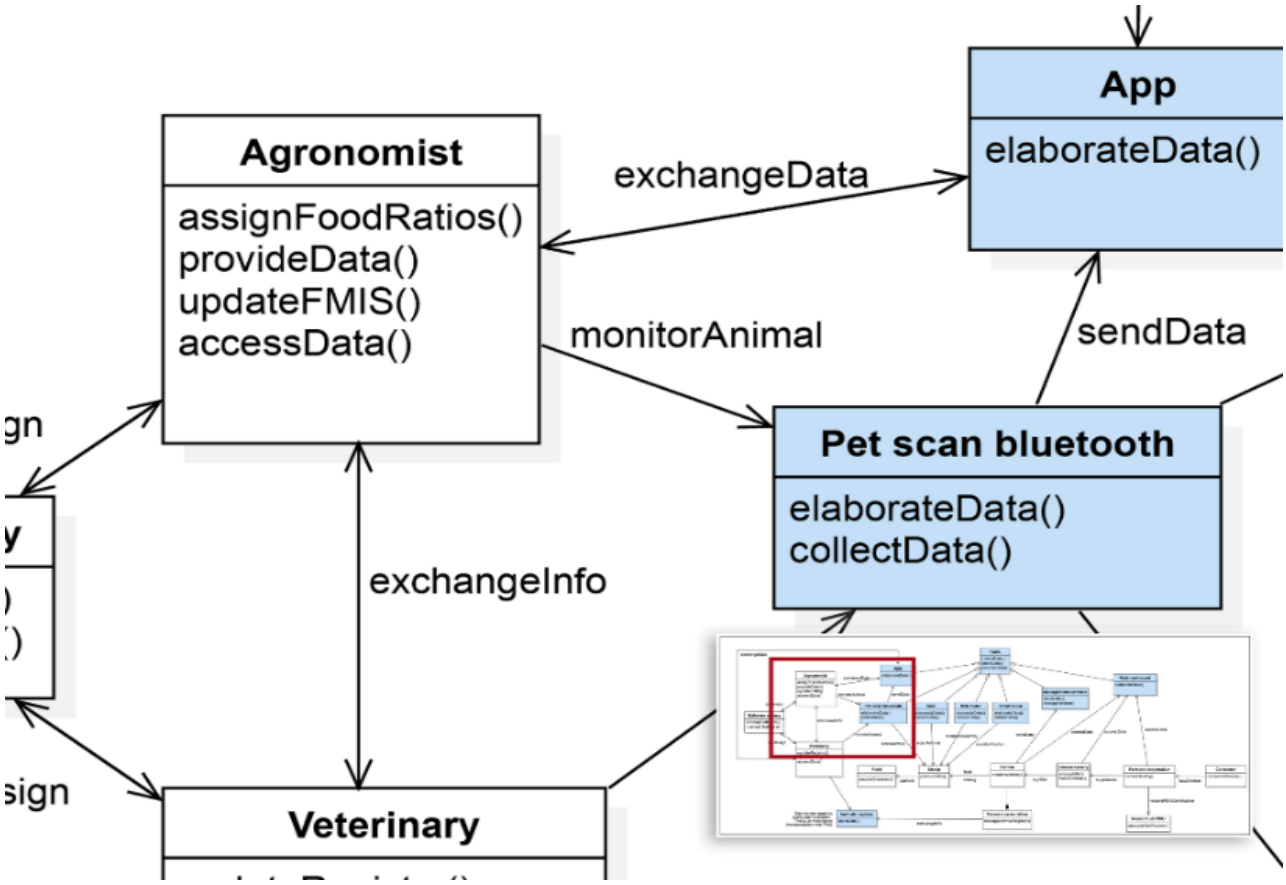

Figure 15. UML class diagram

The second model, represented in Figure 16, is the **iStar diagram**, where we have a circled boundary for each actor involved in the process, e.g., the Agronomist in the figure. Inside the boundary, there are the goals of the specific actor (red ellipses), e.g., “increase milk quality and quantity”. These are decomposed into tasks performed to achieve the goals (blue parallelogram), e.g., “elaborate food ratio”, and into resources that support the tasks (grey rectangles), if, any, e.g., Pet Scan Bluetooth. An actor is connected to another actor if one of its goals require the involvement of the other actor. For example, the Agronomist requires the involvement of the Veterinary to achieve the goal “assign food ratios”.

