UNIVERSITÀ
DEGLI STUDI
DI BRESCIA

DOTTORATO DI RICERCA IN INGEGNERIA MECCANICA E INDUSTRIALE

---

settore scientifico disciplinare
ING/IND 17

CICLO
XXXVI

THE AGRICULTURE 4.0 PARADIGM: STATE OF THE ART, INNOVATIONS AND FUTURE AGENDA

FEDERICO ANGELO MAFFEZZOLI

Supervisor:
Dr. Andrea Bacchetti

Tutor:
Prof. Nicola Saccani

Acknowledgments

Following three years of diligent effort, I find myself nearing the final stages of completing my doctoral thesis. Fortunately, I thoroughly relished this PhD journey as I actively sought out novelty and intrigue, not only in research but also in life. I am grateful to have had the support, wisdom, and motivation of numerous individuals during this journey, and I wish to express my heartfelt appreciation to them.

Firstly, my deepest gratitude to Dr. Andrea Bacchetti, my supervisor, for being a steadfast guiding presence throughout this research journey. He not only provided me with invaluable support in formulating research ideas but also offered encouragement during challenging phases, contributing significantly to the shaping of my PhD research trajectory. Furthermore, his mentorship allowed me the freedom to explore innovative concepts and provided access to a wealth of wisdom and a wide-reaching professional network. His role has been important in both academic growth and the development of a meaningful friendship built on mutual respect.

I am also thankful to Dr. Marco Ardolino, who has helped me tremendously in this dissertation, who guided me in research results analysis and paper formulation, and motivates me to learn and grow; and to Professor Nicola Saccani for his guidance and trust in my contribution to teaching. The expertise and dedication in educating students has been an inspiration to me. It was an honour to be able to collaborate to enrich the students' educational experience and contribute to their learning.

I would like to express my special thanks to Professor Marco Perona for giving me the opportunity to be part of the RISE laboratory team. I am grateful for the valuable opportunity to learn and contribute to this field of study under his expert guidance.

I would also like to express my special appreciation to colleagues from the RISE laboratory for their insights and valuable support in recent years, including Federico Adrodegari, Gianmarco Bressanelli, and other people from the Department of Mechanical and Industrial Engineering.

Finally, thanks my beloved wife Hazal, for her love, understanding, patience, encouragement, and comprehensive support during the last three years, and to my special mom Maura who has always been my life mentor.

Milano, 30th October 2023

Federico Angelo Maffezzoli

Abstract

In the upcoming decades, the global agricultural sector will grapple with significant challenges. Agriculture will experience substantial and transformative changes due to the introduction of new technologies, digitalization of processes and value chains, and the imperative of sustainability. According to this view, companies (farms) can exploit the outstanding improvements in digital technologies (and solutions) whose adoption has brought to the so-called fourth industrial revolution, which in this field of application is known as "Agriculture 4.0" (A4.0). Indeed, numerous literature has investigated A4.0 enabling technologies with regards to their technical specification, architecture, and domain of use, examples are Internet of Things (IoT), Data Analytics and Big Data, Cloud Computing and Cyber-Physical Systems (CPS) technology, Artificial Intelligence (AI) and Machine Learning (ML), Virtual and Augmented Reality (VR & AR), Robotics and Automation, Drones and Unmanned Aerial Vehicles (UAVs), Image Processing, Geographic information system (GIS) and analytics. However, a comprehensive analysis and description of the paradigm, as well as the adoption mode in farms is of less concern, as well as the evidence from empirical studies on how farms are impacted by A4.0.

To fill this gap, this dissertation will make contributions from three perspectives (A, B and C). The first contribution is a systematic literature review (SLR), which explores 1): what are the application domains where Agriculture 4.0 finds its applications, 2): which technologies enable the implementation of Agriculture 4.0; 3): describing the key advantages associated with adopting Agriculture 4.0 (contribution A). The second and third contributions are descriptive and longitudinal survey studies, which 1) investigate the state-of-the-art of A4.0 paradigm in Italian companies (contribution B), 2) compare the I4.0 state-of-the-art advancement in a 2-year gap in Italian agricultural sector (contribution C); these contributions are mainly to provide empirical evidence on how A4.0 solutions are impacting on companies and how the paradigm is evolving.

The results of this research project contribute to Agriculture 4.0 literature. In particular, the SLR for I4.0 applications in the manufacturing context provides a detailed and holistic description of the use cases of I4.0 enabling technologies in the lifecycle processes of manufacturing companies. Second, the descriptive survey of I4.0 state-of-the-art in Italian manufacturing companies provides a concrete description of how I4.0 is known and adopted by companies, as well as the corresponded benefits and obstacles. Third, through a dynamic state-of-the-art study, comparing with the data collected from 2021 and 2023, the evolvement feature of A4.0 is demonstrated.

Keywords: Agriculture 4.0, digital transformation, digital technologies, Agriculture Application domains, systematic literature review, descriptive survey, longitudinal survey, Industry 4.0.

Sommario

Nei prossimi decenni, il settore agricolo globale dovrà affrontare sfide importanti. L'agricoltura subirà cambiamenti sostanziali e trasformativi dovuti all'introduzione di nuove tecnologie, alla digitalizzazione dei processi e delle catene del valore e all'imperativo della sostenibilità. Secondo questa visione, le aziende (agricole) possono sfruttare gli straordinari miglioramenti delle tecnologie (e delle soluzioni) digitali la cui adozione ha portato alla cosiddetta quarta rivoluzione industriale, che in questo campo di applicazione è nota come "Agricoltura 4.0" (A4.0). In effetti, numerosi lavori in letteratura hanno analizzato le tecnologie abilitanti A4.0 per quanto riguarda le loro specifiche tecniche, l'architettura e il dominio di utilizzo; ne sono un esempio l'Internet delle cose (IoT), l'analisi dei dati e i Big Data, il Cloud Computing e la tecnologia dei sistemi cyber-fisici (CPS), l'intelligenza artificiale (AI) e l'apprendimento automatico (ML), la realtà virtuale e aumentata (VR e AR), la robotica e l'automazione, i droni e i veicoli aerei senza pilota (UAV), l'elaborazione delle immagini, il sistema informativo geografico (GIS) e l'analisi. Tuttavia, un'analisi e una descrizione completa del paradigma e delle modalità di adozione nelle aziende agricole sono meno importanti, così come l'evidenza di studi empirici sull'impatto di A4.0 sulle aziende agricole. Per colmare questa lacuna, questa tesi offrirà contributi da tre prospettive (A, B e C). Il primo contributo è una revisione sistematica della letteratura (SLR), che esplora 1): quali sono i domini applicativi in cui trova applicazione l'Agricoltura 4.0, 2): quali tecnologie consentono l'implementazione dell'Agricoltura 4.0; 3): descrive i vantaggi chiave associati all'adozione dell'Agricoltura 4.0 (contributo A). Il secondo e il terzo contributo sono studi descrittivi e di indagine longitudinale, che 1) indagano lo stato dell'arte del paradigma A4.0 nelle aziende italiane (contributo B), 2) confrontano l'avanzamento dello stato dell'arte dell'I4.0 in un intervallo di due anni nel settore agricolo italiano (contributo C); questi contributi sono principalmente volti a fornire evidenze empiriche su come le soluzioni A4.0 stanno impattando sulle aziende e su come il paradigma si sta evolvendo.

I risultati di questo progetto di ricerca contribuiscono alla letteratura sull'agricoltura 4.0. In particolare, la SLR per le applicazioni I4.0 nel contesto manifatturiero fornisce una descrizione dettagliata e olistica dei casi d'uso delle tecnologie abilitanti I4.0 nei processi del ciclo di vita delle aziende manifatturiere. In secondo luogo, l'indagine descrittiva sullo stato dell'arte dell'I4.0 nelle aziende manifatturiere italiane fornisce una descrizione concreta di come l'I4.0 è conosciuto e adottato dalle aziende, nonché dei benefici e degli ostacoli corrispondenti. In terzo luogo, attraverso uno studio dinamico dello stato dell'arte,

confrontando i dati raccolti nel 2021 e nel 2023, viene dimostrata la caratteristica evolutiva dell'A4.0.

Parole Chiave: Agricoltura 4.0, Trasformazione Digitale, Tecnologie Digitali, Domini Applicativi dell'Agricoltura, Revisione Sistematica della Letteratura, Survey Descrittiva, Survey longitudinale, Industria 4.0.

Table of Contents

Table of Figures

List of Tables

Contributions

Contribution A

Maffezzoli F., Ardolino M., Bacchetti A., Perona M., Renga F. Agriculture 4.0: A systematic literature review on the paradigm, technologies, and benefits (2022). *Futures*, available at: https://doi.org/10.1016/j.futures.2022.102998.

Contribution B

Maffezzoli, F.A.; Ardolino, M.; Bacchetti, A. The Impact of the 4.0 Paradigm in the Italian Agricultural Sector: A Descriptive Survey. Applied Sciences. (2022). Available at: https://doi.org/10.3390/app12189215

Contribution C

Maffezzoli F., Ardolino, M., Bacchetti, A. (2023). Unlocking the Potential of Agriculture 4.0: A Comparative Study on Italian Farms' Technological Evolution, Business Demands, and Perceived Benefits. *In Proceedings of XXVIII Summer School "Francesco Turco" – Industrial Systems Engineering.*

Other contributions

1. Maffezzoli F., Bacchetti A., Ardolino, M., Renga F., Pavesi M. (2021). Agriculture 4.0 paradigm: a preliminary systematic literature review. *In Proceedings of XXIII Summer School "Francesco Turco" – Industrial Systems Engineering.*

2. Maffezzoli F., Ardolino, M., Bacchetti, A. (2023). Maturity level and Effects of the 4.0 Paradigm on the Italian Agricultural Industry: A preliminary study *(submitted to 5th International Conference on Industry 4.0 and Smart Manufacturing, awaiting for final acceptance).*

PART I

EXECUTIVE SUMMARY

The 4.0 paradigm, since the proposal of the term "Industrie 4.0" by Germany in 2011, to promote digitalization for German manufacturers, is becoming an exceptionally hot topic across the industries and academic communities. The high-speed diffusion of Industry 4.0 is because industrial enterprises are facing more challenges than ever for competing in the international market, delivering high-quality and customized products in a fast and reliable way. In a similar manner the drivers of industry 4.0 also apply to the Agricultural industry. The 4.0 paradigm in agriculture regards the next industrial revolution/evolution for moving from previous industrial stages to a highly interconnected smart farm, achieving vertical integration, horizontal integration, as well as end-to-end process management. Agriculture 4.0 offers a transformative landscape for the agricultural sector, unlocking numerous promising opportunities. Firstly, advanced technologies like precision agriculture, drones, and IoT sensors allow for precise monitoring and data-driven decision-making. This translates into optimized resource utilization, better crop management, and increased overall productivity. Moreover, automation and robotics play a pivotal role in streamlining repetitive tasks, reducing labour dependency, and enhancing operational efficiency. Additionally, data analytics and artificial intelligence enable predictive modelling, helping farmers anticipate market demands, optimize supply chains, and tailor their product offerings to meet consumer preferences. These technological advancements also foster sustainable practices, promoting environmentally friendly approaches and ultimately benefiting both the agricultural industry and the planet. Furthermore, A4.0 facilitates connectivity and collaboration, enabling farmers to access global markets, engage in e-commerce, and establish efficient trading networks, expanding their reach and potential customer base. Overall, Agriculture 4.0 holds the promise of revolutionizing traditional farming methods, elevating agricultural practices to new heights of efficiency, sustainability, and profitability.

The industrial revolution/evolution is often characterized by its technology, which is the central element of such revolutions (Klingenberg et al., 2019). Indeed, the previous three industrial revolutions are separately characterized by mechanization, electrification, and computerization (Morrar et al., 2017). However, academics and practitioners attribute different technologies to Agri 4.0, and there is no agreed list of Agri 4.0 enabling technologies. In this dissertation, the aim is to investigate the Agri 4.0 enabling technologies by considering the renown academic publications and diverse national initiatives. For

example, Lezoche (2020) identifies a set of 6 technological solution clusters and proposes their set of impact and challenges. As a summary, Internet of Things (IoT), Data analytics and big data, Artificial intelligence (AI) and machine learning (ML), Cloud computing and cyber–physical system (CPS), Image processing, Geographic information system (GIS) and analytics, Robotics and automation, Drones and unmanned aerial vehicles (UAVs), Communication technologies, Blockchain, Augmented reality and virtual reality (AR & VR) are considered as Agri 4.0 enabling technologies. Indeed, Agri 4.0 introduces novel opportunities that may disrupt the traditional processes of farms, where some technologies could have transversal impacts, while others effect on a purely single process. However, current literature lack of linking between Agri 4.0, application domains and expected benefits of agricultural company in a holistic way. More specifically, a comprehensive analysis of what are the Agri 4.0 technologies and which benefits arise from their usage is at the core of the dissertation.

In this digital era, companies are facing up with significant challenges with high-speed advancement of technology evolution, whereas they need to reorganize their resources for digital transformation, understand what kind of benefits can be brought by Agriculture 4.0, and what kind of obstacles are waiting for them. Such doubts are therefore deserving empirical studies for clarification. However, there is little research considering Italy as a target, who is the second most important country in the European Union (EU) referring to Agricultural industry output (The output of the agricultural industry comprises the output of agricultural production and the output of non-agricultural secondary activities that are inseparable from the principal agricultural activity), following France. Moreover, existed research are predominantly cross-sectional studies, and longitudinal type study is not yet considered.

The landscape of research in Agriculture 4.0 reveals distinct gaps. One significant void pertains to the fragmented and non-comprehensive nature of existing contributions, failing to unify the crucial dimensions of technology, application domains, and benefits in a cohesive manner. Another substantial gap lies in the lack of targeted surveys assessing the knowledge and adoption levels of digital technologies in agriculture, alongside an evaluation of associated benefits and obstacles. Moreover, a dearth of longitudinal surveys tracking the evolving paradigm of 4.0 in agriculture within specific regions or countries highlights a need for deeper temporal insights. Furthermore, there is a noticeable absence of specialized articles that delve into dimensions, sub-dimensions, and weighting of a maturity model tailored to agricultural enterprises, particularly within the Italian market. Bridging these research gaps is essential for a comprehensive understanding and advancement of Agriculture 4.0.

This dissertation contributes to filling the aforementioned research gaps by providing more clarity about the phenomenon of Agri 4.0, its application cases, as well as the empirical evidence on how agricultural companies are involved and proceeding towards Agri 4.0. More specifically, this dissertation makes a holistic review of what are the peculiarities of Agri 4.0 in the whole life cycle processes of manufacturing companies; provides empirical testimony on the state-of-the-art of Agri 4.0 in the Italian agricultural companies, investigating the companies' knowledge and utilization level of diverse Agri 4.0 enabling technologies, and their corresponded benefits and challenges; explores the progressing character of Agri 4.0, providing a dynamic state-of-the-art of Italian farms; as well as the embryo of a maturity model to assess the readiness of companies within the 4.0 paradigm in agriculture. The overview of contributions is summarized in Figure 1.

