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Between on-site and the clouds: Socio-cyber-physical assemblages in on-farm diversification

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A R T I C L E   I N F O

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A B S T R A C T

This paper sheds light on the integration of digitalisation in multifunctional and diversified agriculture. In this empirical work based on socio-cyber-physical assemblage thinking, first we found that *on-site* material and immaterial conditions like living on the farm, farm settings, and creative human work still matter and deserve more attention in responsible digital agriculture. Second, in our small sample we found that internet and cloud-computing are the main digital technologies used in on-farm diversification, particularly infrastructures-as-a-service and software-as-a-service. Third, when farmers introduce digital technologies in their diversification, three tentative configurations of socio-cyber-physical assemblages are outlined and can be further assessed in future research: punctiform, horizontal, and vertical configurations, or a combination thereof. For each configuration, we illustrate key features and examples. Nine clusters of factors were identified as affecting these assemblages. These factors could help researchers and practitioners to understand why the digitalisation of diversified farms can be so diverse and needs to be carefully adapted. For policymakers, these factors can also serve to qualify the setting up of conditions to steer integrated agri-food-rural policies towards on-farm diversification, including responsible digitalisation. The paper argues that digitalisation in agriculture can unfold through different strategies (minimising, mutualising, grounding, enlarging digitalisation) and requires holistic and ambitious policy commitments for sustainability. For example, the paper suggests the setting up of a new EU-wide target for increasing the share of farmers engaged in on-farm diversification through the Common Agricultural Policy or European Farm-to-Fork Strategy.

1. Introduction

Digitalisation is becoming the paramount and cross-cutting objective for the future of agriculture and rural areas in industrialised economies, yet both the process and ultimate destination remain unclear, ambiguous, and contested (Gugganig et al., 2023; Klerkx et al., 2019). In terms of its destination, for many years, scientists and society have called on research and innovation policy to shift the mainstream industrial model of agriculture towards alternative paradigms, such as agroecology or multifunctional agriculture for integrated territorial development (Gaupp-Berghausen et al., 2022; IPES-Food, 2016; OECD, 2001; Rotz et al., 2019; SCAR Foresight Exercise Expert Group, 2021). Yet, at least in the European Union (EU), statistics show that agriculture is going predominantly in the opposite direction and becoming increasingly specialised (Dimopoulos et al., 2023; Eurostat, 2017), concentrated in less and larger farms (Eurostat, 2022), and intensified (Dornbush & von Haden, 2017).

In terms of process, the mechanisms by which digitalisation is designed to meet the specific needs of multifunctional agriculture or, vice versa, how farmers already engaged in multifunctional agriculture change their socio-technical arrangements to integrate digital infrastructures, technologies, and tasks are not fully understood. Scholars and policymakers have argued that a responsible research and innovation (RRI) approach based on anticipating the future or potential consequences of digitalisation in a participatory, responsive, and reflexive manner can support the tailored design of digital technologies according to farm specificities and needs, and ultimately steer the digital transformation towards sustainability frameworks (Eastwood et al., 2019; Klerkx et al., 2019; Klerkx and Rose, 2020; Stilgoe et al., 2013). Recently, empirical investigations of the ongoing unfolding of this socio-technical process showed that not only the future, but also the past and present experiences of digitalisation on the ground can be an

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insightful terrain of study and action (Higgins et al., 2023; Martin et al., 2022; Metta et al., 2022).

To advance the understanding of this process from a grounded perspective and beyond the state of art, this paper examines the digitalisation in 13 farms engaged in multifunctional agriculture via on-farm diversification activities, such as agritourism, food processing, direct selling, green care, social farming, pedagogical and recreational activities, contracting work, or the provision of nature-based services (Augère-Granier, 2016; Benedek et al., 2021; Eurostat, 2021b; Huylenbroeck and Durand, 2003; Metta, 2023; Shahzad and Fischer, 2022). The first research question of this paper concerns how digitalisation gets integrated into the everyday life of diversified farms and the second one is about what socio-technical conditions of these farms are to be considered when taking responsibility in the digitalisation of agriculture and rural areas with a multifunctional perspective.

To meet this objective, this qualitative exploration combines and implements concepts of socio-cyber-physical systems (SCPS) (Rijswijk et al., 2021) and assemblage theory (AT) (Brooks, 2021; Higgins et al., 2023; Sutherland and Calo, 2020). In this attempt, this empirical research intends to benefit from the longitudinal and heterogenous perspective of AT, while considering the socio-, cyber-, and physical domains as heuristic tools to explore digitalisation as a complex socio-technical process. To our knowledge, these two theories have not to date been implemented jointly, but only individually in order to study precision farming (Higgins et al., 2023; Rijswijk et al., 2021), climate-smart villages (Jagustović et al., 2019), data assemblages (Kitchin, 2021), wood trade (Ciliberti et al., 2022), digital farmer's configurations (Brooks, 2021), and multiple agri-food, forestry, and rural matters (Metta et al., 2022). Drawing on earlier work that has assessed digitalisation and looked at assemblages (Comi, 2020; Higgins et al., 2017, 2023; Velden et al., 2023), the paper then advances the state in the art in two ways: it deepens assemblage thinking with SCP systems, and it adds a different empirical reality of multifunctional farms.

After this introduction, the second part is devoted to the rationale for combining the concepts of SCPS and AT with respect to on-farm diversification. Thirdly, the methods and data to sustain this research are presented. In the fourth part, the paper presents the main findings, starting from the mapping of the cyber-entities, namely digital technologies used by these farms for carrying out different operations, and shows how *socio-cyber-physical assemblages* (SCPA) can take different shapes or configurations: punctiform, horizontal, and vertical. These stylised configurations emerged as dynamic and influenced by a number of factors. Overall, the insights gained from the ground are key to understand digitalisation not as a predetermined and linear pattern in which farmers are not always passive subject or adopter of new technologies (Brooks, 2021; Rotz et al., 2019), but as a process that can be influenced also by farmers' agency and a bewildering variety of factors that go beyond the agri-tech realm.

2. On-farm diversification as socio-cyber-physical assemblages

On-farm diversification is not the panacea for all the challenges in food and farming, but it is considered by most as one element of many for strengthening the multifunctionality of agriculture and rural areas (Renting and Rossing, 2009; Wilson, 2007, 2008). Differently from off-farm diversification or pluriactive farmers working in gainful activities *unrelated to the farm* (Shahzad and Fischer, 2022), on-farm diversification consists of mobilising farm labour, assets, and outputs in order to carry out extra-farming activities *related to the farm* (Augère-Granier, 2016; Morris et al., 2017). Despite the socio-economic and environmental importance of on-farm diversification in Europe and worldwide (Dessein et al., 2013; McNally, 2001; Ullah and Shivakoti, 2014; Yoshida et al., 2019), farms engaged in these activities or *diversified farms* remain marginal compared to those following a specialised and predominantly productivist farming style, at least in the EU (European Commission, 2013; Eurostat, 2021a, 2022). While diversified farms can share common ground with farms exclusively engaged in farming, their characteristics, needs, and circumstances deserve special considerations. At the same time, diversified farms are very diverse and cannot be treated as a block. Each one presents unique features in terms of attitudes, motivations, labour allocation, skills (Ge et al., 2017; Hansson et al., 2013; Król and Hernik, 2022; Ohe, 2014; Stotten et al., 2019) and other socio-structural factors such as location, equipment, fiscal regimes, exposure to climate change threats (Bartolini et al., 2014; Hansson et al., 2012; Ohe, 2014).

Relevant to this examination is the understanding that on-farm diversification always includes a farming component and, in addition, it can imply cases wherein farms are engaged in just one extra-farming activity (e.g., food processing) and cases where more than one diversification activity occurs at the same time (Augère-Granier, 2016). Some of these diversification engagements can be quite established and stable over time, or they can also be experimental, recent, and transient depending on the different drivers and constrains experienced by the farms (Mc Fadden and Gorman, 2016). A clear example of the contingent nature of on-farm diversification has been well studied and witnessed during the COVID-19 circumstances (Brune et al., 2023; Durant et al., 2023; Mastronardi et al., 2020; Nemes et al., 2021). In terms of labour allocation, there are diversified farms predominately engaged in farming wherein on-farm diversification is only a secondary commitment, or vice-versa. Between these two cases, there are also diversified farms that complement the two sides in a balanced and integrated way (Rivaroli et al., 2017; Wilson, 2008). Regarding the farm structure, on-farm diversification can be practiced by sole farm managers, or by multiple family farm members, salaried and non-salaried workers of an agricultural holding (Fuller, 1990; Hamza, 2014; Shahzad and Fischer, 2022). There are therefore many considerations hinting to the idea that diversified farms are heterogenous and evolving entities.

Turning now to the methodological implications of these considerations, the theoretical approaches to inquire socio-technical changes like the digital transformation in on-farm diversification are multiple, and not necessarily mutually exclusive (Sovacool and Hess, 2017). Two well-known examples are the concepts of socio-cyber-physical systems (SCPS) and assemblage theory (AT). Both have common ground in terms of sensitivity to the context, relationality, and complexity of human and non-human interactions in order to explore digitalisation. At the same time, both are criticised for being too abstract and descriptive, as well as poorly integrated within social theories to study classic equity and environmental injustices in terms of race, gender, and class (Sovacool and Hess, 2017). Notwithstanding these similarities and limitations, they also present differences and opportunities for cross-fertilisation (Spies and Alff, 2020).

The concepts of SCPS suggested by Rijswijk et al. (2021) are conceived to explore both the processes and impacts of digitalisation in terms of complex adaptive systems (CAS) (Jagustović et al., 2019). Concepts based on CAS assume that change in a system is the result of dynamic interactions among its parts or entities, however, for analytical purposes (Rijswijk et al., 2021, p. 82) they set out boundaries to study the system as whole and therefore assume that the interacting parts are homogenous (Bamberger et al., 2019; Midgley, 2006; Williams and Hummelbrunner, 2010). In other words, the parts of a system are studied as if they were internally coherent and functioning mainly towards the system being analysed. In contrast, AT sees digitalisation as more fluid and heterogenous than the circumscribed and homogenous systems assumed by the SCPS (Brooks, 2021; Higgins et al., 2023; Sutherland and Calo, 2020). Furthermore, key for AT is also the understanding that an entity can simultaneously take part in multiple assemblages. Analytically, AT dives more in depth into the (historical) factors behind human and non-human interplays and assumes that these interactions can happen both between entities, but also within them.

At least three reasons underpin the decision to complement the SCPS with the AT in the form of *socio-cyber-physical assemblages* (SCPA) to study the digitalisation in on-farm diversification. Firstly, AT can accommodate the fact that *diversified farmers can be simultaneously involved in multiple assemblages*, and not only one system, like assumed in the case of precision or smart farming studies, which implicitly see farmers predominantly in terms of agricultural commodity production. In other words, on-farm diversification is seen as the sum of all relations with parts exterior to the farming field and the farm itself. Secondly, as argued by McElwee (2011), diversified farms and arguably almost all farms relying intensively on labour and nature, are *heterogenous, and not monolithic elements*. AT can bring additional sensitivity to the intra-family relations and the internal composition of the farm, which can be as significant as the interactions between the farm and other external entities, e.g., artists for on-farm recreational activities or tourist offices for agritourism. Thirdly, the longitudinal perspective of AT can turn the attention of SCPS to dynamics in on-farm diversification that depend on consolidated settings (e.g., regulations, landscape, market), as well as those that do not necessarily follow pre-determined patterns (contingencies, shocks). A well-known example is that of COVID-19, which show that the engagement in on-farm diversification can be contingent and evolving too. As put by McElwee (2011, p. 187), farms engaged in on-farm diversification "*operate in a tightly constrained and regulated, complex and multi-faceted environment*".

