How sustainable is smart farming? The contribution of service platforms to innovate Italian agribusinesses[1]

Received
28th March 2023
Revised
1st June 2023
Accepted
5th February 2024

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Abstract

Framing of the research. *The agrifood industry needs to embrace digitalization by strategically innovating toward ecological transition and sustainable growth. A conceptual framework, empirically informed, is proposed, and a mixed-methods approach in the Italian wineries' context is adopted.*

Purpose of the paper. *This paper aims to analyze how the sustainability of agribusinesses, especially wine producers, could be improved by implementing precision agricultural systems in place of conventional ones with the support of a digital service provider.*

Methodology. *A sequential mixed methods approach based on both secondary and primary data was conducted. The quantitative analysis focused on a cost-benefit comparison between conventional versus 4.0 wineries. The qualitative analysis was performed through a multiple case study, focusing on the interplay between the service provider and the wineries. Ten interviews were conducted with both actors.*

Results. *The results contribute to the literature by enriching the conceptual framework proposed and updated with empirical evidence. It describes dimensions and relationships that enable the actors involved in reaching higher sustainability outcomes at the firm and network levels.*

Research limitations. *The limited investigated sample, based on a low number of interviews, does not allow a consistent generalization of the results.*

Managerial implications. *Evidence from the case studies can inform both practitioners and policymakers about best practices and process innovation activities, which can increase shared value creation in the agrifood ecosystem.*

Originality of the paper. *This is one of the first studies to take into consideration a relevant topic, still poorly investigated, by deepening how a digital service provider supports the wineries' innovation toward sustainable outcomes.*

Key words: *digital servitization; service platform; precision agriculture systems; winery organizations; sustainable ecosystem; smart farming*

1. Introduction

The increasing number of environmental and social challenges evolving worldwide (e.g., climate change, energy demand, nutrition, etc.),

1 Acknowledgement: We would like to thank the company Elaisian Srl for the support in terms of data and technical knowledge.

also speeded by the recent post-COVID-19 pandemic effects, restored the debate about the need for a more sustainable way of doing business. Nowadays, the topics of sustainability and sustainable development are top priorities in global political and academic research. This is evident through the continued launch of new blueprints (e.g., millennium development goals to sustainable development goals) by intergovernmental organizations (e.g., the United Nations) to address the world's growing problems. At the same time, in contemporary research, there is a growing attention to embracing innovative solutions; particularly, there is the need to explore how organizations can reorient their strategies and adapt their business processes to address sustainability at corporate, societal, and environmental levels.

Among the various sectors, the agrifood industry is more vulnerable to global climate change, and it is expected to face several challenges based on some potentially risky global trends (De Clercq *et al.*, 2018). The growing number of people, estimated to reach approximately ten billion by 2050, corresponds to greater demand and, in turn, increased food production.

The use of natural resources, including farmlands and water, is highly unsustainable. The practices of deforestation, inadequate fallow periods, overuse of water resources, vegetation overcutting, and fast urbanization, among others, reduce the efficiency and effectiveness of agricultural management. In addition, inefficient farm machinery practices waste large amounts of energy resources. According to the Intergovernmental Panel on Climate Change (IPCC), agriculture is one of the main sources of greenhouse gases (GHGs), contributing to the largest share of global methane and nitrous oxide emissions (IPCC, 2022). In turn, the various side effects of climate change negatively affect agriculture and food production systems. In addition, the growing percentage of food waste represents a massive market inefficiency as well as another environmental and societal issue. Given these arguments, embracing sustainability in the agricultural sector is urgent for climate change mitigation, natural resources enhancement, and human health preservation.

The European Green Deal supports the key role of digitalization for ecological transition and sustainable growth. The EU Commission pushes to invest in new digital technologies for agriculture activities, aiming to increase the sustainability and competitiveness of the sector while enhancing the conditions of farmers by simplifying their daily work (Savastano *et al.*, 2022).

Digital transformation can be an important driver of sustainability; indeed, following the Industry 4.0 paradigm, European agriculture is experiencing a digital revolution. Technological innovations such as the Internet of Things (IoT), artificial intelligence (AI), smart autonomous robotics, decision support systems (DSS), and blockchain applications enable the possibility to collect and analyze large amounts of data, which supports business actors in making better-informed decisions for optimizing processes and products (Hrustek, 2020). Likewise, Industry 4.0, precision agriculture systems, also known as smart farming or agriculture 4.0, integrate digital technologies into business processes to raise productivity levels and develop new digital ecosystems (Trivelli *et* *al.*, 2019). The collected data through in-field sensors, drones, and satellites allows farmers to monitor crops and livestock. These systems help improve crop yields, reduce costs, including labor costs, and optimize process inputs (Tantalaki *et al.*, 2019). At the same time, smart systems can lead to increased profitability, improved work safety, and reduced environmental impacts of farming management, thus contributing to the sustainability of agricultural production (Barnes *et al.*, 2019).

However, despite some important investments and financial options to foster a smooth digital transition, their diffusion proceeds slowly, particularly in the agricultural business sector (Sarri *et al.*, 2020). The transition to digitalization seems far from easy, and firms undergo a process of profound changes that require a deep reconfiguration of the business structure and related ecosystems. More research about how farming businesses could strategically exploit digital technologies to pursue sustainable goals is demanded. Particularly, the literature contends that the application and diffusion of complex technologies such as precision agriculture systems cause much uncertainty among farming businesses. They struggle with the lack of human, territorial, and knowledge resources for successfully embracing digital transformation. Then, the involvement of different actors who support their practical adoption and implementation is required (Smania *et al.*, 2022). Indeed, introducing disruptive innovations in such a traditional sector may lead to the upheaval of a prior organization, especially in small businesses, requiring digital skills and related capabilities and novel configurations of sustainable business models. Theoretically, scant literature addresses digital transformation in agricultural settings by combining a socio-technical perspective (Moretti *et al.*, 2023). Scholars underline that digital technologies do not deliver as much value in practice as providers promise, calling for a reformulation from the user's perspective (Silvi *et al.*, 2021). Against this backdrop, the study proposes Digital Servitization (DS) as both a theoretical lens and a practical solution able to valorize users' needs by affording both technological and social facets. DS has been defined as digital-enabled services relying on technological components embedded in physical products (PSSs) that enable new ways of value creation by combining tangible and intangible elements (Ciasullo *et al.*, 2021; Schiavone *et al.*, 2022). Particularly, knowledge acquisition and inter-firm collaborations assume a key role in shaping new digital modalities of innovation towards sustainability. Then, DS allows for the enhancement and integration of socio-technical systems, focusing on the development, diffusion, and use of digital solutions. As previously stated, a lack of digital skills in acquiring technical knowledge limits farming actors ability to exploit the strategic potential of digitalization for achieving sustainable goals. Accordingly, this paper assumes that a digital service platform could support farming businesses both in acquiring new knowledge from data and in activating and nurturing collaborations with networked actors able to frame a digital sustainability-oriented ecosystem.