From contribution A, it is found out that Agriculture 4.0 lies its primary focus into two domains: crop applications and livestock applications. Surprisingly, the spotlight tilts heavily towards crop-centric domains, indicating a prevailing preference. Yet, it's crucial not to overlook the rising significance of sustainable practices in livestock farming, considering the ethical, economic, and sustainability aspects associated with intensive livestock operations to sustain a growing global population. What truly drives Agriculture 4.0 is technology. Notably, IoT and data analytics take centre stage in the literature, basking in extensive exploration. However, technologies like blockchain and AR & VR seem to be underplayed, presenting a promising opportunity. Providers of these less explored technologies should seize this chance to pioneer applications in the agriculture 4.0 domain, reaping both economic and sustainability benefits. Yet, a critical observation is the absence of a structured approach to evaluating technology readiness in relation to Agriculture 4.0. Another notable observation is the lack of a comprehensive framework or standard model to gauge the readiness of various technologies concerning Agriculture 4.0. Delving into the technical functioning of digital technologies in agricultural processes is a predominant research focus. However, a structured approach to analyzing the benefits of Agriculture 4.0 is conspicuously absent. Moreover, a quantitative perspective, particularly a KPI framework comparing metrics from Agriculture 4.0 implementations and traditional farms, is notably lacking. Further research should channel its focus towards comprehensive case studies to generate substantial statistics, encompassing key aspects of benefits, whether economic, environmental, or social.

From contribution B, which highlights the varied levels of familiarity Italian farms have with proposed Agri 4.0 solutions, showcasing a diverse distribution of knowledge, most farms possess deep knowledge about only one solution. Furthermore, certain factors significantly influence awareness levels. Specifically, turnover and cultivable area positively correlate with a higher average awareness of Agri 4.0 solutions. Notably, the study underlines that awareness of each digital solution remains uneven across the identified options, indicating a lack of widespread knowledge. Additionally, the percentage of those familiar with practical implementations for each solution remains notably low. Adoption rates follow a similar trend, increasing with higher turnover and arable land size. On average, the maturity level of adoption remains relatively low, particularly among smaller companies that face barriers such as financial constraints. Consequently, larger companies lead in the adoption process due to their greater investment capacity. Nevertheless, for companies that have embraced the Agri 4.0 transformation, the journey appears less obstructed, indicating that initial steps into Agri 4.0 reduce perceived barriers. The study also delves into perceived benefits and challenges of implementing Agri 4.0 solutions. Notably, users perceive reduced technical inputs and water usage as primary benefits, positively impacting both the economic and environmental aspects for entrepreneurs. Conversely, a major obstacle lies in the limited interoperability among 4.0 systems, signalling a critical area for the stakeholders and technology providers in the Agri 4.0 value chain to focus on to extract maximum value from agricultural systems' digitalization.

From contribution C, it figures out the considerable disparity in technology acceptance across the agricultural sector, highlighting the imperative to comprehend the drivers of adoption and the associated perceived benefits. This understanding can be instrumental for policymakers, researchers, and industry stakeholders, aiding in the identification of barriers and the formulation of effective strategies to facilitate the broader integration of Agri 4.0 solutions. The findings shed light on the spectrum of business needs expressed by farmers, placing a strong emphasis on optimizing resources and enhancing operational efficiency while gaining better insights into farm operations. Furthermore, a significant revelation is the alignment between the perceived benefits of embracing Agri 4.0 solutions and the identified business needs. These encompass a focus on reduced consumption of technical inputs, improved working conditions, and lowered production costs. However, it's worth noting the evolving nature of perceived benefits over time, with a decreasing emphasis on environmental impact and consumer engagement. Additionally, concerning technology implementation, the research identifies a shift in priorities within the surveyed companies. Notably, monitoring and control systems for machinery and decision support systems have experienced substantial increases in adoption, reflecting a growing inclination towards enhancing efficiency and bolstering decision-making processes within the agricultural landscape. This evolving technology landscape within the agricultural sector holds promise for the future, heralding a more efficient, sustainable, and technology-driven approach to farming practices.

Contribution A — ***Agriculture 4.0: A systematic literature review on the paradigm, technologies, and benefits***

- **Methodology**: Systematic literature review
- **Journal**: Futures
- **Status**: Published

Contribution B — ***The Impact of the 4.0 Paradigm in the Italian Agricultural Sector: A Descriptive Survey***

- **Methodology**: Descriptive survey
- **Journal**: Applied Sciences
- **Status**: Published

Contribution C — ***Unlocking the Potential of Agriculture 4.0: A Comparative Study on Italian Farms' Technological Evolution, Business Demands, and Perceived Benefits***

- **Methodology**: Longitudinal survey
- **Conference**: XXVIII Summer School "Francesco Turco" - Industrial Systems Engineering (2023)
- **Status**: Accepted for publication

Figure 1. Overview of contributions

This comprehensive dissertation is divided into two main sections:

Part I offers a comprehensive outline of the entire thesis. In Chapter 1, a theoretical foundation covering essential concepts for this thesis is presented. Chapter 2 elaborates on the research design, emphasizing three key aspects: research gaps, inquiries, and methodologies. Moving on to Chapter 3, it provides a synthesis of overarching discoveries and contributions. Chapter 4 delves into a discussion of the results, considering both theoretical and practical perspectives, while also addressing limitations and proposing future directions. Lastly, Chapter 5 draws conclusions.

Part II consists of three distinct research papers, each tackling various facets of the primary research gaps and inquiries. These individual publications have been standardized into a common format, with references organized separately for clarity. For clarification, contributions A and B have been published in reputable international peer-reviewed journals, while contribution C has been accepted for publication in respected international peer-reviewed conferences.

1. THEORETICAL OVERVIEW

The literature review for this project examines the following aspects related to Agriculture 4.0: 1) Concept and principles of Agriculture 4.0; 2) Agriculture 4.0 enabling technologies; 3) Empirical studies on Agriculture 4.0; 4) Agriculture 4.0 evolution and Maturity model design. It's important to note that the literature review is an ongoing activity throughout the entire Ph.D. project, with varying focuses during different phases. In the initial year, the emphasis was on comprehending the concept of Agriculture 4.0, its rationale, and its fundamental principles. Moving into the second year, the primary focus shifted towards understanding the enabling technologies of Agriculture 4.0 and how businesses are influenced by it, particularly from an empirical standpoint. In the third year, greater attention was given to exploring the evolution of Agriculture 4.0, along with the design of a strong maturity model (derived from Industry 4.0 studies) for companies adopting digital solutions.

1.1 Agriculture 4.0

In the forthcoming decades, the global agricultural sector is poised to confront significant challenges that will profoundly impact overall operations. This era will witness transformative shifts in agriculture driven by the integration of cutting-edge technologies, digitalization of processes across the entire value chain, and a paramount focus on sustainability. Like the other economic sectors, agriculture grapples with the greatest challenge in fully embracing the fourth industrial revolution. This presents a clear opportunity for the widespread dissemination and adoption of smart technologies within the agricultural domain. However, the contemporary challenges faced by agriculture extend beyond mere technological concerns. The confluence of critical developments, as highlighted by The World Government Summit of Farming Technology in 2018, includes demographic shifts characterized by a growing global population expected to reach 9 billion by 2050, resulting in a 70% increase in food demand. Simultaneously, natural resource scarcity, amplified by a projected 41% increase in water consumption in agriculture, further strains existing resource utilization. Furthermore, climate change poses a substantial threat to agriculture, undermining productivity and limiting arable land. Additionally, the issue of massive food waste underscores inherent market inefficiencies.

The intersection of advancements in Information and Communication Technologies (ICTs) with the imperative to enhance agricultural productivity has driven noteworthy innovations in the field. Agriculture, similar to other sectors of the economy, is embracing digitalization. This transition, known as Agriculture 4.0 or Agri 4.0, finds its parallels with the industry 4.0 paradigm, where digital technologies are leveraged to optimize manufacturing processes. Extensive research efforts have been directed towards investigating Agri 4.0 across various scientific domains, encompassing activities related to land cultivation, engineering, economics, and management.

Must be said that agriculture holds a fundamental role in global economies, being an integral part of the Fourth Industrial Revolution, like other key sectors. The shift of the primary sector towards digitalization is not merely a prevailing trend; it is a proactive response to imminent macro challenges. These challenges include enhancing crop efficiency and effectiveness while progressing in an environmentally sustainable manner. The strong connection between sustainability and digital innovation extends beyond the primary sector, encompassing all major economic sectors. This approach gives rise to the phenomenon known as Agriculture 4.0 (or Agri 4.0), which emanates from the broader concept of Industry 4.0. Digitalisation exhibits significant potential in providing digital solutions to address fundamental issues encountered by traditional agriculture. It supports farmers in making swift decisions, achieving higher process efficiency, and promptly meeting market demands. The terminology for this emerging phenomenon varies in the literature, sometimes referred to as 'smart agriculture,' drawing parallels with the concept of 'smart manufacturing' already prevalent in the industry. Scholars have also used terms like 'smart farming' or 'digital farming.' These terms can be regarded as interchangeable; for simplicity, this paper will use the term Agri 4.0. Scholars have devoted their attention to examining how digital technologies influence the agricultural sector and how the adoption of the Agri 4.0 paradigm can revolutionize production processes and business strategies. While the literature provides insights into categorizing the potential benefits, challenges, and specific digital technologies associated with this paradigm, there is a noticeable gap regarding a comprehensive study focusing on the awareness and utilization of digital solutions in agriculture. Additionally, the scientific literature lacks contributions that survey the extent of knowledge and utilization of these solutions among farmers, as well as the overall impact experienced from using these solutions. This applies both generally and specifically within the Italian context. Furthermore, research on Agri 4.0 often overlooks the utilization of empirical methods, such as surveys, to derive scientific findings from information provided by farmer practitioners. The few empirical surveys conducted by scholars have primarily focused on other driving factors or a specific aspect throughout the questionnaire, as seen in studies by Bolfe (2020) and Chuang (2020).

So, Agri 4.0 is an evolving field with limited existing literature that delineates its fundamental characteristics. Researchers have defined Agri 4.0 as the integration of diverse technologies to automate cyber-physical tasks, enabling enhanced planning and control of agricultural production. Furthermore, it involves the establishment of an integrated value chain connecting organizations, customers, and stakeholders through technology adoption. Agri 4.0 signifies a pivotal shift in agricultural processes, necessitating the transformation of traditional business models into digital ones. This paradigm emphasizes the centrality of data, interconnecting disparate systems and actors along the agricultural supply chain. At its core, Agri 4.0 embodies the evolution of precision farming, facilitated by automated data collection, integration, and analysis from the field, equipment sensors, and external sources. The overarching objective is to transition from traditional to digital systems, ultimately optimizing cost-efficiency, profitability, and the environmental and social sustainability of agriculture. Therefore, Agriculture 4.0 is the seed of the forthcoming transformation of the agricultural industry landscape, for both developed and emerging economies.

1.2 Agriculture 4.0 enabling technologies and maturity models

The journey to the agriculture 4.0 paradigm has been a progression driven by rapid advancements in technology. It began with Agriculture 1.0, characterized by manual labour and the use of basic tools. The advent of the Industrial Revolution marked Agriculture 2.0, introducing mechanization and the use of steam power. Agriculture 3.0 emerged with the advent of computers and automation, integrating data processing into farming practices. The current leap, Agriculture 4.0, is propelled by a convergence of cutting-edge technologies like IoT, AI, data analytics, and cloud computing. This fusion enables a data-centric approach, empowering farmers to make informed decisions and optimize agricultural processes for greater efficiency, sustainability, and productivity.

Following this set-up, in the domain of Agriculture 4.0, a multitude of transformative technologies are at the forefront of innovation and digitalization. The foundation of this paradigm rests on several enabling. At the heart of this revolution is the Internet of Things

(IoT), which forms a system of interconnected devices capable of seamless data exchange, eliminating the need for direct human interaction. IoT finds widespread application in agriculture, notably in optimizing fertilizers and irrigation systems. Sensors integrated through IoT enable remote data analysis, sparing the necessity for physical farm visits (Elijah et al., 2018). Data analytics and big data play a pivotal role, involving the collection and analysis of extensive datasets to derive valuable insights and enhance yields. Key data elements encompass fuel rates, hydraulics, diagnostics, and moisture levels at harvest time (Pham & Stack, 2018). Augmented by Artificial Intelligence (AI) and Machine Learning (ML), this data drives predictive algorithms, aiding in pattern classification and problem-solving (Lezoche et al., 2020). Cloud computing and Cyber-Physical Systems (CPS) provide the necessary infrastructure, integrating with IoT to enhance response times and service quality. Moreover, the advent of image processing and Geographic Information System (GIS) technologies further propel data analytics, employing images and geographic data to monitor crop growth, health, and positions of various agricultural assets (Hamuda et al., 2016). Robotics, drones, and UAVs form a crucial part of the digital agricultural landscape, automating various processes and enhancing efficiency and precision in agriculture (Ramin Shamshiri, Weltzien, et al., 2018). Communication technologies, particularly 5G networks (and communication networks in general), form the information highways, crucial for real-time data exchange and swift decision-making in this technologically advanced era (Tang et al., 2021). While blockchain technology is relatively less explored, its potential in ensuring traceability, security, and privacy along the agri-food data supply chain is increasingly recognized (Gupta et al., 2020). Augmented and Virtual Reality (AR & VR) are emerging technologies, promising to revolutionize agriculture by providing farmers with comprehensive data insights and analytical capabilities through wearable glasses and smartphones, albeit requiring further exploration to unlock their full potential in agricultural practices (Tang et al., 2021; Zhang et al., 2020). In this evolving landscape, these technologies converge and synergize to drive Agriculture 4.0, promising a future where agriculture is more efficient, sustainable, and data driven.

Moreover, in rounding out the emphasis on technologies and their uptake, there is a noticeable absence of scientific contributions regarding tailored maturity readiness models designed to comprehensively evaluate agricultural companies in the context of Agriculture 4.0. These models are essential for assessing the degree to which farms have adopted and integrated digital technologies and practices associated with Agri 4.0. Unlike some other industries that have well-established frameworks, such as Schumacher (2016) and grey literature studies such as Boston Consulting Group's Digital Acceleration Index or CRDC a digital maturity index and assessment tool for the agricultural industry (in this case designed specifically for Australia) to gauge their readiness for digital transformation, the agricultural sector lacks standardized models that account for its unique operational and technological landscape. The absence of such models presents a challenge in objectively measuring the readiness of farms to embrace Agriculture 4.0, hindering strategic planning, resource allocation, and informed decision-making necessary for sustainable and efficient agricultural practices in the rapidly evolving digital age. Developing and implementing specialized maturity readiness models for Agriculture 4.0 is crucial to guide farms in their digital journey, enabling them to harness the benefits of technological advancements and navigate the complexities of modern agricultural systems.

2. RESEARCH DESIGN

To guarantee the quality of research, a suitable and rigorous research design is necessary. Thus, in this section, research gaps, research objectives (RO), as well as research methodologies (RM) will be presented. A research framework is designed as a guide, which is shown in Figure 2.

