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Unveiling digitalisation in Italian viticulture: a field study on drivers and barriers

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Abstract

Purpose – This study investigates the drivers and barriers to digitalisation in viticulture, focusing on the Italian wine sector. Although digital transformation is widely recognised as necessary for its potential to bring significant improvements to this industry, the determinants and barriers to this process are still unappreciated by research in the field.

Design/methodology/approach – Due to the emerging nature of the research field, the paper adopts an explorative field study based on focus groups involving a total of 36 participants as keynote actors in the wine sector industry, including entrepreneurs, wine producers, agronomists and representatives of wine consortia across Italy.

Findings – The study reveals that various factors can promote the adoption and implementation of digital technologies in viticulture. One of them is the large availability of data, innovations that improve business models, and the quality and sustainability of wine production. However, the study also reveals perceived barriers regarding digital technologies, such as economic constraints, a lack of digital skills, increased complexity in the operation processes and a potential loss of wine tradition.

Originality/value – This paper explores an understudied area and uncovers several factors previously overlooked by academia. It points out inconsistencies between the perceived drivers and barriers, demonstrating the divergent perspectives among entrepreneurs regarding digitalisation.

Keywords Digital technologies, Digitalisation, Viticulture, Wine sector, Wine, Focus groups, Agriculture 4.0

Paper type Research paper

1. Introduction

Vine-growing and winemaking processes have traditionally relied on manual labour, with workers overseeing operations from vineyard management to harvest and production. However, this long-standing practice is evolving as the agricultural sector increasingly embraces digitalisation. Digital agriculture is reshaping the global wine industry by merging tradition with technology and enhancing decision-making through greater data availability (Da Silveira *et al.*, 2023; Dibbern *et al.*, 2024; Marczewska, 2024). The digital transformation has great potential for viticulture, and some studies have underlined its power to address grand challenges such as climate change, labour shortages, increasing demand for sustainable and

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high-quality products (Albuquerque *et al.*, 2023), and efficiency in wine management and production (Cantino *et al.*, 2019; Moggi *et al.*, 2022; Abbate *et al.*, 2023).

Despite extensive research on the potential benefits of digital technologies (DTs) in other sectors (Chakraborty *et al.*, 2022, 2023), agriculture and the specific case of the wine sector remain underexplored. For instance, a review on DTs in the agri-food industry by Abbate *et al.* (2023) proposes three main classifications for these technologies: *Agriculture 4.0* technologies, DTs for the *Circular Economy* and tools for *Supply Chain management*. Conversely, Trablesi *et al.* (2023) narrow the focus by examining the implications of artificial intelligence for the agri-food industry. Despite increasing attention to these practices in agriculture, little attention has been paid to how their implementation works in practice in the peculiar sector of viticulture (OIV, 2021). Studies on DTs in viticulture are still in their infancy and have mainly focused only on specific issues. Some scholars have explored how DT shapes new wine marketing strategies (Egaña *et al.*, 2021; Kladou *et al.*, 2024) and the internationalisation of wine products (Finotto and Mauracher, 2020; Hu *et al.*, 2024) or wine tourism enabled by DTs (Tasci *et al.*, 2024). Although these studies have described the potential of digital transformation for marketing and commercialisation, they typically have not considered the drivers and barriers that shape its development specifically within winery businesses.

Given the wine industry's distinctive characteristics (e.g. diversity of grape varieties, terroir variability and the emphasis on cultural tradition), the present study explores the peculiar enablers and challenges of the digital transformation within viticulture. In examining this underexplored issue, the present study is based on the following research question:

RQ. What are the main drivers and barriers to digitalisation in viticulture?

The Italian context has been investigated to answer this research question. Italy is one of the most important wine-producing countries worldwide, given its variety of production and environments, and thus presents a unique setting for this research (OIV, 2023). Considering the explorative nature of this study, a qualitative field study methodology has been employed, and 36 key informants (e.g. entrepreneurs, wine producers, agronomists and representatives of wine consortia across Italy) were involved through the focus group (FG) method. The authors then focused on identifying the drivers and barriers of digitalisation in viticulture through a manual coding process.

By addressing its research objectives, the contribution of the paper is twofold. First, the present study improves the understanding of the levers that entrepreneurs can manage to enhance digitalisation inside their organisations. The paper also proposes insights for policymakers and key players in the wine sector to overcome the barriers hampering this innovation process. Second, the study provides important clues for the context of the digital farming tout court, as the barriers and drivers highlighted are part of more comprehensive managerial systems in which agriculture is embedded.

The remainder of the paper is organised as follows. The next section summarises a literature review on the development of digitalisation in agriculture and viticulture. The methodology of the field study developed on the Italian viticulture is described in the third section, considering the FG method and the main strategies for the manual coding. In the fourth and fifth sections, the main drivers that enhance digitalisation in viticulture and the barriers that hamper it are presented, discussing their main theoretical and practical implications. Finally, the paper provides conclusions on the development of digitalisation in viticulture and the main directions for future research in the field.