Then, the leading research question arises as follows:

RQ: *How do digital service platforms allow farming businesses to achieve sustainability gains?*

Moreover, to deepen the interconnected socio-technical components of the study, the following sub-questions emerge:

RQ1.1: *What are the effects of precision agricultural systems on farming businesses' operations management?*

RQ1.2: *How does the interaction between digital service platforms and farming businesses contribute to achieving sustainable outcomes?*

Empirically, the study focuses on the Italian wine sector due to its relevance in terms of sales and product quality (Stanco *et al.*, 2020), as well as the recent investments in innovation for smarter and greener production processes, along with renewed organizational and managerial models (Nazzaro *et al.*, 2022). Methodologically, the research design embraces a mixed-methods approach based on sequential quantitative and qualitative data analysis (Tashakkori and Creswell, 2007).

The paper is structured as follows: in Section 2, the theoretical background is analyzed, and a framework is proposed. Section 3 illustrates the research methodology. Sections 4 and 5 provide the results and the discussion, highlighting the contributions of the study. Section 6 underlines theoretical and managerial implications, and Section 7 proposes concluding remarks, limitations, and future research.

2. Literature Review

2.1 Digital transition for sustainability in the agri-food sector

The digital transition of the agrifood sector depends on paradigm shifts throughout the decades (Dayioğlua *et al.*, 2021). Indeed, if Agriculture 1.0 referred to the conventional agricultural age, where basic instruments were utilized in agricultural activities, Agriculture 2.0 developed when industrialization arose. In this scenario, farmers operated agricultural machinery, and plenty of chemicals were used, so productivity and efficiency significantly increased. However, this considerable advancement has provoked unfavorable side effects such as field chemical pollution, ecological environment degradation, and excessive power use, affecting an overall loss of diversity, both biological and cultural. The Green Revolution in the 20th century accomplished the Agriculture 3.0 era, which allowed both to automate processes and to reduce the use of chemicals. The development of cutting-edge technologies has initiated the agri-tech paradigm of Agriculture 4.0, also known as smart agriculture. It represents the latest evolution in precision agriculture and involves the mentioned technological innovations of Industry 4.0, combined with sensors, robots, and AI, especially machine learning (ML) techniques, for advanced data analysis (Sott *et al.*, 2020).

The need to digitalize agricultural activities appears essential to improve the quality and sustainability of crops (Shepherd *et al.*, 2020), to ensure better food production using few natural resources (Lezoche *et al.*, 2020), to reduce food loss and waste, and to enhance food safety by enabling product identification, tracking, and tracing throughout the overall supply chain (Akyazi *et al.*, 2020). Many of the expected advantages of digitalization focus on higher efficiency via precision mechanization, automation, and better decision-making, as well as higher food traceability through real-time data collection.

As a result, digital transformation is playing a central role in shaping the future of the agri-food sector, embracing the challenges towards environmental, social, and economic sustainability (Abbate *et al.*, 2023).

European policies have certainly guided these choices, particularly promoting the Sustainable Development Goals (SDGs), which are part of the 2030 Agenda. They encompass concerns related to environmental and economic sustainability, as well as social issues such as hunger, poverty, job opportunities in rural areas, and knowledge transfer to new generations. Among the 17 goals, precision agriculture systems can positively impact SDG 2 related to food, SDG 6 (water), SDG 7 (energy), SDG 13 (climate change), and SDG 15 (ecosystems) (Dayioğlu and Turker, 2021).

Nevertheless, digital technologies per se do not allow the consequent accomplishment of sustainability goals at the corporate level. Indeed, assuming a socio-technical perspective, the literature stresses the need for organizations to start a profound transformation through radical changes in business models, organizational layouts, and related processes (Abbate *et al.*, 2023). Furthermore, several scholars have outlined the difficulties of embracing digital technologies and related tools, particularly those linked to farmers' resistance to technology, data analysis, and data management, as well as the need to develop new digital skills and related capabilities (Smania *et al.*, 2022). All in all, scholars have particularly focused on the technical facets of digitalization. More research is demanding about the levers through which agri-food companies can exploit the strategic potential of digitalization for achieving sustainable goals.

2.2 Innovation for sustainable value creation: the role of Digital Servitization

Business customers' expectations shifted from mere product acquisition to adopting sophisticated solutions that enable both the search for new economic opportunities and the tracking of new ways to reduce the environmental and societal impact. This means that users increasingly appreciate the inherently offered value by consuming it as a service instead of paying for the product or technology itself. Servitization, which describes the shift from a product-centric to a service-centric logic (Kowalkowski *et al.*, 2017), entails a transformation journey deeply embedded in the company's value-generating mechanisms and acts as a manifestation of the firm's business strategy (Gebauer *et al.*, 2021).

DS is based on the interplay between digitalization and servitization (Kohtamäki *et al.*, 2020; Paschou *et al.*, 2020). To approach DS, firms require both digitization and digitalization. The first one refers to the conversion of analog information into a digital format. The second one refers to the combination and recombination of digital technologies to create and harvest value in new ways through business processes automation. New technological applications unlock the potential of digital technologies such as AI and DSS to collect data, identify patterns, and make smarter business decisions (Rupeika-Apoga *et al.*, 2022). Managerial research describes

DS as a shift in service offerings towards digitalization, necessitating a reconfiguration of business models (Paschou *et al.*, 2020) towards a service orientation (Adrodegari and Saccani, 2017; Ciasullo *et al.*, 2021). Furthermore, Sjödin *et al.* (2020) define DS as "the transformation in processes, capabilities, and offerings in industrial firms and their associate ecosystems to progressively create, deliver, and capture increased service value arising from a broader range of enabling digital technologies". Thus, DS can impact both internal and external processes of firms (Coreynen *et al.*, 2017). Particularly, the back-end perspective focuses on enhancing firms' internal processes, fostering innovation, improving operational performance (Klingenberg *et al.*, 2021), and increasing decision-making transparency.