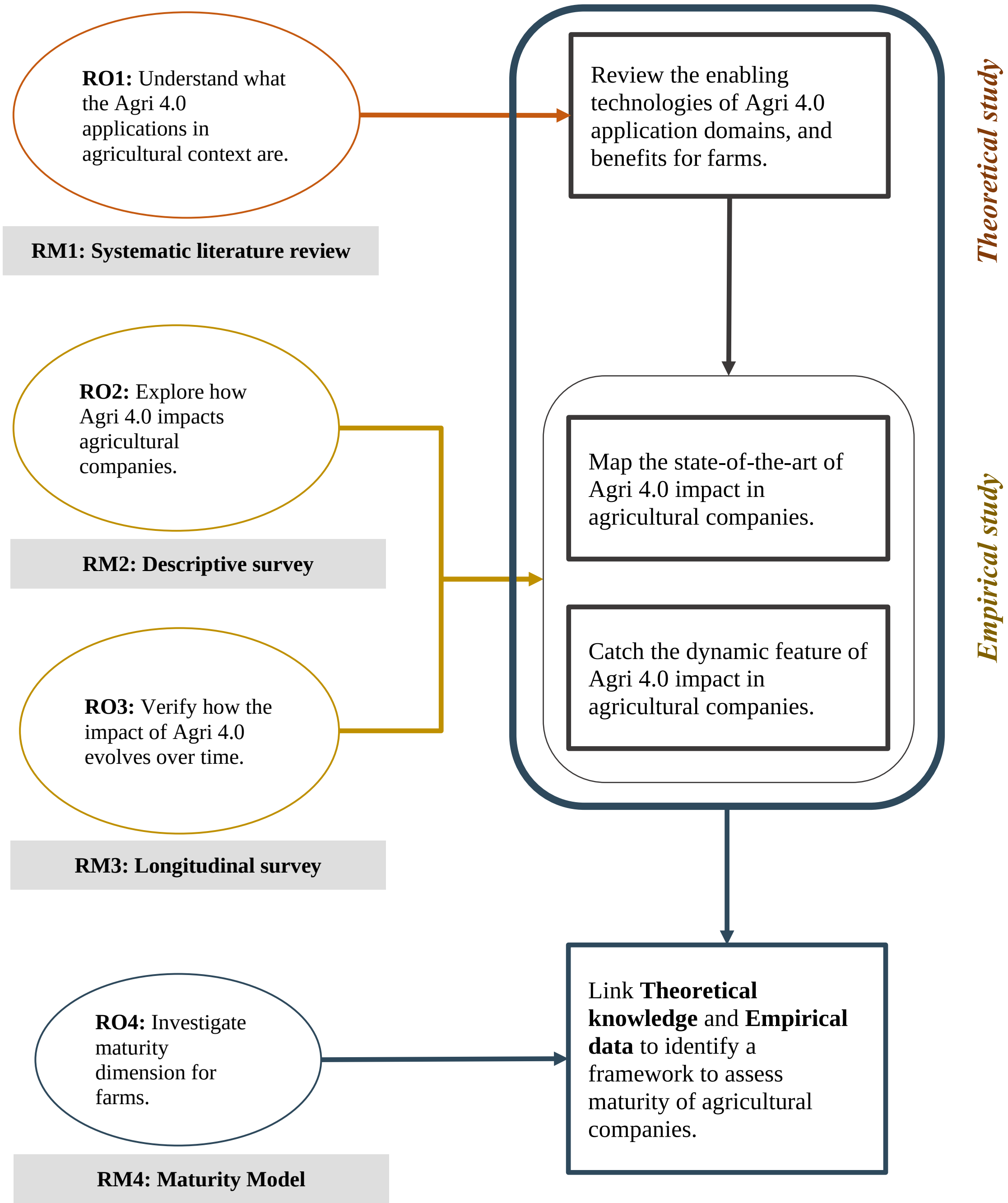

Figure 2. Research framework

2.1 Research gaps and questions

Agriculture 4.0 has obtained significant attention since its inception, capturing the interest of both practitioners and academics alike. Technological advancements in this field continue to progress at a constant and rapid pace. The rising demand for customized high-quality products and services, coupled with efficient delivery, has become an inevitable trend. In response, companies find themselves grappling with this demanding shift, seeking a deeper understanding of how they can adapt to the agriculture 4.0 paradigm, how technology can present opportunities, and what transformative steps should be taken to fully embrace this evolution. Hence, it becomes evident that delving into the impact of Agriculture 4.0 on agricultural companies is a worthwhile endeavour.

GAP 1. Little attention to the holistic definition of Agriculture 4.0, defining the paradigm and its core traits, such as Technologies, Application domains and Benefits

The topic of Agriculture 4.0 has been much debated in the literature and many of the published articles deal with the analysis of the single enabling technology and its technical function framework. So, within the scholarly body of literature, research predominantly delves into the domain of enabling technologies, focusing vertically on individual technologies and their applications and effects. However, there is a notable gap of comprehensive studies that systematically categorize the potential application domains and analyse the combinatorial effects of technology adoption within the agricultural sector. This gap highlights a critical need for a holistic analysis that aligns technology categorization with application domains, elucidating the multifaceted benefits of adopting the Agri 4.0 paradigm. Indeed, it is important to take a holistic analysis to map the relationship between Agri 4.0 enabling technologies, application domains and the arising benefits, in order to provide companies with a clear vision on what are specific traits of Agri 4.0 and its potential benefits. Hence, the attempt to narrow such a gap has been made by conducting a systematic literature review (SLR). Consequently, the following research question has been proposed, which is aimed to address the overall exposition of the agriculture 4.0 topic and introduces the convergence of Agriculture 4.0 technologies, application domains and benefits achievable:

- **RQ1: What is Agriculture 4.0 and the applications of Agri 4.0 enabling technologies on the processes of agricultural companies?**
    - RQ 1.1 Which are the main *application domains* of Agri 4.0?
    - RQ 1.2 Which are the *enabling technologies* of Agri 4.0?
    - RQ 1.3 Which are the main *benefits in the adoption* of Agri 4.0?

GAP 2. Limited empirical support to understand how Agriculture 4.0 is impacting on agricultural companies

After conducting the SLR, it is noticed that there are a few studies carried out to investigate the agriculture 4.0 phenomena from a national point of view empirically. While there has been extensive examination of this paradigm in academic literature, presenting specific instances of categorizing potential benefits, challenges, and specialized digital technologies, there is a notable lack of a comprehensive study delving into the understanding and utilization of digital solutions within agriculture. Additionally, the scientific literature has not contributed significantly to investigating the knowledge state of these solutions among farmers and the extent of their implementation, along with the associated impacts, both in a general context and specifically within Italy. Moreover, research on Agri 4.0 overlooks the application of empirical methods like surveys to derive scientifically grounded conclusions from insights provided by practicing farmers. The limited empirical surveys conducted by researchers have often concentrated on alternative driving factors or singular aspects within the entire questionnaire.

Thus, to fill the gaps, descriptive survey research has been conducted in 2021 and 2023 separately, focusing on Italian agricultural enterprises, aiming to have a deep overview on how the Agri 4.0 paradigm is understood and diffused in Italian farms, the main benefits achieved, the challenges faced, and the dynamic evolvement. Consequently, the second and third research questions are proposed, RQ2 is mainly aimed at mapping the state-of-the-art of Agri 4.0 in the Italian agricultural context, which is then composed by 4 sub questions. RQ3 is targeted to understand the dynamic change of state-of-the-art at different time slot through a two-wave longitudinal survey.

- **RQ2: How is Agriculture 4.0 impacting on Italian agricultural companies?**
    - RQ 2.1: What is the level of awareness of Agri 4.0 solutions among farm enterprises?

    - RQ 2.2: What is the level of adoption of Agri 4.0 solutions?
    - RQ 2.3: What are the main benefits perceived in adopting Agri 4.0 solutions?
    - RQ 2.4: What are the main challenges perceived in adopting Agri 4.0 solutions?
- **RQ3: How is the progressing and advancement of Agriculture 4.0 impacting the Italian farms?**

GAP 3. Few empirical studies assessing Agri 4.0 maturity levels within agricultural companies

Based on the empirical findings from the current state-of-the-art study within Italian agricultural enterprises and corresponding research focusing on the adoption levels of digital solutions in agriculture, it is evident that evaluating maturity and assessing the pertinent aspects and domains for gauging maturity are a critical topic. This hold significance in comprehending the readiness of the business community for the imminent transition towards the novel 4.0 paradigm. When focusing on the integration of technologies and their adoption, it becomes apparent that there is a noticeable gap in the scientific literature regarding tailored maturity readiness models specifically crafted to comprehensively evaluate agricultural enterprises within the context of Agriculture 4.0. These models are pivotal for evaluating the extent to which agricultural operations have embraced and integrated digital technologies and corresponding practices associated with Agri 4.0. In contrast to several other industries benefiting from well-established frameworks like Schumacher (2016), alongside tools from grey literature such as Boston Consulting Group's Digital Acceleration Index and CRDC's digital maturity index and assessment tool for the agricultural sector to assess their preparedness for digital transformation, the agricultural domain lacks standardized models that account for its distinct operational and technological environment. For this reason, it is relevant to investigate the maturity models for agriculture 4.0 and given the absence of sector-specific scientific contributions, shift the focus and take ideas from established models in the broader topic of Industry 4.0. The following research question is then proposed, which aims at describing and designing a maturity model for Agriculture 4.0:

- **RQ4: How can the farms digital maturity level be addressed?**

2.2 Research methodology

RM1. Systematic literature review

To address RQ1, an investigation of academic publications has been undertaken, following the process of Systematic Literature Review (SLR). The research methodology employed in this study followed an inductive-deductive approach, as advocated by Seuring and Gold (2012). A conceptual framework, illustrated in Figure 1, was developed as the foundational construct. This framework delineated the potential impact of various technologies on specific application domains, thereby identifying benefits arising from their intersections. The primary objective was the systematic categorization of these dimensions of technology, application domains, and benefits according to the triple bottom line framework encompassing people, planet, and profit. The focus was on three key elements: technologies as enablers of change and innovation in agriculture, application domains representing the contexts of technological solutions, and the resulting benefits. These elements constituted the central focus of the research and were explored comprehensively in subsequent sections. Constructing the conceptual framework also facilitated the planning and execution of the systematic literature review (SLR), guided by Tranfield et al.'s (2003) methodology. The SLR, adopted for selecting relevant scientific literature related to Agri 4.0, is a method that entails collecting all evidence meeting specific eligibility criteria. It involves summarizing existing knowledge, scrutinizing available research, and addressing knowledge gaps in a specific study domain.

The SLR followed the preferred reporting items for systematic reviews and meta-analysis (PRISMA) approach (Figure 2), ensuring clarity and transparency in the process. A set of preliminary keywords related to Agri 4.0 was used to identify relevant literature. The Scopus search engine and Clarivate Web of Science, recognized as authoritative sources, were employed to ensure comprehensive coverage. The sample was meticulously screened based on inclusion and exclusion criteria, yielding a final database of 1,957 studies. Only journal publications in English related to engineering, business management, economics, or computer science were included, and publications before 2011 were excluded due to the introduction of the industry 4.0 paradigm. Further screening and quality control measures were applied, resulting in 354 eligible articles for full-text screening. During the final screening, papers outside the main study scope, primarily focusing on technical aspects or not directly related to agriculture or the Agri 4.0 paradigm, were excluded. A final dataset of 107 papers was systematically analysed to consolidate knowledge in this research field, identify knowledge gaps, and propose future research directions.

RM2. Descriptive survey

Descriptive survey research is to address the RQ2. Survey research serves as an effective means to gather specific information regarding a phenomenon within a broad population, offering a satisfactory level of accuracy. The current study utilizes descriptive survey research as it aims to comprehend the significance of a phenomenon and delineate its prevalence within a population. Descriptive surveys prove invaluable in acquiring data from diverse populations, enabling precise extraction of respondents' attitudes and characteristics [40]. Moreover, they afford an effective representation of the investigated phenomenon, providing a basis for evidence. Therefore, a descriptive survey is apt when the understanding of a phenomenon is reasonably developed, variables and context can be detailed, and the aim is to ascertain the extent of a given relationship. The primary focus of descriptive surveys is not necessarily on theory development; instead, they excel in investigating a representative sample and collecting data on specific issues, laying the foundation for future decision-making activities. In this study, the primary research objective is not theory development but rather an exploration of the impacts of the Agri 4.0 paradigm within the Italian primary sector by describing knowledge levels, achieved benefits, and perceived challenges.

To achieve the outlined objectives, a three-step survey research process was employed: survey design, pilot testing, and data collection and analysis. The questionnaire comprised 18 questions, employing a combination of open and closed formats, structured into four sections. The first section aimed to gather general information and registry details about the company and respondents. The second section assessed the respondents' knowledge levels regarding each proposed solution, providing a description of each technological solution through a "link" button to ensure consistent interpretation and mitigate biases related to ambiguous questions. The third section explored the company's perceptions of the benefits of Agri 4.0. Finally, the fourth section delved into the challenges and obstacles hindering the adoption of the Agri 4.0 paradigm.

To maximize respondent participation, a web-based survey was utilized for data collection, aligning with the contemporary trend of online surveys that offer advantages over traditional paper-based approaches. Web surveys eliminate the need for manual data entry, minimize costs compared to other distribution methods, and ensure greater anonymity, reducing interviewer biases. Additionally, they enable the segmentation of specific participant groups who share common characteristics. Pilot testing was conducted to evaluate possible question biases, translation accuracy, and the logical flow of the survey before its distribution. The process involved soliciting feedback from a group of colleagues to assess readability and alignment with study objectives. Subsequently, the questionnaire was sent to seven beta-tester companies, seeking their feedback to further enhance the survey's content and validity before its official launch. The survey sample consisted of Italian agricultural companies and farms, encompassing various types of agricultural companies, excluding livestock farms, and without restrictions regarding size and cultivation sector. The survey was conducted from January to October 2021, with multiple reminders and recall activities facilitated by major Italian agricultural associations. Initially, 1,273 responses were received, and after eliminating incomplete, duplicate, and internal test responses, a validated sample of 670 companies was obtained. The respondents, typically company owners or decision-makers, possess a comprehensive understanding of their respective farms.

RM3. Longitudinal survey

To address RQ3, which is designed to catch up with the evolvement feature of Agriculture 4.0 impact in the Italian agricultural companies, a two-wave longitudinal survey is then designed and conducted. With respect to the cross-sectional survey, the longitudinal survey has distinct analytical advantages, such as the analysis of gross change, as well as catching up with time-related characteristics of events or circumstances.

As mentioned in RM2, the survey is targeted at all types of agricultural companies with all sizes and specific agricultural sectors. A static population based on the population at the time the first wave sample is selected, which implies that the second wave survey has the same population with respect to the first one. In this context, although there is a risk that some "birth" and "death" are ignored from the population, such determination considers the fact that there is a high industry engagement threshold for manufacturing companies and the availability of resources for conducting the survey. Moreover, a repeated-panel sample design is chosen, which guarantees the equivalent population of two waves, with two panels that may or may not overlap in time. Indeed, to obtain the optimal data collection period, the survey was launched at two-time slot, which is separately in the first semester in 2021 and first quarter of 2023, such interval between waves is selected, because it is a reasonable slot to capture the evolvement feature of Agri 4.0 impact. Meanwhile, two panels share the same data collection methods, whereby the self-completion web-survey is administered (using a survey digital tool: Qualtrics).

Overall, in second-panel survey was carried out in the last quarter of 2022 and the first quarter of 2023, 543 validated responses are taken into consideration, among which, 168 companies have participated the survey both in 2021 and 2023.

RM4. Modelling Digital Maturity Framework

To address RQ4, we utilized Becker's incremental process for developing maturity models, deeply rooted in Hevner's design science approach, as the guiding framework to construct our model. This approach provided a solid theoretical foundation and a rigorous methodology. Following Becker's prescribed steps, we employed a multi-methodological development approach, encompassing systematic literature research and review, expert interviews, conceptual modelling, validations, and real-world testing of the model. The development process was divided into three distinct phases. Initially, we thoroughly delved into the domain of Industry 4.0 to establish a comprehensive understanding. The subsequent core development phase focused on designing and architecting the model's structure, ensuring practical applicability. Lastly, the implementation phase involved validating the resulting tool in real-life scenarios.