In summary, the socio-cyber-physical domains and their interactions as proposed by Rijswijk et al. (2021) are used here as basic heuristic tools to map the entities and interactions entangled in on-farm diversification. In addition, concepts of assemblage theory such *historicity* and *unpredictable emergence* of human and non-human interactions, as well as *heterogeneity* and *relations with exteriority* (Anderson et al., 2012; Brooks, 2021; Latour, 2013) can be deployed to analyse digitalisation more longitudinally and in-depth, by accounting for the above mentioned considerations in on-farm diversification. While some of the operational limitations of SCPS are not solved with this theoretical twinning, the combination with AT allows for some of its theoretical shortcomings to be overcome, namely the *homogeneity* and *ontological separateness of systems and their parts* (Spies and Alff, 2020), which especially in the case of on-farm diversification cannot be overlooked.

To grasp the differences between SCP system (SCPS) and SCP assemblage (SCPA), one would need to imagine diversified farms not as a single, homogenous system with defined boundaries but, using DeLanda (2019)'s conceptualisation, as an evolutionary and trans-boundary network of multiple assemblages taking place as results of the interactions within and outside the farm and farming spheres. The particular alignment, combination, and arrangement of entities and interactions in an SCPA give rise to different *configurations*. Configurations are both properties and analytical research tool used to explore assemblages (Kohtamäki et al., 2019). Differently from SCPS, the configurations of SCPA recognise that the components of an assemblage can simultaneously function in multiple assemblages and, as put by Sutherland and Calo (2020 p. 534), these arrangements are "*context specific, situated historically, and evolving*".

To provide deeper explanations of the theoretical foundation underpinning this research, Fig. 1 provides a graphic example of SCP assemblages in its three domains. Assemblages are a way to unravel the dynamics and interactions within each domain, and between domains. The top green part displaying socio-entities and the orange one containing physical-entities are a fictious illustration of the reality based on the extensive literature and authors' direct experience in the field of on-farm diversification. Cyber-entities in on-farm diversification are reported in details among the findings of this paper and based on the empirical analysis in a small sample of 13 diversified farms located in very different contexts.

3. Data collection and methods

Our methodology is based on semi-structured interviews with 13 farms carried out between March 2020 and March 2023. Farmers were selected across different geographical settings to maximise the variety of perspectives and enrich our collection of experiences in very different contexts. We used internet, agricultural expositions, rural gatherings, and collaborations with researchers sharing common interests (e.g., Tokyo University of Agriculture, Hiroshima University, Gembloux Agro-Bio Tech, University of Perugia) to search for farms that seemed to us to have an integrated and balanced engagement in both farming and, at least one or more on-farm diversification activities. The use of at least one digital technology (e.g., farm social media profile) and the possibility to contact or physically reach out to the farm were other two criteria behind our final sample.

To adapt to the COVID-19 pandemic situation, three interviews were conducted online and lasted around an hour and a half. The remaining ten interviews were undertaken in-person, on the farm. Depending on the availability of the farmers and the COVID-19 situation, interviews were accompanied by farm walks or fieldwork, which lasted between half a day to a maximum of one week living and working on the farm. Interviewees were anonymised and new pseudonyms were created to respect their privacy. Table 1 presents some descriptive statistics of our data sample.

Except for cooperatives Esciros and Gelsomin (IT), the remaining farms identified themselves as family farms, with their labour prevalently involving family members but at times including some external salaried workers or volunteers. In five cases, multiple people took part in the interview to reflect the governance structure of the farm. For instance, in Gelsomin (IT), we spoke separately with the project manager who helped us understanding the background history and context, and then joined the interview with the president and director of the cooperative. In Farm Hitchmatcho, we gathered insights from both the spouses of the family farm since they were equally engaged in the farm management and available to describe their own experience with digitalisation. In any case, we interviewed at least one manager or head per farm or cooperative in our data sample.

In total, we interviewed nine women, nine men, and one farmer who did not identify within these gender categories. Five out of 19 interviewees had exclusively worked in agriculture throughout their life, yet they had completed at least their secondary or post-secondary school education. The remaining ones currently work in the farm but come from different professional employments and had formal degrees beyond high school (e.g., in international development, consultancy, management, finance, marketing, education, animation). The age of the respondents was not collected, but the sample is fairly mixed between 25 and 70 years old.

Common semi-structured interview questions were posed to all farms, but the procedure followed a colloquial approach, often revisiting some elements. This means that some of the order and depth of the questions had to be adapted to the situation and attitude of the farmers when they accepted to talk about their farm and digitalisation. Generally, we started by trying to understand the context, on-site conditions, workload, products, services, and history of the farm in order to get a general idea of the interviewees. Then, we moved more specifically towards the on-farm diversification activities. In this second part, we asked descriptive questions in order to understand the main socio-cyber-physical entities involved in the different type of activities, how they interact with, and for what purpose. We used open questions like "*why so?*" to illicit more in-depth reflections on the use of digital technologies. During the interviews, we took handwritten notes in different ways: bullet points, drawings, socio-cyber-physical mapping, and timelines in order to crosscheck our understandings of the answers.

After the interviews, we exchanged email or phone contacts in order to exchange observations from both sides, send the interviewees our transcripts as material for their work, share updates about important changes in the farm (if any), exchange ideas and lessons learned from other farmers, or validate facts and statements in cases of doubt or misunderstandings. We recorded, transcribed, and anonymised all the interviews to remove personal information and protect the privacy of the farmers.

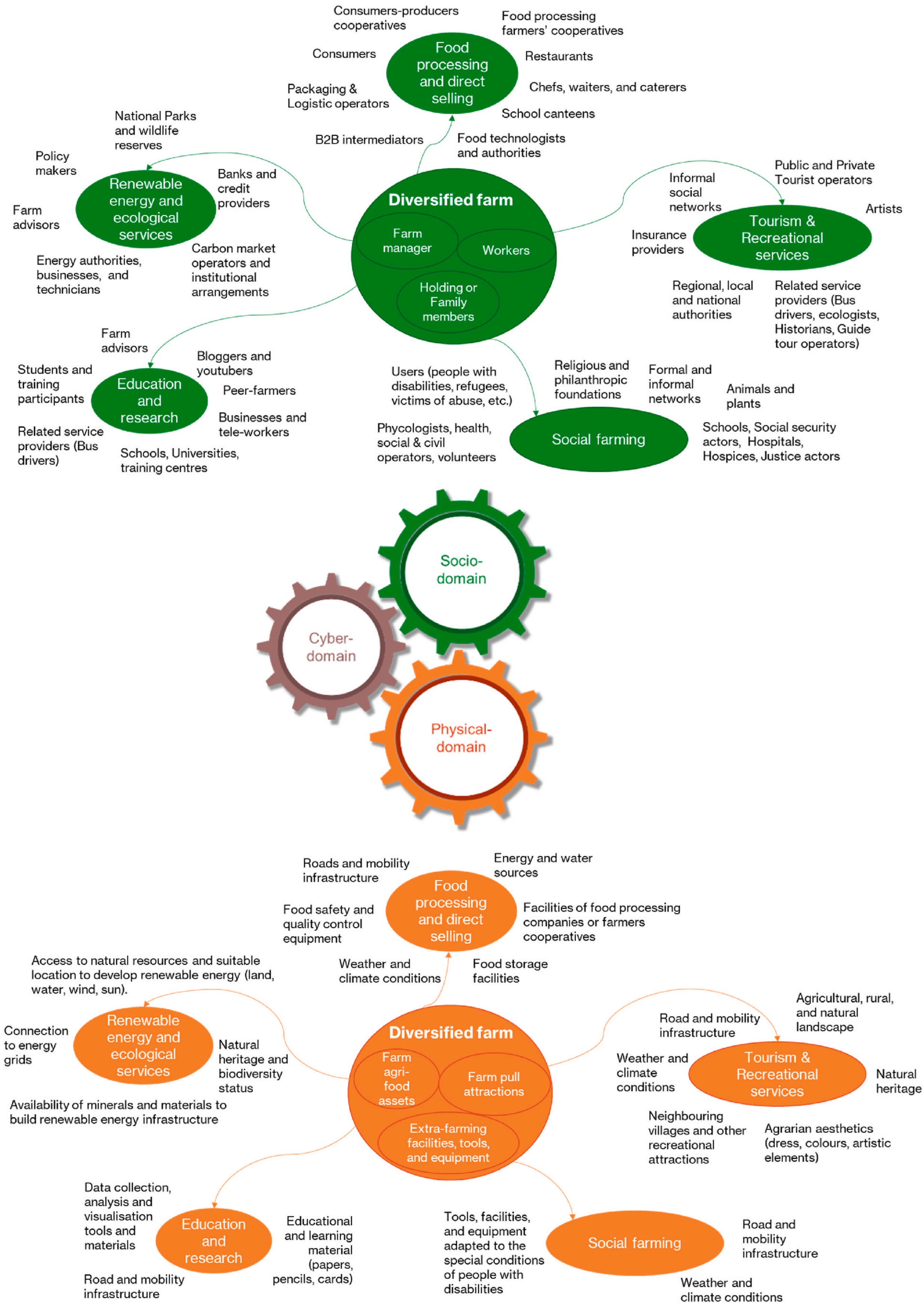

Fig. 1. Illustration of on-farm diversification as socio-cyber-physical assemblage, with a zoom into socio-physical domains.

Table 1
Descriptive, anonymised statistics about the interviewed farms (n = 13).