The front-end perspective emphasizes firms' external processes, fostering customer interactions and promoting closer integration with the actors' networks (Perks *et al.*, 2017; Sklyar *et al.*, 2019). Despite the clear back-end and front-end perspectives, the literature stresses the complexity that arises in handling DS all along the value chain (Tóth *et al.*, 2022). However, navigating DS along the entire value chain poses considerable complexity, necessitating coordination among intra- and inter-activities to effectively address change and adapt value propositions accordingly (Baines and Lightfoot, 2014). In this scenario, digital platforms emerge as focal drivers for addressing DS as a capability through the reconfiguration of sustainable-oriented network ecosystems in terms of both relational and structural features (Ciasullo *et al.*, 2021; Schiavone *et al.*, 2022). Such a systemic approach emphasizes the need for a progressive and comprehensive transformation of the company's ecosystems. The strategic objective is a configuration in which value is co-created through the optimization of resource usage, effective operation, and the leverage of digital technologies (Parida *et al.*, 2019). Typically, this shift can be described by the transition from product platforms to platform ecosystems built on network interactions, which represent the backbone of successful servitization strategies in sectors undergoing digital transformation (Cenamor *et al.*, 2017). A digital platform can reconfigure and reuse certain assets through modularity (Andersen *et al.*, 2022) by exploiting economies of scale and scope for reshaping the design of the product, the manufacturing process, or the distribution channel. Indeed, modularity allows a flexible configuration of several offerings using different combinations of modules for servitized products (Bask *et al.*, 2010) and an improvement in communication regarding the value proposition (Böttcher and Klingner, 2011). Moreover, digital platforms can intervene as a booster of interactions and the sharing of knowledge in the network ecosystem. Then, a digital platform may track the path for a reconfiguration of firms for better implementing DS. Consequently, it is meaningful to consider the orchestration role of a digital platform in empowering network ecosystems toward sustainable trajectories (Chen *et al.*, 2020; Schiavone *et al.*, 2022). The digital transformation brought by those platforms and the relevant digital ecosystems is thus shaped by the interaction between technologies and the people who use these technologies, as well as by innovation policies (Brunetti *et al.*, 2020).

DS represents a challenging journey, especially for SMEs, which often require collaborative partnerships to integrate new capabilities and navigate complex innovations. By analyzing the digitalization of agricultural systems, Fielke *et al.* (2020) find that the transparency of practices and informational interactions between farmers, advisors, agri-businesses, consumers, and regulators are driven by growing connectivity. When DS is successfully implemented, firms can expand their offerings through higher differentiation from rivals, increase revenues and profits, and become more resilient to changes and crises. In broader terms, considering also environmental and social aspects, DS was also found to lead companies in the manufacturing sector to increase their sustainability (Paiola *et al.*, 2021). By conducting a systematic literature review, Paschou *et al.* (2020) report several benefits of DS for society and the environment: reduction in energy consumption, decrease in environmental impact, increase in social sustainability, value delivery for the entire society, and implementation of sustainable production processes. However, this interplay remains understudied (Gebauer *et al.*, 2021), particularly concerning sustainability benefits (Paiola *et al.*, 2021) and agricultural innovation systems, despite being based on both knowledge and technological infrastructures. Particularly, Smania *et al.* (2022) discover that the DS process for original equipment manufacturers (OEMs) is driven by the implementation of precision agriculture (Agriculture 4.0) and by the changing needs of agribusinesses. Furthermore, the scholars observed: (i) an increase in productivity to compete with countries where costs are lower, and legislation is less restrictive; (ii) continuous investments in facilities to maintain efficiency; (iii) adherence to new environmental standards; and (iv) the reduction of the typical risks and uncertainties of agricultural activity.

2.3 Theoretical speculations

The analysis previously conducted highlights some important evidence in terms of antecedents and consequences of the transformation brought by the development of innovative product-service systems (PSSs) grounded on DS enabled by a platform provider.

Particularly, starting from the current trends that characterize the agrifood sector, such as digital transformation, servitization, and the circular economy pushed by sustainability policies both at global and local levels (e.g., UN SDGs, EU Green Deal, New PAC, etc.), the literature emphasized the key role of partnerships. They are based on the exchange of technological innovation and knowledge as a service to support the digital transition of agribusinesses, especially SMEs (Paiola *et al.*, 2021). This helps overcome the lack of resources and competencies to reach positive outcomes in terms of economic, environmental, and societal sustainability enabled by digital innovation (Smania *et al.*, 2022).

However, this process is twofold, necessarily involving two levels of analysis (Paiola *et al.*, 2021; Parida and Wincent, 2019): (1) the transformation at a network level, where the trends can boost the interplay among partners and ecosystem orchestration; and (2) at the firm level,

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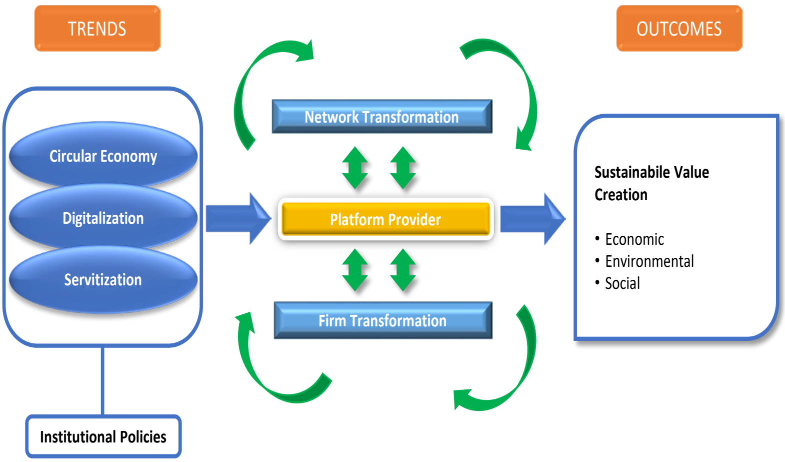
italian journal of management
Vol. 42, Issue 1, 2024

where the transformation builds on the need for updating corporate resources and capabilities through the new knowledge acquired.