The **initial steps** involved evaluating domain complexities and conducting a gap analysis of existing maturity models suitable for assessing Agri 4.0 maturity. **Next**, we conducted an extensive literature review in English on maturity models. During this exploration, we found no existing model suitable for the agriculture 4.0 domain. However, by comparing models from other domains, we formulated a design strategy, leveraging the foundational architecture of previously proven assessment tools as a starting point for our model. We extensively examined various works on maturity models, extracting relevant concepts to shape the structure of our model. This included aspects such as maturity levels (typically five, with 0 being the lowest), dimensions (our model was developed with three dimensions and several sub-dimensions), mode of assessment (defining different possible maturity clusters), and mode of representation (typically numerical, often visualized using charts). The **third** and final phase involved transforming the model into a practical and usable tool. The results are therefore numerical, but companies were also categorised and clustered into: "Star", "On the Way" and "Lagging".

3. SUMMARY OF RESULTS

This research project consists of four pieces of research that contribute to the overall goal of understanding Agriculture 4.0, its enabling technologies, and how Italian agricultural companies are involved in such a journey for the transformation of their organizations. Contribution A lays out the theoretical perspective, harmonizes the existing knowledge of Agri 4.0 with its concept, principles, enablers, as well as application domains and benefits; contribution B delineates the impact of the Agri 4.0 paradigm in Italian agricultural companies, describing the company's knowledge and adoption mode with regards to Agri 4.0 technologies, as well as their perceived benefits and obstacles; contribution C makes a further step for a dynamic state-of-the-art comparison, with empirical analysis for Agri 4.0 impacts in Italian farms at two-time slots, one in 2021 and one in 2023, trying to depict the evolvement feature of Agri 4.0 impacts; lastly, without contribution, the design and definition of maturity model axes for Agriculture 4.0, as well as preliminary results on the Maturity score of the Italian market. In the following section, a more detailed illustration of results and discussions will be shown for each research strand.

3.1 The applications of Agriculture 4.0 technologies: a systematic literature review on application domains, technologies, and benefits

Refer to RQ1, a systematic literature review is conducted, aiming at providing a holistic review of the main applications of Agriculture 4.0 enabling technologies.

Indeed, 11 enabling technologies and 11 application domains have been investigated and cross-checked. Agri 4.0 technologies considered have been: the Internet of Things (IoT), connecting devices and systems for data exchange and automation; data analytics and big data, allowing for in-depth analysis and insights; Artificial intelligence (AI) and machine learning (ML) empower intelligent decision-making processes, optimizing various aspects of agriculture; Cloud computing and cyber–physical systems (CPS) offer platforms for seamless integration and interaction; Image processing enhances visual data analysis; geographic information systems (GIS) and analytics that provide spatial insights crucial for agricultural strategies; Robotics and automation revolutionize farming operations; drones and unmanned aerial vehicles (UAVs) offer aerial perspectives; communication technologies facilitate connectivity; Blockchain contributes to secure and transparent data management; lastly, augmented reality and virtual reality (AR & VR) open up innovative ways for training, simulation, and visualization within the agricultural landscape. On the other hand, investigated application domains comprehend: Water management; Crop management and monitoring; Precision microclimatic prediction and monitoring; Agrochemical and fertilizer management domain optimizes resource utilization; Land and soil monitoring; Livestock regulation and monitoring; Greenhouse cultivation; Autonomous vehicles and machinery navigation system domain; Hydroponics and aquaponics, focusing on water-efficient; Product monitoring along the chain ensures quality and safety. To be clarified, the results shown below are mainly taken from the paper published in Futures in July 2022.

From technology perspective, IoT stands out as a key technology, revolutionizing fertilization, irrigation, and crop analysis. Data analytics and big data enable real-time monitoring and valuable insights, from fuel rates to moisture levels. AI and ML algorithms drive predictive modelling, optimizing processes using historical data. Cloud computing, intertwined with IoT, enhances responsiveness and service quality. Image processing validates innovative irrigation approaches, while GIS and GPS facilitate seamless data collection and analysis. Robotics, drones, and UAVs offer diverse applications, from pest control to precision farming. Communication technologies serve as vital information channels, and blockchain holds promise for secure supply chain traceability. AR & VR technologies, though underexplored, show significant potential, offering farmers valuable insights for decision-making. The examination of existing literature highlights a noticeable 'vertical' trend in the explored studies. Additionally, a distinct preference towards specific technologies, like IoT and data analytics, is observed, while others, notably blockchain and VR & AR, receive comparatively lesser attention. Hence, future research endeavours should delve into the rationale behind the varying degrees of attention certain technologies receive. Understanding whether this bias is influenced by their readiness for practical application or their significance within the Agri 4.0 paradigm is crucial for advancing our understanding of the field.

For Application domains perspective, Water management stands at the forefront, offering critical insights for irrigation optimization and reduced water consumption. Crop management and monitoring are pivotal, enabling data-driven decisions for crop health, growth, and efficient resource utilization. Precision microclimatic prediction and monitoring tackle climate variability, aiding sustainable agricultural practices. Reducing agrochemical usage through Agri 4.0 positively impacts costs, the environment, and production. Land and soil monitoring optimize crop cultivation, enhancing yield and minimizing waste. Livestock regulation and monitoring, though underexplored, hold significant potential within this paradigm. Greenhouse cultivation and vertical farming, driven by technology, optimize plant productivity and address land-use concerns. Automation, a dominant field, integrates various technologies for autonomous agricultural machinery and robotics. Hydroponics and aquaponics, though less discussed, offer innovative soilless cultivation methods, enhancing yield and sustainability. Finally, product monitoring along the chain utilizing IoT and blockchain presents a promising frontier for enhanced traceability and quality control throughout the value chain.

Benefits, on the other hand very from three main axis: People, Planet and Profit.

It is important to start from the latter of the dimensions, Agriculture 4.0, ensures food authenticity and safety. It emphasizes quality, reducing agrochemicals, and simplifying post-harvest processing, enhancing consumer well-being. Automation minimizes farmers' time spent on critical activities, notably irrigation. This paradigm also offers a more attractive work environment, potentially attracting the younger generation to agriculture. From an environmental perspective, Agriculture 4.0 significantly reduces polluting inputs, optimizing water consumption and land use. It aids biodiversity restoration by guiding crop choices through historical data, thus fostering sustainable agriculture. Addressing soil degradation, it boosts productivity per unit area, curbing land consumption.

Profit dimension must not be forgotten, embracing Agriculture 4.0 means lower operational costs through reduced input usage and improved efficiency, notably in vertical farming. It elevates productivity, optimizing resource allocation and increasing overall revenues. Quality improvements attract consumers, amplifying farm sales and contributing to economic growth. Economic and environmental benefits intertwine in Agriculture 4.0. By minimizing agricultural inputs, it paves the way for cost-efficient farming and reduced pollution. Establishing a comprehensive Key Performance Indicator (KPI) framework and examining benefits at different levels will steer us towards a sustainable and prosperous agricultural future.

3.2 The impacts of Agriculture 4.0: A descriptive survey in the Italian agricultural sector

Refer to RQ2, a descriptive survey is conducted and results of a total of 670 respondents have been scrutinized. In this study, 14 specific Agri 4.0 enabling technologies have been considered: Business management software, Decision support system (DSS), Agricultural machinery and equipment, Crop and soil, Enterprise infrastructure, Indoor cultivation, Precision irrigation systems, Variable rate distribution system, On-field treatment with drones, Satellite technologies, Mapping equipment installed on machinery, Mapping drones, Robot for field activities and Satellite guidance. Clustered in 5 different solution domains: Decision support system software, Monitoring systems, Systems for precision activities, Mapping systems and Autonomous systems. The knowledge and utilization level of these 14 technologies (grouped in 5 clusters) have been investigated, as well as corresponded benefits and obstacles. To be clarified, the following results are mainly taken from the paper published in the Journal Applied Sciences in September 2022.

The primary objective of this study was to comprehensively explore the Agri 4.0 landscape in Italian farms using a descriptive survey. Our approach delved into awareness levels and adoption patterns, aiming to discern the most valued benefits among users and differences within nonuser clusters. Concurrently, we sought to identify pivotal factors and challenges that influence a company's inclination towards Agri 4.0 solutions. The research encompassed a robust analysis of 670 agricultural companies in Italy, focusing on distinct digital solution clusters, including DSS software, monitoring systems, precision activity systems, mapping systems, and autonomous systems. Furthermore, in the study it is present a meticulous categorisation of benefits, aligning them with the Triple Bottom Line (TBL) framework, encompassing economic, social, and environmental dimensions. Simultaneously, we probed various challenges impeding the seamless integration of Agri 4.0, categorizing them as technological, economic, implementation, and cultural and organizational obstacles.

In a broad context, the findings underscore the heterogeneous distribution of awareness regarding proposed Agri 4.0 solutions across Italian farms. Notably, a limited number of farms possess comprehensive knowledge about more than one solution. The study revealed specific control variables that exert a more pronounced influence on the awareness levels. As the turnover and cultivable area increase, there is a corresponding uptick in the average awareness level regarding Agri 4.0 solutions. Crucially, the analysis shed light on the unevenness in awareness levels for each digital solution, indicating that pervasive knowledge across all identified solutions is yet to be achieved. Understanding practical implementations of these solutions remains a challenge, with a relatively low percentage of respondents claiming familiarity with such examples. The degree of adoption exhibited a notable trend - a rise in average adoption level as turnover and arable land size increased. However, the overall maturity level remains modest on average, indicating a less dynamic market transformation, particularly in smaller companies constrained by investment capabilities.

Significantly, we unveiled a positive correlation between company size, level of adoption, and perceived barriers. Smaller companies face greater obstacles due to economic constraints, leading to a more significant adoption shift towards larger companies. Encouragingly, companies already on the Agri 4.0 journey reported lower perceived barriers compared to those yet to initiate this transformative process.

Lastly, the study delved into the perceived benefits and encountered challenges in implementing Agri 4.0 solutions. Notably, users recognized the significant advantages of reducing technical inputs and water consumption, translating into economic benefits for entrepreneurs while positively impacting the environment. However, a critical hindrance emerged - the limited interoperability between 4.0 systems in the field. Addressing this issue is crucial, necessitating focused efforts from all stakeholders within the Agri 4.0 value chain to maximize the potential of agricultural systems' digitalization.

3.3 Unveiling Agri 4.0 Evolution through the longitudinal analysis of Technology Adoption, Business Needs, and Perceived Benefits in Italian farms

Refer to RQ3, a survey conducted in two-time slots have been compared, the conduction time was separately in 2021 and 2023. The idea of such an analysis is to understand whether companies are more involved in the Agri 4.0 journey, and what are the changes in a two-year period. To be clarified, the comparison result is based on the analysis taken from the paper presented at the XXVIII summer school of Francesco Turco in Industrial Systems Engineering.

This study represents a pioneering effort in capturing the dynamic evolution of Agri 4.0 impacts. The sample size for the two surveys was substantial, totalling 670 and 543, respectively. A static population of 168 companies was chosen for the analysis. The comparison is anchored in four fundamental dimensions: 1) the level of knowledge regarding Agri 4.0 technologies, 2) the extent of Agri 4.0 technology adoption, 3) the tangible benefits derived from employing digital solutions, and 4) the business needs that steer investments in Agri 4.0. Delving into the subset of common companies, comprising 168 farms, a focal point is the "utilizer" sample, revealing a significant 6.1% increase in users from the initial to the subsequent survey. This spike signifies an increasing interest in Agri 4.0 technologies. Specifically, monitoring and control systems for machinery demonstrated the most substantial positive delta at 16%, showcasing a marked enthusiasm to enhance operational efficiency and productivity through these systems. Correspondingly, decision support systems exhibited an impressive 11% positive delta, signifying a substantial surge in adoption, providing invaluable insights for precise agricultural decision-making.

In the realm of technology utilization, remote monitoring systems for crop and land experienced a notable 10% increase, empowering farmers to make more informed decisions regarding their land and crops. Farm management software showcased a positive delta of 13%, indicating a growing adoption trend. However, mapping services through satellite data saw a surprising negative delta of -7%, a shift potentially attributed to the rising preference for alternative mapping services like Drone mapping. An insightful exploration of positive and negative deltas revealed shifting priorities within surveyed companies. Notably, there's a noticeable trend towards optimizing technical inputs and reducing water usage, juxtaposed with a decrease in environmental impact assessment and direct product promotion to consumers. Understanding the rationale behind this shift and its correlation with external factors presents an intriguing avenue for further investigation. Furthermore, the study uncovers compelling insights from the changing perception of benefits. Efficiency-related benefits are embraced more positively, evident in the significant 15% delta related to lower consumption of technical inputs. Conversely, there's a palpable decrease in focus on soil quality and water pollution, evidenced by negative deltas of -18% and -15% respectively, signalling a reduced emphasis on environmental concerns.

The critical correlation between expressed business needs and perceived benefits emerges as a pivotal observation. Farms articulate their specific needs, predominantly focusing on reducing production costs, optimizing resource utilization, and enhancing awareness of farm operations. Remarkably, these articulated needs closely align with perceived benefits, encompassing lower input consumption, reduced machinery utilization, and improved working conditions. This alignment underscores the adaptability of the industry to changing dynamics and sustainability considerations, highlighting the importance of aligning agricultural solutions with evolving farm demands. Understanding and leveraging this relationship is paramount in developing targeted agricultural solutions that cater precisely to the evolving needs of farms, ultimately promoting sustainable and efficient farming practices.

3.4 Design and development of Digital maturity Framework

The designed maturity model for Digital Agri 4.0 incorporates three overarching dimensions, each providing a numerical assessment of different aspects crucial for evaluating the level of digital maturity within the agricultural sector. However, it should be specified that the research and thus also the definitive results on the maturity model have not been achieved, the work is however at an advanced stage, and has allowed us to draw preliminary results on the maturity of Italian farms. The results are described first by describing the output of the theoretical background work, defining the dimensions and sub-dimensions of the maturity model. Then the messages arising from preliminary numerical results are presented. The study comprehends 664 farms.

The first dimension of the maturity model is the **Technological Dimension**, which focuses on the technological landscape. It evaluates the total number of technologies implemented concurrently, the proportion of implemented technologies in relation to those known and assesses the innovativeness of these technologies by weighing them based on their level of advancement. Additionally, it includes an evaluation of the company's investment-to-revenue ratio, offering insights into the financial aspects of technology integration.

The second dimension, the **People Dimension**, sheds light on the role of individuals within the organization. This dimension considers the number of technologies known to the personnel, their average level of knowledge regarding these technologies, and their awareness of available incentives. It also evaluates the extent to which incentives are utilized and whether the organization would invest in technology regardless of available incentives.

Lastly, the **Process Dimension** examines the actual operational processes within the agricultural context. This dimension measures the proportion of agricultural land utilizing 4.0 techniques, the ratio of field-specific solutions to those not limited to the field, and the inclination towards investing in these technologies in the coming years. These dimensions, with their respective sub-dimensions, collectively form a comprehensive framework for assessing the digital maturity of Agri 4.0, providing valuable insights into technological integration, organizational readiness, and process advancements within the agricultural sector. As previously depicted, each sub-dimension ranges from a Likert scale made of 5 levels in order to jointly assess the single dimension score (from 0 to 100), as well as the overall score. Preliminary results show a low overall score of 38 out of 100. In fact, companies belonging to the 'star' class turn out to be only 8% of the total, 'on the way' the 50% of the sample and 42% of the sample is 'lagging'.