Farms	Farm History	Size (ha)	Farming [a]	Organic [b]	Workers [c]	Diversification activities
1. Social cooperative Gelsomin (Italy, IT)	>40 years	46	Mixed crop-livestock	Certified	50 salaried workers (included people with disabilities) + self-employed + volunteers	• Food processing • Direct selling • Social farming • Agritourism and recreation • Education and research
2. Social cooperative Esciros (IT)	>20 years	10	Multicrop	Certified	15 salaried workers (47% of them with disabilities) +5 self-employed	•Food processing •Direct selling •Social farming •Education and research •Ecosystem services
3. Farm Transumanza (IT)	>20 years	14	Multicrop (Animals mainly for didactic purposes)	Certified	3 family members + around 10 salaried workers + around 20 seasonal self-employed	•Food processing •Direct selling •Agritourism and recreation •Education and research
4. Farm Verdi Prati (IT)	13 years	15	Multicrop	Organic, but non-certified	2 family members + seasonal self-employed + volunteers (two retired family members)	•Food processing •Direct selling
5. Farm Seasonal Circles (Ireland, IE)	10 years	11,33	Multi-species livestock	Certified	2 family members	•Food processing •Direct selling
6. Farm Linfa Knot (IE)	>20 years	2.4	Multicrop + chicken	Certified	1 family member + volunteers	•Direct selling •Education •Social farming
7. Farm Naranja (Belgium, BE)	>50 years (Since, 1972)	75	Mixed crop-livestock	Organic, but non-certified	2 family members + self-employed + volunteers (retired family members)	•Food processing •Direct selling •Agritourism and recreation •Social farming •Education and research
8. Farm Chèvres en Allegretto (BE)	>25 years	20	Mixed crop-livestock	Certified	5 family members + 2 salaried + self-employed and volunteers	•Food processing •Direct selling •Agritourism and recreation •Education and research
9. Farm Chantal (BE)	>300 years	80	Multicrop (Animals mainly for didactic purposes)	No	2 family members + seasonal self-employed workers + volunteers (ERASMUS students)	•Agritourism and recreation •Education and research •Equine pension
10. Farm Butter-fly (BE)	>30 years	45	Mixed crop-livestock	Organic, but not certified	2 full time family farm workers + part-time family volunteer	•Food processing •Direct selling •Educational and recreational activities
11. Farm Hitchmatcho (Japan, JP)	>20 years	1.2 ha	Multicrop + chicken	Organic, but non-certified	2 family members + volunteers	•Direct selling •Education
12. Farm Hippo (JP)	>50 years	6 ha	Specialised in dairy farming	No	5 family members + 7 salaried workers	•Food processing •Direct selling •Education
13. Farm Umitosan (JP)	>5 years	2 ha	Mixed crop-livestock	Organic, but non-certified	2 family members + volunteers	•Direct selling •Education

[a] Specialised in one crop or livestock, multicrop, multispecies livestock, mixed crop-livestock.
[b] Certified; ONC (organic, but non-certified); No (=conventional).
[c] Only family farm members (FFM); FFM + salaried/self-employed workers; only salaried/self-employed workers; volunteers.

Interview transcripts were printed and analysed in several reading cycles to identify commonalities and relationships. To ensure a minimum comparability across the farms and interviews, we took a very basic set of operations in on-farm diversification as a foundation to discern the application of digital technologies across on-farm diversification activities and entities. Like Schuritz & Satzger (2016), we built this list of operations with a sequential of inductive and deductive approaches, considering both our data and frameworks suggested by the existing literature mentioned in Chapter 2 to map the components or flows of business value chains (de Bruin, 2018; Porter, 1985). In particular, we considered frameworks accounting for a business value chain approach to diversification (Osterwalder, 2004; Osterwalder and Pigneur, 2010; Porter, 1985), and those like Merung et al. (2019) emphasising operations reflecting the social, non-profit, and collective action of this farming style (Vanni, 2014). In total, eight clusters of basic operations were identified in our sample.

1. *Administrative tasks* such as accountability and reporting towards authorities (El Benni et al., 2022; Vărzaru et al., 2023);
2. *Management* to govern people, machinery, and resources in the farm (Buller et al., 2020; Kaloxylos et al., 2012);
3. *Networking and cooperation* with key external partners, business operators, or peer farmers (Kernecker et al., 2021); and
4. *Community relationship* such as interacting with individual citizens, civil society organisations, urban and rural communities (Riley and Robertson, 2021).
5. *Creating and proposing an added value* via resource mobilisation, product processing, service development, labelling, marketing research and efforts (García-Cornejo et al., 2020);

6. *Delivering the added value* to the final user via booking procedures, logistic processes, social encounters; and finally,
7. *Capturing the added value* via payment systems, subscriptions, in-kind exchanges (Saul, 2012).
8. *Data storage and management* encompassing the organisational, infrastructure and human capacity necessary to collect, protect, process or interpret data (Ingram and Maye, 2023).

The first four can be considered common to all farmers, whereas the following three are quite unique to farmers engaged in on-farm diversification. The eighth cluster concerns data storage and management, which stood out to us when analysing the interviews and indeed represents a specific operation for farmers dealing with digital technologies. Data storage and management is a core element of digitalisation in agribusinesses and rural areas (Birnbaum et al., 2021; Bowen and Morris, 2019; van Dijck, 2014; Vărzaru et al., 2023).

We proceeded our comparative analysis by finding similarities and differences in the way digital technologies were arranged around socio-physical entities and these eight clusters of operations in on-farm diversification. First, we mapped out the cyber-entities used by these farms. Then, to identify different types of SCPA configurations, we searched for the combination of a) socio-physical entities interacting through these technologies; b) operations that were carried out; and c) the diversification activities involved in these technologies. Each of these criteria could be checked quantitatively and systematically for each digital technology via methods like social network analyses (Pisani and Burighel, 2014; Pisani and Franceschetti, 2011), but we followed a more thematic and qualitative approach to synthesise and interpret more complex patterns (Garcia et al., 2002; Sandelowski and Barroso, 2007).

4. Findings

4.1. Cyber-entities in on-farm diversification

To advance the understanding of socio-cyber-physical assemblages in on-farm diversification in a short and legible way, the findings obtained report the cyber-entities first as single elements and then in relation to their assemblages. Fig. 2 outlines a holistic view of the cyber-entities usually connected to digital agriculture (Schroeder et al., 2021), but highlights (in yellow, on the top) only the categories of digital technologies that were more commonly retrieved in our sample, namely internet connectivity and cloud computing.

Among all digital technologies currently associated with agriculture 4.0 (Bacco et al., 2020; Berger et al., 2018; Oztemel and Gursev, 2020), we found that diversified farmers rely mainly on internet connectivity and cloud computing technologies. These cloud technologies allow the sharing of digital software and infrastructure over the internet, so that information can be stored and accessed remotely by diverse actors (Ardito et al., 2019). This type of technology can be distinguished into three sub-categories: cloud-as-infrastructure, cloud-as-software, and cloud-as-platforms. Among these, most of the cloud computing technologies used by diversified farmers were infrastructure- and software-as-a-service (IAAS and SAAS). No farmers mentioned the use of platforms-as-a-service (PAAS), which relates to operating systems capable of developing new software like mobile applications.

Except for a few cases, the interviewees did not mention any of the remaining technologies marked in grey in Fig. 2. These exceptions were retrieved in Naranja and Butter-fly (BE), who use *sensing and internet of things* in their farming activities, such as monitoring livestock welfare and weather conditions (e.g., Sense-hub). Chantal and Chèvres en Allegretto (BE) use geocaching to propose farm games based on *augmented reality* (e.g., Intrigue á la ferme). *Data analytics* was also used exceptionally, but rather than using big data, farmers used the basic functionalities of social media analytics from Facebook or Twitter.

It is worth mentioning that some farmers still rely on digital technologies and infrastructures that are not necessarily connected to the Internet, such as PCs; scanners; purchased accountability, word processing, or spreadsheet software; or data storage units running on local drive. However, these on-site digital technologies were too few compared to those mentioned on the cloud. From the hardware point of view, several farmers mentioned that their PC was outdated or needed repairing and maintenance investments. Often, these farmers used the PC of their children or from previous jobs because they could not afford to buy a new one. Smart phones were common but not the rule. Farmers mentioned that their smartphones had limited capacities to store data and store it safely, that they cannot run multiple mobile applications, and they cannot take high quality pictures. Given the preponderance of cloud-computing technologies, Fig. 3 provides a deeper overview of the technologies used by our sample and for what purpose, organised around eight clusters of operations (Chapter 3).

Fig. 3 illustrates how the application and functionalities of cloud-

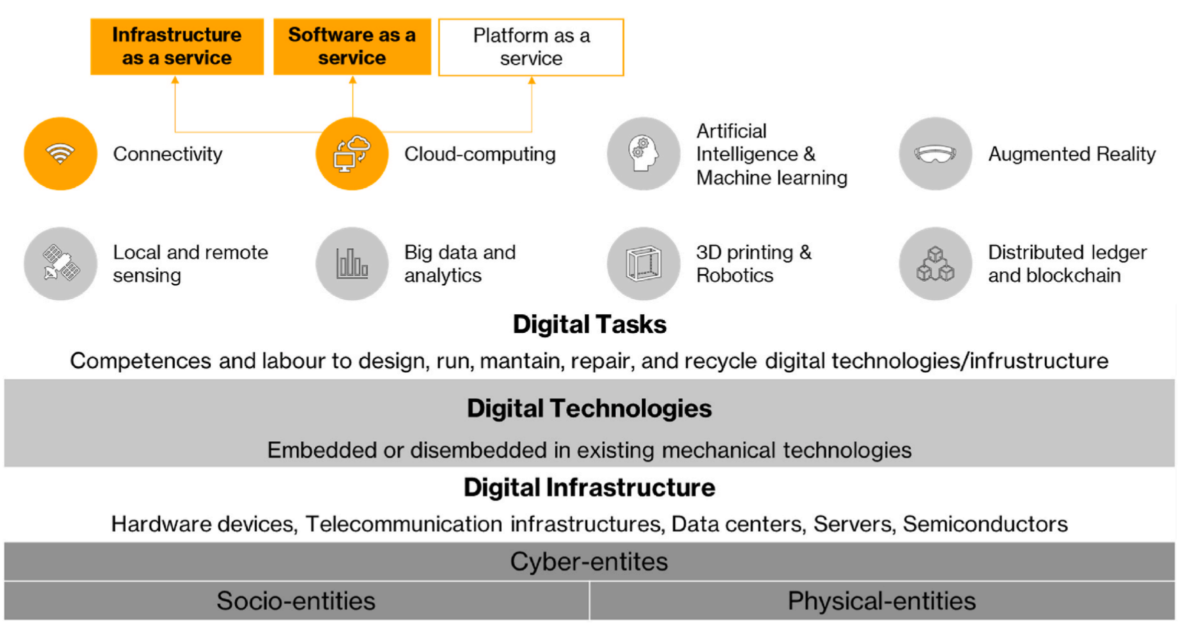

Fig. 2. Empirical unpacking of cyber-entities of socio-cyber-physical assemblages in diversified farms.