Based on these relationships, a conceptual framework is designed (Figure 1), which guided the empirical phase of the study.

Fig. 1: Conceptual framework of the study



Source: our elaboration

3. Methodology

3.1 Study strategy and design

To understand how a solution provider sustains sustainability gains in the agrifood ecosystem, this study adopted a sequential mixed-methods approach based on quantitative and qualitative analyses (Tashakkori and Creswell, 2007).

Firstly, to answer RQ1.1, a quantitative analysis was performed. It was based on secondary data gathered from the literature as an in-depth cost-benefit analysis. Particularly, a bibliographic analysis was carried out to identify the main operations management metrics (e.g., costs, revenues, and profits, especially connected to the phases of wine-grape growth, harvesting, and winemaking). The aim was to find out the potential improvements in terms of sustainability performance due to the adoption of innovative practices enabled by a digital PSS. Then, a comparison was performed between two types of agribusinesses: conventional firms (i.e., not supported by the services of the platform provider) and 4.0 firm (i.e., supported by precision agriculture systems).

Secondly, to answer RQ1.2, an explorative multiple case study was performed. It was useful both to capture and describe contemporary and practice-based phenomena within their natural setting, especially when the boundaries between them are blurred (Gummesson, 2017), and to conduct the analysis according to the respondent's attitude, experiences, and behavior. The multiple case study methodology allowed researchers to deepen the phenomenon under investigation by shedding light on any differences and similarities between the cases considered. Accordingly, the reliability of the research, the replication of the analysis, and the comparability of the results can be improved (Yin, 2017). In this study, both the service provider (e.g., the focal actor) and the winery organizations were analyzed, investigating how the service platform provides smart solutions and how wineries accomplish transformational processes both at the firm and network level.

3.2 Data collection and data analysis

3.2.1 First Phase: Quantitative analysis of secondary data for the comparison between conventional and 4.0 agribusinesses

A comparison between "conventional" and "4.0" agribusinesses was performed, also pointing out the type of farming and production (e.g., organic or not). The analyzed sample was divided into different size classes: up to 2 hectares, from 2 to 20 hectares, and from 20 to 100 hectares, and the classic structure of a company income statement was considered.

Data collection was based on secondary data, considering both bibliographic studies and the focal actor's documentation. Particularly, the following studies served as the basis for the comparison: Maddalena *et al.* (2023) for the number of treatments and for costs; Caffi *et al.* (2012) and Donna *et al.* (2011) for fertilization, where the reduction in the use of fertilizers was calculated thanks to the support of satellite analysis and the use of VRT (variable rate technology) for optimizing fertilization.

The measures concerning the "conventional" farm were defined by following the study by Condifesa (2023), in which agrifood investment costs are collected from Condifesa's 10,000 members. Related findings show that the average quantity produced by the conventional vineyard and the wine yield from grapes were set at 65% accordingly.

The costs for the vinification and bottling phases were extracted from the study by Ismea (2020) and represent 35% of the total costs; moreover, average prices for non-organic and organic wines were also derived from this study.

Finally, the cost of pesticide treatments and the cost of fertilization were calculated and compared in both conventional and 4.0 farms to assess the main benefits of using smart farming systems.

3.2.2 Second Phase: Qualitative follow-up based on primary data

Both primary and secondary data were collected following a data triangulation strategy. Secondary data was collected mostly from corporate websites and internal documentation. Primary data were gathered from 10 in-depth interviews both with the service platform's founders and agronomists, as well as with the owners of wineries operating in different Italian regions that adopted services provided by the platform.

In line with the aim of the research, the unit of analysis was represented by the interplay between the service platform and the wineries to understand how the focal actor contributed to the complex transformation of wineries and their network towards sustainability gains. Data collection lasted 3 months between September 2022 and January 2023.

The authors interviewed service provider co-founders (i.e., CEO and CMO) and winery owners.

A semi-structured questionnaire was performed aimed at analyzing which services were provided by the focal actor, how these services were implemented by wineries, and which processes were renovated, thereby affecting the overall ecosystem. The interviews were audio-recorded and transcribed. Once the data was collected, it was analyzed through a content analysis, in which the authors individually examined and evaluated the interview transcripts with respect to the research's aims after sharing the research materials, methodology, and interpretive logic beforehand (Eisenhardt, 1989).

3.3 Empirical context

Elaisian is one of the first agri-tech Italian ventures, and it was founded in 2016. Its mission is "Revolution", intended as a priority in supporting the transition and renewal of local areas toward progress, competitiveness, and knowledge through innovations and new technologies. By considering business customers' needs, it provides tailor-made services and solutions, particularly precision agriculture systems. The innovative business idea has gained several awards, such as the best 100 Italian start-ups in 2020 and the best 500 FoodTech startups worldwide in 2021. The company is present in 16 worldwide countries, and more than 2,000 farming organizations are served.

4. Findings

4.1 Quantitative analysis of the empirical data from the literature

To assess the sustainability gains, findings of the comparative analysis, focus on the reductions in (i) the number of pesticide treatments and (ii) the costs for fertilization and pesticide treatments.

Particularly concerning pesticide treatments, based on the study by Maddalena *et al.* (2023) and Caffi *et al.* (2012), an average reduction of 59.5% was calculated in terms of the number of treatments and associated farm emissions and costs.

Concerning fertilization, based on the study by Donna *et al.* (2011), a 30% reduction in the use of fertilizers was calculated.

Then, the comparison between farming practices and the outputs of a winery without and with the support of 4.0 services was calculated. For pesticide treatments, an estimation of savings ranging from € 707 to € 47.320 (Table 1) and of fertilization from € 198 to € 13.860 (Table 2), respectively, for farms of 1 ha and 100 ha, was highlighted. Differences in costs and profits correspond to a decrease of 46% in pesticide treatments and a 30% reduction in fertilization, thanks to on-field smart sensors and big data analytics. These technologies enable the precise detection of infections to prevent pathogen attacks, along with the analysis of satellite imagery by pinpointing areas requiring fertilization. Consequently, this targeted approach enhances efficiency while minimizing unnecessary impacts and soil pollution. Based on Wu *et al.* (2018), an examination of economies of scale in relation to farm size reveals significant reductions in both pesticide and fertilizer usage and costs. The study indicates that as farm size increases, there is a corresponding decrease in the use and cost of pesticides and fertilizers. Specifically, for farms both with and without agriculture 4.0, a statistical analysis demonstrates that a 1% increase in farm size corresponds to a 0.3% reduction in fertilizer use per hectare and a 0.5% reduction in pesticide use per hectare.