More key messages arise from preliminary results. Technology adoption increases with revenue, there is a clear correlation between revenue clusters and technology adoption. As the revenue cluster increases, the percentage of technology adoption also rises. This suggests that companies with higher revenues tend to invest more in digital technologies. Gradual improvement across all revenue clusters, there is a noticeable progression in the adoption of technologies, involvement of people, and advancement in processes. This indicates a positive trend of digital maturity as revenue increases, affirming the importance of technology in modern agricultural practices.

Preliminary results highlight a significant focus on involving people and enhancing processes alongside technology adoption. Even in lower revenue clusters, attention is given to educating and involving individuals in technology utilization, showcasing the understanding of the pivotal role people play in digital transformation.

On the other hand, there is higher maturity in larger companies. Companies with larger revenues exhibit higher levels of digital maturity across all dimensions - technologies, people, and processes. This suggests that larger companies are more proactive in embracing and integrating digital advancements to optimize their operations and stay competitive in the market. While there is a positive trend in technology adoption, people involvement, and process enhancement, there is still room for improvement in all revenue clusters. Regardless of the revenue size, companies can enhance their digital strategies to further optimize operations and maximize the benefits of technology.

4. DISCUSSION

4.1 Theoretical and Practical Implications

The domain of Agriculture 4.0 research is expansive, and given its critical importance and direct practical applicability, it presents ample opportunities for additional research. Considering the novelty of this concept and the initial stage of current research efforts, this study has certain limitations that should be considered in future investigations.

This study bears practical and theoretical implications of significant consequence for professionals and practitioners seeking a comprehensive understanding of the dynamic landscape of smart agriculture. By offering a systematisation of the present state of research, with a specific emphasis on the advantages and amalgamation of digital technologies across diverse agricultural domains, it furnishes valuable insights into the evolving domain of Agri 4.0, particularly as it gains substantial traction in recent years. Stakeholders can glean meaningful perspectives from this dissertation, setting the stage for a deeper exploration of the subject matter. As of now, the realm of Agriculture 4.0 in Italy and Europe lacks a thorough examination of its penetration levels and adoption rates. This study takes a crucial step forward by presenting empirical evidence of the state of adoption of the paradigm in Italy, serving as a potential representative for similar European economies. The burgeoning momentum of Agri 4.0 is primarily attributed to the pressing need for sustainability, efficiency, and an increasing reliance on circular approaches powered by digital advancements. However, within the realm of feasible solutions, there exists a nuanced hierarchy of awareness, suggesting that some solutions might not yet have reached a level of maturity conducive to meeting farmers' requirements.

This disparity between theoretical expectations and practical application represents a substantial implication, underlining a possible mismatch between the theoretical promise of Agri 4.0 and its actual operational manifestation. Moreover, the simultaneous utilization of multiple solutions appears to align expected benefits more closely with their actual realization, hinting at a synergistic effect. The exploratory survey results, expounded in this article, offer valuable insights that can guide professionals within the agricultural sector, technology providers offering Agri 4.0 solutions, and public administration decision-makers. Notably, the digitalization of agricultural processes seems currently viable for companies of all sizes, irrespective of their revenue or arable land metrics. This underscores the potential democratization of Agri 4.0 adoption. The identification of the most recognized solutions within the sample prompts two significant implications for practitioners: firstly, for public institutions, it provides a roadmap to effectively communicate and disseminate knowledge about potential solutions; and secondly, it guides solution providers in understanding the most well-known solutions and their potential for widespread usage, particularly in the short term. Furthermore, the benefit analysis reveals that while the average benefit among users falls short of the expectations held by non-users, those utilizing a plethora of solutions concurrently achieve an average benefit per solution comparable to their anticipated levels. Simultaneously, challenges appear to be more daunting in the eyes of non-users than for actual users. The findings emphasize that technological hindrances, especially regarding interoperability between various systems and field connectivity, represent the most formidable challenge. Policymakers should prioritize addressing these aspects to incentivize investment in Agri 4.0, especially by farms yet to embrace this paradigm. Effective implementation of Agri 4.0 necessitates the development of an integration strategy plan, seamlessly linking not only the solutions but also ensuring adequate training and skill alignment among personnel. By doing so, a successful implementation of Agri 4.0 can be orchestrated.

Moreover, the results spotlight varying levels of awareness and adoption among farmers, emphasizing certain solutions like business management software and remote monitoring systems garnering greater acceptance. The study's revelation of evolving priorities in the technologies implemented, notably the increasing adoption of monitoring and control systems for machinery and decision support systems, underlines a shifting focus towards efficiency enhancement and informed decision-making. However, comprehensive investigations that contextualize agricultural settings or regional disparities are vital for a more understanding of Agri 4.0 adoption dynamics, factoring in socio-economic conditions, infrastructure availability, and regulatory frameworks. Ultimately, this study underscores the critical need to align Agri 4.0 solutions with farmers' specific requirements and priorities, offering a foundational pillar for the targeted development of agricultural solutions that cater to evolving needs and promote sustainable and efficient farming practices.

4.2 Limitations and future directions

Like any research, the current doctoral study is not exempt from limitations. Primarily, its focus on comparing technology utilization and the 'needs vs. benefits' nexus brings to light a significant gap concerning the barriers encountered by user companies in adopting Agri 4.0 technologies. A more comprehensive examination of these impediments is crucial for a holistic understanding of the challenges faced by stakeholders in the agricultural sector. Additionally, a critical avenue for improvement lies in conducting in-depth investigations that incorporate contextual information specific to varied agricultural settings or regions. Factors such as socio-economic conditions, infrastructure availability, and regulatory frameworks play pivotal roles in influencing the adoption and awareness of Agri 4.0 technologies. Without accounting for and understanding these contextual nuances, complete interpretation and generalization of the findings remain challenging. To sum up, while this study sheds important light on aligning Agri 4.0 solutions with farmers' needs and priorities, addressing these limitations will pave the way for more comprehensive and insightful research, crucial for the advancement of sustainable and efficient farming practices.

Specifically, regarding empirical research streams, the sample utilized in this study does not perfectly align with the current Italian agricultural landscape concerning revenues and land size. This deviation from the Italian average, characterized by smaller arable land and turnover, indicates the necessity for adjustments and further refinement to enhance representativeness. Additionally, the study is confined to Italian agricultural companies, potentially limiting the generalizability of the findings. However, it's crucial to note that the Italian agricultural sector holds a significant position in the national economy, making substantial contributions to the country's GDP. Lastly, it's essential to acknowledge some constraints in this literature review. Firstly, we focused solely on academic journal papers in English, potentially excluding relevant studies in other languages and types of publications like conference papers. Secondly, the findings of a literature review are influenced by the authors and reviewers' experiences and educational backgrounds. Thirdly, we must acknowledge that we primarily considered two main sources of literature (Scopus and Web of Science), potentially missing out on important literature on Agri 4.0. However, must be pointed out that this research doesn't aim to weigh the pros and cons of the Agri 4.0 paradigm, leaving this potential research direction for future studies on this topic.

5. CONCLUSION

This section is dedicated to making a summary of the efforts contributed to this dissertation. To this end, this section 1) revisits the research questions and objectives; 2) integrates the respective findings with research gaps; 3) assesses the value of the key findings; and finally, 4) synthesis new contributions to knowledge.

Agriculture 4.0 is critical to the business of agricultural companies and provides a range of new opportunities. Nevertheless, understanding the principles of Agri 4.0, and initiating effective transformation towards Agri 4.0 is not only a technological remoulding but also a complex and non–routine managerial mission. Therefore, the objective of this dissertation is to explore the Agri 4.0 phenomenon by reviewing its applications in agricultural companies through SLR, mapping empirically state-of-the-art of Agri 4.0 impact in Italian farms, and assessing dimensions for a maturity model for agricultural companies; aiming at creating value for academia by adding to the body of knowledge in the field of Agri 4.0, as well as for practitioners by offering systematic summaries of how Agri 4.0 can be applied in companies, and providing inspirations to help them better tackle practical challenges. The following sets of research questions are strengthened again to reach the previously defined objectives and summarize the contributions of this dissertation.

RQ1: What are the applications and Benefits of Agriculture 4.0 enabling technologies on the processes of agricultural companies?

The answer to RQ1, comes from the meticulous analysis of 107 carefully selected articles. The primary objective of this analysis is to comprehensively understand the trends within the body of literature focused on Agriculture 4.0 (Agri 4.0). The analytical approach encompasses a descriptive breakdown by year of publication, the number of citations per year, and the type of study.

Notably, the analysed papers are predominantly concentrated within the time frame of 2016 to 2020, with exceptions being a few contributions in 2012 and 2021. A significant surge in literature is particularly evident from 2018 onwards, underlining a noteworthy surge of interest in the Agri 4.0 domain. Specifically, a substantial portion, 94 out of 107 articles (i.e., 88% of the studies), were published between 2018 and 2020, reflecting the growing attention and scholarly activity in this field during recent years.

The application domains of Agri 4.0 encompass vital areas that are being revolutionized through technological integration. Water management, crop monitoring, and precision microclimatic prediction are pivotal for optimizing resource usage, ensuring crop health, and adapting to changing climatic conditions. Reduction of production inputs, focusing on minimizing the use of agrochemicals, is crucial for both economic and environmental sustainability. Land and soil monitoring optimize land use, livestock regulation and monitoring cater to animal husbandry, and greenhouse cultivation provides controlled environments for optimal productivity. Hydroponics and aquaponics offer sustainable alternatives, while autonomous vehicles and machinery signify a shift towards automated, efficient farming practices. Additionally, product monitoring along the supply chain ensures traceability and quality assurance. The core of Agri 4.0 lies in a suite of enabling technologies. Internet of Things (IoT), data analytics, and artificial intelligence (AI) are prominent, providing real-time data processing and insights crucial for decision-making. Cloud computing and cyber-physical systems enable remote monitoring and control, enhancing efficiency. Image processing, Geographic Information Systems (GIS), and robotics enhance data collection and analysis, essential for precision agriculture. Drones and UAVs offer versatile applications, while communication technologies facilitate seamless data exchange. Blockchain technology ensures security and traceability, and augmented reality and virtual reality (AR/VR) present innovative ways to interact with agricultural data.

Agriculture 4.0 promises benefits across the triple bottom line - people, planet, and profits. Improved food authenticity and reduced workload for farmers contribute to societal benefits. Environmental advantages include reduced environmental impact, biodiversity enhancement, and efficient land use. Economic benefits encompass cost reduction, enhanced farm productivity, and improved product quality, driving profitability. Notably, economic and environmental benefits are interconnected, emphasizing the need for a holistic approach to measure and compare their significance.

Key findings from the literature analysis, highlighting a bias towards certain technologies and emphasizing the need for future research to explore less covered technologies like blockchain and AR/VR in Agri 4.0. Additionally, the chapter underscores the interconnectedness of economic and environmental benefits, suggesting the importance of developing a comprehensive framework for benefit assessment. Future research should aim to delve deeper into technology integration, exploring its potential at various levels within the agricultural landscape. Understanding the transformative potential of Agri 4.0 is paramount for envisioning the future of sustainable, efficient agriculture.

RQ2: How is Agriculture 4.0 impacting on Italian agricultural companies?

Despite the efforts of Contribution A in the field of scientific literature, deepening knowledge on the paradigm, its business domains and related benefits, it is imperative to emphasize the need for more empirical evidence gathering information from the real world. Contribution B, on the other hand, focuses on examining the impact of Agriculture 4.0 on Italian agricultural companies, taking into account factors such as the company's knowledge level, utilization of technology, perceived benefits, and challenges related to Agriculture 4.0 enabling technologies. Additionally, the research delves into the involvement of the company's various business functions in the transformation towards Agriculture 4.0. This study employed a descriptive survey to investigate and evaluate the stance of Italian agricultural companies in the Agri 4.0 journey, involving a total of 670 respondents. The findings from this research contribute valuable insights to the scientific understanding of how Italian agricultural companies are approaching the digital paradigm in agriculture. This understanding can assist managers in assessing their organization's current state and devising a strategic course of action. The association analysis presented in Contribution B aims to uncover the factors linked to the knowledge and utilization of Agriculture 4.0 enabling technologies. Nevertheless, each company must make informed decisions regarding the suitable, viable, and pertinent activities aligned with its business model, digital transformation strategy, and competitive landscape. In summary, Italian farms vary in their knowledge and understanding of proposed solutions related to Agri 4.0. Notably, few farms possess in-depth knowledge of more than one solution, showcasing a heterogeneous distribution of awareness. Furthermore, results reveal that certain control variables have a notable influence on awareness levels; specifically, as turnover, and cultivable area increase, there is a noticeable rise in the average awareness of Agri 4.0 solutions.

One critical aspect is the level of familiarity with each digital solution, which is not yet widespread across all identified solutions. A comprehensive understanding of these solutions remains uncommon. Additionally, the percentage of individuals claiming to have practical implementation examples for each solution is quite low. Another significant aspect pertains to the degree of adoption. Here, the central message is that the average adoption level rises with increasing turnover and arable land size. On average, the maturity level remains relatively low, and the market lacks dynamism, especially for smaller companies that are further from the change process due to limited investment capacity. This contributes to a higher adoption rate among larger companies, aligning with the identified barriers to adoption, particularly the economic challenges.

Furthermore, there's a discernible upward trend in the degree of adoption. While the average penetration rate is not notably high, companies already embracing the transition to Agri 4.0 generally perceive fewer barriers compared to those yet to initiate this transformation. Lastly, Contribution B explores the advantages and potential obstacles associated with implementing Agri 4.0 solutions. The analysis highlights that users primarily perceive benefits related to reduced technical inputs and water usage, resulting in economic gains and positive environmental impacts. Notably, a major obstacle encountered is the limited interoperability or even the absence thereof, among 4.0 systems in the agricultural domain. Addressing this obstacle should be a focal point for actors and technology providers in the Agri 4.0 value chain, enabling them to maximize the value derived from digitizing agricultural systems.

RQ3: How is the progressing and advancement of Agriculture 4.0 impacting the Italian farms?

Based on contribution B, contribution C makes a further step by conducting a two-wave longitudinal survey in Italian manufacturing companies, comparing the results of the survey launched in two-time slots, separately in 2021 and 2023, which is one of the first attempt to capture the evolvement feature of Agri 4.0 impacts. Sample numbers are 670 and 543 respectively, whereby the static population is chosen of 168 companies in total. Then the comparison is mainly derived from the following four aspects: 1) Agri 4.0 technology knowledge level; 2) Agri 4.0 technology utilization level; 3) Benefits from using Digital solutions; and 4) Business needs driving investments in Agri 4.0.

The sub-sample of common companies, comprising 168 farms, primarily focuses on the "utilizer" sample, which saw a notable 6.1% increase in users from the first survey to the second, indicating a growing interest in Agri 4.0 technologies. Monitoring and control systems for machinery experienced the most significant positive delta at 16%, underlining a pronounced interest in enhancing efficiency and productivity through these systems. Likewise, decision support systems saw an 11% positive delta, showcasing a significant surge in adoption, providing valuable insights for agricultural decision-making. The utilization of remote monitoring systems for crop and land monitoring also witnessed a noteworthy increase of 10%, enabling farmers to make more informed decisions about their land and crops. Farm management software exhibited a positive delta of 13%, indicating an upswing in its adoption. However, mapping services through satellite data stood as an exception, displaying a negative delta of -7%. This decline could potentially be attributed to the rising popularity of alternative mapping services like Drone mapping, suggesting shifting preferences within the sample. Analysing the positive and negative deltas provided insights into changing priorities within surveyed companies. There is a notable shift towards optimizing technical inputs and reducing water usage while decreasing environmental impact assessment and direct product promotion to consumers. Understanding the reasons behind this shift and its correlation with external factors could present an intriguing area for further study. Further insights emerge from the evolving perception of benefits. Efficiency-related benefits are perceived more positively, with a significant delta of 23% related to improving working conditions, particularly reducing physical fatigue. Conversely, there's a notable decline in attention towards soil quality and water pollution, with negative deltas of -18% and -15% respectively, signifying a reduction in environmental emphasis.