2. Literature review

2.1 Digitalisation in agriculture

As some scholars have pointed out, the agricultural sector relies traditionally on "manual labour and hands-on techniques", but this has not prevented companies from embracing new

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technologies (Bastard and Chaillet, 2023, p. 1). Indeed, as many authors affirm, digitalisation is rapidly spreading within the agricultural sector (MacPherson *et al.*, 2022; Abbate *et al.*, 2023). The digitalisation of agriculture refers to "the development, adoption and iteration of digital technologies" (Fielke *et al.*, 2020). Digital transformation has been applied in agriculture due to Industrial Revolution 4.0; it is considered one of the last digitalised sectors (Dressler and Paunovic, 2020); Industry 4.0 aims to enable companies to incorporate DTs such as the Internet of Things, big data and artificial intelligence into their business practices (Abbasi *et al.*, 2022; Cricelli *et al.*, 2024). This brought about a substantial transformation in business that has affected firms as a whole (Annosi *et al.*, 2020). In agriculture, digitalisation permits farmers to work on larger fields and farms, thus increasing efficiency and productivity thanks to economies of scale (Finger *et al.*, 2019; Trabelsi *et al.*, 2023). When talking specifically about the agricultural sector, this phenomenon is known as Agriculture 4.0 or smart agriculture; it started to take place around the early 2010s as a consequence of the development of several technologies, such as sensors, microprocessors, cellular communication, cloud-based systems and big data analytics (Kovács and Husti, 2018; Abbasi *et al.*, 2022). The term refers to the integration of technologies in all farm sectors and processes, while the word "smart" in smart agriculture explains the introduction of smart devices (Kovács and Husti, 2018; Bacco *et al.*, 2019).

Precision agriculture enables the monitoring of cultivation and improves control over agricultural practices like soil management and irrigation. This streamlines operations and favours optimal resource use (Benyam *et al.*, 2021; Khanna, 2021; Benavides-Espinosa *et al.*, 2024). Indeed, adopting smart technologies is frequently associated with the transition towards more sustainable business models and agricultural practices (Annosi *et al.*, 2020), and some scholars have pointed out that DTs can help tackle numerous sustainability challenges like climate change, biodiversity loss and water management (Foley *et al.*, 2011; Garske *et al.*, 2021; Büyüközkan and Uztürk, 2024; Latino *et al.*, 2024), which supports the reduction of environmental impacts (MacPherson *et al.*, 2022). In some cases, digital transformation can also contribute to improving crop yields and production (Smidt and Jokonya, 2021; Benyam *et al.*, 2021).

Despite these potential benefits, research has indicated that the adoption of DTs in agriculture remains relatively underdeveloped. Some explanations in the literature highlight the scarce digital literacy of people working in agriculture (Garske *et al.*, 2021; Khan *et al.*, 2021), as well as the high investment costs required to acquire digital solutions (Annosi *et al.*, 2020; Benyam *et al.*, 2021). As some authors have highlighted, agri-food companies are often characterised by various resource constraints (Smidt and Jokonya, 2021; Costa *et al.*, 2023).

2.2 Digitalisation in viticulture

Societies and markets have changed profoundly in recent years, becoming increasingly interconnected and complex. To gain and maintain competitiveness, it is fundamental for wine sector companies to achieve high-quality standards and implement innovative practices (Matese and Di Gennaro, 2015; Silvestri *et al.*, 2023; García-Cortijo *et al.*, 2024). The agricultural revolution 4.0 and associated technologies have automated many processes, which has allowed wine producers to work less and more efficiently (Tardaguila *et al.*, 2021; Sabbagh *et al.*, 2024).

Precision viticulture has emerged in this context as a contemporary approach designed to enhance traditional viticultural practices through the application of standardised techniques directly in the field (Arnó *et al.*, 2009). This includes the use of humidity sensors and weather stations. The primary objective of precision viticulture aligns with the broader goals of precision agriculture – namely, optimising the management of crop variability, enhancing decision-making processes, maximising economic returns and minimising environmental impact.

Scholars have also emphasised that digital tools and platforms unlock more effective communication between wine consumers and producers, which allows them to align with

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consumers' evolving expectations and values, notably sustainability, authenticity and traceability (Bastard and Chaillet, 2023; Bhardwaj *et al.*, 2024; Chakraborty *et al.*, 2024). A few studies have investigated how the application of DTs in viticulture could help to address issues related to resources or climate change (Costa *et al.*, 2022; Depetris *et al.*, 2023), examining the relationship between digitalisation and viticulture performance (Cimini and Moresi, 2022).