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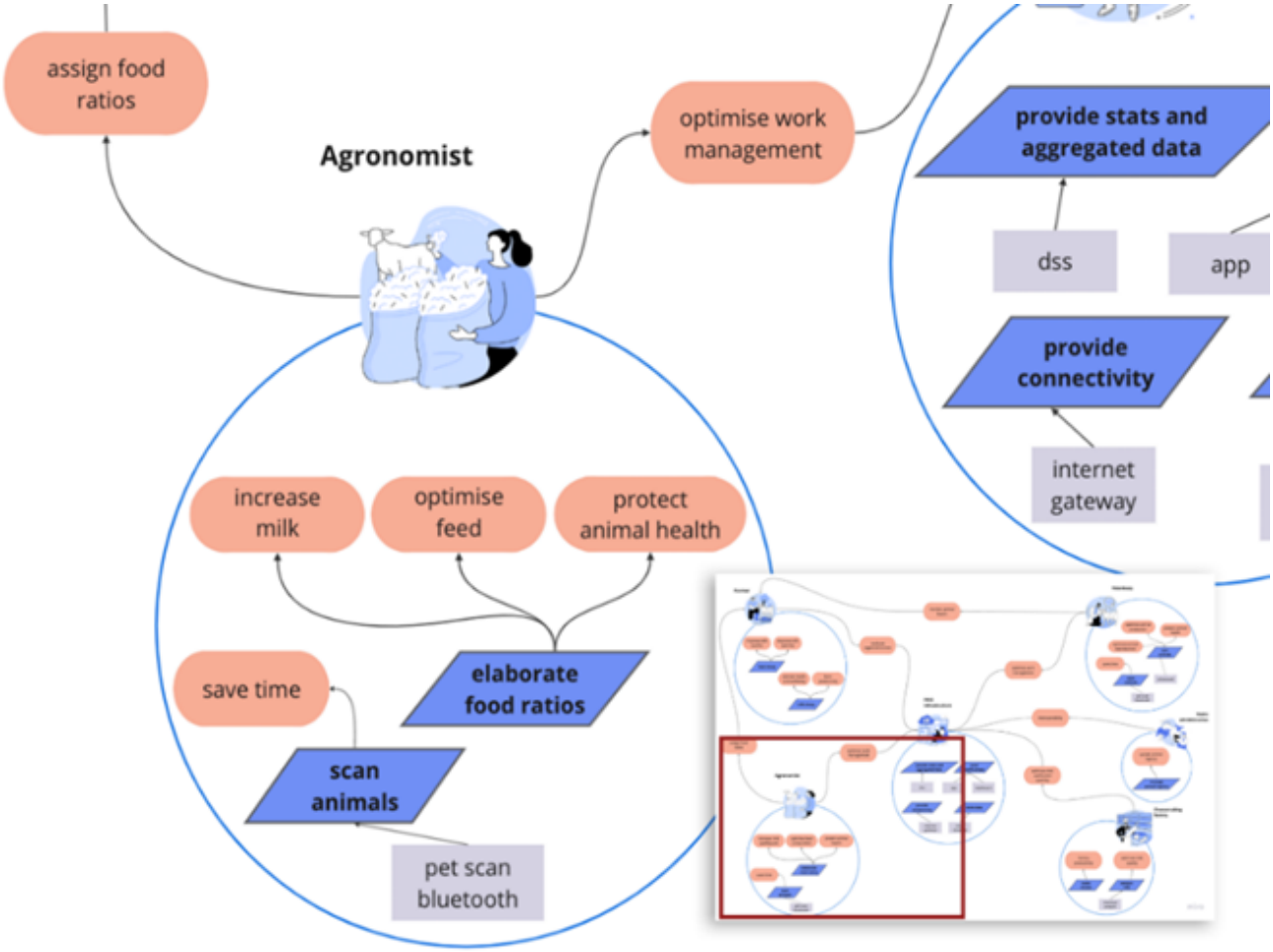

Figure 16. iStar goal diagram

The third model, represented in Figure 17, is the **BPMN diagram**, which consists of three different diagrams. These represent the process before the introduction of the digital technology, the process after the introduction of the digital technology, and an overlap of the two processes, respectively. For the sake of conciseness, here we report only the third diagram.

The BPMN diagram consist of a set of activities performed by actors, possibly based on some conditions. The activities are represented as boxes. When two activities are sequential, these are connected through an arrow, e.g., “visit scheduled farms” is followed by “request animals’ information”. A set of sequential activities creates a linear flow, e.g., the one that goes from “visit scheduled farms” to “update FMIS”.

Sequential flows can be performed in parallel, and this is modelled via the rhombus with the “+” symbol, which separates the different flows. Some activities or flows depend on certain conditions, and the condition is represented through the rhombus with the “x” symbol, e.g., “is day 1 of 30?”. In the overlapped diagram reported here as example, the green elements represent those elements that do not change in the process transformation; the blue elements those that are introduced due to the introduction of a digital technology; the red elements those that are removed after the introduction of the digital technology.

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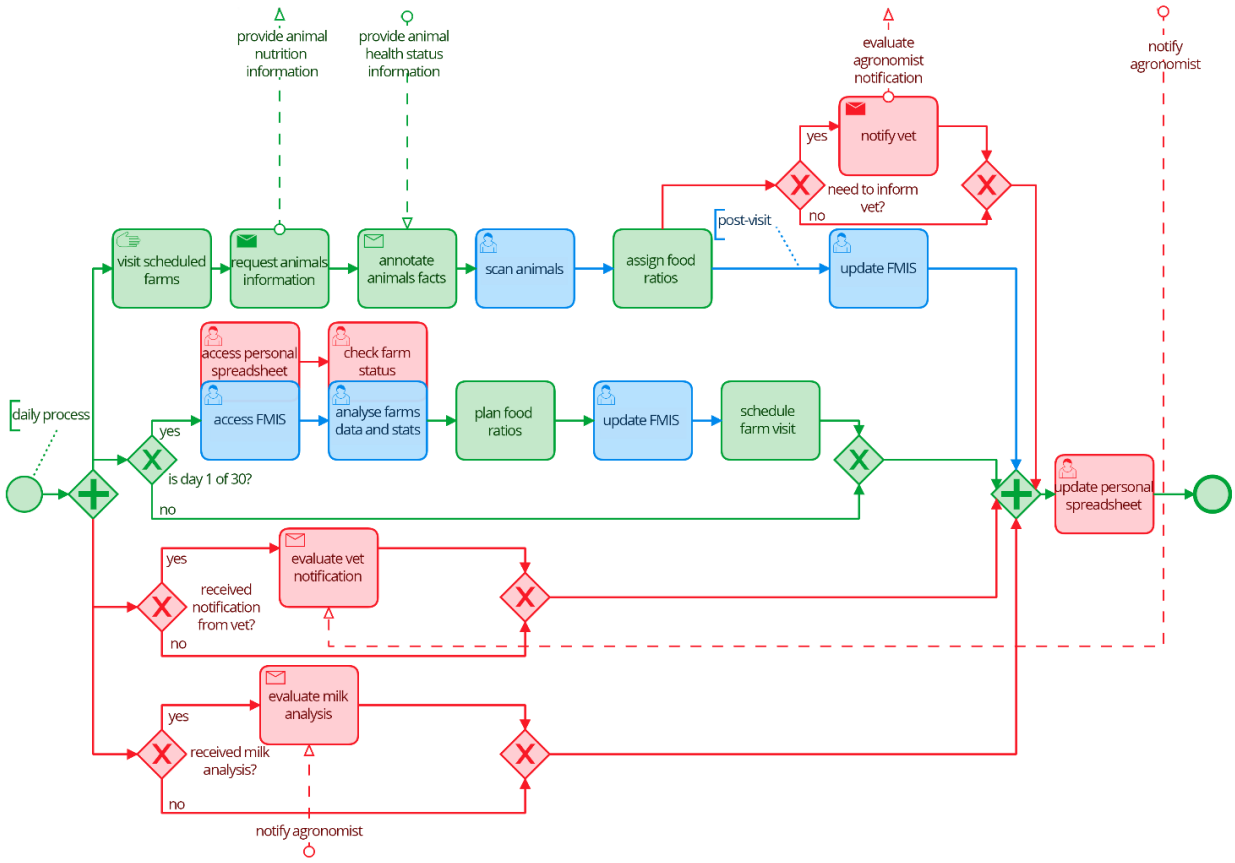