Tab. 1: Pesticides - Convenience in using Agriculture 4.0

Farm dimension	1 ha	2 ha	20 ha	100 ha
Pesticides without 4.0 services				
No. of treatments	26	52	494	1.300
Pesticides (€)	780	1.552	14.820	39.000
Transport and distribution (€)	520	1.040	10.400	52.000
TOTAL COST (€)	1.300	2.592	25.220	91.000
Pesticides with 4.0 services				
No. of treatments	10	21	198	520
Pesticides (€)	312	621	5.928	15.600
Transport and distribution (€)	281	562	5.616	28.080
TOTAL COST (€)	593	1.182	11.544	43.680
COST SAVINGS (€)	707	1.410	13.676	47.320

Source: our elaboration

Tab. 2: Fertilisers - Convenience in using Agriculture 4.0

Farm dimension	1 ha	2 ha	20 ha	100 ha
Fertilisers cost without 4.0 services				
Fertilisers (€)	500	997	9.700	35.000
Fertilisation (€)	160	319	3.104	11.200
TOTAL COST (€)	660	1.316	12.804	46.200
Fertilisers cost with 4.0 services				
Fertilisers (€)	350	698	6.790	24.500
Fertilisation (€)	112	223	2.173	7.840
TOTAL COST (€)	462	921	8.962	32.340
COST SAVINGS (€)	198	395	3.841	13.860

Source: our elaboration

Further insights were obtained through a comparison between conventional (non-organic) and organic winemakers. The implementation of agriculture 4.0 resulted in a quantitative reduction in pesticide treatments and fertilization by 46% and 30%, respectively, compared to conventional farming (Table 3). In addition, the total cost savings are also positively affected by the reductions due to economies of scale deriving from the size of the farm, ranging from 5% to 9%. This leads to cost savings ranging from € 564 for farms of 1 ha to € 92.411 for farms of 100 ha. Comparing total cost savings with farm profits through the utilization of precision farming systems illustrates increased profits ranging from € 3.738 to € 409.811 for conventional farms and from € 5.854 to approximately € 621.000 for organic farms, for farms of 1 ha and 100 ha, respectively.

Tab. 3: Improved sustainability by using Agriculture 4.0

	1 ha	2 ha	20 ha	100 ha
Interventions Reduction				
Pesticide Reduction	-46%	-46%	-46%	-46%
Fertilisers Reduction	-30%	-30%	-30%	-30%
Economic of Scale Reduction in Fertilisers		0,3%	3%	30%
Economic of Scale Reduction in Pesticides		0,5%	5%	50%
Total Cost Savings				
Cost Savings (€)	564	1.892	21.917	92.411
Cost Savings (%)	5%	8%	9%	8%
Non-Organic Profits				
Higher Profits (€)	3.738	8.240	85.397	409.811
Higher Profits (%)	35%	38%	40%	36%
Organic Profits				
Higher Profits (€)	5.854	12.472	127.717	621.411
Higher Profits (%)	23%	24%	25%	24%

Source: our elaboration

In the appendix, the values related to the comparative analysis are provided (Tables 6 and 7). The section "Other Operations" describes and summarizes the main additional operations useful in wine and production. They are grouped to simplify the reading and include weeding (€210), plant replacement (€500), pruning (€2,070), uprooting plants (diseased and old) (500 €), shredding (640 €), other work (checking structures and anchorages) (150 €), harvesting (860 €), and insurance (700 €), for a total of 5,360 €.

4.2 Second Phase: Qualitative Follow-up

4.2.1 Case companies' description

All wineries are SMEs, with four of them organized as cooperatives. Table 4 shows the case companies' profiles. These wineries engage in the entire wine production process, from cultivating crops to bottling and selling the wine under their labels. They established close collaborations with Elaisian. Winery owners listed several reasons for partnering with the focal actor: "*We need to digitalize our activities to preserve the biodiversity of our terroir*", emphasizing the importance of safeguarding environmental conditions that contribute to the uniqueness of their wines; "*We need to* *better manage the riskiest danger for a winery business: vine infections*", looking for preserving and valorizing natural resources through innovative systems.

Tab. 4: Case companies' profile

	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6
Location	Puglia	Campania	Campania	Tuscany	Abruzzo	Piedmont
Vineyards extension	40 ha	175 ha	100 ha	14 ha	22 ha	1 ha
Farming management	Organic	Conventional/ Biodynamic	Organic	Organic	Organic	Organic
Number of employees	10	35	3	20	5	3
Annual turnover range (€)	600.000	4Mln	35.000	1 Mln	130-140.000	15.000

Source: our elaboration

4.2.2 Digital Servitization: firms' and networking' effects

A cyber-physical system and its associated solutions, such as a cloud-based big data analytics tool, are being developed across various fields. These solutions encompass climate sensors, drones, global positioning systems (GPS), Internet of Things (IoT) devices, cloud computing, and machine learning algorithms, which collectively characterize the service platform. Its modular design allows high customization and operational adaptability, facilitating monitoring and predictive maintenance for crop management. Climate sensors allow for the control of outside temperature, humidity, solar radiation, and wind speed so that winemakers can regulate the irrigation of fields according to weather conditions. For instance, they can decide to start irrigation automatically in very cold temperatures, avoiding frost, or they can reduce the use of water when sensors perceive high humidity, which already makes fields wet. Drones can detect dry areas and address problems that traditional watering equipment may have missed.

Furthermore, they can stitch thermographic photos together over time to detect the direction of water flow and locate geographical features that may affect water dispersion, thereby preventing an ineffective and unsustainable use of water. GPS enables the coupling of real-time geospatial data, spreading accurate position information about water dispersion and dry fields. IoT is used for remote image capture and processing for the detection of insects and vine diseases and for pesticide, herbicide, and fertilizer tracking, allowing continuous and constant control and improvement of their use. The IoT is composed of interconnected sensors that collect data that is aggregated through cloud computing.