However, some studies have also pointed out that the overall level of digitalisation within the wine industry is lower than that achieved by other agri-food sectors. Dressler and Paunovic (2020) note that research on digitalisation in the wine sector would be particularly relevant given the low-tech nature of the industry. Similarly, Richter and Hanf (2021) argue that the small size of cooperatives and companies that typically characterise the wine industry makes digitalisation research in this sector particularly significant. Waye *et al.* (2023) also highlight that the predominance of small and medium-sized enterprises in the wine sector often exposes them to various constraints, thus limiting their ability to embrace digital transformation fully. Their study also offers a cross-country comparison between Italy and Australia as wine-producing countries as they confront the constraints arising from common policy and regulatory environment. Therefore, as emphasised by a report of the International Organization of Vine and Wine (OIV, 2021) – "*Digital trends applied to the vine and wine sector*" – the digital transformation of the wine industry might entail specific and intrinsic challenges which need greater attention.

However, this research field remains insufficiently understood and somewhat opaque (Festa *et al.*, 2023). The determinants of digitalisation in the wine sector remain underexplored, with existing studies often fragmented and lacking comprehensive analysis, thus leaving space for further research (e.g. Bastard and Chaillet, 2023). Given these gaps, the present research conducted an in-depth exploration of the drivers and barriers to digitalisation in viticulture, focusing on understanding the perspectives of professionals actively engaged in the field.

3. Methodology

To answer the RQ, the authors conducted this empirical study from January to May 2024, focusing attention on the Italian wine sector. The decision to consider Italy as the focus of our research was driven by the recognition of the country as one of the major wine-producing countries in the world; wine also constitutes both a traditional element of the Italian diet and a cornerstone of the Italian economy (Pomarici *et al.*, 2021; OIV, 2023). The wine sector in Italy is characterised by a mix of large producers and numerous small, family-owned businesses, which contributes to the regional diversity of wine production. Despite increasing competition in this sector, the Italian wine industry has sustained its market position and significantly enhanced it, acquiring the second position as a wine producer globally (OIV, 2023). Digital agriculture is increasingly recognised in Italy as an important opportunity, with the market for Agriculture 4.0 growing steadily in recent years. However, only 8% of Italian farms can be considered digitally "mature", as most agri-food companies – including wine-producing ones – still lag far behind in the adoption of DTs (Smart Agri-food Observatory, 2023).

Given the novelty of this research field, the present study employs the qualitative field study methodology. Field studies are suitable for exploring still understudied contexts and permit the collection of data retrieved from the direct involvement of the researcher with key informants in the field of study (Gioia *et al.*, 2013; Patton, 2014). The FG method was employed to improve knowledge in this field and is a method commonly employed in studies requiring the investigation of a novel research field (Mahdad *et al.*, 2022). FGs are primarily engaged when the field of analysis is still underdeveloped, and an initial exploration is necessary to define the main issues of the phenomenon in question. Here, five FGs were organised in various Italian regions to collect relevant information on the determinants of digitalisation in viticulture across varied companies in Italy.

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Table 1 summarises the details of the five FGs, which included 36 individuals. The companies in this study were selected through Italian consortia and trade associations in key wine-producing regions of Italy, leveraging a public call for wineries that manifested an interest in digital transformation. Participants included entrepreneurs, wine producers, agronomists and representatives of wine consortia across the Italian territory, and multiple perspectives on the topic have been collected (Tongco, 2007). To improve data reliability, the participants were not acquaintances and were balanced according to their gender and competencies. This approach permitted the collection of various opinions on the same topic of discussion but with a different point of view deriving from the participants' experiences (see Kitzinger, 1994; Moggi, 2017). The FGs involved from 6 to 9 people and lasted an average of 1 h and 5 min. Two researchers conducted each FG: the gatekeeper conducted the interviews, managed the dialogue among participants and ultimately solved any impasse or conflict (Krueger and Casey, 2000).

The authors designed and planned the FGs significantly in advance by building a semi-structured interview framework and a guide to topics to discuss during the FG. This framework encompassed a first "warm-up" phase, during which participants were requested to present themselves, and a subsequent phase that allowed people to reflect on the meaning, examples, enablers and barriers to digitalisation within the wine sector.

Discussion during the FGs supports the emergence of multiple points of view among participants, as the group setting helps to uncover reasoning that might not emerge through individual interviews (Stewart *et al.*, 1991). Following Bergen and Labonté (2020), the authors

Table 1. Focus Groups details

Code	Number of people involved	Roles of people involved	Duration
A	6	• 3 quality control technicians • Winemaker and producer • President of wine cooperative and wine consortium • Wine cooperative manager	1:39:32
B	6	• 2 winery producers • Regional official • Quality manager • Wine cooperative manager • Production and certification manager	2:14:48
C	8	• Regional official and viticulture manager • Winery owner • 2 wine producers • 2 agronomists and technicians • Winery manager and cooperative president	2:11:02
D	9	• Winery owner • 3 agronomists and vineyards manager • 3 administrative managers • Employee • Provincial agri-food manager	2:40:27
E	7	• Financial manager • Marketing manager • Winery owner • 2 agronomists and winemakers • Winemaking consultant for wine consortia • Production and transformation manager	1:59:33

Source(s): Authors' own work

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adopted various approaches to limit social desirability bias. For instance, during the FGs, the gatekeeper facilitated a relaxed environment to favour open discussion (Bloor *et al.*, 2001). Moreover, during the discussion in the FGs, the gatekeeper maintained the flow of the discussion and also sought to ask participants follow-up questions, receiving further details of their thoughts and enabling in-depth data collection.