Figure 17. Overlap of two BPMN diagrams

It should be noted that the UML and iStar diagram to be designed will be based solely on the process *after* digitalisation, while the BPMN diagram will represent the process *before* and *after* digitalisation. This choice was driven by the prominent focus on the process of the proposed Socio-technical Process Modelling method, and the need to simplify the procedure by avoiding the proliferation of the number of diagrams.

5.1 Feedback results on training

Feedback after the training activities was collected through Mentimeter during the training itself. The feedback sheds light on participants' familiarity with process modelling approach, their comfort level in applying it to LLs, the state of digitalisation within their LLs, the availability of necessary information and the preferred data collection methods for process modelling activities.

By examining these insights, we can better understand participants' willingness, potential challenges, and areas requiring further support or training.

Question 1. Experience with Process Modelling. The majority of respondents have encountered process modelling before but mostly indirectly. 46% have seen it in publications, and 21% have some experience with it but in a different way. Only 4% have direct experience in a similar setting, while 29% are unfamiliar with the concept. The overall feedback shows that a significant portion of the group has limited hands-on experience, indicating a need for foundational knowledge and training in process modelling.

Question 2. Comfort with Process Modelling Activity in the LL. The largest segment (43%) feels cautiously optimistic, though 30% express doubts. A small group (17%) is enthusiastic or willing to proceed, while 9% are unsure about what process modelling entails.

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In conclusion, while optimism exists, there are notable concerns and uncertainties. Further clarification and confidence-building measures are essential for smoother implementation.

Question 3. State of Digitalisation in the LL. Most LLs are in the digitalising state (67%), with 30% reporting a digitalised state. No respondents selected "Zero Digital," and only one LL needed more time to assess the digitalisation state.

Question 4. Amount of Information Available. The largest group (56%) estimates they have 41-60% of the necessary information, while fewer (19%) have less than 20%. No participants reported having more than 80% of the data, reflecting that further data collection activities are necessary to integrate the information.

Question 5. Planned Data Collection Activities. Participants prefer direct and diverse approaches to data collection. 1-to-1 interviews are the dominant method planned by 48% of respondents. Combining multiple activities is also widely chosen (29%) and can help triangulate data effectively.

Question 6. **Impact of Training on Understanding Process Modelling Data Collection.** The last question aims to get overall feedback on the training activity. The group is split between cautious optimism (38%) and readiness to proceed (38%). However, 23% still have doubts about the clarity of the upcoming activities.

While many feel ready or optimistic, a notable portion has lingering uncertainties. Additional support or follow-up training might be needed to fully resolve doubts.

Preliminary Feedback Summary

The group is cautiously moving toward process modelling with mixed levels of prior experience. While enthusiasm for data collection exists, many participants still lack sufficient information. In case these doubts persist after carefully reading the guidelines, direct support and further meetings with LL coordinators may be necessary to ensure confidence in both process modelling and data collection activities.

5.2 Overview of the socio-technical processes in Living Labs

The presented guidelines for data collection and reporting were used in LL, and reports have been consolidated by the LL leaders and then sent to the task leaders. Hereafter, we summarise the reports of the LLs and then we provide some general reflections on their state of digitalisation and a general grouping. The in-depth analysis of these reports, and the design of the models based on their content will be part of the next deliverable.

Summary of the Reports. Italy's solutions include a Farm Management Information System (FMIS) and a smart irrigation system, while Greece and Belgium are exploring drone technologies for sustainable pesticide application and pest detection, respectively. Latvia and North Macedonia have developed platforms for marketing and agricultural decision-making. Spain and Slovakia are piloting integrated systems for comprehensive data management. Hungary and Germany focus on real-time soil analysis, and France has solutions for pig farming and dairy sheep management. Scotland uses online platforms for weather monitoring and marketplaces, and Slovenia employs IoT for vineyard monitoring and beekeeping. These LLs demonstrate a range of maturity levels, from prototypes to mature systems, showcasing diverse approaches to integrating digital technologies in agriculture.

Feedback on Guidelines Application. The produced reports include feedback on the experience from the LL contact points who applied the guidelines, both in narrative format and through a short survey. Furthermore, we asked the LL contact points to provide feedback also about their impression on the experience of the participants. In the following, we summarise the feedback.

5.2.1 Feedback from LL Contact Points – Narrative Format

The feedback from the LLs contact points is structured around several questions and focuses on evaluating various aspects of the guidelines. These include assessing the adequacy of information collected, the clarity and usefulness of templates and guidelines, challenges in completing templates, primary obstacles in following procedures, specific

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difficult questions, suggestions for procedural improvements, and overall experience with the survey. The questions, and a summary of the answers with represented excerpts are reported below:

Were you able to collect sufficient information? Contact points reported that they were able to gather sufficient information to answer all survey questions, thanks to data collected from focus groups, workshops, and previous interviews.

"Yes, we were able to answer every question with the data we gathered from the focus group and workshop in 2023 and previous interviews we conducted before.".

"Yes, we have been able to collect enough information to answer the questions during the different activities organised throughout the project."

Were the templates and guidelines helpful? The templates and guidelines provided were considered well-structured, clear, and helpful, especially with the inclusion of examples and training sessions.

"The template was well structured and easy to follow."

"Yes, very clear instructions and examples."