These digital solutions at the firm level allow for the collection of real-time data throughout all winery processes, which, thanks to machine learning algorithms systems are analyzed and shared through alerts in mobile apps as valuable information. Indeed, a higher awareness of the concrete possibility of facing sudden ecological and social issues and improving the effectiveness of crop management affects winemakers. As one of the winemakers illustrated: "*Now we can map the field. For example, if you are going to fertilize a certain area or correct the soil, you can collect data in various areas where you are going to plant: soil pH, what is needed to treat the soil, and what fertilizer is missing. You can put this data into a program, and your machine, when applying fertilizer or soil correction, can apply it there via satellite*". Other winemakers affirmed: "*The quality of life of my teamwork is improved because we can now regulate water distribution and pesticide irrigation from our homes*". Moreover, thanks to GPS systems, workers' safety is reinforced because they allow to avoid human activities when adverse weather conditions arise. Accordingly, digitalization contributes to attaining service innovations both in agricultural processes and in overall value propositions, stimulating the development of innovative sustainable practices. Firstly, the large amounts of data collected and analyzed allow to better dose the water and introduce a more precise application and reduction of chemicals, tracking the path for the implementation of non-polluting pesticides, herbicides, and fertilizers. A winery owner affirmed: "*We can finally improve our complex agricultural activities by monitoring physical, chemical, and biological processes, taking into account what is best for our wineries*". Secondly, winemakers innovate the value proposition by proposing certified eco-friendly products. More in-depth, thanks to bio-organic productions, an eco-label certifies sustainable practices throughout the production cycle, from natural resource management to bottling and transportation. The winery eco-label certification enables the traceability of the product by improving its quality in terms of origin and sustainable production processes (e.g., vine protection, watering, fertilizer use, harvesting, winemaking, bottling, etc.), reinforcing its safety and reliability along the food value chain. Indeed, a winemaker affirmed: "*The digitalization of production data enables automatic transfer of data to customers, enabling them to profit from better and more reliable data*".

Winemakers' digital readiness is stimulated through interactive services that Elaisian provides through user-friendly interfaces such as machine-visual boards and mobile applications (i.e., mobile apps) that allow easy access to data. Besides, skilling and up-skilling services are provided to facilitate technical knowledge in big data analysis. As a winemaker declared: "*The building of digital skills is essential to enhance real-time communication for monitoring crop yields*". In the same direction, a winery owner stated: "*The ability to analyze data should be associated with methodological sensitiveness; data analysis can be a source of many biases. Not only should we collect information, but we should compute and interpret data in line with strategic goals to identify solutions for the development of services, products, and processes*". Given these insights, one of the Elaisian CEOs affirmed: "*We do not only provide digital solutions, but we also train our partners because they need to learn*". Also, the other Elaisian CEO declared: "*It is fundamental to allow our partners to leverage the value of digital technologies... To make data useful information, it is needed to continuously learn through various techniques, such as foresight exercises and scenario building*". Indeed, digital skills are stimulated through interactive services that Elaisian provides through user-friendly interfaces such as machine visual boards and mobile applications (i.e., mobile apps) that allow easy access to data. Besides, skilling and up-skilling services are provided to facilitate technical knowledge in big data analysis. Particularly, the systematic computation and interpretation of data allow for the development of forecasting abilities, thereby improving overall business activities. More in-depth, the human resources involved can advance a more informed decision-making process in foreseeing pathological and physiological weather conditions.

At the network level, the digital solutions and the related services provided by the Elaisian allow winemakers to get in touch with other actors, such as suppliers of ecological raw materials, agronomists, biologists, and software engineers. Indeed, relational capabilities are fostered through the activation of synergistic interactions between winemakers and business and non-business actors. A winemaker stated: "*We collaborated with a software engineer to develop tailor-made solutions to prevent freezing temperatures, which are becoming more frequent*". Another one affirmed: "*We established new partnerships and new close relationships to share knowledge and experience in realizing sustainable solutions able not only to reduce unnecessary costs but also to generate value for our territories*". In this way, knowledge recombination within and outside winery organizations is promoted, stimulating value co-creation processes that allow to better address sustainability issues.

Tab. 5: Representative quotes

Interviewees	Representative quotes	Main Effects
Winemaker	We decided to implement new digital solutions to get a more sustainable way of doing business, but we need to be able to use them.	Managing digital solutions to shape a sustainable business model
Elaisian CEO	It is fundamental to allow our partners to leverage the value of digital technologies. To make data useful information, it is needed to continuously learn through various techniques, such as foresight exercises and scenario-building.	Providing a socio-technological infrastructure which is scalable, modular, easily accessible
Elaisian CEO	We do not only provide digital solutions, but we also train our partners, because they need to learn.	
Winemaker	The quality of life of my teamwork is improved, because we can now regulate water distribution and pesticide irrigation from our homes.	Stimulating service innovations both in business processes and in organizational processes
Winemaker	We can finally improve our complex agricultural activities, by monitoring physical, chemical, and biological processes considering what is best for our wineries.	
Winemaker	The digitalization of production data enables automatic transfer of data to customers, enabling them to profit from better and more reliable data.	
Winemaker	We collaborated with a software engineer to develop tailor-made solutions to prevent freezing temperatures which are more and more frequent.	Generating sustainable co-create activities in actors' network
Winemaker	We established new partnerships and close relationships to share knowledge and experience in realizing sustainable solutions able not only to reduce unnecessary costs but also to generate value for society.	

Source: our elaboration

5. Discussion

The two phases of the empirical analysis allowed us to explore how sustainable gains are achieved when winery businesses embrace a digital transition orchestrated by a digital service platform. By combining the evidence obtained through the primary and secondary data analysis, we detected socio-technical dynamics of change in the companies involved in the transformation operated by a service platform provider.