Each FG was recorded, transcribed verbatim by the authors and supplemented by field notes taken during the FG by the observer. The volume of information collected through the involvement of 36 key informant actors permitted us to reach saturation with the fourth FG (Patton, 2014). Transcription, field notes and further documentation (e.g. Website information, OIV reports, documents provided by interviewees) were embedded in the hermeneutic unit [1] and permitted triangulation among the sources of data (Guest *et al.*, 2006).

Two separate coding processes were developed (e.g. drivers and barriers). Starting with the drivers, two individual researchers manually coded the material included in the hermeneutic unit. The first coding phase allowed for generic code generation without adopting an *a priori* theoretical framework (open coding) partially based on an OIV study that explored some of the main factors driving digital transformation in wineries (OIV, 2021), including codes such as efficiency, productivity, transparency, value production and sustainability. However, in the open coding, further codes were identified as factors shaping wine companies' DTs adoption. In the second phase (axial coding), the researchers compared and synthesised their emergent codes. This second screening led to the consolidation of similar codes into macro-categories to highlight drivers of digitalisation. In reducing these codes, the two researchers identified a total of nine drivers that were ultimately used in the final (definitive) coding phase. In this last phase, in case of disagreement, a third researcher was called as an arbitrator to supervise the reduction phase and audit the results (O'Dwyer, 2004; Miles *et al.*, 2014). The same coding process was then applied to detect the barriers to DTs adoption in the wine sector, thus providing a final number of nine main obstacles.

4. Results

4.1 Drivers enabling digitalisation in viticulture

This study reveals various factors that encourage digitalisation in the wine sector. Specifically, through the discussions with FG participants, nine drivers emerged that motivated entrepreneurs to pursue the digitalisation of their business operations in viticulture. The enabling factors are interlinked, so they can be grouped into three major categories, which are described below.

4.1.1 Data availability for decision-making. First, the FGs revealed that adopting DTs in viticulture is perceived as an opportunity to expand the range of data available within the business and as a tool that facilitates the management of the collected data. DTs enable the acquisition of more detailed information about the conditions of the vineyards, thus supporting the understanding of critical factors needed to manage the business. For example, a manager underlined that DT: "has allowed me to obtain a quantity of data that I didn't have before or which I had to find in ten different places, ten different databases, but above all on papers [. . .] today I have the possibility of drawing on information from multiple sources that are much more precise and therefore much more useful for analysing the context" (Certification manager – FG B).

The interviewees also underlined that the employment of DTs in viticulture increases the precision and reliability of information, thus enhancing the overall understanding of aspects such as disease control, the use of pesticides, soil composition and the production process. At the same time, the higher quantity of available data calls for storage, management and efficient use. DTs fulfil these needs and enable the systematisation and interpretation of information. Various participants also noted that using DTs and the resulting increased availability of data can substantially improve decision-making within the business. Measuring data from the vineyards and monitoring production stages increase control over processes and

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create historical records of inputs and outputs used in production. This empowers the wine producers to continuously improve their operations by making decisions based on accurately measured data. Some examples of the assessment tools mentioned by participants include satellite images and probes measuring soil humidity. One participant explained that "the larger data availability translates into a sounder analysis of operations, enabling one to make forecasts and strategic planning" (Wine cooperative manager – FG A).

Many interviewees emphasised that DTs are also instrumental in enhancing the efficiency of operations. The large amount of data available for decision-making streamlines operations and improves the precision of interventions. Various participants mentioned the significant optimisation in the production process as a core motivation for adopting DTs in their business. Additionally, efficiency gains were highlighted in terms of reduced bureaucracy and paperwork thanks to the digitalisation of material and information on online platforms. Many participants liked the increased efficiency and reduced time required to conduct the business and make interventions. For example, a wine producer in FG A stated that DTs promote: "Acceleration! (emphasis added) . . . acceleration of times in processes and data analysis because [. . .] Currently, it takes time, as I have to prepare the data both in paper and digital form [. . .] Speeding up, therefore, means the reduction of time and bureaucracy" (Wine Producer – FG A). Similarly, some participants identified the potential of DTs for providing information necessary for accessing financial support and public funds (e.g. the common agricultural policy) and disclosing the use of the shared public resources.