"The templates and guidelines were more than helpful, especially provided examples and the training sessions."

Did you encounter problems in filling the template? There were minor issues with the templates and guidelines, such as the need for easier access to the templates and some unclear distinctions between sections.

"The template was useful but a link to it when asked to prepare this would have been helpful. It is difficult to remember after a few months where everything is stored and can increase the workload."

"The difference between 1.4 and 1.5 was perhaps not immediately clear, but this was a minor issue."

What were the main challenges in following the proposed procedure? Procedural challenges included a strong focus on technical processes without considering underlying agronomic processes and the need to organize meetings according to the needs of various actors.

"The guideline focuses very strongly on describing the technical process around one technology, while it doesn't include the underlying agronomic process."

"Organise meetings according to the needs of the various actors."

What were the most challenging questions? There was an agreement that most challenging questions were associated with the detailed descriptions of the future processes and detailed activities for all actors involved.

"Questions of segments 4.3 and 5.5 were the most challenging as we should list activities for all actors involved."

"Definitely questions about the future because the actual solution and the way it will work in practice is still being articulated."

Would you suggest any changes to the procedure? Why? Suggestions for procedural adjustments included focusing more on the farm level rather than the LL one and have a less strict format for the answers. Furthermore, the contact points observed that the processes are assumed to be linear, which can be a strong simplification of the reality:

"For this case, I would suggest focussing on model the agronomic production process at farm level, instead of technology adoption at LL level."

"Perhaps when describing processes, actors, and resources, leave a less strict format, and avoid repetition of some questions."

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"We believe that there is an implicit assumption that the process is linear and implemented in a structured manner. This may result in a rational reconstruction of the process, rather than empirical account."

Please report anything relevant about the overall experience. This question was mainly left blank.

5.2.2 Feedback from LL Contact Points - Survey

The following Likert Scale questions were asked to the LL contact points. The questions, together with a summary of the answers, are reported below. Figure 18 visually reports the results.

It was easy to come out with answers. The majority found it relatively easy to come up with answers, with 7 agreeing (43.75%) and 1 strongly agreeing (6.25%). However, 3 disagreed (18.75%) and 5 were undecided (31.25%), indicating some room for improvement in clarity or simplicity.

I think I will reuse the procedure in the future when dealing with the analysis of process transformation. Most participants (10, or 62.5%) agreed they would reuse the procedure for future process transformation analysis, showing a positive reception. Yet, 3 disagreed (18.75%) and 3 were undecided (18.75%), suggesting that while the procedure is generally well-received, it may not be universally applicable.

I made a lot of effort to think about actors, resources and activities. A significant number (8 agreed, 50%, and 6 strongly agreed, 37.5%) felt they had to put in a lot of effort to think about actors, resources, and activities, indicating that the procedure is thorough but possibly demanding.

I would recommend the use of this procedure. The responses were mixed, with 8 undecided (50%) and 5 agreeing (31.25%) to recommend the procedure. This suggests that while some see value, others are unsure, possibly due to the effort required or the specific context of use.

The procedure helped us to better realise the impact of the digital transformation. Most participants (7 agreed, 43.75%, and 2 strongly agreed, 12.5%) felt the procedure helped realize the impact of digital transformation, which is a positive outcome. However, 4 were undecided (25%), and 3 disagreed (18.75%), indicating varied experiences, and the need for an additional focus on impact.

I found the question on the transition useful to reflect on the steps taken. The majority (10 agreed, 62.5%, and 2 strongly agreed, 12.5%) found the transition questions useful, highlighting this as a strong point of the procedure.

It was challenging to recall the process before digital solution. Responses were varied, with 6 disagreed (37.5%), 5 agreeing (31.25%) and 5 undecided (31.25%), indicating that recalling pre-digital processes was challenging in a substantial number of cases.

The procedure followed did not help to describe the process transformation. A significant number (9 disagreed, 56.25%, and 2 strongly disagreed, 12.5%) felt that the procedure helped describing the process transformation, indicating that this is a strong point of the procedure.

I would apply a different procedure if I had to repeat a similar activity. Many subjects (9 undecided, 56.25%, and 3 disagreed, 18.75%) were unsure if they would use a different procedure, indicating mixed feelings about the current one. The weaknesses pointed out by the narrative part of the feedback indicate points of improvement that may trigger more intention to use the method in the future.

I had to highly adapt the questions when collecting data directly from stakeholders. Responses were varied, with 6 undecided (37.5%) and 5 disagreeing (31.25%), but 4 strongly agreeing (25%), indicating that adapting questions was necessary in some cases.

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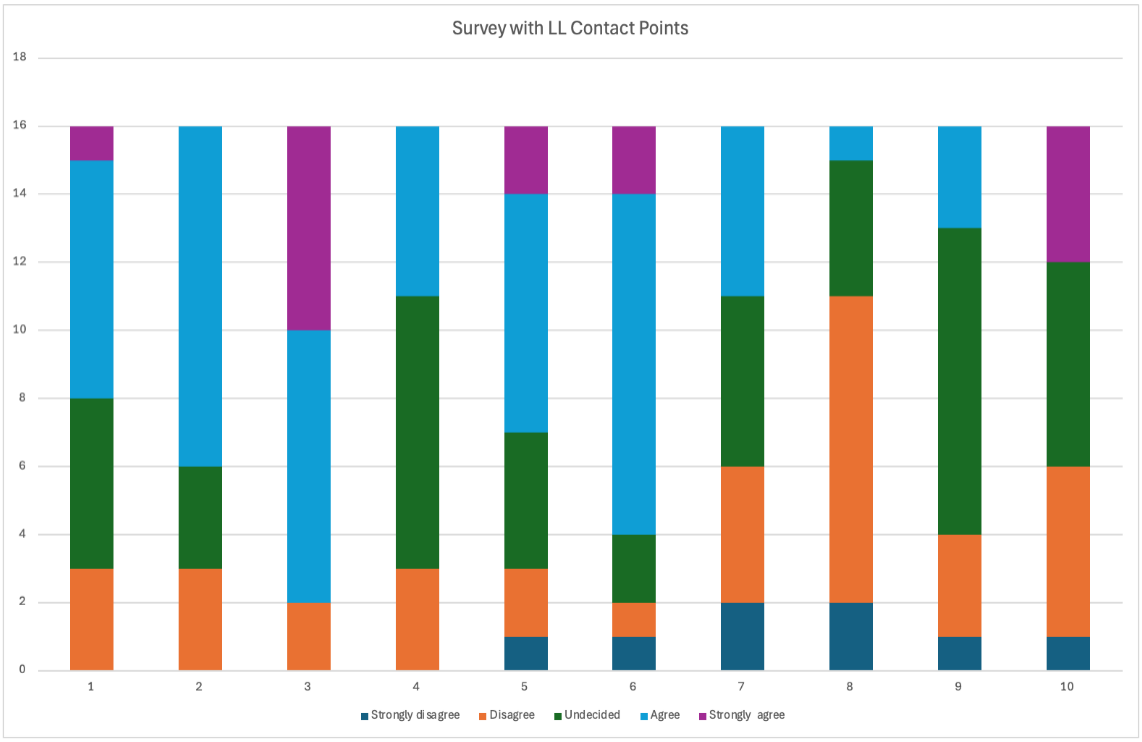