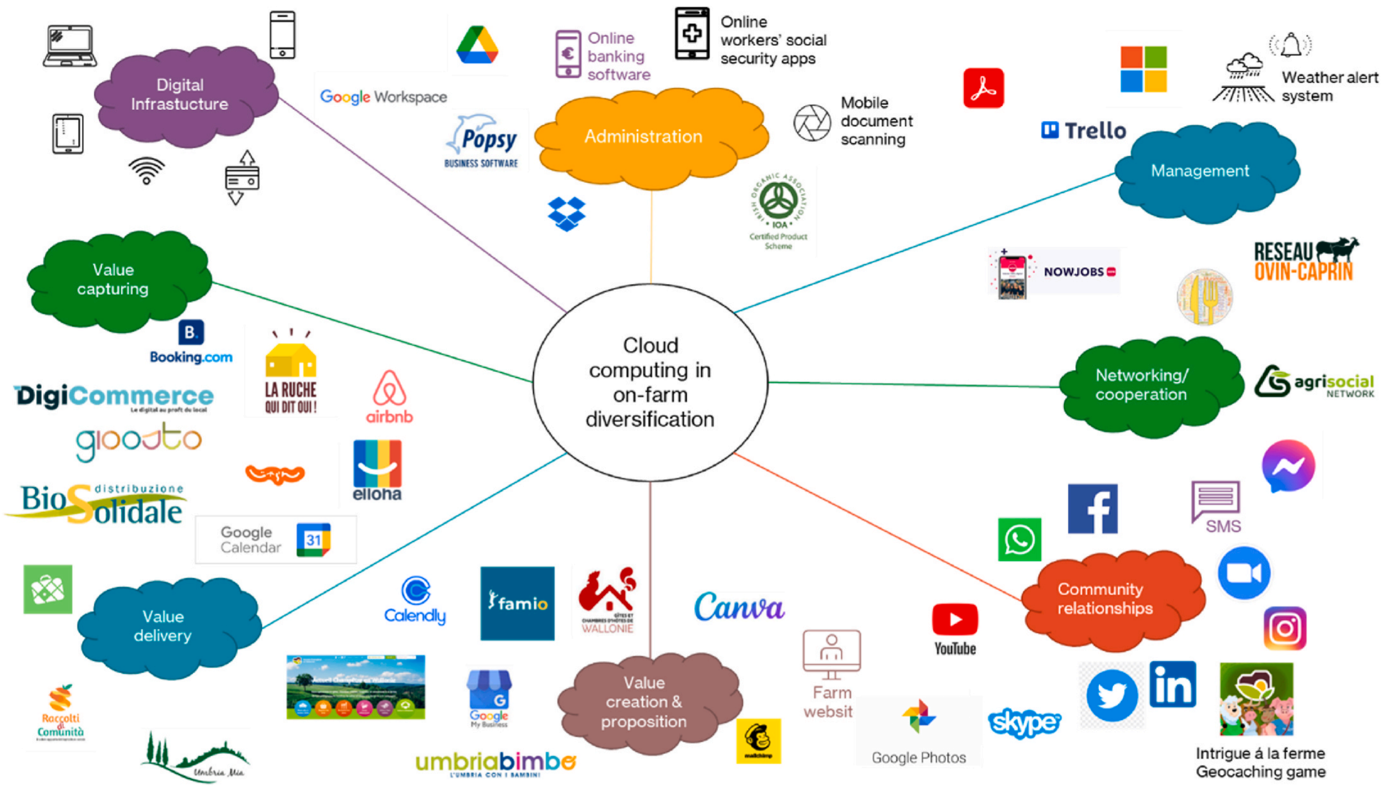

Fig. 3. Overview of cloud computing as software and infrastructures currently used in 13 farms engaged in on-farm diversification.

computing software and infrastructure in on-farm diversification tend to flow in-between or across multiple operations (see coloured clouds). The graphic distribution of technologies around these cluster must be imagined dynamically since these technologies can be multifunctional and can simultaneously serve for multiple clusters of operations. For instance, in our sample, instant-messaging platforms were deployed for internal management, but also for receiving weekly food product orders (value delivery), to collect and remind customers about payments (value capturing), or to collect users' feedback, reviews, personal experiences (value proposition).

4.2. *Configurations of SCP assemblages*

Table 2 illustrates the basic differences among three tentative configurations of SCPA that we observed and outline from the sample: punctiform, horizontal, and vertical. These three simplifications are meant to facilitate the understanding of different arrangements of technology incorporations and digital transitions happening in on-farm diversification. Some of these three configurations were retrieved and combined at farm level, which suggests that they are not mutually exclusive. Before illustrating their specificities, the next sub-chapter presents some generalities and common threads among the three of them.

4.2.1. *Generalities*

Even if immersed in an increasingly more digitally exposed society, SCPAs in on-farm diversification show a ***strong on-site component and in-person field of action***. This is to say that direct interactions between people and the physical environment appeared irreplaceable by digital technologies and screens (e.g., sensorial experiences, caring for animals, farm walks). Such on-site components are rooted in immaterial and material conditions. Inter-personal relationships and human factors are examples of immaterial conditions. Diversified farmers have the social capacity to assemble people, institutions, markets, and networks around diversification activities. One remarkable example of immaterial condition worth highlighting is the "*farm historicity*", which appeared to be so powerful for Butter-fly (BE) to reduce their dependency and reliance on digital technologies like social media and other e-commerce platforms to promote and inform the community about the quality and offer of their dairy products. Other examples of immaterial conditions are the

Table 2
Simplified configurations of SCP assemblages.

CONFIGURATIONS OF SCPA	SOCIO-PHYSICAL ENTITIES ASSEMBLED	OPERATIONS PERFORMED ALONG THE VALUE CHAIN	DIVERSIFICATION ACTIVITIES INVOLVED	EXAMPLE
PUNCTIFORM	Multiple	Only a few	Only one	Farmers using Calendly.com to help customers, families, or enterprises with searching the date availability of farm rental spaces or recreational activities without having to call the farm.
HORIZONTAL	Multiple	Only a few	*Many or all*	Farm workers using Google Workspace for managing data storage and administration across on-farm diversification activities
VERTICAL	Multiple	*Many or all*	Only one	Farmers and visitors using Booking.com for managing agritourism operations (value creation, proposition, and capturing via payments and reviews)

Source: own elaboration

farmers' sense of belonging, emotional attachment to the land, mutual trust with the community, creativity, informal collaborations with peer farmers, search for authenticity, state of being socially and physically present in difficult areas and circumstances (e.g., pandemics, wars, economic crisis, marginalisation of rural areas).

From the material point of view, ***living on the farm in the 'paysan' way*** was another remarkable common feature across the interviewed farms. When we refer to 'paysan', we recall Mendras (1967, 2019), who expresses peasantry not as a profession, but as a condition of being and living in the countryside, in direct contact with nature and the means of livelihoods. The fact that all interviewed farmers lived permanently on the farm (alone, with their family, or other workers) was not a criteria in our sample selection, but finally emerged and meant many things to understand digitalisation. For instance, farmers or family farms able to host trainees or volunteers can (potentially) access new skills and worldviews. Because the farm is their daily living environment, farmers cared so much about the health, authenticity and aesthetical beauty of their natural surroundings. The reality on the farm has to match with what is virtually promoted online. We noted how *on-farm/on-site* elements like soil, cooking equipment, shops, small playground, parking sites, but also *off-farm/on-site* elements like landscape features, forests, water basins, are preconditions that no digital technologies were able to replace or provide for on-farm diversification.

The ***diversity of know-how*** in these farms was another general element we retrieved across these assemblages. This is at the core of value creation in on-farm diversification, which continues to rely on artisanal, handcrafted, living, social and physical resources (e.g., cheese or jam making, flower drying). Working in on-farm diversification assemblages means dealing with a wide diversity of specialised tasks and skills, from manual to computational, social, artistic, and so forth. In Butter-fly (BE), a 27-year-old farmer rears 21 dairy cows with his mom, processes milk alone to produce 25 types of dairy products (from yogurt to cheese and tiramisù), and then sells the products at the farm shop and local market. These métiers are combined autonomously and creatively with the resources at their hand. Some farmers mentioned that they decided to carry out these activities to purposefully escape from office settings and digital screens. For instance, the two daughters and friends in Chèvres en Allegretto (BE) offer sensorial experiences in agro-forestry, ecological farm tours, animal care, farm cooking, and summer camps where digital connections are encouraged to be left outside these deep experiences. While walking or working with the interviewed farmers, the classic division between outdoor (farming or animal husbandry) and indoor labour (accountability or planning) appeared to us much more blurred given that smart phones could allow farms like Naranja (BE) and Verdi Prati (IT) to do digital marketing or check invoice payments even from the fields. Farmers recognised that they spend increasingly more time on digital tasks, yet, being outside the office, on-site, off the screens, is still the prevailing field of métiers for farm diversification.

The ***division of on-farm diversification labour*** matters in these assemblages and is very diverse. In some farms, cognitive tasks like planning and administration are performed by the same person who carries out manual tasks like rotational grazing and milk bottling. In others, these are separated and distributed internally in the family or delegated externally, e.g., by paying an accountant for the annual tax declaration or farm advisor for applying to subsidies. This and other distinctions between *front-office* (i.e., tasks that are visible and in physical contact with people, clients, users) and *back-office* tasks (i.e., accountability, processing food, handcraft, cleaning, rearing animals) reflect the social, labour, and educational conditions in the farm. Digital labour in on-farm diversification seems to be gendered too. In nine out of the 13 interviewed farms, digital tasks such as those related to administration, marketing, and relationship management were predominantly or exclusively performed by women farmers (e.g., setting file storing system, posting on Facebook, replying to online reviews, farm financial monitoring and accountability, ordinary administration).

In on-farm diversification, ***digitalisation prevalently mediate socio-socio types of interactions***, such as for team management, administration, marketing, community relationship. This is also the case for digital technologies used to monitor the temperatures of cows (for oestrus, pregnancy, digestion, and health in general) or trace sheep, since animals are treated like social beings with names and mutual recognition. Nevertheless, we also retrieved a few examples of complete socio-cyber-physical interactions in on-farm diversification, like cameras, smart devices, software, and mobile apps used by the farmers for the geographical and real-time monitoring of food delivery with other workers, farm energy consumption, fridge temperature of wine cells, or remote surveillance of farm assets and equipment from robbery and damages.

We noted that these ***SCP assemblages were transitory and evolving*** in nature. Thanks to our contacts with farmers after the interviews, we learned that these assemblages changes over time. Naranja (BE) moved from taking consumers' orders through multiple decentralised channels (WhatsApp, SMS, and Messanger) to set up a fully-fledged e-commerce software plugged into their own farm website to centrally manage "click & collect" channel for their direct sales. During the interviews, farmers explained how they went from testing some digital technologies to then dropping, modifying, putting it in stand-by, or permanently incorporating them into their daily operations. Here an illustrative example from Linfa Knot (IE):

> "During the COVID-19 lockdown, my daughter came from the city to stay in the farm. She had the idea of enrolling me on Facebook, so I could share some stories from the farm, but frankly speaking I do not like appearing and spending time on media. The truth is that I can sell my produce anyway because people know me well. As soon as my daughter left, I stopped using Facebook".

Finally, we realised that these assemblages are ***transboundary and heterogenous in nature***. The transboundary character of these farms that assemble actors and actions across sectors is the driving force that brings the farming sector closer to other spheres of society, economy, and environment. This is visible already by looking at the farm labour composition, which in a diversified farm, includes members or salaried workers with different backgrounds, interests, and competences. The farms' field of action can stretch from farming to gastronomy, logistics, health, art, education, tourism, energy, handcraft. Each of these domains opens the farms to a multiverse of digital technologies, actors, procedures, challenges, and opportunities.

4.2.2. Punctiform configuration of SCP assemblages

This type of SCPA configuration is formed when multiple entities – like the farmer and consumers – interact through digital means to perform a delimited set of operations in *just one diversification activity* (e.g., sending and selecting food orders to collect them on the farm). Fig. 4 displays three examples of punctiform SCPA around two distinct diversification activities (green boxes). In the first example (yellow dotted box), an e-mail sent by farmers, containing a link to a product list and selection panel to collect orders from consumers or members of their community supported agriculture is an emblematic example of this punctiform configuration, which we retrieved in Farm Linfa Knot (IE) and Farm Butter-fly (BE). During the COVID-19 pandemic, Farm Linfa Knot supplied over 60 green vegetable boxes per week, alongside supply a health food store in Sligo with less than 1 ha. Yet, their direct food sales relied on a simple e-mail containing the seasonal product list, price, and ordering instructions. After they are informed, consumers reply via e-mail to express their selections. The remaining interactions between the farmers and consumers unfold in the socio-physical realm and the rules of these transactions are deeply ingrained in the minds, habits, and historicity of the farm in the local area.