Other efficiency gains supporting the adoption of DTs in viticulture include increased productivity and lower associated costs thanks to a more efficient organisation. The reduction of costs appeared multiple times in connection to decreased water use and unnecessary treatments (e.g. pesticide use and vineyard operations). At the same time, participants also highlighted the potential of using DTs to improve traceability, transparency and communication as key motivators for adoption. The FG results indicate that the information collected through DTs along the supply chain can improve the traceability of wine products. This is becoming increasingly important in promoting communication between wineries and consumers and allowing a better understanding of wine customers' needs and desires. For example, blockchain ensures that all actors along the supply chain can generate and share data securely. From a marketing perspective, wine entrepreneurs appear to be motivated to improve their external communication through specific DTs, thus enhancing their visibility and connecting more effectively with their audience.

4.1.2 Innovation management journey. Another theme that emerged from the FG discussion is connected to the various types of innovations that DTs can introduce in the wine business context. Digital transformation involves changes in the production process, packaging and business model. Because the Italian wine industry is characterised by the presence of old entrepreneurs, generational change usually enhances the introduction of new technologies. New and young entrepreneurs can promote the renovation of the wine industry, thus attracting a younger and updated skilled labour force. An interviewee in FG A mentioned this point: "We are a fairly old cooperative, and digitalisation brings . . . I say renewal, because especially in agriculture, there is a very high average age, and this brings a renewal, therefore a rejuvenation" (President of a wine consortium – FG A). Others believed that adopting DTs cannot be avoided but instead represents something businesses must adapt to, trusting the changes introduced to remain competitive and move with the times. Participants highlighted that the digitalisation process can also create innovation regarding business opportunities. Acquiring new knowledge about technologies and improving the quality and quantity of information available can expand business horizons. This emphasises the potential influence of DTs on business model innovation. At the same time, it generates the need for specialised job positions in the wine industry and enables wine businesses to access new markets and commercial opportunities. However, according to various participants, cooperation between companies is a key factor in achieving these innovations and introducing DTs in the wine sector. In particular, cooperatives and consortia play a key role in enabling digitalisation at the firm level.

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4.1.3 Improving quality and sustainability. A further key factor driving the digitalisation of the wine business is its potential to tackle some of the contemporary challenges related to sustainability, like climate change, biodiversity protection and the reduction of pesticide treatments. If temperatures rise, there is a risk that the vegetative cycle of the vine will be altered, stressing the vines and anticipating the grapes' sprouting and harvesting times. This can pose a problem in areas susceptible to spring frost, damaging premature sprouts. Water stress has also emerged as another challenge due to climate change, ruining the ripening and leaves of the grapes. Digital transformation offers powerful tools and technologies (e.g. sensors, satellite imagery, drones) that can help winemakers confront these complex issues more effectively by adopting advanced measurement and data analysis technologies, which provide insights into vineyards, allow resource use optimisation and the implementation of more sustainable practices.

Given the more significant variability of climate conditions that companies in the wine sector are now facing, DT presents an opportunity to improve forecasts and estimates for improving soil conditions and efficient water use for more precise irrigation. As one of the manager from FG B explained: "New aspects of climate change, biodiversity protection and the division of pesticides have probably taken over. This has complicated the life of the winemaker compared to that of 30 years ago when we were doing calendar treatments with lots of nitrogen. The system has certainly become much more complex and therefore also requires a greater quantity of data and interconnection of data" (Certification manager – FG B). The employment of DTs also enables companies to lower their environmental impact by reducing waste and pollution. DT can also enhance the energy transition by monitoring energy consumption and renewable supply. This suggests that DT provides substantial help for improving the sustainability of winemaking.

4.2 Barriers to digitalisation in viticulture

Despite the general interest in digitalisation in viticulture perceived during the FGs, doubts and criticisms were also raised. The analysis indicated the existence of nine key barriers to digitalisation, which can be grouped into four separate categories.

4.2.1 Economic constraints. The primary barrier identified in the FG discussions pertains to the cost of DT implementation. These innovative instruments are commonly quite expensive, so the initial investment required at the firm level for their adoption can represent a significant burden for the small and medium-sized wine-making enterprises that characterise the Italian wine sector. These businesses often lack the necessary financial resources to afford large investments in DTs. One participant stated: "I am a small producer, and I recognise that being innovative is a good thing, but the only problem is to bear the costs for buying such innovations" (Winery owner – FG D).

The FG participants also noted that the adoption of these technologies would require additional expenses to have the appropriate software capable of interpreting and using the resulting data within the business. Employing a skilled workforce would also be an unavoidable need, thus marking an increase in the associated human resource costs. Finally, concerns about the return on investment and the questionable value added by introducing DTs for wine firms complicate these companies' decisions. In particular, one participant admitted wondering whether the final consumer would recognise the investment or the value added to the final product: "We are doing all this, but we will find ourselves with a consumer who continues to buy the 2-euro bottle rather than the one that costs 6 euros but with a digitalised production process [. . .] Then we might ask ourselves, as a producer, every year you go forward with DT use, is it showing any results? Maybe yes for me in terms of vineyards [. . .] but on an economic level, will there be any advantage?" (Wine quality manager – FG B). If DTs can enhance cost reduction through greater efficiency, an initial investment is also necessary for providing and implementing this innovation.