Figure 18. Feedback from LL Contact Points

Overall, while the procedure has several strengths, particularly in helping realize the impact of digital transformation and reflecting on the transition. However, there are areas for improvement, especially in making the procedure easier to use.

5.2.3 Feedback from LL Contact Points - Participant Engagement

In the following, we report the questions asked about the perception of LL contact points concerning the engagement of the participants, and the difficulties encountered. We also provide a summary of the answers, with associated excerpts.

Did the participants encounter difficulties in answering your questions? Some of the questions required clarifications and adaptations to the specific context, language, and viewpoint. However, the contact points were able to collect the required information, highlighting the importance of the role of the moderators.

> "At some point, some clarifications were needed in order to make it completely understandable for the users."

> "Yes. In fact, they refused to answer the questions that were set. Fortunately, the answers came out in the discussion."

What were the most challenging questions? Also, for the participants, the most challenging questions were associated with the process after the digitalisation and the details on the activities.

> "The most challenging part was to understand the process after introduction of the digital solution."

Were they engaged in the conversation? The responses indicate a high level of engagement and willingness to share information among participants. The participants appeared to feel involved in the process, with comments highlighting their active participation and interest in the discussions.

> "They were engaged for all questions asked."

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"Yes, the debate about digitalisation, what is needed and its impacts on agriculture is in itself an interesting topic for them."

Did they feel involved in the process? The perception of involvement was varied across LLs, with some contact points indicating a high degree of involvement, and other a lower one, especially due to specific LL contexts, and, in one case, difficulties in translating questions for a non-academic public. This suggests the need to simplify questions or suggest specific adaptations.

"The participants had the opportunity to be highly involved in the process through questions and tasks."

"In general, advisors and farmers do not feel as involved in the digitalisation process."

"No. Most of the questions were far to academic and difficult to translate for the native Latvian speaker."

Were they willing to share information? In the majority of the cases, the participants appeared to be willing to share information and opinions, but in some specific situations it was also observed a distrust on the authorities, and thus the need to preserve privacy on business-sensitive data.

"All the actors asked to participate were willing to share their opinions."

"Informal discussions were fruitful, but they did highlight their distrust of the authorities."

Please report anything relevant about the overall experience. A few LL contact points answered this question, but all indicated that a large part of the information was available to them also thanks to previous interactions with the LL participants, suggesting that the required template to can be filled also without strictly following the guidelines, thus highlighting the flexibility of the overall procedure.

"We used material and results that have been collected in the previous period."

"We used existing data from previous data collection activities."

Overall, while the participants were engaged and willing to share information, the responses highlight the importance of simplifying the language and providing more context to enhance understanding and participation. Addressing these issues could lead to even more effective involvement, ensuring that all participants can fully comprehend and contribute to the discussions on digitalisation in agriculture.

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6 Observations on Digital Ecosystems for sustainable digitalisation of farming

In this D3.1 (M24) we have set up a process within the socio-ecological system framework (SESF) to gather data on, and subsequently describe, the agricultural digital ecosystems of 19 LLs, as well as an overview and piloting of socio-technical process modelling.

In addition, we have taken a multi-level systems approach, taking into account the FAS, the DE, the four subsystems and an AKIS perspective in order to unpack the dynamic processes and results of digitalisation. We have laid the basis for future crafting of SESF and LL indicators of conducive DEs, which allow capabilities to be considered in concert with resources.

The narratives of these 19 LLs presented herein describe the DE through the four subsystems of the SESF: actors, resource units, resource systems, and governance systems, including an infrastructure perspective of AKIS, as well as those actors involved in value chains and networks implicated in the LLs.

In order to understand better the four subsystems and the DE and to link them to the FAS in each LL, we have used a RCCIs approach in the LL SES workshops. This has:

Made the SESF more understandable and less abstract for the LLs in their study of the FAS.

The information provided on RCCIs linked the FAS to the SESF, shedding light on the DEs.

Allowed us to collect a wealth of data on these four SESF subsystems in relation to the FAS and DEs, as well as AKIS, through the identification of various capabilities, resources, collaborations and innovations in these dynamic systems.

The basis is now set for the next version of this D3.1 in M36 where more extensive analysis or coding of the SES LL workshop results will be carried out. In this version M24, some preliminary coding of subsystems from the AKIS perspective has been presented. In addition, the methodology for socio-technical process modelling has been developed, pilot tested on a LL, and the data collection for the process modelling has been carried out. By M36, a more complete analysis of the socio-technical process modelling results will be carried out, demonstrating the "before" and "after" of the introduction of digital technologies. The intermediate results of this activity have also been exploited as part of the cost-benefit analysis of WP4.