In the red dotted box, Farm Seasonal Circles (IE) complained about how official e-governance websites lack interoperability, which means that they cannot be easily integrated into the rest of the farm

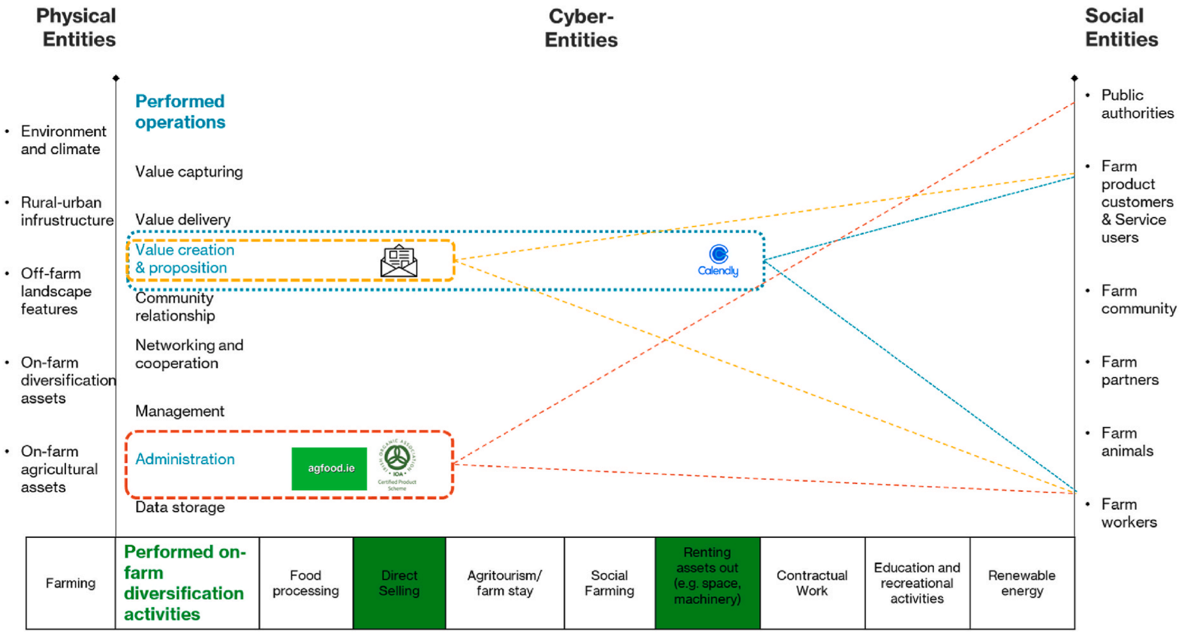

Fig. 4. Example of *punctiform* configuration of socio-cyber-physical assemblage units in on-farm diversification.

management and marketing tools. In the example marked with blue dotted box, Farm Chantal (BE) explained how they used free scheduling automation platforms like Calendly in their farm website to help both farmers and external clients to reduce information asymmetry and interact more synchronically when it comes to booking farm rental spaces or recreational activities. However, since they use Calendly, the head of Farm Chantal still has to replicate the management work by synchronising Calendly with other farm calendars for family members and trainees who cannot access it or are not at ease with this tool (due to passwords, reluctant attitudes, high workload in other farm works). Ultimately, the specific assemblage around Calendly (farmers, customers, space for rental, and the technology) remained confined for this small set of farm rental space operations (finding a common date), but the rest of the operations for renting out assets occurs outside (negotiations, payment, feedback).

Overall, a punctiform configuration is characterised by the fact that the entities and operations performed via one or a small bundle of digital technologies remains only loosely connected or even totally disconnected to any other SCPA that exist inside and outside the farm. In some cases, this is an arbitrary decision of the farmers, who use the technology moderately to enhance or facilitate the human and physical interactions without jeopardising them. In other cases, farmers would like to have a more integrated and interoperable configurations covering more operations and diversification activities (see horizontal or vertical), but they are not there yet.

4.2.3. *Horizontal configuration of SCP assemblages*

A horizontal configuration of SCPA takes place when multiple entities – like farmers and citizens – interact through digital means to perform one delimited set of operations (e.g., promotion, advertisement, search for services) across *multiple diversification activities*. This configuration has the peculiarity of being more transversal across multiple diversification activities, but like the punctiform case, it tends to remain loosely connected to or totally disconnected from other digitally mediated assemblages inside and outside the farm.

Regional websites like Accueil Champetre en Wallonie in Belgium or Multinet (Umbria, IT) that promote and provide basic information to citizens about all sort of farm diversification activities in the region in one single online portal are examples of SCPA taking the shape of an horizontal configuration. Other examples of horizontal configurations embracing multiple diversification activities are software-as-a-services like farm accountability (e.g., Popsy), Google Workspaces, collaborative working tools (e.g., Trello), which are used by multiple entities inside the farm (farmers, workers) and outside the farm (accountant, suppliers, across all the diversification activities).

In this type of configuration, multiple entities across many diversification activities (and not only one like in the punctiform configuration) are connected together just for performing a specific set of operations. However, to complete the consequential operations necessary in order to fully execute diversification activities, these entities must go outside these assemblages and perform the remaining ancillary operations elsewhere, sometimes relying on additional digital tools. For instance, Accueil Champetre en Wallonie or Multinet offer a unique online portal to find and connect users (i.e. citizens can retrieve basic information about farmers location, offers, and contacts), but operations like the actual reservation of farm accommodation, the ordering and delivering of food, or the online payments for the products and services happen outside these online platforms. Therefore, while horizontal configurations integrate multiple diversification activities together via digital means, this is not the case in terms of operations.

Horizontal assemblages like Accueil Champetre en Wallonie or Multinet (red dotted box in Fig. 5) are quite unique networks because they strive to embrace multiple diversification activities performed together by the farms or even a region, as opposed to others that are tailored to one specific diversification activity. Some examples of these specific ones, for instance in social farming activity, are Forum Nazionale Agricoltura Sociale, Agri-Social Network, Agriculture Social en Wallonie. Another example in the field of agritourism is Umbriamia.de.

In some cases, horizontal configurations are not horizontal enough to meet their purpose, which means that even if they are transversal in terms of dealing with multiple diversification areas, the access to the technology and inclusion of key social entities can be still restricted. For instance, external accountants can use online software like Popsy (yellow dotted box) to manage the finance and accountability across all farm activities, but farm managers or heads would like to access the same software of the external accountant in a synchronised and protected way, and yet this is not possible. Here an extract from Naranja (BE):

> "I am really trying to simplify and speed up the data flows between me and my accountant, but this unfortunately depends also on the

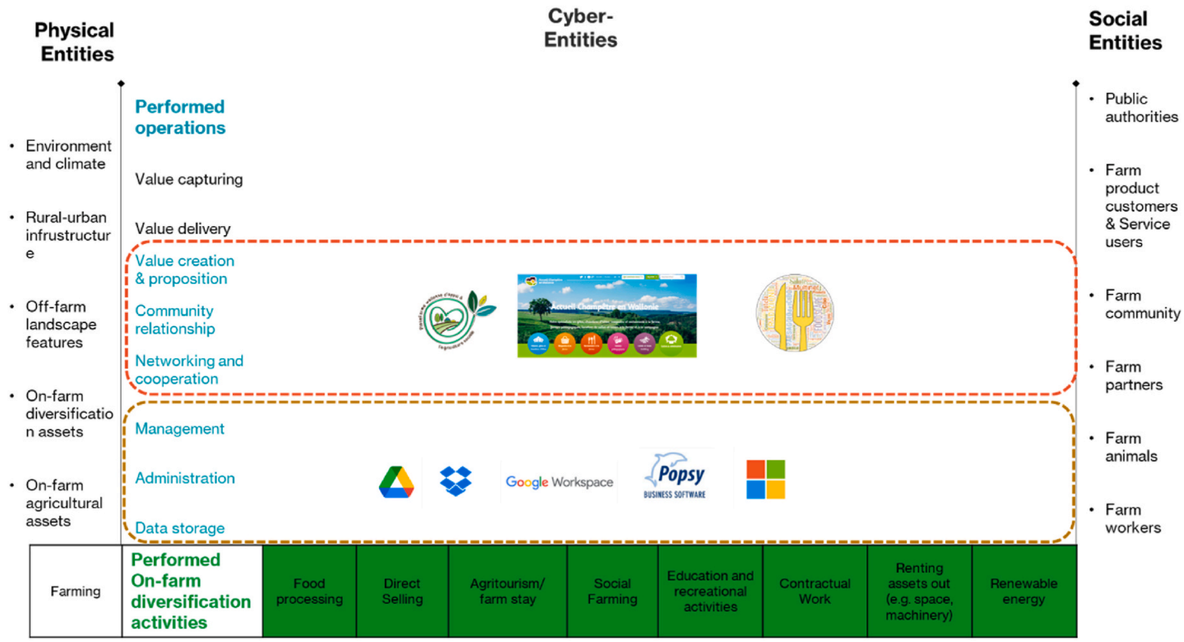

Fig. 5. Example of *horizontal* configuration of SCP assemblage units in on farm diversification.

partner farmers we work with […] they still hand us invoices in paper. Until other farmers do not digitalise, I believe we need to invest in a scanner or slow down our digitalisation. I want to have an automatic and synchronised access over my dossier, which is so far only in the accountant's software".

4.2.4. *Vertical configuration of SCP assemblages*

A vertical configuration of SCP assemblages takes place when multiple entities interact through digital entities to perform almost all the consequential set of operations along one single diversification activity. Like the punctiform and horizontal configuration, this assemblage can remain loosely connected to or totally disconnected from other SCPA inside and outside the farm.

As illustrated in the yellow dotted box of Fig. 6, online direct selling platforms like La Ruche qui dit Oui or Digicommerce assemble consumers, producers, and logistic operators along all the cognitive operations that are needed to sell products, from creating and updating an offer list to submitting orders, completing payments, transmitting and storing invoices, and collecting reviews. In different ways, the multifunctionality of these technologies allows farmers to address many consequential operations and interrelated entities without having to switch between technologies. Online platforms like Booking.com, Airbnb, Gite et Chambre d'hôte Wallonie are other examples because they mediate many operations needed for farm stays and services, and integrate agritourism into the wider tourism economy. While vertical configurations tend to specialise on one diversification activity, we retrieved cases like Gioosto or Bio-solidarity distribution that manage to

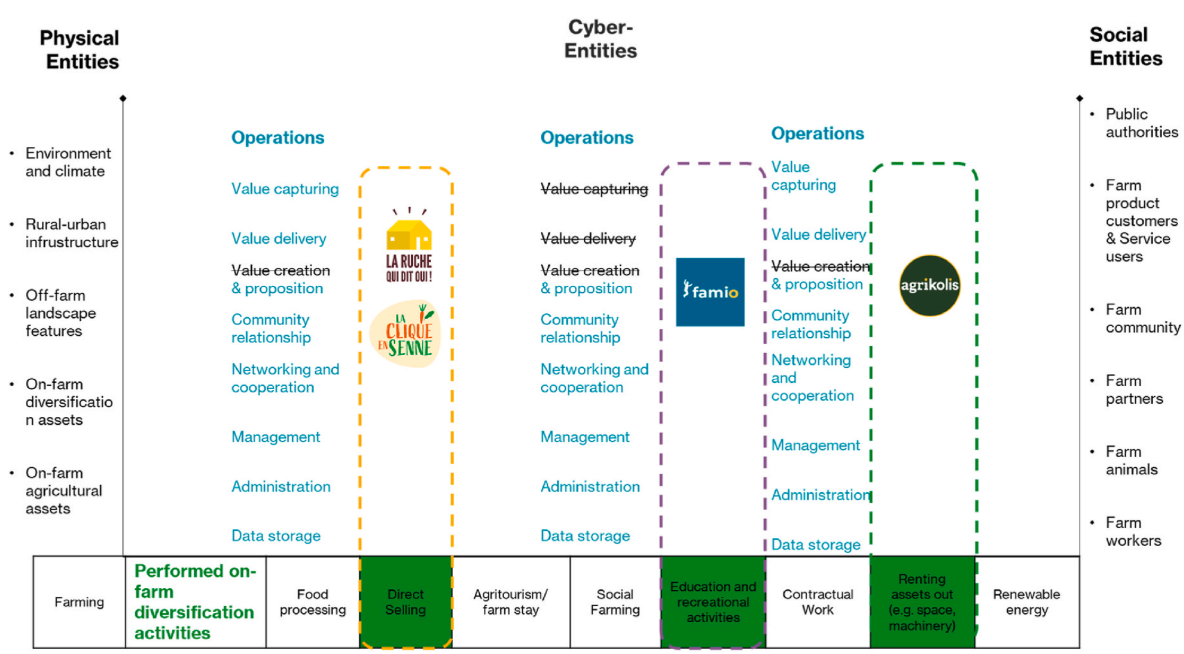

Fig. 6. Example of *vertical* configurations of SCP assemblage units in on-farm diversification.

integrate two diversification activities (direct selling and social farming) by proposing a vertical e-commerce assemblage specific for social farmers.