The correlation between expressed business needs and perceived benefits is a pivotal observation. Farms articulate their specific needs cantered around reducing production costs, optimizing resource utilization, and enhancing awareness of farm operations. These align closely with perceived benefits, encompassing lower input consumption, reduced machinery utilization, and improved working conditions. This alignment underscores the adaptability of the industry to changing dynamics and sustainability considerations, emphasizing the importance of aligning agricultural solutions with evolving farm demands. Understanding and leveraging this relationship is key to developing targeted agricultural solutions that catch the evolving needs of farmers, ultimately promoting sustainable and efficient farming practices.

RQ4. Which are the dimensions to define the digital maturity of Agricultural companies?

In conclusion, the designed maturity model for Digital Agri 4.0 presents a structured and comprehensive framework for assessing the digital maturity of the agricultural sector. While the research is ongoing, preliminary results have provided valuable insights into the state of digital maturity in Italian farms. The three dimensions of the maturity model - Technological, People, and Process - offer a multi-faceted view of digital readiness within the agricultural context. The Technological Dimension evaluates the adoption of technologies, the proportion of implementation, innovativeness, and financial investment. The People Dimension examines the role of individuals, their knowledge, awareness of incentives, and willingness to invest in technology. The Process Dimension focuses on the application of 4.0 techniques in agricultural processes, the use of field-specific solutions, and the propensity to invest in technology in the future.

Preliminary results indicate an overall digital maturity score of 38 out of 100, with a majority of companies falling into the 'on the way' and 'lagging' categories. Technology adoption is positively correlated with revenue, suggesting that larger companies are more inclined to invest in digital technologies. However, there is a noticeable trend of gradual improvement across all revenue clusters, indicating a positive trajectory in digital maturity as revenue increases. One key message from the preliminary results is the emphasis on people involvement and process enhancement alongside technology adoption. Even smaller companies recognize the importance of educating and involving individuals in digital transformation. Furthermore, the data highlights that larger companies exhibit higher levels of digital maturity in all dimensions. This underscores the proactive stance of larger enterprises in embracing digital advancements to enhance their competitiveness.

In summary, the preliminary findings of the maturity model suggest that while there is a positive trend in digital maturity, there is room for improvement across all revenue clusters. Regardless of their size, companies in the agricultural sector can enhance their digital strategies to optimize operations and reap the benefits of technology fully. The model provides a valuable tool for ongoing evaluation and improvement in the journey towards digital transformation within the agricultural sector, even though the proposed model requires further development and refinement, and a systematic testing activity must be made to generalize results that have emerged.

6. REFERENCE OVERVIEW OF ARTICLES

This section provides the full bibliographical information of the articles included in this dissertation. They jointly address the formulated research objective and form the core part of the thesis. Full articles are presented in Part B.

6.1 Agriculture 4.0: A systematic literature review on the paradigm, technologies, and benefits

Table 1 Bibliographic information of Article A

Title	Agriculture 4.0: A systematic literature review on the paradigm, technologies, and benefits
Authors	Maffezzoli Federico, Ardolino Marco, Bacchetti Andrea, Perona Marco and Renga Filippo
Outlet	Futures - (20 Scopus Citations)
Year	2022
Status	Published

Abstract

Demographics will increase the demand for food and reduce the availability of labour in many countries all over the world. Moreover, scarcity of natural resources, climate change and food waste these are issues that are strongly impacting the agricultural sector and undermining sustainability. Digitalisation is expected to be a driving force in tackling these problems that are characterising agriculture. In particular, the adoption of digital technologies to support processes in the primary sector goes by the name of Agriculture 4.0. Although the number of contributions related to these issues is constantly growing, several areas are still unexplored or not fully addressed. This paper addresses the adoption of digital technologies and investigates the application domain of these technologies, presenting a systematic review of the literature on this subject. Moreover, this research shed light on the technologies adopted and related benefits. Hence, the research has turned its attention to the description of the main pillars, such as the categorisation of its main application domains and enabling technologies. The results of the research show that the different technologies applied in the various fields of application provide benefits both in terms of efficiency (cost reduction, farm productivity) and reduced environmental impact and increased sustainability.

Keywords: Agriculture 4.0, Smart agriculture, Digital technologies, Systematic literature review

In the present study, I have conducted the systematic literature research, analysis, and interpret the result while the co-authors advised me during the journal paper formulation and methodology application.

6.2 The Impact of the 4.0 Paradigm in the Italian Agricultural Sector: A Descriptive Survey

Table 2 Bibliographic information of Article B

Title	The Impact of the 4.0 Paradigm in the Italian Agricultural Sector: A Descriptive Survey
Authors	Federico Maffezzoli, Marco Ardolino, Andrea Bacchetti
Outlet	Applied Sciences - (3 Scopus Citations)
Year	2022
Status	Published

Abstract.

This paper investigates how much Italian farms are involved in the so-called "Agri-culture 4.0" (Agri 4.0) journey. The paper focuses on analyzing the knowledge and adoption levels of specific 4.0-enabling technologies while also considering the main benefits and obstacles. A descriptive survey was carried out on a total of 670 respondents related to agricultural companies of different sizes. The findings from the survey demonstrate that Italian farms are in different positions in their journey toward the Agri 4.0 paradigm, mainly depending on their size in terms of revenues and land size. Furthermore, there are strong differences concerning both the benefits and obstacles related to the adoption of the Agri 4.0 paradigm, here depending on the technology adoption level. Regarding future research, it would be interesting to carry out the same study in other countries to make comparisons and suitable benchmark analyses. Although scholars have debated about the adoption of technologies and the benefits related to the Agri 4.0 paradigm, to the best of the authors' knowledge, no empirical surveys have been carried out on the adoption level of digital solutions in agriculture in specific countries.

Keywords: Agriculture 4.0; smart agriculture; digitalization; descriptive survey; digital technologies

In this work, I analysed the literature, conducted the results analysis, and enhanced the methodology, while the co-authors tutored me during the journal paper formulation.

6.3 Unlocking the Potential of Agriculture 4.0: A Comparative Study on Italian Farms' Technological Evolution, Business Demands, and Perceived Benefits

Table 3 Bibliographic information of Article C

Title	Unlocking the Potential of Agriculture 4.0: A Comparative Study on Italian Farms' Technological Evolution, Business Demands, and Perceived Benefits
Authors	Maffezzoli Federico, Ardolino Marco, Bacchetti Andrea, Perona Marco
Outlet	XXVIII Summer School "Francesco Turco" – Industrial Systems Engineering
Year	2023
Status	Accepted for publication

Abstract

This paper aims to investigate the state-of-the-art of Agri 4.0 adoption in Italian agricultural companies and to understand variations in business needs, technologies implemented, and benefits perceived. The study utilizes a descriptive approach with longitudinal features, examining 543 Italian agricultural companies through a survey and comparing the responses of 168 sub-samples in common with a similar survey launched two years prior. The results show that Italian agricultural companies still have limited awareness of Agri 4.0 technologies, with company size (in terms of hectares and revenues) influencing technology adoption. Knowledge and adoption of Agri 4.0 technologies increase over a two-year interval. Companies are primarily seeking Agri 4.0 solutions to improve environmental sustainability and product quality, and the perceived benefits are related to the number of Agri 4.0 technologies used. The paper acknowledges some limitations, such as the limited number of subjects involved in the longitudinal study and the focus on a limited geographical area (Italy) and suggests incorporating additional Agri 4.0 technologies in future surveys to gain further insights into Agri 4.0 development. This study provides one of the first attempts to assess variations in Agri 4.0 implementation concerning technology adoption, business need expressed by farmers, and the alteration of benefits, filling a gap in the literature of longitudinal studies investigating the development of the Agri 4.0 paradigm in a specific agricultural context.

Keywords: Agriculture 4.0, Smart Farming, Survey, Longitudinal Study

In the present work, I have analysed the literature, designed the survey protocol, enhanced the methodology and analysed the results, while the co-authors advised me during the paper formulation.

PART II

A. Agriculture 4.0: A systematic literature review on the paradigm, technologies, and benefits

Title	Agriculture 4.0: A systematic literature review on the paradigm, technologies, and benefits
Authors	Maffezzoli Federico, Ardolino Marco, Bacchetti Andrea, Perona Marco and Renga Filippo
Outlet	Futures
Year	2022
Status	Published

Abstract.
Demographics will increase the demand for food and reduce the availability of labour in many countries all over the world. Moreover, scarcity of natural resources, climate change and food waste these are issues that are strongly impacting the agricultural sector and undermining sustainability. Digitalisation is expected to be a driving force in tackling these problems that are characterising agriculture. In particular, the adoption of digital technologies to support processes in the primary sector goes by the name of Agriculture 4.0. Although the number of contributions related to these issues is constantly growing, several areas are still unexplored or not fully addressed. This paper addresses the adoption of digital technologies and investigates the application domain of these technologies, presenting a systematic review of the literature on this subject. Moreover, this research shed light on the technologies adopted and related benefits. Hence, the research has turned its attention to the description of the main pillars, such as the categorisation of its main application domains and enabling technologies. The results of the research show that the different technologies applied in the various fields of application provide benefits both in terms of efficiency (cost reduction, farm productivity) and reduced environmental impact and increased sustainability.
Keywords: Agriculture 4.0, Smart agriculture, Digital technologies, Systematic literature review

1. Introduction

Over the next decades, the world will face important issues with massive effects on the agricultural sector. Agriculture in the coming years and decades will undergo major changes, some of which are transformative in nature, such as changes associated with the introduction of new technologies to support the farmer, the digitalisation of processes and the entire value chain, and the sustainability of this sector. At the moment, among the various economic sectors, agriculture is the one that is struggling the most to fully embrace the fourth industrial revolution, and for this reason there is obvious room for greater diffusion and adoption of smart technologies. The challenges facing agriculture today, however, go far beyond those that are merely technological. In 2018, The World Government Summit of Farming Technology highlighted four critical developments that are increasing pressure on agriculture: (1) the first considers demographics, the global population will reach 9 billion people by 2050, increasing the food demand by 70%, in this first point is also worth mentioning that the ageing population in developed economies necessitates automating and digitalising agriculture to maintain current output levels and increase productivity (Guo et al., 2015). (2) the second must consider the natural resource scarcity, with current natural resource uses are critically under pressure (and water consumption in agriculture is estimated to increase by 41%) (Sott et al., 2020), (3) climate change, which threatens agriculture by eroding productivity and reduce the extension of arable land (Sott et al., 2020), and (4) massive food waste, indicating market inefficiency.

The advances in different areas of information and communication technologies (ICTs), combined with the need for improvement of agriculture productivity, have brought significant innovations in this field (Kiani & Seyyedabbasi, 2018). Similar to other sectors of the economy, agriculture is also moving towards digitalisation (Dufva & Dufva, 2019).

This concept's relation to that of the Industry 4.0 paradigm (i.e., the adoption of digital technologies to support the processes of manufacturing companies) is evident (Zheng et al., 2020, 2021). The phenomenon has been investigated according to different scientific research fields, where some are directly related to activities concerning land cultivation (water control, crop growing, harvesting, etc.), while others are extensions of the agricultural boundaries field to other disciplines, such as engineering (Ramin Shamshiri, Weltzien, et al., 2018), economics (Lezoche et al., 2020) and management (Zhai et al., 2020).

Agri 4.0 is a growing topic and the literature presents few contributions aimed at identifying its main characteristics (Escamilla-García et al., 2020; Monteleone et al., 2020), but rather has some contributions that present definitions of Agri 4.0. For instance, some researchers have made efforts to conceptualise the phenomenon and define it as the integration of different technologies to automate cyber-physical tasks, allowing better planning and control of agricultural production (Escamilla-García et al., 2020). Sott (2020) presents an important point of view, which refers to Agri 4.0 as the adoption of technology to create a value chain that integrates the organisation, customers and other stakeholders. Agri 4.0 is thus associated with a change in agricultural processes, shifting business models from traditional to digital, as well as the development of new strategic skills related to digital technologies, and establishing the centrality of data in the new paradigm to interconnect different systems and actors along the agricultural supply chain. Therefore, Agri 4.0 can be described as the evolution of precision farming, realised through the automated collection, integration, and analysis of data from the field, equipment sensors and other third-party sources. The new paradigm requires the evolution from a traditional to a digital system, with the final aim and benefits to enhance cost reduction, profitability and environmental–social sustainability of agriculture.

In the body of literature, one of the most investigated elements is the domain of enabling technologies, generally focusing on a specific technology's applications and effects. Most contributions focus vertically on a single technology; good examples are Tsouros's (2019) review of unmanned aerial vehicles (UAVs) applications, Kamilaris's (2017) contribution on the use and applications of big data in agriculture and Ray's (2017) review of Internet of Things (IoT) technology in agriculture, with some examples of practical applications. An exception is Lezoche et al. (2020) who review the set of smart technologies applied in agriculture, adopting a supply-chain perspective and identifies the technologies and relevant decision-making methods for agricultural supply chain domains. Additionally, most of the studies (Elijah et al., 2018; Hamuda et al., 2016; Kamilaris et al., 2017) focus on vertical applications of technologies, dealing only superficially with the resulting benefits. On the other hand, no contributions in literature focus on systematising the potential application domains, i.e., for which specific purposes digital technologies are being adopted in the agricultural sector. Indeed, the knowledge about the different fields is drowned inside contributions focused on technologies. For example, Alreshidi et al. (2019) deal with the application related on a single specific technology, while Sahmshiri et al. (2018) focus on greenhouse automation and controlled environment agriculture. In addition, to the best of our knowledge, there is a lack of holistic analysis regarding the benefits of adopting the Agri

4.0 paradigm, coupling the combinatorial effect of categorization of technologies and application domains.

Therefore, based on a systematic literature review (SLR), this article systematises scientific knowledge (which is rather sparce and diverse in related research streams) and sets directions for future research. With this study, the authors worked to extend the current research knowledge by addressing the paradigm from a holistic perspective and multiple dimensions, focusing on enabling digital technologies, agricultural domains of application and potential benefits. Consequently, three research questions (RQs) have been formulated:

RQ 1. Which are the main *application domains* of Agri 4.0?

RQ 2. Which are the enabling *technologies* of Agri 4.0?

RQ 3. Which are the main *benefits* in the adoption of Agri 4.0?

We have structured this article as follows: In Section 2, we describe the research methodology used. In Section 3, we present the thematic analysis. In Section 4, we list and discuss the findings and in Section 5 present our proposal for future research agenda. In Section 6, we draw the conclusions.

2. Research methodology

2.1 Conceptual framework

As described by Seuring and Gold (2012), when developing a systematic literature review it is important to adopt an inductive-deductive approach. As a starting point, a conceptual framework was developed (Figure 1). Each of the intersections in the framework represents the potential impact of the technologies on the application domains and identify the benefits arising from the intersection of these. The main objective of the research was precisely the systematisation of these two dimensions and the categorisation of the achievable benefits according to the triple bottom line guidelines (people, planet, and profit).