The initial analysis of the data according to the four SESF subsystems (including AKIS) revealed notable relationships, and noteworthy characteristics, both in terms of enablers and hinderances in DE. Below we set out the subsystems and observations related to some of the most relevant categories of RCCIs:

Resources Units

There is a clear relationship between resources (resource units and resource systems) and capabilities (individual and collective actors, personal and organisational/institutional). Capabilities allow resources to be put into action and leveraged to create value and resources are necessary to acquire or create capabilities.

Financial resources:

The necessity of functional resources, above all financial resources, incentive schemes, subsidies, research funds, etc. is still very evident. However, many LLs noted that traditional finance and financing sources to enable digitalisation were not fit for purpose.

Funding for acquisitions of digital tools and systems, particularly those that are innovative, is necessary due to high costs of such cutting-edge tools or systems (financial resources).

Technological resources:

There is also a significant need for tailored software and other technology which is designed for small or diversified farms (technological resources).

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Lack of domestic tech developers and producers affects not only affordability, but also the customisation of technical solutions tailored to local social, economic, and environmental conditions.

Human, informational resources and absorptive capabilities:

Human resources in terms of knowledge are the most important resource in the LLs as they consist of a "variety of experience and knowledgeable individuals". They are necessary for implementation of digital technologies, sharing and collaborations with similar systems and aims.

Human resources and corresponding knowledge (also covered under Actors) is a central element of resources, as many LLs noted a lack of untrained or unprepared farmers, advisors, and other related stakeholders. While reference was made to the presence of large quantities of data, it was noted that farmers may have little critical capacity to understand if that data is useful and how to use it (absorptive capabilities). As well, advanced aging of European farmers was also noted as a challenge to sufficient human resources for sustainable digitalisation processes.

Acquisition of knowledge, access to knowledge, creation of knowledge, storage of information/data, and in general the ability to use it, benefit from, and control data and knowledge/information related to digitalisation were recurring themes across LLs [and are a main topic to be developed for M36].

Knowledge from farmers and agronomists is needed to enhance technical information, for example, sensor measurements are found but they need to be interpreted and "proper models need to be built upon which farmers can react".

Funds for human resource/actor knowledge and expertise such as digital marketing specialists, specialist Agri digitalisation advisors, ICT specialists were also noted as relevant.

The necessity to allocate time for learning new digital skills is emphasised. Training resources are needed as there is a lack of educational programs and trained human resources, and advisors and private technical advisors are seen to be expensive. This gap in human resources and informational and knowledge resources hinders digital readiness.

Material resources and innovation:

There is a need for testing and innovation infrastructure in digitalisation (test before investing, as well as testing for "right scaling"). Infrastructure resources such as demo farm infrastructure, and technical equipment are necessary for practical implementation and experimentation with, and creation of, digital technologies, including digital systems solutions, platforms, etc. These infrastructures support the operational aspects of digitalisation, providing the physical space and equipment for training, research, and demonstration purposes. They enable "trial fields" and facilitate "practical experience with digital technologies" thus enhancing both material, human and technological resources. These resources ensure that the required tangible resources to support digitalisation goals are present and that farmers can trial digital solutions without risking primary income sources. Finally, they are important for scaling digital innovations.

Other natural and non-technical material resources have an impact on digitalisation processes. For example, outdated infrastructure for energy or steady availability of water.

Farm size matters.

Resource Systems

Human (knowledge and information) resources:

- **Ineffective knowledge and information resource dissemination** systems hinder "stakeholder awareness and understanding". **Farmers need continuous and updated information** to stay up to date speed on technological advancements and best practices. There are **insufficient communication of farmers' needs to IT developers** and other key stakeholders, which hinders the development of tailored

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digital solutions.

Collaborations, attitudes and values:

- How private ownership is organised has a direct effect on the interoperability of technologies and the sharing of data and information, and can hamper collaboration, particularly monopolistic ownership.
- Data security systems are crucial and could enable collaborations such as online payment processes through intermediaries. The importance of secure transactions was emphasised, as it directly impacts consumer trust and the efficiency of digital payment systems (attitudes and values/ financial res.). Along the same lines, payment systems that offer fast and easy checkout processes enable the capabilities of digitalising actors by improving the customer experience and in general promoting online sales.
- The integration of ecological considerations (natural resource systems) into the digitalisation process, is necessary in the creation of a sustainable and efficient farming environment. [This highlight is interesting in terms of the SES framework, which originally was based on natural ecological systems and may be further developed in CODECs with respect to indicators and sustainable digitalisation].

Technological, informational, organisational resources and innovation:

- Broadband connectivity is an ongoing problem for the many rural users, “many farmers are …[still]… struggling with connectivity issues, trying to find workarounds, though often these (e.g. Starlink) are too expensive for a small-scale farm to justify”.
- A clear, supportive and non-discriminatory regulatory environment for digitalisation and data/knowledge/information resources is necessary-one which does not favour or penalise actors based on size, crop diversifications strategies, agricultural product, etc. [This point is applicable to governance systems as well].
- Lobbies, seed companies, and large producers of technical means were seen to direct and control technology choices, therefore influencing and “regulating” the market in ways that may not align with the interests of smaller producers. This misalignment hinders the digitalisation process by imposing market-driven guidelines that may not support sustainable practices.
- Need for new services such as certification and methodologies, i.e. development of new analytical methods to support results from the use of digital tools is needed.
- Conversely, environmental certification bodies ensure that the LL's practices meet regulatory standards and industry best practices. These bodies enhance the credibility of the LL's initiatives and promote wider adoption of proven digital solutions (capability to anchor and scale digitalisation). However, navigating the certification process can be challenging, particularly for smaller producers who may lack the necessary resources and support.
- Some LLs mentioned resource subsystem lock-ins as a hinderance to innovation and sustainable digitalisation where the commitment of strong market players to specific technologies may be potentially restrictive.
- Similarly, digital technology systems such as DSS (Decision Support Systems), open data, and software, among others, enable digital solutions and simplify the use of innovations and “knowledge transfer in a simplified and usable way” for example, “simplified devices that are easy to interpret”, facilitating technological knowledge.
- However, there is a lack of data sharing, which hinders the potential for integrated computerised systems for production data, used for knowledge management, aligned with the needed innovation for “standards for data and technology interoperability”. Data resources may be present, but some LL noted that there is no standard that can be used in different contexts”, e.g., models for standardisation of irrigation systems.
- Potential for data platforms as both technical and organisational resources suffer from lack of standardisation.