As illustrated in the purple dotted box of Fig. 6, through Famio, a cloud software and mobile app, recreational activities and operations between farmers and families are integrated vertically in a step-by-step procedure, from offering services, completing bookings, adapting the meals to children allergies or intolerances, paying, receiving automatic invoices, leave reviews. At the same time, the platform also indirectly connects the farmers and families to the Belgian social security by automatically generating a security fiche. In this way, families can directly download these security fiches and send them to the social security insurance for receiving partial reimbursements of farm summer schools. Another case is Agrikolis.com (green dotted box in Fig. 6). This French start-up is booming in the sector of farm rental spaces and rural logistics. The web-based software, operative on phones, tablet, and PC, is connecting farmers with logistic operators (delivers and receivers). By subscribing their farm spaces on the Agrikolis website, farmers make their physical infrastructure (and labour) available for the online network who digitally connect the farmers with the logistic operators who are looking for a space to hand over parcels for nearby customers.

While the high number of consequential operations and connected entities are common features defining these vertical configurations, there could be other factors to account for their qualification. There can be differences within the same type of vertical configurations, for instance in terms of ownership, ethical standards, governance arrangements, efficiency, and power relationships in the data and value distribution.

Bearing in mind these factors, we were not able to map out precisely and compare point by point the different features of vertical configurations. However, we recognised two opposing typologies that are worth further exploring. In the ***"digitalisation englobing diversification"***, the vertical assemblage is created around international cloud software that offer a standard, but customisable platform in which farmers can propose their diversification products and services. In exchange, farmers pay for the subscription or pay a commission fee as a share of every business transactions. Some examples in our sample were Booking.com, Airbnb (agritourism) or La Ruche qui dit Oui (direct selling).

Ultimately, the digital technological provider, which was initially outside the diversification assemblage, permeates far and wide across rural territories, business operations, and social groups in order to sustain their technological apparatus, accumulate marginal profits, reach network effects, and establish itself as the primary medium to complete diversification activities. This was remarked by Transumanza (IT), which uses Booking.com given its large users-base, but would like to quit the platform because of the high commission fees transmitted either on the final consumers or on the service provider (the farmer). They also found notes that the platform prioritises standards and filter options typical for urban types of accommodation rather than those more suitable to rural and farm stays (e.g., landscape views, farming activities). While the technological provider and solution can move across locations thanks to internet, the farmers′ diversification work is instead bound to the site.

Differently, in the "***diversification englobing digitalisation***", the existing actors of a farm diversification activity lead the development or incorporation of digital technologies into their unique arrangements. They can rely on external experts but still they lead and maintain high control of the digitalisation fitting into their diversification endeavour. One example is Chèvres en Allegretto (BE), which created "La clique en Senne", a cooperative of farmers in Wallonia who organised themselves and developed their own web-based software to deal with many consequential operations in direct selling, from proposing the goods, to selecting, paying and collecting them in different partner locations. The web-based software is located and operates mainly at regional level, under the control and responsibility of the farmers' cooperative. The value generated through the online platform stays in the cooperative. The diversifying actors become owners of the technology, and the technology becomes an asset of the diversification. This configuration emerges bottom-up by the on-site actors who are already providing diversification activities. Another example is Accueil Paysanne, an association of "*éducation populaire*", which is integrating a cloud booking software with a long history of networking and capacity building services for farmers engaged in on-farm diversification. The platform is free from commission fees, but only accessible to the farmers who become members of the association by agreeing with the paysan ethical code and governance mechanism of the platform.

4.3. Factors affecting the configurations of SCP assemblages

This chapter summarises some of the factors that were prompted by the farmers when explaining why and how they incorporated technologies giving raise to different configurations of SCPA. These factors are organised in nine thematic clusters to simply their display and should not be seen as rigorous categorisations. Each of these clusters can play both an enabling or hindering role in integrating digitalisation in on-farm diversification, depending on the specific contexts and farm circumstances.

4.3.1. Technological factors

In many instances, farmers recognised that design features and intrinsic technical proprieties of digital technologies can be beneficial and instrumental for on-farm diversification, from aiding fast and remote communications to creating digital marketing content. Storing and retrieving longitudinal data and documents; oversighting and monitoring processes; sensing and transmitting information; and much more technological factors can help farmers in routine tasks and prompted farmers' decision to embed digital technologies in their arrangements.

On the other hand, purely technical factors can also play an opposite role, and farmers acknowledged that digital means could defeat their assumed purposes and diverge from their needs. For instance, this happened when cloud software and databases were not interoperable; software bugs and codes became dysfunctional, search engines' index concealed farms locations and ratings, file and data flows' rules were ineffective or biased, internet speed and stability was too weak to be functional. In other cases, technological factors might be ineffective in terms of forming and sustaining SCPA because of their incompatibilities with customary rules and labour conditions in the farmers' habitus.

4.3.2. Farm autonomy and human labour factors

Existing precarious conditions in terms of farm autonomy and human labour can be the source of favouring and antagonistic factors in the formation and dynamics of SCP assemblages. Among the favouring factors leading to the integration of digital technologies were the availability of human capabilities, knowledge, and labour resources in the farm to master and combine both social skills and digital tools. This twinning of digital-social skills is a capital that can be accumulated not only by the farm manager, but also by other actors and institutions at household, community, or regional level. The digital-social capital includes also the human labour needed to run, upgrade, and repair digital technologies overtime. Part-time farmers, household members, volunteers, advisers, or salaried workers can all contribute to this labour, especially if they have been exposed to social and digital activities happening in other spheres of life. Similarly, farmers' previous professional experiences before moving to farming can add to this digital-social capital and facilitate the formation of coherent SCPA.

The same exact factors can have an opposite role too. The precarious situation with farm autonomy and human labour can make the formation or stabilisation of these assemblages a tough undertaking. Several times in our interviews, farmers admitted to having had already reached the maximum of their workload and could not find the time even to figure out what they exactly needed from digitalisation, or to experiment with digital or non-digital alternatives to improve the current situation. Embarking on new and standardised digital tools without full control was seen as something that could threaten their own identity, freedom, independence, and creativity in terms of mobilising resources and people. For instance, the experience with cloud data storage systems or collaborative online tools created further frustration, information mess, and labour demotivation for the Gelsomin (IT) and Farm Esciros (IT), who can rely only on short-term volunteers and unsteady personnel with different levels of digital literacy. The work of managing farm communities online through farm websites, social media profiles, YouTube channels, and online network was dismissed when farmers recognised that these challenged their self-reputation or added *cloud-labour* to their already extensive *on-site labour*.

4.3.3. Gender and intergenerational factors

In on-farm diversification, we noticed that the digital labour of women is quite substantial and widespread. The division of digital labour between women and men is not always standard. In the case where this separation was more discernible and sharper, like in Chantal (BE) or Hippo (JP), men were predominantly dealing with farming whilst women were dealing with on-farm diversification and the related digital labour. In other cases, this division was much more blurred and dynamic, and women and men tended to blend and allocate their digital labour on a task-by-task basis.

Blended with a gender dimension, there is also a generational element in the digitalisation of on-farm diversification. Younger generations can make farm digitalisation more expedited, but we met older farmers who were also ahead of the times. In Hippo (JP), it is the very young son's girlfriend of a three-generation family farm who developed a website and direct selling platform for the farm during the COVID-19 lockdown. She helped the mom of her boyfriend to manage online sales and the farm Facebook profile. Similarly, in Chèvres en Allegretto (BE), website management, community relationships, and digital marketing of farm recreational activities are dealt by the two young sisters of the family farm. Despite their common and collaborative engagement in digital labour, one of them is also responsible for goat farming and cheese making, whereas the other sister prefers staying out of farming and bring digital experience from other occupations outside the farming spheres. Similarly, in Naranja (BE), farm digitalisation is exclusively handled by two young sisters, one of them with a professional background in rural development consultancy before returning to help her sister on the farm.

4.3.4. Physical factors

To some extent, the idea that digitalisation could break any physical boundaries between farmers and the rest of society remains a mirage for many farms. Physical factors really matter for SCPA in on-farm diversification. Rural infrastructure, equipment, materials, packaging, logistics, and delivery are still a pebble in the shoe for diversified farmers. Although online food platforms have rapidly proliferated in the last years, the packaging and distribution of products to a geographically dispersed consumer-base were still experienced as physical constrains by the interviewees, and Farm Verdi Prati (IT) mentioned that long-distance, online, door-to-door sales were dropped for the high use of plastics, paper, energy. In social farming, Esciros (IT) argued that no matter how many new websites or online platforms can be created, the physical factors like bus, cars, roads, farm accommodation, or special mobility equipment were still the pre-conditions for providing social farming services to people with disabilities. Digital platforms can help with the standardisation, filtering, and matching of social farming actors in a region, but not necessarily solve the physical constrains to have more connections between farmers, health and social care providers, and people with disabilities. Farm Chèvres en Allegretto (BE) noted that the quality and presence of on-site landscape features and beautiful agrarian aesthetics are very important factors for offering educational or recreational experiences that aim to create detoxing space from digital imagery and connections.

On the other hand, physical factors can justify the integration of digital technologies in on-farm diversification. A prominent example is Farm Umitosan (JP), which is located in the small island of Mukaishi-macho (Hiroshima prefecture). As part of their community supported agriculture, they organise regular on-farm community gatherings and workshops. Given the proximity of many small-size farms, the narrow streets to reach the farm by car, and the limited parking areas, online geolocalisation linked to the farm website or communications can help to inform visitors about how to reach the farm via different mobility means, and if by car, how to find nearby parking sites which are usually tiny and easily full in that area. Other farmers engaged in direct selling or agritourism have explained that thanks to digital tools, they can better monitor and track things remotely or help customers retrieve their remote locations and facilitate physical urban-rural encounters.