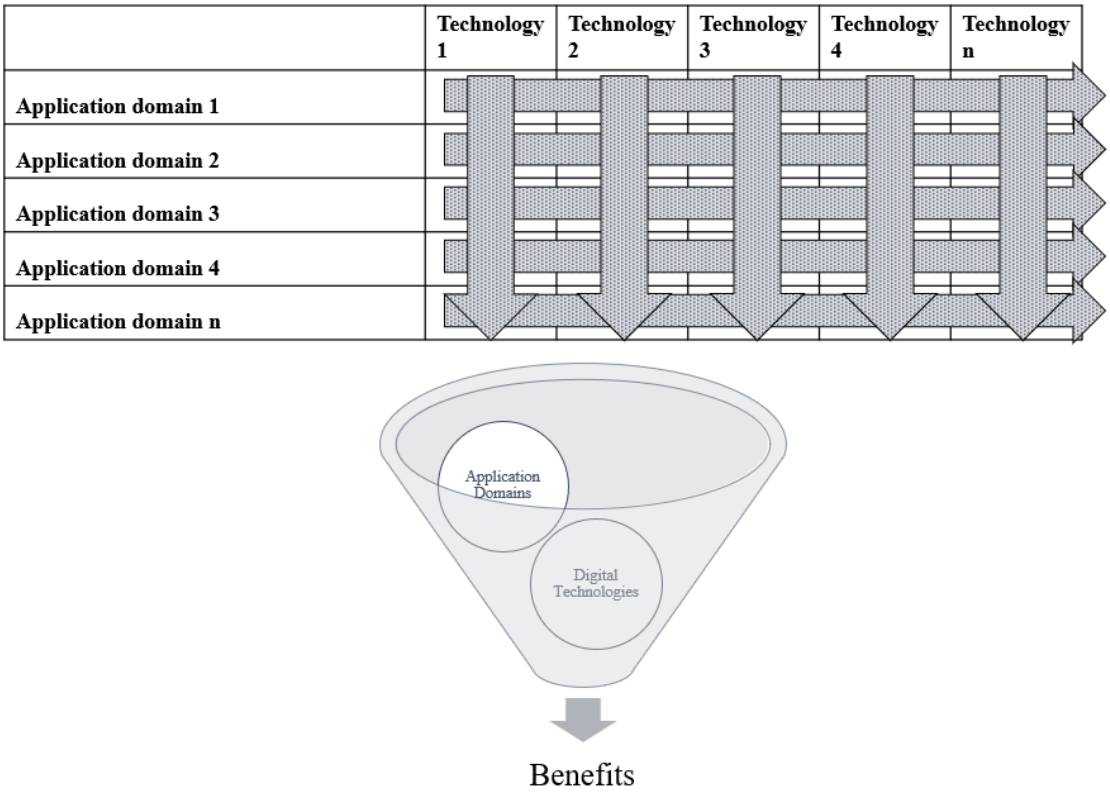

Figure 3 Theoretical Framework

Based on what is depicted in Figure 3, the key elements focused on are (1) technologies, which represent the tools with which new techniques can be developed in agriculture, playing a role as enablers of change and innovation in this sector; (2) application domains, which represent the context of use of technological solutions; and (3) the benefits, which turn out to be the effects of using the technologies in the different application domains. These elements constitute the object addressed by this research and will be shown in detail in the following sections of the article.

The activity of constructing a conceptual framework also served the purpose of supporting the planning and conduct of the review, two main steps identified by Tranfield et al. (2003).

2.2 Data collection

The SLR, which is the method adopted for selecting the scientific literature related to Agri 4.0, is presented in this section. In an SLR, researchers collect all the evidence fitting specific eligibility criteria, summarise the existing body of knowledge and scrutinise available research, aimed at filling its gaps and improving awareness in a specific field of study (Petticrew & Roberts, 2006). Although this approach evolved from the field of medicine, in recent years, systematic reviews have also been undertaken in the social and management sciences (Da Silva et al., 2020; Ülgen et al., 2019).

This SLR was conducted according to the preferred reporting items for systematic reviews and meta-analysis (*PRISMA*) approach (Figure 2) because it entails using an evidence-based checklist linked to a four-phase flow diagram and ensures clarity and transparency (Moher et al., 2015).

In principle, to identify the body of literature regarding the Agri 4.0 paradigm, a set of preliminary keywords was used: "Smart Agrifood, Smart Agriculture, Smart Farming, Agrifood 4.0, Agriculture 4.0, Farming 4.0, Internet of Farming, Digital Agrifood, Digital Agriculture, Digital Farming, Precision Agriculture, Precision Farming, Agriculture 4.0 Platform and Smart Agriculture Platform".

To ensure quality and extract the whole set of relevant articles, the Scopus search engine and Clarivate Web of Science were used, which are endorsed as world-leading sources that provide extensive documentation for many research areas (Sott et al., 2020). Keywords were searched within the titles, abstracts, and lists of keywords in the articles to ensure total coverage of the sample. The sample was extracted in late December 2020 and a subsequent extraction following the same criteria and timespan of the first extraction in early 2022 Overall, a database of 1,957 studies was retrieved. At this stage, following PRISMA principles, our objective was to identify the publications and apply practical screening. In this SLR, only journal publications were included; conference papers, book chapters and company reports were excluded (141 papers). This is the usual procedure for systematic reviews since this process acts as a quality control mechanism that confirms the knowledge provided (Light & Pillemer, 1984). Additionally, only English-language papers were chosen (54 papers excluded), and only published studies were included (61 papers excluded). Articles published before 2011 (30) were also excluded because the Industry 4.0 paradigm was first introduced in Germany at the end of 2011, and as mentioned above, the concept of Agri 4.0 has spread as a result of the digital transformation phenomenon applied to the industry sector (Lezoche et al., 2020). Moreover, 952 studies were rejected because they were published outside the subject area of engineering, business management, economics, or computer science.

In this way, we identified the set of papers eligible for screening; 176 studies were excluded because they were published in journals whose impact factor was lower than 1. The use of the journal impact factor to evaluate the quality of single articles is intended to assure a high level of objectivity and broad acceptance (Pagani et al., 2015). Finally, articles without a DOI identification were excluded (18), and duplicates between the different search sources were removed (171).

The remaining 354 articles were eligible for full-text screening. In this final step, 247 papers were considered out of scope. Specifically, 169 focused on technical aspects of technologies, such as specific standards and protocols or plant type-specific field monitoring systems, thus outside the main scope of this study. For the rest of the excluded papers, 22 did not deal with agriculture, and 23 were considered unrelated to the Agri 4.0 paradigm. In addition, other 4 articles have been cross-referenced and added to the article dataset.

In sum, we selected and analysed 1077 papers to systemise the knowledge in this research field and to identify knowledge gaps and future directions.

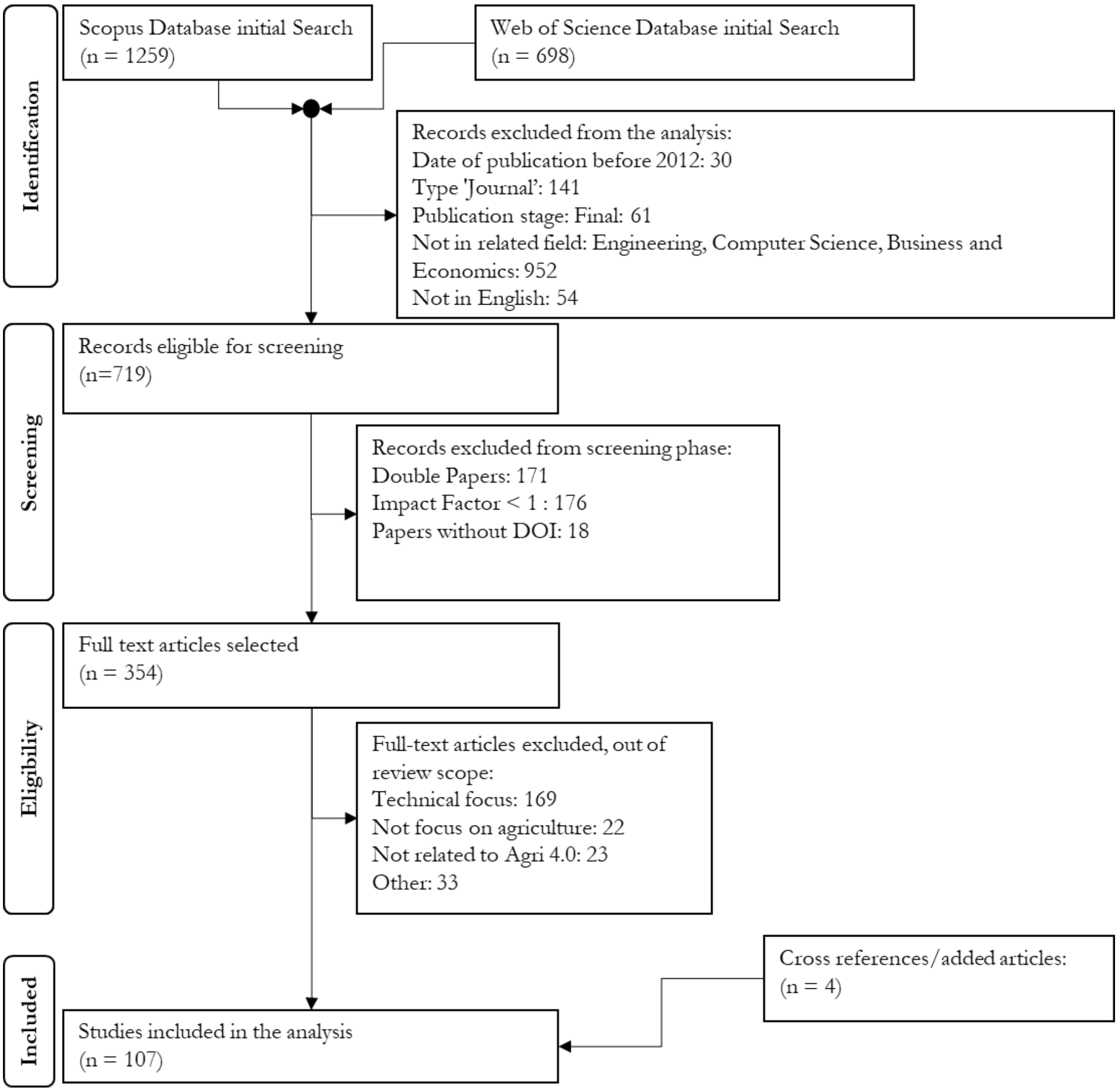

Figure 4. Flow diagram for the selection of literature reviewed based on PRISMA methodology.

2.3 Sample descriptive analysis

The 107 selected articles are analysed descriptively in this section by year of publication, number of citations per year and type of study to identify trends in this body of literature. Figure 3 illustrates the time distribution of the papers and the number of citations per year. With the exceptions of one contribution in 2012 and two in 2021, the analysed papers were all published between 2016 and 2020. In particular, a significant increase of literature streams emerged only from 2018 onwards. Specifically, 94 articles (i.e., 88% of the 107 studies) were published between 2018 and 2020, pointing out a growing interest in the field in recent years.

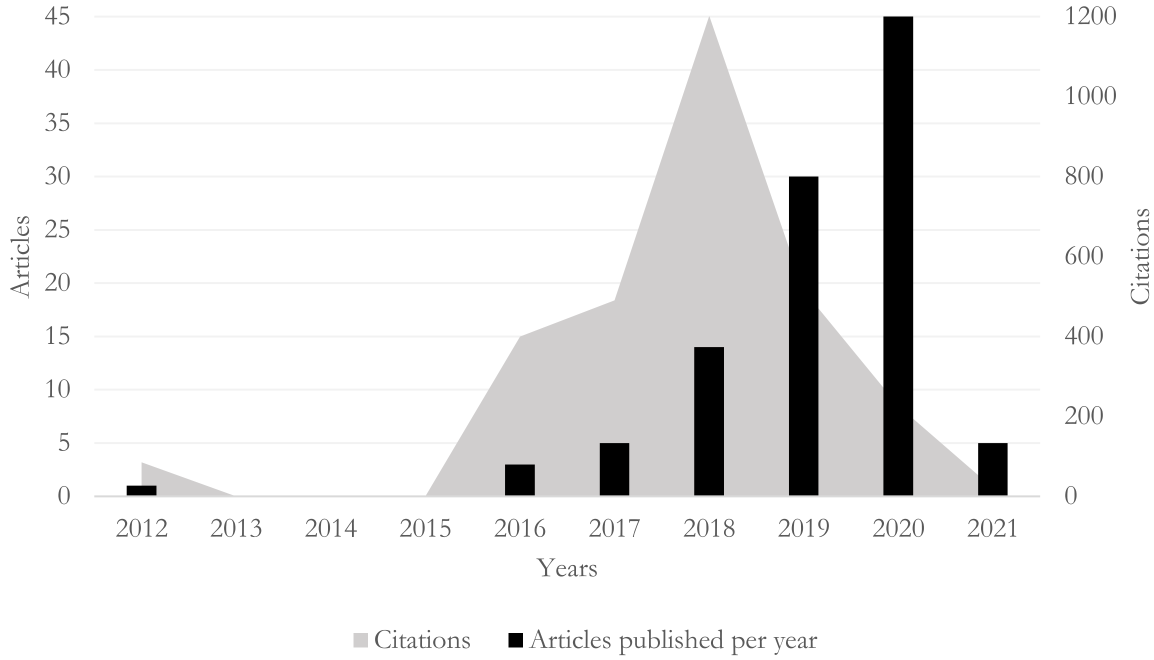

Figure 5. Publication volume and citations.

Afterwards, the contributions were classified, according to the methodological approach, as either theoretical or empirical. The theoretical papers were divided into three subcategories: (1) literature reviews, (2) SLRs and (3) concept research. The papers in the first category present a thorough review of the studies on a given topic. Those in the second category show a defined methodology, while the articles in the third category assume a specific position regarding how the selected issue is grounded in theory. We used the following three subcategories to classify the empirical papers: (1) case studies, which employ empirical research methods; (2) surveys, which employ interviews with representatives or owners of real enterprises, officials of public institutions, and experts; and (3) modelling and simulation.

The above-mentioned categories are presented in Table 4. In terms of the number of papers, it is possible to observe a balance: 49% of the studies are classified as empirical and 51% as theoretical. From the empirical perspective, modelling and simulation is the most prevalent category (28 papers, 26%), but further analysis is needed to identify their nature. The large number of papers categorised as modelling and simulation refers to technological aspects, where the focus is primarily on the technical viability of a given model or solution. This aspect is evident in some of the most representative articles, such as Partel and colleagues' (2019) study that discusses a specific solution of a precision sprayer, utilising artificial intelligence (AI), and Kiani and Seyyedabbasi's (2018) study, which explains the processes that they consider to be supported by IoT in agriculture.

Table 4. Paper type and choice of method.

Paper Type	Method	Total	Percentage %
Theoretical	Literature reviews	34	32
	Systematic literature reviews	9	8
	Concept research	11	11
	Total	54	51
Empirical	Modelling and simulations	28	26
	Case studies	17	16
	Surveys	8	7
	Total	53	49
	Overall total	***107***	***100***

Fifty-four theoretical papers account for the other half of the selected papers. The prevalent category is literature reviews (34 articles, 32%), followed by Concept research (11 papers, 11%).

Figure 4**Errore. L'origine riferimento non è stata trovata.** presents the articles categorised as literature reviews and SLRs combined. Most of the articles focus vertically on technologies (IoT above all), and all the SLRs are vertical on a single paradigm technology or application domain. However, we pay attention to the remaining articles to understand those studies adopting an application domain overview in the field of Agri 4.0. In particular, these articles define the state of the art and future trends for some of the most important areas of Agri 4.0. For example, an article (Shamshiri et al. 2018) covers a systematic analysis of automation in greenhouses. Similarly, the article of Yanes et al. (2020) has a vertical focus on aquaponics, while in the article of Saad et al. (2020), the topic of interest is water management.