4.2.2 Lack of digital skills and scepticism regarding digitalisation. Financial resources are one of many assets required to support the digitalisation of the wine sector. Several other

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factors present a major barrier to the digital transformation of wine businesses. The analysis of the FGs underscores that many participants perceive a lack of necessary skills and "digital literacy" within their companies that is holding back their digital transition. Several participants agreed that the wine sector does not possess these skills, and workers are not adequately competent to use DTs. For this reason, training and knowledge building emerged as essential in supporting the digitalisation of viticulture.

However, several interventions also revealed that the present lack of skills is also attributed to cultural factors like the older age of people working in this sector and their resistance to change, as emerged during FG B: "There is poor receptivity on the farmers' side, in the sense that since the farmer has a fairly high average age, I think that these technologies, like all innovations, require a lot of time or even specific skills to understand and use these technologies" (Wine quality manager – FG B). Accordingly, several interviewees admitted a personal lack of knowledge about the potential uses of DTs and their inability to interpret the outputs generated by these technologies.

This also underscores the need to renew the labour force of the wine industry by introducing experts capable of managing DTs and integrating these technologies into current operations in viticulture. This knowledge gap has significantly affected the cultural outlook within the wine industry and led to resistance to change. This appears to be symptomatic of the limited understanding of the potential and functionality of DTs. As underscored by one of the wineries owner: "There is a resistance to change, where there is resistance from those who say that they are already working a lot, and now they have to put this other thing (digitalisation) in the middle as well, they would say they just don't have the time to do it" (Winery owner – FG D).

Resistance to change is also evident in some participants' lack of trust in and scepticism about digitalisation, which has guided a mindset gap for these innovative technologies. The outcomes of the digitalisation process in viticulture are difficult to forecast, and expectations may only sometimes be met. Technologies like blockchain have been questioned, with debates on their application in viticulture. Some pointed out that the use of blockchain within vineyards and cellars might be too complex and not worth the expense. Some interviewees also raised concerns about the reliability of data produced by DTs for monitoring vineyards and suggested that these tools might generate faults. In this vein, a wine producer stated: "Fine! We have fair expectations because, like all new things, you start, and then gradually, these [DTs] have been improved. [. . .] For example, nothing was left in the vineyard once the harvest was done, but the device kept showing the alert: 'There are grapes to harvest on these vines. Intervene!!!' [mimicking the IT tool alert sound]. Then I understood [digitalisation] was just a dream, and that I couldn't rely on this device" (Winery owner – FG D). This underscores the inevitable role of humankind in checking and interpreting the outputs of such technologies.

4.2.3 Rise of complexity. On the one hand, digitalisation requires specific digital skills. On the other hand, using DTs in viticulture presents significant challenges due to the inherent complexity of managing these instruments, which hinders their adoption in the sector. Several participants noted that, in their opinion, the data provided by DTs are often very complex to understand. Comprehending such data might increase the time required to perform operations, and this increased amount of information available to wine entrepreneurs generates an overload of data, which might be futile and needless. For this reason, DT application is perceived as potentially increasing the work needed at the business level and providing more formal procedures to follow. Due to the perceived complexity, concerns about data validation were raised, as well as fears about a plausible falsification of data measured and reported by farmers. The issue of data protection was also raised during the FG, revealing another aspect that currently hampers the sector's digitalisation.

Related to the macro-category of complexity, several individuals within the FG emphasised the specific challenges of adopting DTs given the state of Italian infrastructure. First, various places in the hinterland still lack some of the prerequisites for the digitalisation of businesses, notably an internet connection. The Italian territory is highly varied; some vineyards are still isolated and remotely connected to the rest of the world. Several wine companies, particularly

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the small ones, still lack sufficient infrastructure to adopt DTs. Given the territorial fragmentation and small size of these firms, there is a lack of collaboration between companies that further challenges the adoption of innovative DTs.

The complexity surrounding the adoption of DTs also raises concerns about technostress. FG participants expressed that managing DTs and interpreting their output can lead to increased tension and anxiety. Individuals noted that using DTs might diminish enthusiasm for working in this environment and increase workload. Indeed, the efficiency gains of operating with DTs might lead entrepreneurs to undertake more tasks while needing control over the multitude of digital tools employed and their outputs. One participant remarked: "Maybe with the digitalisation you shorten the time it takes you to do things, thanks to the greater efficiency, but then you will have to do more tasks to manage it" (FG A – Winemaker and producer). This stress is also linked to the hyperconnectivity deriving from using multiple mobile apps simultaneously, which allows constant information monitoring and keeps farmers perpetually connected to work-related data. This inevitably undermines the workers' work–life balance.