The comparison between conventional *versus* 4.0 farms showed that investing in precision agriculture systems generates both process efficiency and cost savings, thereby positively affecting economic and environmental value. The reduction in the use of pesticide treatments and fertilization, such as the reduction of chemical inputs in the air and the soil, increased wineries' profitability, affecting at the same time ecological sustainability. Nevertheless, a smaller reduction in the quantity and costs of pesticide treatments and fertilization is noted in the interviewed companies rather than those described in the literature. This could be explained by the average lower technological capabilities and knowledge of the analyzed organizations, which probably do not exploit the maximum benefits of smart farming services. Probably, the anomalous climatic trends of the last two years are also an explanation for this reduction.

Despite all, findings from the case studies analyzed showed a strong sustainability orientation among entrepreneurs as well as the need to innovate their business to actively resolve sustainability issues.

Then, digitalization allowed them to realize service innovation at operational and business levels by better performing agricultural processes and by proposing and communicating a new value proposition. On the one hand, agricultural processes are renewed and innovated towards bio-organic productions, where energy and natural resources are responsibly exploited. The decision-making support, based on the alerts and data provided by the platform as well as on the technical support by the agronomists, helps the users to make more effective decisions about different management issues, such as multiple pest and disease risk, the best time to start the treatment, the optimal dose of pesticide to purchase and use, the protection provided by the last treatment, the risk of abiotic stress (frost, drought or heat), the need for watering (Zhao *et al.*, 2022). On the other hand, certified eco-friendly products are designed, which improve quality and traceability. At the same time, social well-being is sustained by enhancing workers' quality of life and safety and increasing digitally specialized labor; thus, workers can perform less strenuous and more specialized tasks. Then, the value received from the platform provider sustains the optimization of back- and front-end activities, in terms of both technological and knowledge support, by creating opportunities for innovation. Indeed, the digital platform facilitated the extension of the wineries' relational system, where new collaborations and co-created partnerships were embraced, which allowed a value network transformation. Wineries' organizations embraced new value-creation modalities by engaging eco-friendly professionals (e.g., suppliers of ecological raw materials, agronomists, biologists, and software engineers), thereby going beyond the agri-food supply chain.

Consequently, new knowledge, experience, and expertise are exchanged and potentially renovated through a continuous learning process in the actors' value network. Then, a virtuous cycle of knowledge exchanges is stimulated, and a constant tension towards knowledge recombination is developed. Through the enrichment of data analytics skills in winery organizations, market intelligence activities are improved. This stimulates the activation of new modalities of interactions that boost ecosystem responsiveness in achieving sustainable innovations.

Past literature has demonstrated that standalone interventions are often not sufficient to tackle digital transformation processes from a systemic perspective (Brunetti *et al.*, 2020). This is particularly true in the case of SMEs that need partners to integrate their capabilities, considering that they operate in complex contexts characterized by transitional processes such as the agrifood industry (García-Álvarez de Perea *et al.*, 2019).

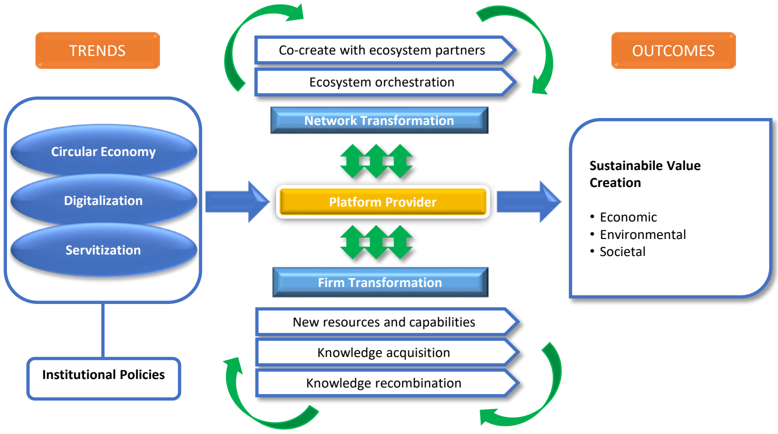
Tracking, measuring, and then identifying innovative solutions to shared problems is the key to facing common challenges and fostering sustainable outcomes in fast-changing contexts (Kamilaris *et al.*, 2017).

5.1 Revised conceptual model

The evidence obtained from the two phases of the analysis performed allowed us to update and improve the initial conceptual model (Figure 2). In the revised model, the initial two levels of analysis (Paiola *et al.*, 2021; Parida and Wincent, 2019) were confirmed and enriched by further elements: (1) at the network level, the ecosystem transformation brought about by the platform provider gives an actual boost to value co-creation among partners. This interplay, based on the exchange of information and resources among the different actors, is enabled by the ecosystem orchestration performed by the platform provider (Rapaccini *et al.*, 2023). These dynamics positively affect competitiveness at the network level and have an impact on overall sustainable value creation. At the firm level (2), this transformation allows to overcome corporate resources shortages. The continuous technical and human support received stimulates innovativeness through knowledge acquisition and new knowledge recombination, triggering innovative processes (Ayre *et al.*, 2019). This transformation represents for firms a concrete lever for achieving competitive advantage by servitizing their value propositions (e.g., organic and quality-labeled products) and the clear communication of higher sustainable performance.

Our results detect an innovation ecosystem characterized by DS and positive network effects influencing different levels of positive outcomes at the economic, environmental, social, and societal (Paiola *et al.*, 2021; Smania *et al.*, 2022).

Fig. 2: Conceptual framework updated by the empirical research



Source: our elaboration

6. Theoretical and managerial implications

The study investigates how sustainability is enhanced in farming businesses through the involvement of a digital service platform. The study has both theoretical and managerial implications.

Theoretically, by assuming a socio-technical perspective, the research contributes to advancing the scant managerial literature focused on digital transformation in the agricultural setting. Indeed, it provides an empirically informed conceptual framework that illustrates the enabling effects that shape a sustainability-oriented ecosystem. The close collaboration between the digital service provider and the analyzed wineries encompasses technological advancement, hard and soft skill development, and actors' network interactions, creating and nurturing a more sustainable value-driven ecosystem.

From a managerial viewpoint, this study helps managers understand how to effectively combine data management strategies and human resources management to turn meaningless data into valuable knowledge. This, in turn, promotes the alignment of complex innovation processes that influence the sustainability of the company and potentially other connected stakeholders.

In addition, evidence from the case studies can inform both practitioners and policymakers about the best practices and process innovation activities that can increase shared value creation in the agrifood ecosystem.