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Data storage systems need to be very accessible and relevant, ensuring that data is stored, accessed, utilised, and traceable/verifiable, facilitating real-time decisions making and supporting both technological and organisational needs.

Public data collection and accounting systems have the potential to enable the innovations addressing the LLs FAS regarding interactive digital marketing and product traceability. The ability to transfer data seamlessly from one organisation to another supports the development of high-quality digital marketing systems promoted by knowledgeable consultants and advisors.

However, the lack of responsiveness of public institutions controlling databases may present barriers. This hindrance directly affects the ability to utilise data for innovation and is connected to data availability and data compatibility. And in this regard, innovative management systems which promote "data from different public institutions, compatibility as well as transfer of data from one organisation to other" would facilitate data entry for farmers, addressing the need for integrated data systems.

Several LLs noted that public systems require digital data collection but highlighted the obligation of farmers to register the same data in different public systems and organisations.

The digitalisation of product logistics system and product supply chains are important to maintain the quality of food products during transportation, providing appropriate temperature and other conditions and safeguards product integrity and consumer satisfaction, thus adding value for farmers.

Financial and public support systems responsible for funding agriculture and innovation need to adjust to higher risk scenarios that climate change brings.

Global economic and political instability impact the availability of resources and the implementation of innovative agricultural practices.

Access to markets enhances/drives the innovation needed to achieve interoperability between technologies at the farm and value chain level.

Actor subsystem

Human resources and adaptive capabilities:

Types of actors in the LLs include farmers and farmer associations, education and research, knowledge exchange actors that act as bridging institutions, public authorities, value chain enterprises and actors, and non-formal knowledge exchange actors. The most predominant actors are farmers/farmer associations, private companies, and researchers and advisors.

With respect to private companies, they include agri tech providers and developers, input and machinery providers, telecommunications/internet providers, private advisors, certification and audit entities and market players such as marketing entities, retailers and consumers.

The number (2-10) and types of actors within each of the LL varies greatly, the variability being higher for those actors that are furthest away from the FAS but still related.

The composition of the actors evolves according to the AKIS system and with respect to the current CAP policy, new entrants include actors that are experts in the development and support of digitalisation.

The aging farmer population and their shortage of digital skills also present ongoing barriers to leveraging digital platforms and marketing tools.

Research institutions, are key contributors to human resources and knowledge/information within the LLs, underpinning the development and refinement of new technologies and anchoring innovation.

Accredited laboratories are strongly linked to markets, either hindering or enabling LL success and profitability. They determine procedures which can influence types of digital technologies adopted for ensuring compliance with standards (quality, safety, etc.)

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Collaboration, informational resources and functional capabilities:

"Bridging" institutions for formal knowledge exchange were frequently mentioned, particularly the presence of advisors or advisory services, varying according to national AKIS structures. Bridging institutions are important as local advisory services, but innovation groups, networks and associations are relevant for co-production of knowledge exchange, confirming that complex agricultural innovation requires collaboration and diffusion that transcends scale and traditional public-private distinctions.

Farmers act as data providers, implementers/users of digital solutions, and as testers. Their level of proactiveness and willingness to engage with new technologies, as well as knowledge and skills, can either facilitate or hinder digitalisation and the resolution of problems. They are in charge of data recording (thus creating the data resource) and must guarantee the veracity of the data. This is related to the need for data traceability, which allows for trust building.

Technology providers may enable or hinder sustainable digitalisation. They may offer digital platforms that support data driven decisions in farming, but they may also limit integrations with other platforms, thus restricting broader collaborations and interoperability between different systems.

Collective action or collaborations between actors, sharing initiatives, collective and common property entities such as marketing cooperatives or CUMAs (machinery sharing cooperatives), irrigation communities, etc. that were found amongst the actors of LL were seen to create improved dynamics for innovation in digitalisation and sharing of decision-making, knowledge and risk, yet were also seen to present challenges in terms of interaction with other (non-collective actor) actors, such as finance institutions, investors and insurers, as well as conventional supply chain actors. [Note: the non-alignment of property rights assignments and incentives is often a cause for such challenges]. In some cases, cooperatives were seen to hinder innovative digitalisation due to organisational and technical lock-ins.

Research institutions acting as enabling institutions and environments strengthen informational resources by providing training and knowledge and facilitate collaborations and innovations through "an existing community of practice".

Capability to anchor and scale digitalisation:

Certification bodies in the value chain are the key in many cases to opening up markets in Europe and beyond, and these processes should require that added value of digitalisation is integrated in all stages of the value chain, not just production. This is a contentious issue, as the distribution of costs and benefits of digitalisation along the value chain is not evident.

Platforms [dealt with in resource systems as well] are increasingly key players as they acta a complementary interface for dematerialised data exchanges, facilitating to some degree the integration of various data sources enhancing data compatibility and data sharing capabilities.

Informal farmers groups: the integration of informal farmers, as informal local food initiative entities, and their collaboration with food safety regulators, tech providers and consumers present challenges and opportunities for the digitalisation of agriculture in that digitalisation has the potential to function as, or provide for, a governance system for such actors.

Consumers play an important role in sustainable digitalisation:

- Awareness of consumers (attitudes and values) and their demands and needs may drive the digitalisation and innovation process, ensuring that new products meet market needs and promote sustainability.
- Digitalisation also allows farmers and other actors to access more information on markets and from consumers and to build relationships with them.

- Actors that were *not present* within LLs were also pointedly mentioned by some LLs:

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The absence of IT developers (i.e. not enough development of adequate digital technologies and solutions) and tech companies, particular those willing to invest time and collaborate and co-create with farmers, were seen to inhibit innovation, particularly with respect to the lack of appropriate adaptation and addressing specificities of digitalisation needs.