4.2.4 Risk of standardisation and loss of wine traditions. One last aspect that has discouraged wine entrepreneurs from adopting DTs is that the use of DTs might also comprise the human ability to make decisions autonomously, as DTs may be used as a substitute for critical thinking skills. Participants in the FGs expressed apprehension that reliance on DTs could lead to an over-dependence on automated systems, thus leading to a potential loss of traditional knowledge and expertise. One entrepreneur from FG A stated: "And in my opinion, those who are very accustomed to digital technology lose the spark for finding solutions, and thus their sense of imagination and creativity" (Wine cooperative manager – FG A). Various interviewees suggested that although DT employment might be beneficial, human supervision remains fundamental, and individuals should always retain control over decision-making processes. Digitalisation also entails forms of depersonalisation and loss of connection with the human dimension. Particularly in terms of communication processes, people pointed out that using DTs entails a loss of "personal touch" and direct contact with customers. There is also concern that the employment of DTs in winemaking might lead to standardisation in production, thus resulting in an industrialised product that lacks authenticity and quality.

5. Discussion

Consistent with the Organization of Vine and Wine (OIV, 2021), the present study revealed several factors favouring the adoption of digital solutions in viticulture, highlighting key advantages favouring wine entrepreneurs' willingness to digitalise their businesses. Nevertheless, the study also underscores the perceived threats and doubts regarding DTs, with several factors simultaneously acting as both drivers and barriers, thus revealing key discrepancies. This section discusses our findings in light of the existing literature and emphasises the novel insights and future research directions suggested by these results.

5.1 Trade-off between economic efficiency and required investment

Aligning with previous research by Garske *et al.* (2021), this research finds that DT adoption significantly improves technical efficiency in viticulture and aligns with sustainability objectives. Resource efficiency and economic considerations emerged as pivotal drivers for DT adoption. As underlined by previous studies in agriculture (Khanna, 2021; Benavides-Espinosa *et al.*, 2024), digital innovations are perceived as enhancing precision, streamlining operations and reducing costs. However, echoing concerns raised in other studies (Benyam *et al.*, 2021; Bastard and Chaillet, 2023), many interviewees voiced concerns that the high investment costs associated with digital transformation render adoption too expensive. This tension between economic gains and investment costs highlights the persistent uncertainty regarding the financial benefits of digitalisation, a finding that aligns with but expands upon existing literature.

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5.2 Digital transformation: efficiency gains or excessive burden

A novel contribution of this study is the finding that despite improving operational efficiency by providing data-driven vineyard and cellar management (Tardaguila *et al.*, 2021), DTs also introduce operational complexity and additional tasks. The hyperconnectivity required to use digital mobile apps for vineyard monitoring exacerbates this complexity and raises uncertainty about whether the efficiency gains outweigh the additional burden. This result resonates with Zscheischler *et al.* (2022), who observed that contemporary digital systems in agriculture can sometimes complicate farmers' work and requires a shift in their role to adapt to modern operational processes that demand new skills and adaptive capacities.

The underscored operational complexity ties directly to a broader challenge noted in our study: the tension between the innovation potential of DTs and the resistance to change within the wine industry. While digitalisation is widely recognised for catalysing modernisation, enabling wineries to achieve high standards and maintain competitiveness (Matese and Di Gennaro, 2015; García-Cortijo *et al.*, 2024), our findings indicate that this transformation is not without difficulties. Reasoning with scholarly research, the present study finds that digitalisation favours generational renewal within companies and contributes to innovation. However, the interviewees also remarked that the wine businesses in Italy are currently dominated by older generations, who are mistrustful of DTs. Bastard and Chaillet (2023) define this resistance to change as typical of agricultural companies. The trade-off uncovered in our study underscores the importance of the entrepreneurial culture behind the wine company, emphasising the role of entrepreneurial attitudes and beliefs in supporting digitalisation, as well as the need for specific training and skills development for digitalisation, as formerly underlined by Khan *et al.* (2021) and Garske *et al.* (2021).

5.3 Digital technologies and the loss of human touch and control

An important divergence from prior research concerns the perceived impact of DTs on communication and the human dimension of business operations. While previous studies have suggested that digital adoption improves overall efficiency, communication and transparency (Bastard and Chaillet, 2023; Bhardwaj *et al.*, 2024), as well as enabling new interactions through social media, our research uncovered concerns about depersonalised interactions and a diminished human element in the wine sector. This nuance challenges the dominant positive framing of digital communication in existing research and suggests a more complex relationship between DTs and relational practices.

A similar concern emerged regarding production control. While previous research (Arnó *et al.*, 2009) has emphasised the benefits of precision viticulture in improving production consistency and standardisation, our findings reveal a more complex scenario. Participants expressed fears that the increased control attributed to DTs might lead to over-standardisation, thus compromising the authenticity and distinctive qualities associated with artisanal wine production. This insight highlights a previously unexplored tension between technological precision and the preservation of traditional craftsmanship. These insights underscore a broader concern about the potential loss of the human touch and control within digitalised viticulture. Whether in communication or production processes, the adoption of DTs seems to challenge deeply rooted relational and artisanal values.