7. Conclusion

The results obtained through the mixed-method design of this study allowed a direct comparison between secondary and primary data. In the first case, data have been standardized for "typical companies" and represent a guideline for comparative analyses of agrifood companies' operations management performance in the wine-growing business. Primary data from case studies are more representative of the current Italian scenario of winery companies implementing smart farming services.

Particularly in the investigated context, significant benefits in terms of sustainable outcomes were observed for companies implementing smart farming services, which are, however, supported by the continuous training offered by the platform provider. In this way, companies can contribute positively to both society and the natural environment. Indeed, they improve the sustainability of production processes by innovating with highly efficient and cost-effective systems, both in terms of business and collective well-being, thanks to the observed network effects. The synergic interplay with the service provider allows wineries to exploit the platform value by acquiring and exchanging knowledge in their value network towards an improvement of sustainable outcomes both at firm and network levels.

As per the limitations of the study, our evidence is mainly based on the analysis of Italian wineries enhanced by a specific innovative platform provider. The limited number of collected cases discourages a consistent generalization of the results achieved so far, which will have to be confirmed by further investigation. Particularly, more empirical evidence is needed to generalize the observed technology-driven transformation dynamics and outcomes. Moreover, further research could focus on other agrifood industries or niches in different geographical areas, as well as different types of platform providers and related business models, in which different sustainable benefits could be achieved. At the same time, the collection of quantitative primary data would allow future researchers in this field to confirm the overall results presented above. The experience of agribusinesses from different countries and crops may also be beneficial to add further elements to the relationships included in the present conceptual framework, which is highly dynamic for its nature.

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Appendix

Tab. 6: Profit and loss account - Without 4.0 services

FARM NOT USING 4.0 SERVICES	1 ha	2 ha	20 ha	100 ha
COSTS				
Fertilisers	500,00 €	997,00 €	9.700,00 €	35.000,00 €
Fertilisation	160,00 €	319,04 €	3.104,00 €	11.200,00 €
FERTILISERS TOTAL COST	660,00 €	1.316,04 €	12.804,00 €	46.200,00 €
No. of pesticide treatments	26	52	494	1300
Pesticides	780,00 €	1.552,20 €	14.820,00 €	39.000,00 €
Pesticide transport and distribution	520,00 €	1.040,00 €	10.400,00 €	52.000,00 €
PESTICIDES TOTAL COST	1.300,00 €	2.592,20 €	25.220,00 €	91.000,00 €
OTHER OPERATIONS TOTAL COST	5.630,00 €	11.260,00 €	112.600,00 €	563.000,00 €
Total cost Vinification and bottling	4.086,00 €	8.172,00 €	81.720,00 €	408.600,00 €
TOTAL COST WITHOUT 4.0 SERVICES	11.676,00 €	23.340,24 €	232.344,00 €	1.108.800,00 €
	11.676,00 €	23.340,24 €	232.344,00 €	1.108.800,00 €
INCOME				
Grape production q/ha	100	200	2000	10000
Wine production l/ha	6500	13000	130000	650000
Price €/l - Non-Organic	3,45	3,45	3,45	3,45
Price €/l - Organic	5,75	5,75	5,75	5,75
TOTAL INCOME NON-ORGANIC WITHOUT 4.0 SERVICES	22.425,00 €	44.850,00 €	448.500,00 €	2.242.500,00 €
TOTAL INCOME ORGANIC WITHOUT 4.0 SERVICES	37.375,00 €	74.750,00 €	747.500,00 €	3.737.500,00 €
PROFITS NON-ORGANIC WITHOUT 4.0 SERVICES	10.749,00 €	21.509,76 €	216.156,00 €	1.133.700,00 €
PROFITS ORGANIC WITHOUT 4.0 SERVICES	25.699,00 €	51.409,76 €	515.156,00 €	2.628.700,00 €

Tab. 7: Profit and loss account - With 4.0 services

FARM NOT USING 4.0 SERVICES	1 ha	2 ha	20 ha	100 ha
COSTS				
Fertilisers	350,00 €	697,90 €	6.790,00 €	24.500,00 €
Fertilisation	112,00 €	223,33 €	2.172,80 €	7.840,00 €
FERTILISERS TOTAL COST	462,00 €	921,23 €	8.962,80 €	32.340,00 €
No. of pesticide treatments	10,4	21	198	520
Pesticides	312,00 €	620,88 €	5.928,00 €	15.600,00 €
Pesticide transport and distribution	280,80 €	561,60 €	5.616,00 €	28.080,00 €
PESTICIDES TOTAL COST	592,80 €	1.182,48 €	11.544,00 €	43.680,00 €
OTHER OPERATIONS TOTAL COST	5.630,00 €	11.260,00 €	112.600,00 €	563.000,00 €
Total cost Vinification and bottling	3.927,00 €	7.585,00 €	74.620,00 €	369.869,00 €
SMART FARMING SERVICES TOTAL COST	500,00 €	500,00 €	2.700,00 €	7.500,00 €
TOTAL COST WITh 4.0 SERVICES	11.111,80 €	21.448,71 €	210.426,80 €	1.016.389,00 €
INCOME				
Grape production q/ha	106	212	2120	10600
Wine production l/ha	7420	14840	148400	742000
Price €/l - Non-Organic	3,45	3,45	3,45	3,45
Price €/l - Organic	5,75	5,75	5,75	5,75
TOTAL INCOME NON-ORGANIC WITHOUT 4.0 SERVICES	25.599,00 €	51.198,00 €	511.980,00 €	2.559.900,00 €
TOTAL INCOME ORGANIC WITHOUT 4.0 SERVICES	42.665,00 €	85.330,00 €	853.300,00 €	4.266.500,00 €
PROFITS NON-ORGANIC WITHOUT 4.0 SERVICES	14.487,20 €	29.749,29 €	301.553,20 €	1.543.511,00 €
PROFITS ORGANIC WITHOUT 4.0 SERVICES	31.553,20 €	63.881,29 €	642.873,20 €	3.250.111,00 €

sinergie
italian journal of management

ISSN print 0393-5108
ISSN online 2785-549X
DOI 10.7433/s123.2024.03
pp. 45-69

FONDAZIONE CUEIM

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Italian Society of MANAGEMENT