Lack of engagement with vocational and higher educational institutions, thus hindering the development of human resources and related knowledge/workforce skilled in digital technologies.

Financial institutions and service providers as well as funding entities were mentioned by various LLs as being absent, having far too complex procedures, or not fit for purpose. A lack of financial or funding providers for small farmers and businesses to innovate with digitalisation was noted, along with the perception across several LL that financial institutions were interested in financing large agri-industrial businesses, and thus were absent in smaller scale digitalisation initiatives, inhibiting both innovations in digitalisation and also the ability to scale.

An important element of such financing is also the absence/presence of insurers who are willing to reduce risk for farmers and other entities who seek to invest in innovations for digitalisation.

Advisors that were knowledgeable of digitalisation issues and processes, as well as the involvement of public advisors

The "lack of network" among farms and insufficient collaboration between research institutions and farm companies indicate gaps that need to be addressed to foster a more supportive environment for digitalisation.

Lack of producer's organisations and other collective action, which resulted in intermediaries and large-scale retail trade to exercise control, amplified by digitalisation processes, who often follow a market logic that is not necessarily in the interests of sustainability or producer´s needs.

While the absence or presence of certain actors vary, there was generally a sense of "imbalance" of actors or of "missing" some important actor in many of the LLs.

Governance subsystems

Organisational resources:

Governance subsystems are relevant to AKIS given that they are the "enabling environments and support system coordination" and encompass **policy instruments and strategies to facilitate innovation** support and structural and functional capacities.

Initial categories of governance systems were identified through an AKIS analysis: local association norms; private company and market rules; public policy and regulations; EU level public policy and regulations; education related guidelines; farm objective and incentive expectations; social rules or norms; network rules; and global macro-trends.

Legal systems determine what may be used, traded, protected, etc. as a common good. However, they also create gaps if they are too restrictive, not restrictive enough, or not well aligned with technological advancements or farmer need. Regulatory fragmentation or incompatibility is also a hinderance. In addition, data ownership laws such as GDPR introduce additional complexity.

Financial management, regulatory compliance, and educational frameworks are also seen as elements which influence in shaping digitalisation processes within LLs. In addition to compliance with regulatory requirements, industry standards were highlighted by LLs.

Many LLs noted that comprehensive technological integration, standards and interoperability were fundamental.

Tension between regulation that is precise and stable vs. overly strict and thus not inclusive of smaller players

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was mentioned by LL (e.g. reputation and legitimacy created by strict requirements vs. burdens related to digitalisation processes regarding traceability, record keeping, food safety, etc.)

Frequent "**changes and complexities in food legislation enforcement**" were described as a "minefield" by LL stakeholders, hindering farmers' ability to comply consistently, **affecting operational efficiency** and digitalisation thereof. At the same time, strict food labelling regulations which require significant effort and time", impacting the logistics and increasing the costs were seen to affect the ability to anchor or scale digitalisation.

Informational resources and functional capabilities:

With respect to AKIS coordination mechanisms, some CAP and national strategies were identified as useful for transfer of knowledge.

The consideration of **knowledge**, **information and/or data** related to the digitalisation of agriculture, mentioned in almost all LLs, is closely tied to the analysis of both resource subsystems and governance subsystems. Knowledge, information and data were also considered in resource units (intangible property or capabilities linked to human resources). When dealing with the governance of such intangibles, both **resource subsystems and governance systems were relevant to understand the rights and obligations related to individual and collective property** (e.g. to use, control, benefit, exclusion rights, etc.), **as well as knowledge flows between actors** (individual, collective, organisational, institutional). [Note:in light of the above, governance of digitalisation, data, information and knowledge is a complex topic which will be developed further within the SESF for M36, relying further on Ostrom et all´s work on commons, common pool resources and collective action.]

Digitalisation processes may in and of themselves create new governance systems, whether technological, social or economic.

Collective organisations may anchor the processes of digitalisation, knowledge sharing, risk sharing, and provide an alternative governance structure for digitalisation and digital assets. Mention was made often of sharing economies in LLs with respect to data management, collection, access, use, benefit, and control.

LLs underscored the importance of **data accessibility and transparency**, as "not all data is open (accessible)" [this is also relevant for Resource subsystems].

With respect to precision farming, it was noted that **non-data-based precision farming can negatively impact the entire sector**. The integration of data-driven technologies is necessary to optimise farming practices and ensure sustainable agricultural development. This aligns with the **need for "access to global geoinformatics databases"** (technological res.) and "continuous training (…)" to raise skill levels and enhance the adoption of digital technologies.

Stakeholders have emphasised the need for a centralised, easily accessible source of **updated food legislation information**, where information is digitised and easy to find, thus facilitating regulatory compliance, actors requiring administrative resources, as well as market commodity information such as accurate pricing and costs.

Collaborations:

Insufficient collaboration between different levels of government and public entities **limits the ability to provide the RCCIs** needed for digitalisation.

Some LLs underscored the need for **contractual arrangements to counterbalance lack of information exchange** throughout the supply chain, for example, supply chain agreements in production and branding or in trademark collaborations.

Digital platforms were mentioned in several LLs, calling for **collaboration between advisors and farmers**.

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It was noted that although, platforms are available, there is a lack of know-how and digital skills (for farmers), to adapt them and use them the most efficiently, particularly aging farmers (functional capabilities).

b) Socio-technical process modelling:

The majority of the LL position themselves either as digitalising (70%), i.e., in the process of introducing a novel technology, or digitalised (30%), i.e., in a situation in which the technology has already been adopted. None of the LLs is in the process of identifying the technology to be introduced, making the LL contexts amenable to the detailed process modelling to be carried out.

The LL contact points consider the guidelines for data collection useful to reflect on the digital transformation, and rich in information and examples. However, some issues emerged that need to be considered in further activities. Specifically, the guidelines should be more concise and use a language that is already accessible to farmers.

The LL participants, including farmers, were highly engaged in the discussions during the data collection activities, and were willing to share information and viewpoints. Some distrust remained towards authorities, which suggests the need to find solutions to preserve farm data confidentiality.

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