4.3.5. Regulatory factors

Mandatory regulatory requirements from public authorities in terms of reporting or compliance can push the formation of SCPA in farm diversification. Gelsomin (IT) explained how their cooperative was obliged to digitalise their accountancy, food safety protocols, health and safety insurances, labour contracts, and much more. Requirements and technologies in the field of e-governance can be an assembling force, though the cooperative deplored the fact that the costs to digitise and digitalise were at the sole expense of the cooperative, while it ultimately brings major benefits for public authorities who can simplify their job and improve the accuracy of control tasks. The costs of digitising can be very high in Italy and include paying annual fees for officially accredited e-mails issued by private companies, the hiring of skilled staff, the purchase of smart-phones or other scanning devices, as well as spending of time for learning new and always evolving requirements.

Hindering regulatory factors could also come from the complementary rules rising when farm diversification is moving from on-site to the cloud, such as compliance with consumer protection rights in e-commerce platforms (avoiding fraudulent practices, dealing with reimbursements), users' data security and privacy protection, or compliance with copyrights rules. On the other hand, meeting these requirements in the digital way is also a factor that can stimulate the formation of these assemblages. Seasonal Circles (IE) really appreciated when data inserted in the Irish Ministry of Agriculture's official website is then integrated with and swiftly transferable to other official portals, like the organic farming association or animal identification and registration. Chantal (BE) expressed appreciations for the online mobile app NowJobs, a tool created by a private enterprise to aid employers to regularly hire and register temporary workers. Even if the use of this digital technology is not directly integrated with the public authorities in order to complete all the chain of operations (vertical configuration), it still reduce the procedural hassles and help the Chantal to respect social security norms of seasonal work in many diversification activities (horizontal configuration).

4.3.6. Social and demographic factors

Specific socio-economic sectors or groups can influence the digitalisation in on-farm diversification. As reported by Seasonal Circles (IE), restaurants, shops, individual consumers can approach farms via social media or digital platforms with predefined rules, and this can change the way the farm is adapting their attitude and communication strategies. Chèvres en Allegretto (BE) has invested in Famio, a cloud software for families to find basic information, book, leave dietary and medical instructions, pay, and receive automatic fiscal and insurance receipts all online. This can streamline the tasks for both sides of the service (providers and users), though it should be mentioned that this outcome is only possible when a critical flow of local families invest in farm educational experiences, and they are already equipped with minimal digital devises and competences.

The surrounding society can boost, but also constrain or refrain farmers from adopting certain technologies. In Hitchmatcho (JP), food orders from the consumer-cooperative Coop-Kobe are still handled via fax and communications in rural areas are only starting to become digitalised. Farm Hitchmatcho explained: *"In Japan, many older rural households or dwellers really struggled with the widespread use of laptop and smartphone. Only new generations or people who had the chance to learn the western alphabet letters and handle PC keyboards were apt to adopt modern and western digital tools. That is why we still keep both paper and digital systems in parallel."*

4.3.7. Strategic and economic factors

Among other reasons, interviewees mentioned that they engaged in diversification also to survive and capture higher added value from farming. In these efforts, we noticed farmers that diversify in a cooperative way and others individually to achieve economies of scope and scale. One way did not always exclude the other. For those who cooperate, digital technologies like resource management software, simple messaging platforms, websites, apps, collaborative working tools, videoconferencing can play an instrumental role in joining efforts (*mise en commun)*, and achieve the efficiencies needed to compete with the corporate industry in large scale food processing, direct selling and delivery, marketing, inputs purchase and machinery sharing. We saw this cooperative approach integrated with digital tools when we visited La Clique en Senne (BE), but also in Fuori di Zucca, a solidarity purchasing group in Perugia (IT) and Accueil Paysan (FR). Accueil paysan is a farmers-led network to book farm stays, recreational and educational experiences following a peasant ethical code. Here digitalisation was strategically assembled for achieving a cooperative cause and mutualise costs and resources. The farmers who instead pursued diversification alone sought to use digitalisation in an entrepreneurial way and faced alone the costs and benefits of digitalising the chain of operations. When the costs to own or develop digital technologies internally are too high for their capacities, these farmers relied on external software by paying a fee for the technology service, like Booking.com, Airbnb, La Ruche qui dit Oui.

4.3.8. Political factors

Farmers are interrelated with other societal actors and try to make decisions concerning the distribution of resources, power relations, definition of status, setting up and protection of standards and worldviews. In this arena, we met a woman farmer in Chantal (BE), who openly explained why they offer a digital interactive game called "Intrigue á la ferme" based on geocaching and augmented realties: "*With this game, I wanted to portray a new modern outlook of agriculture in the region. I wanted to show that agriculture is not a thing of the past.*".

No so far away, in the same region, Chèvres en Allegretto (BE) explained that digitalisation in direct selling is something they want to appropriate and have a stronger control over decisions like what defines "local" in food sold via online platforms, who should be working in the local subsidiaries of international food platforms, and how much the platform shall charge the farmers with commission fees. Gelsomin (IT) made clear that for them, going digital means working in line with their ethical standards: commercial food platforms or human replacing technologies do not have space in their social cooperative's philosophy. Esciros (IT) went even further and explained that Raccolti di Comunitá, which is a whole online community, brand, ethical code, and e-commerce platform, was jointly created in Umbria region to support social farming as a political objective but also as a mean for networking, sharing good practices, and trade products issues by social farming.

4.3.9. Contingent factors

The eight clusters of factors mentioned above are not fixed rules of thumb to understand or design SCPA. Their weight and role can change over time and the conditions on the field can be unpredictable. To give some examples of contingent factors, Umitosan (JP) explained: "*W*e started selling online during the COVID-19 [...] but after a while, the shipping fees to bring our food from Hiroshima to Kyoto started to increase. That is why this year, we changed our direct selling model and created a community supported agriculture (CSA) scheme for nearby dwellers. Our CSA is on a membership base. We had ten members to begin with, but we can increase it. We left the online direct sale platform also because I was offered the opportunity to teach three days a week for a language school, and privately every Tuesday. This keeps me very busy to check the online orders and prepare the boxes to be shipped".

Another example of contingency was reported by Linfa Knot (IE), a single senior farmer who lives alone in the farm and started posting farm videos on social media and YouTube channel only because his daughter returned to the farm for a while during the COVID-19 lockdown. As soon as she returned back to the city, these digital profiles were no longer updated. Another example of contingencies as opposed to assemblages formed as result of long-term strategy or planned decisions comes from Gelsomin (IT), which explained how they momentarily joined different online social networks due to an ERASMUS funded project for social farmers, but as soon as the project ended, these online networks were no longer active and therefore they decided to drop out.

5. Discussion

5.1. Understanding digitalisation in the context of multifunctional agriculture

The initial objective of the paper was to advance the understanding of digitalisation in a multifunctional agriculture from the grounded perspectives of farmers engaged in on-farm diversification. The relational, heterogenous, and longitudinal perspectives of this inquiry revealed that diversified farmers are by nature already plugged into many socio-economic arrangements beyond farming, but recently, digitalisation is becoming a more prominent mediator and reality. Similarly to idea of distributed farmers (Comi, 2020), the interplay between multiple actors in on-farm diversification echoes the understanding of digitalisation not as the practice and decision of "individuals, but rather [of] a critical group of human and material actors". What our findings add to this is that the case of digitalising multifunctional farms might differ from the case of precision farms as a wider set of actors and considerations within and outside the spheres of farming come intrinsically into play and are not at the margin of farm decision making, e.g., family members, volunteers, advisors, local restaurants, logistic operators, regional tourism operators, surrounding community. This is to say that the agency of diversified farmers in relation to digitalisation can be similar and at the same time also very different from, if not opposite to the one of the cyborg farmers using precision farming technologies (Velden et al., 2023). To understand the digitalisation of diversified farmers requires a deeper appraisal of their farming style first, also including their territorial embeddedness, and cannot be limited to consider their nuanced ability of making sense and taking decisions in a spectrum between algorithmically-driven or intuitive agroecological farming. In some cases, the small-scale or highly precarious nature of diversification activities like processing dairy or selling food boxes on the top of full-time farming make it hard for diversified farms even to jump in that spectrum. In other circumstances, this research found that the agency of diversified farmers goes beyond the ability of using the products of predefined technologies, and can even entail the design and regulation of socio-cyber-physical assemblages, like the farmers in Accueil Paysan using a collective digital platform in France or Raccolti di Comunitá for social farming in Italy. This gives hope that a vast spectrum of *multifunctional farming styles* can become the priority of agricultural policies in the era of digitalisation (e.g., from strong to weaker multifunctionality), instead of supposing a future with multiple *digital farming styles,* which implicitly categorise farmers on the basis of their engagement and embodiment of digital technologies (Velden et al., 2023).

5.2. Assemblages as tools to dive deeper into the complexity of digitalisation

In addition to existing studies exploring digital agriculture only in terms of number of digital technologies adopted mainly for productivity purposes (Basso and Antle, 2020; Caria et al., 2019; Gabriel and Gandorfer, 2022), the findings brought new insights about multifunctional farming styles through the lenses of socio-cyber-physical assemblages. What stands out from this exploration is that digitalisation in diversified farms is cross-sectorial and it embraces actors, technologies, regulations, markets, and physical elements that are usually at the margins of a productivist understanding of agriculture. For instance, intergenerational relations, members of family farms, care of the living nature, informal social rules, on-farm housing conditions, artisanal and creative skills are core elements on the ground to sustain diversification, even if we learned that many operations in diversification activities are increasingly moving to the clouds.

Instead of a uniform system in transition, it is very likely that digitalisation in on-farm diversification evolve in the form of multiple assemblages or the combination thereof, rather than a monolithic one. The unique conditions in on-farm diversification, and probably also the early stage of digitalisation in our sample gave a picture of diversified farms different from a futurist one, which has stylised farms as data-driven entities operating in a highly integrated "system-of-system" (Bonneau et al., 2017) or "digital twins" (Tzachor et al., 2022), remotely controlling every transactions from farm to fork via digital means. In terms of quality (i.e., what digital technologies are used), this exploration found that internet connectivity and cloud-computing were the most prominent cyber-entities in these assemblages, at least in our sample. The clouds (as software and infrastructure) are increasingly used for networking, collaborations, business, e-governance, community, and farm management. These digital technologies are therefore different from the ones based on big data flows and embedded into machinery or mechanical components as proposed in smart farming and agriculture 4.0, like automatic milking systems, geo-referenced soil sampling, robots, drones, blockchains, or artificial intelligence (Bonneau et al., 2017; Daum, 2021; Schroeder et al., 2021).