5.4 Wine-making and climate variability

Finally, while in line with prior literature emphasising the role of DTs in promoting sustainability (MacPherson *et al.*, 2022; Festa *et al.*, 2023), our findings advance a new perspective on how DTs can help adapt to climate variability. Participants noted that improved vineyard management through DTs plays a critical role in protecting the organoleptic characteristics of wines, which are very sensitive to soil, climate and seasonal patterns. This underlines the importance of digitalisation in safeguarding the identity and quality of high-value products amid climate change.

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6. Conclusions

This study examined the complex digitalisation landscape in the wine sector and identified key enablers and barriers to adoption. Through a field study in Italy involving FG discussions with industry experts, this study provides insights into the perspectives of wine entrepreneurs. Notably, the results underscore several tensions between digital transformation's perceived benefits and challenges, thus revealing the trade-off entrepreneurs must consider when digitalising their business. This research has several implications for theory and practice, which are described below.

6.1 Practical implications

This study offers guidance for policymakers and wine companies aiming to integrate DTs into the wine sector. First, the research highlights the need for robust digital infrastructure, particularly in rural areas, where reliable internet connectivity remains a major issue. Second, successful digitalisation also requires appropriate training programmes to equip winemakers and vineyard workers with digital skills (e.g. data analysis and digital platforms). This can be achieved by fostering collaboration among industry stakeholders, including researchers, policymakers and wine producers, or through collective aggregation (e.g. consortia or cooperatives), which can facilitate knowledge exchange and accelerate the adoption of best practices. The costs of the digital transition also emerged as a critical aspect hindering DT adoption. These three issues thus represent key areas where policy and government intervention are needed to enable the digital transformation of the viticulture sector.

These findings also benefit companies interested in digitalisation, as they clearly outline the key benefits and challenges expected in this field, while also shedding light on potential trade-offs. For instance, the results underline the tension between the propensity for innovation and the preservation of traditional winemaking practices, unveiling an interesting area that needs careful consideration, especially for traditional and high-value products like wine.

6.2 Theoretical implications

This research makes a significant contribution to the scholarly literature on viticultural digitalisation. The wine sector is a key industry in countries like Italy, and it stands out for its distinctive production processes, deep-rooted traditions and cultural significance. Despite extensive research on digitalisation in agriculture, studies focusing specifically on the digital transformation of wine companies remain limited. This paper addresses this gap by providing valuable insights into the factors influencing DT adoption in this unique sector, thereby advancing the understanding of digitalisation in contexts where tradition and innovation must coexist. The present research also provides a multi-faced perspective that reveals the trade-offs and uncertainties associated with digitalisation that have been largely ignored in previous research.

6.3 Limitations

Because this was an explorative study, it has some limitations. First, despite appropriate measures undertaken to limit potential bias, FGs generally entail some degree of social desirability bias, which appears in the opinions and behaviours of interviewees. We therefore suggest that different methodologies should investigate this topic further to provide insights through alternative methods, like longitudinal analysis and quantitative approaches. Second, the research involved a limited number of actors who can only partially represent the wine sector and the Italian context. Extending the study to other countries and including different perspectives, like policymakers and technology providers, would enhance its generalisability.

6.4 Future research lines

To advance contemporary research on digitalisation in viticulture, the present study suggests that future studies investigate the constructs revealed by this research by exploring other

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contexts. Beyond studying the drivers and barriers of digitalisation, this study also draws attention to the inconsistencies remarked in the findings. For instance, more research is needed to shed light on the trade-off between the required investments to digitalise a company and their returns in terms of economic benefits, while also considering the size of these effects.

A key novel insight from this study is the operational complexity associated with DT adoption. Future research could explore user-centred approaches for digital solutions and seek insights into reducing the cognitive and time burden on farmers. Similarly, future works could examine strategies to overcome the resistance to change typical of this sector by exploring tailored training programmes or mentorship initiatives with technology providers and evaluating their role in digital transformation.

The contrast between digital control and the preservation of traditional craftsmanship represents an underexplored area of the literature. Future research should investigate how DTs can be tailored to safeguard the artisanal identity of wine production. Despite the study highlighting that DT adoption is perceived as instrumental in improving sustainability performance in viticulture, there is space for more investigation of this relationship within the wine sector. Finally, an aspect that might be explored in future research is the investigation of enablers and barriers across different phases of digital adoption, as this would help to identify the key factors that influence progression to more advanced levels of digital maturity within the wine industry.

Note

1. A hermeneutic unit is a folder that contains everything that is relevant to a particular project (e.g. an ongoing research study) and physically resides in an electronic environment (see, e.g. Schreiber and Cramer, 2024).

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