Moreover, this inquiry found that these technologies were mediating predominantly socio-socio interactions, with some exemptions mainly in the farming side of diversified farms (e.g., livestock management). In terms of cyber-cyber interactions, we observed the growing need to use *platforms of platforms* like Elloha, a software used by Farm Chantal to manage multiple online farm booking channels in a synchronised way as opposed to technologies that are not yet able to interact with each other and may create additional burden to the farmers. Furthermore, we noted that most of these technologies were not owned but used and paid as a service by the farmers. This trend is similarly retrieved in other small-medium enterprises, rural communities, and agribusinesses outsourcing digital technologies in order to reduce the development and updating costs (Bayrak, 2013; Sebesta, 2013; Townsend et al., 2017). At the same time, the lack of ownership over the digital means of diversification could raise some concerns in terms of monopoly position, data extractions, and technofeudalism (Varoufakis, 2023). Some of the insights we collected about cyber-technologies in diversified farms indicate that the socio-physical dimensions such as hardware components (PCs, phones, tables, office furniture), telecommunication infrastructures (broadband, data centres), and digital skills cannot be taken for granted even in a multifunctional digital farm, and therefore should not be overshadowed by the high expectations raised by new, more sophisticated technologies (Berger et al., 2018; Rizk et al., 2018; Schroeder et al., 2021). In terms of level of adoption (i.e., how many technologies are used), being exploratory in nature, this inquiry is limited and cannot offer statistically significant evidence for experimental or comparative studies. More quantitative research in this area could complement nation-wide statistics, such as those in Italy indicating that diversified farmers tend to use more digital technologies than those who do not diversified (Istat, 2022).

This study has demonstrated that different socio-cyber-physical assemblages (SCPA) can exist at level of diversified farms, but also beyond (Fig. 7). To identify and further explore these SCPA, the paper advanced at least three possible configurations formed around digital technologies, or a combination thereof, namely punctiform, horizontal, and vertical SCPA.

5.3. Implications of multiple configurations of socio-cyber-physical assemblages

The implications of this study can be manifold and linked to farm, collective, farm advisory, research and innovation, or policy decisions. We limit here to some examples. In terms of research and innovation, punctiform assemblages characterised by the isolated and circumscribed use of a digital technology (e.g., email for direct selling) might offer insights into the circumstances and strategies of diversified farms for *minimising digitalisation* only around a small niche of operations and actors for carrying out a specific diversification activity. Like in the case of Farm Linfa Knot (IE) and Farm Butterfly (BE), these strategies can be put in place when the diversified farms have a long-standing history and reputation in the area, so they do not see digital marketing or online community management as a priority, or instead because they lack the capacity to take additional risks connected to data-driven processes (e.g., cyber-security, labour externalisation). In contrast, farmers can also find themselves stuck into poorly functional punctiform assemblages; therefore, research could explore the risks and opportunities for *enlarging digitalisation* in terms of actors, scope, interoperability, and functionalities in order to cover more operations, diversification activities, or interactions via digital means.

Similarly, the concept of horizontal assemblage can help the understanding, but also call the attention of innovation efforts to support strategies for *mutualising digitalisation* in agriculture and rural areas. In our sample, this was exemplified by non-profit regional websites connecting citizens with farms offering diversification activities or cloud-based software for collaborations. Other authors have called for multi-farms digitalisation policies (Finger, 2023), and this paper adds that such mutualisation and collective efforts are needed also in on-farm diversification to overcome barriers and reach economy of scale beyond the farm. There is abundant room to explore the challenges and opportunities of digitalisation in collective social settings such as agrarian movements, consumer-producer cooperatives, or non-profit networks engaged in on-farm diversification (rural tourism, renewable energy, social farming).

In terms of vertical assemblages, the case of Accueil Paysan and La clique en Senne can signal the capacity of existing diversification actors at individual or collective level to design bottom-up, scalable, and secure data systems covering diversification activities step-by-step, from the creation to the provision, payment, and evaluation of products and services. Looking at these existing examples, considerably more work will need to be done to understand the infrastructure, requirements, constrains, and challenges of strategies for *grounding digitalisation* within the agency of existing on-farm diversification networks and actors, in terms of benefits, design, governance, and ownership. Past and present real-life experiences of *diversification englobing digitalisation* would be a fruitful area for future research and innovation. In our sample, big-tech led vertical assemblages capable of standardising almost all the operations of a multi-actors diversification activity through digital technologies were seen as interesting developments by some farmers, while others saw them as a threat and problem for on-farm diversification.

In relation to the second research question of this paper, the nine clusters of factors attempted to explain the complexities behind assemblages in on-farm diversification in a non-exhaustive way. At the same time, these factors can be of interests to those setting up the criteria to steer digitalisation and assess whether and how this process is moving responsibly towards the conditions of diversified farmers and the rest of

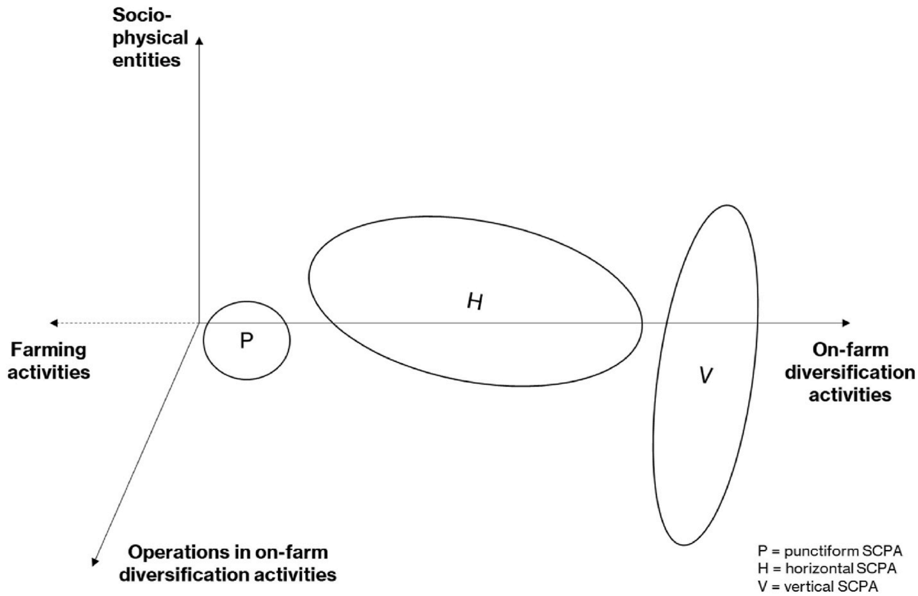

Fig. 7. Multiple socio-cyber-physical assemblages in on-farm diversification at farm level and beyond.

society demanding a paradigm shift in agriculture (Cowie et al., 2020; Klerkx and Rose, 2020; Owen et al., 2012; Rose and Chilvers, 2018). Our analysis went beyond the technical dimensions and surfaced the material and immaterial conditions that are still extremely vital for farmers to create and retain value. As argued by previous research (Grande, 2011; Pölling and Mergenthaler, 2017), our findings confirm that in the digitalisation of on-farm diversification, material elements like farm equipment, buildings, traditional processes, location, and landscape matter as much as on-site, immaterial elements like the farm workforce (Cofre-Bravo et al., 2019; Ryan, 2023).

6. Conclusions and future research

This study set out to understand the integration of digitalisation in multifunctional agriculture. The findings demonstrated that this socio-technical process is already unfolding but it is heterogenous and many factors need to be considered if digitalisation is to be made responsible, at least from the perspectives of diversified farmers. Perhaps the most interesting finding is that digitalisation is already being adapted to the relational, creative, and on-site nature of diversified farms. However, diversified farms struggle to exert their agency against an overly specialised agri-food system in terms of technology development, adaptation, and maintenance. When digital technological enrolment occurs at single farm, collective group or higher levels, we demonstrated that a vast array of socio-cyber-physical assemblages can emerge. This means that a correlation between digitalisation and multifunctional agriculture already exist, but this is not necessarily synergic and linear. Many factors need to be accounted to balance trade-offs and adapt future research, policy, and practices in this field.

We followed a farm-level approach to fill knowledge gaps on the specific agency of diversified farmers in the digital era (Knierim et al., 2019; Wiseman et al., 2019), but our lack of structural or macro-level analyses still leaves many open questions on the capacity of digitalisation to change the current rules of the game and power dynamics at higher levels (international trade rules, agri-business market concentrations, legislations, policies). For instance, large scale online travel agencies like Booking.com or Airbnb currently excluded by new rules of the European Digital Service Act package could still strongly shape the landscape of actors and practices in rural tourism (e.g., displacing regional travel agencies or bottom-up quality standards for agritourism). Overarching paradigm shift in agriculture will depend also on the capacity of decision makers to take responsibility in the direction setting of agri-food-rural policies in general, and not only in their cross-cutting digitalisation. For instance, this paper would suggest that an EU-wide target to substantially increase the share of farmers engaged in on-farm diversification could be integrated into the EU Farm-to-Fork strategy and Common Agricultural Policy. This holistic and targeted commitment is currently missing. It could be monitored through available Eurostat data and supported by policy interventions, changes in market and legislation rules, support to the co-creation of technologies and skill developments in the fields of rural tourism, education, mobility, land access, and so forth.

Several questions still remain to be answered. How do different assemblages interact with each other, especially between those in the farming and extra-farming spheres? Perhaps horizontal assemblages can strengthen multifunctionality via the integration of data collected from crops or livestock with direct selling or educational activities. As another option to enhance multifuncitonality, more digital tools reducing barriers and costs for producing positive externalities in agriculture and rural areas (Lynn et al., 2022; Metta, 2023) can be an alternative or complement to the widespread diffusion of vertical assemblages that are designed to internalise positive externalities via monetisation mechanisms, like the case of carbon farming or online platforms regulating the rental of farm spaces (Capello et al., 2022; Metta, 2023; Ohe, 2011, 2019). Another question concerns the actors driving the digitalisation of on-farm diversification. As argued by Sutherland and Calo (2020), small-scale farmers alone can have relatively little room for manoeuvre in relation to shaping digitalisation to their multifunctional trajectories. Therefore, future systematic mapping of the actors in digital agriculture such as those proposed by Birner et al. (2021) and Kernecker et al. (2021) can be extended to include the insights gained in this research about farm diversification.

Among the limitations of this paper, we tried to be open and understand the digitalisation unfolding transversally in a broad spectrum of diversification activities, but finally our interviews were limited to farmers engaged in activities like food processing, direct selling, social farming, recreational and educational activities, and agritourism. Therefore, we did not collect farmers' perspectives in the area of digitalisation and renewable energy production, contractual work, or landscape services (e.g., conservation grazing). Furthermore, we deepened our knowledge on the experiences of farmers, but the perspectives of other actors involved in on-farm diversification such as consumers, public authorities, or logistic operators could have deserved more attention and could enrich the future empirical validation of the tentative configuration concepts outlined in this paper. In terms of data collection tools, some of our interviews were carried out online due to the COVID-19 pandemic, while others took place onsite and with (unstructured) repetitive encounters. Our recommendation for future research in on-farm diversification based on assemblage thinking is to rely on longitudinal qualitative methods covering longer timeframe or digitalisation journey like those already reported in the literature (Moroney et al., 2016; Rolland and Hanseth, 2021). Finally, we paid extensive attention to the assemblage properties and how they evolve, somehow remaining descriptive and exploratory without entering into implications of digital technologies regarding issues like farm autonomy, vale chain performances, or changes in traditional rules and standards. Therefore, we call for further research to shed light on the direct and indirect consequences of digitalisation, to complement our research, which is somehow limited only to understanding how this process is unfolding in this particular farming style.

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CRediT authorship contribution statement

Matteo Metta: Formal analysis, Visualization, Writing - original draft, Writing - review & editing, Methodology. **Joost Dessein:** Supervision, Writing - review & editing. **Gianluca Brunori:** Resources, Supervision, Writing - review & editing.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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