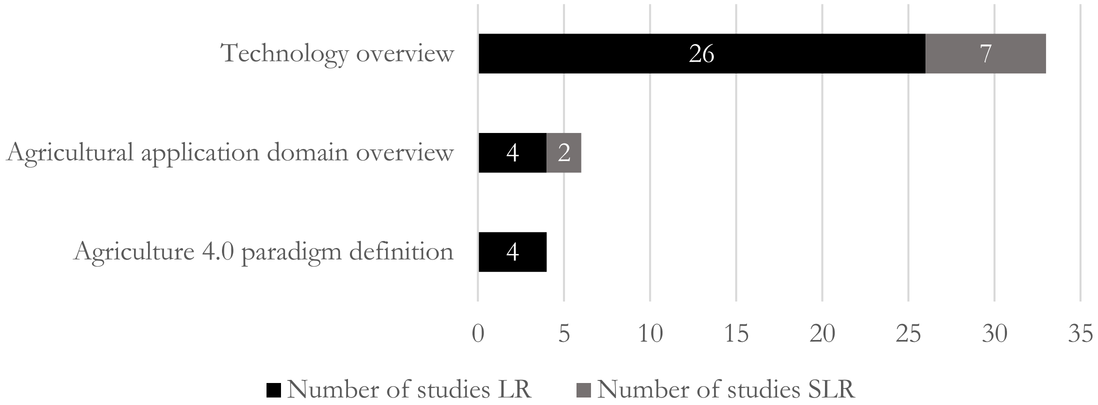

Figure 6. Overview of literature review (LR) and systematic literature review (SLR) studies.

From this focus, an important aspect is that only two paper aims to define the Agri 4.0 paradigm; the first one is Lezoche and colleagues' (2020) study, which is not an SLR and pays attention to the enabling technologies, from the specific perspective of the agricultural supply chain. The second one is Liu et al. (2021) that describes the relationship between Industry 4.0 and Agriculture 4.0, focusing on the main digital technologies.

3. Results

3.1 Main application domains (RQ 1)

In the reviewed literature, ten main application domains of the Agri 4.0 paradigm are identified and summarised in Table 22.

The first area of application researched is water management. Irrigation is one of the crucial activities in agriculture, and for certain crops, it plays a fundamentally important role. Knowing when and how much to irrigate is a valuable piece of information that allows optimisation of production and potential reduction in water consumption, an increasingly scarce resource (Khanna & Kaur, 2019). The impact of Agri 4.0 is potentially high, given the effect of agriculture on the use of fresh water (Kamienski et al., 2019) and how there is a positive impact from the perspective of the costs incurred by the farmer, especially from the environmental standpoint (Angelopoulos et al., 2020).

Second, we find crop management and monitoring (growth and health) tied in with the application areas where the aim is to rationalise the use of productive inputs in agriculture. Digital technologies applied to crop management and monitoring comprise a fundamental application domain (S. Kim et al., 2018). The data obtained and analysed through the use of digital technologies allow monitoring of crop health and growth (Partel et al., 2019) so that timely action can be taken in case of diseases or other dangerous situations (Kamilaris & Prenafeta-Boldú, 2018). They also enable the programming and development of new production and business plans (Alreshidi, 2019).

The third application domain – which is of great interest, given its potential benefits – is precision microclimatic prediction and monitoring. The variability of climate conditions is one of the main problems in agriculture; thus, data analysis and the ability to grow crops while keeping track of climate conditions in a timely manner hold great potential. The application of 4.0 technologies in this domain brings advantages to the field management (Erukala B. & Mekala R., 2019) and will be fundamental in preserving biodiversity and agricultural production in the context of climate change (Ray, 2017).

Reducing production inputs is the basis for the use of 4.0 technologies in agriculture. Reducing the use of agrochemicals (pesticide, herbicides, fungicides, etc.) is one of the main goals of Agri 4.0 (Hamuda et al., 2016). Their decreased use brings not only reduced costs to farmers (Kamilaris et al., 2017) but also huge benefits to the whole environment, given the pollutant content of these products (Alreshidi, 2019).

Following the lead of the application domains mentioned above, another aspect where technologies play a decisive role involves land and soil monitoring. Land suitability analysis is a prerequisite for crop cultivation, which helps farmers obtain maximum production and increase yield (Villa-Henriksen et al., 2020). Soil monitoring solutions help the agricultural community improve its yield and mitigate waste in the agricultural process.

Of no less importance, but less studied in the considered sample, is livestock regulation and monitoring (growth and health status). Conceptually, this domain is similar to crop management and monitoring. In this literature review, we have noticed that the set of papers is focused more on crops, but the use of the Agri 4.0 paradigm in livestock is widely used and represents one of the application domains (Jukan et al., 2017).

A wide application domain is greenhouse cultivation (indoor farming), which refers to protected environment cultivation (Ramin Shamshiri, Kalantari, et al., 2018). Due to the advances in precision technology, data processing and smart agriculture, protected cultivations have changed from simple covered greenhouse structures to high-tech plant factories that optimise the productivity of plants and human labour (Escamilla-García et al., 2020). A technique that has recently gained importance is vertical farming, which involves the production of plants in a soilless culture with a nutritive solution and tackles land-use issues, including the need for herbicides, pesticides and fertilisers (Ramin Shamshiri, Kalantari, et al., 2018).

The use of digital technologies has automation as one of its main fields of application (Zheng et al., 2020). Here, many technologies work together, allowing the deployment of autonomous, algorithmically driven robots and agricultural machines using advanced positioning systems (Ramin Shamshiri, Weltzien, et al., 2018; Roshanianfard et al., 2020). Agricultural machinery is equipped with systems that can recognise the environment where they operate, due to a platform that is able to merge signals from different types of sensors and make information unique and manageable by the system (Ding et al., 2018).

Moving down to the application domains less mentioned in the literature, we find hydroponics and aquaponics. The first is the cultivation of plants without soil. It uses a sponge in which plants sink their roots; it replaces natural soil and contains coco fibre and mineral salts, a method that allows increased yield and growth control (Terence & Purushothaman, 2020). Aquaponics is a technique of growing plants with the aquaculture effluent (Zamora-Izquierdo et al., 2019). This technique claims to have better water efficiency, does not use pesticides and reduces the use of fertilisers, making this technology greener and more sustainable (Yanes et al., 2020).

Last but not least, but with the potential to play a key role in the agriculture of tomorrow, we find product monitoring along the chain. Digital technologies play a central role in product tracking; IoT technology, together with blockchain solutions, can be implemented for product tracking and localisation throughout the value chain (Navarro et al., 2020).

Table 2. Application domains identified.

Application Domain	**Description**	**References**
Water management	Optimising water usage, this domain refers to improved irrigation techniques and processes.	*(Angelopoulos et al., 2020; Kamienski et*

		al., 2019; Khanna & Kaur, 2019)
Crop management and monitoring (growth and health)	Application of smart technologies in agriculture for the monitoring of parameters related to crop growth and health	*(Alreshidi, 2019; Kamilaris & Prenafeta-Boldú, 2018; S. Kim et al., 2018)*
Precision microclimatic prediction and monitoring	Involves the control of climatic parameters; ensures suitable growing conditions for each type of plant	*(Erukala B. & Mekala R., 2019; Ray, 2017)*
Agrochemical and fertiliser management	This refers to the management of fundamental inputs in agriculture. The improved management and precision of the technologies used allow input reduction.	*(Alreshidi, 2019; Hamuda et al., 2016; Kamilaris et al., 2017)*
Land and soil monitoring	Area of application where different monitoring and analysis technologies are used to evaluate land suitability	*(Kolipaka, 2020; Villa-Henriksen et al., 2020)*
Livestock regulation and monitoring (growth and health)	Area of application of 4.0 technologies in agriculture that refers to the monitoring of key parameters related to livestock	*(Jukan et al., 2017)*
Greenhouse cultivation	This is a specific scope of application for indoor farming. Within this specific domain are a number of other areas, such as vertical farming.	*(Escamilla-García et al., 2020; Ramin Shamshiri, Kalantari, et al., 2018)*
Autonomous vehicles and machinery navigation system	Employment of autonomous machines and robots to increase operation efficiency in the fields	*(Ding et al., 2018; Ramin Shamshiri, Weltzien, et al., 2018;*

		Roshanianfard et al., 2020)
Hydroponics and aquaponics	Provides efficient usage of water; cultivates plants without soil	*(Terence & Purushothaman, 2020; Zamora-Izquierdo et al., 2019)*
Product monitoring along the chain	Identifies, tracks and traces the elements of a product as it moves through the supply chain from raw material to finished product.	*(Navarro et al., 2020)*

Finding 1: *The main domain of application implicitly reveals the macro-field (Agri 4.0 as 'crop' applications or rather, 'breeding' ones) that is the focus of the literature (i.e., crop applications). Only one of the identified domains makes specific reference to livestock; the remaining ones are either specific to the other crop-focused macro-category of Agri 4.0 or are ambivalent domains that are treated under the latter in the literature set under consideration. One example is water management and precision microclimate forecasting and monitoring, which is always studied through the latter lens.*

3.2 Enabling technologies of Agri 4.0 (RQ 2)

The second thematic analysis concerns the enabling technologies of the Agri 4.0 paradigm. The identified technologies are IoT, data analytics and big data, AI and machine learning (ML), cloud computing and cyber–physical system (CPS), image processing, geographic information system (GIS) and analytics, robotics and automation, drones and UAVs, communication technologies, blockchain, and augmented reality and virtual reality (AR & VR) (Table 33).

Table 3. Enabling technologies for Agri 4.0.

Technology	Description	References
Internet of Things (IoT)	System of interrelated computing devices and digital machines that are provided with the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction	*(Chen & Yang, 2019; Elijah et al., 2018; Oztemel & Gursev, 2020;*

		Trappey et al., 2016)
Data analytics and big data	Collection and analysis of a large amount of data using techniques to filter, capture and report valuable insights, where data are processed at higher volumes, velocities and variety	*(Fosso Wamba et al., 2015; Pham & Stack, 2018)*
Artificial intelligence (AI) and machine learning (ML)	AI and ML offer formal algorithms for prediction accuracy and performance evaluation, as well as pattern classification that might solve knowledge issues.	*(Lezoche et al., 2020; Monostori, 2003)*
Cloud computing and cyber–physical system (CPS)	This remote software platform provides monitoring and control management. This technology can be extended on demand because data are stored and computed in virtual servers. The CPS monitors physical assets, creating virtual copies of them.	*(Lee et al., 2015; Roopaei et al., 2017; Xu, 2012; Zamora-Izquierdo et al., 2019)*
Image processing	This branch of data analytics refers to usage as the input data that the images capture during operations.	*(Barbedo, 2019; Horng et al., 2020)*
Geographic information system (GIS) and analytics	This set of technologies includes geographic positioning system (GPS), GIS, remote sensing (RS) and geo-mapping. GIS is a computer system that is able to associate data with their geographical positions and process them to extract information.	*(J. Kim et al., 2019; Shashikala S V, 2019)*
Robotics and automation	Machines that automate processes to offload physical human labour and increase productivity and product quality	*(Oztemel & Gursev, 2020; Ramin Shamshiri, Weltzien, et al., 2018)*

Drones and unmanned aerial vehicles (UAVs)	Aircraft that can fly autonomously, up to the point of being able to fly automatically, due to GPS and sensors	*(J. Kim et al., 2019; Shafi et al., 2019; Tsouros et al., 2019)*
Communication technologies	Highways over which data can be exchanged. In particular, 5G provides lower latency, enhanced broadband and massive machine-type communication.	*(Ayaz et al., 2019; Ray, 2017)*
Blockchain	Focuses on services, such as public ledgers and distributed databases in real time, and offers timestamps of blocks maintained by every participating node	*(Bodkhe et al., 2020; Sikorski et al., 2017)*
Augmented reality and virtual reality (AR & VR)	VR emphasises the immersion of the virtual world, while AR emphasises the ability to incorporate virtual information into real-world scenarios.	*(Wang et al., 2016; Zhang et al., 2020)*

Each listed technology has a wide range of applications in agriculture. The technology most commonly found in the studied literature is IoT (Jayaraman et al., 2016). The most frequent examples include the use of IoT technologies in fertilisers and irrigation systems; furthermore, by applying IoT technologies through sensors, crop data could be analysed by experts, without having to physically visit farms (Elijah et al., 2018). Moreover, Chen and Yang (2019) identify IoT as main technology for the innovation transition, through the functions of sensing, identification, transmission, monitoring, and feedback of the Internet of Things, related agricultural activities can be accurately completed.

Another technology that plays a key role in the digitalisation process of agriculture is data analytics and big data. Due to big data, the large data sets collected will allow farmers to monitor their activities and the state of their fields in real time. In this way, it will be possible to gather essential information and increase yields significantly (Saggi & Jain, 2018). Examples of data include fuel rate, speed, direction, hydraulics, diagnostics, planting and fertilising target and actual population, spacing, total acres, moisture levels at harvest time, and grain temperature (Pham & Stack, 2018).

To analyse large datasets, new methods are emerging, such as AI and ML algorithms. Building models based on AI (e.g., artificial neural networks, convolutional neural networks, reinforcement learning, etc.) is a demanding task, but the parametric estimates are useful for solving problems in a forward-looking manner. The agricultural data are analysed with various ML algorithms (Vincent et al., 2019), analysing historical information enables useful predictions and forecasts (Zhai et al., 2020). Maximising the outcome is the order of the day for any model (Sharma et al., 2020), and evaluation metrics are useful for analysing the obtained results, which in the agricultural domain means optimising the usage of inputs or pest identification and correct treating methods (Lezoche et al., 2020).

Another enabling technology that describes the paradigm is cloud computing (and CPS). The concept of cloud computing in agriculture is essential for the operation of IoT systems, so it is not a stand-alone technology but integrates with others (Alonso et al., 2020). From a conceptual standpoint, it is used to reduce the response time of devices and enhance the quality of services, providing an extra level of flexibility (Zamora-Izquierdo et al., 2019).

A topic that has gained much attention in agriculture is image processing. It refers to an approach where the collected and analysed data are images taken from the field. In the study of AlZu'bi et al. (2019), the concept of image processing is used to validate Internet of Multimedia Things (IoMT) approaches, where multimedia sensors are employed in the proposed intelligent system to optimise the automatic and unsupervised irrigation process. This technology is a specific part of data analytics that plays a major role in agriculture and is also used to monitor crop growth and health (Hamuda et al., 2016).

Using the same perspective as that of image processing, GIS and analytics include the ability to collect large amounts of data; mapping entire areas and monitoring the positions of various machines are highly relevant in this context. Agriculture requires different technologies to work in synchronisation to enable data collection and analysis. Two of the main sources of information are GIS and GPS, which allow other technologies to analyse these data and take action (J. Kim et al., 2019; Shashikala S V, 2019).

In the coming years, an important piece of innovation will be brought by robotics and automation because with higher throughput and quality standards, more Agri-robots will be deployed in the fields (Farooq et al., 2019). Applications of robots in smart agriculture have gained a growing interest because they are now capable of performing various operations, including crop scouting, pest and weed control, harvesting, targeted spraying, pruning, milking, phenotyping and sorting (Ramin Shamshiri, Weltzien, et al., 2018).

Subsequently, kept separately from robotics and automation, we find drones and UAVs. According to Kim et al. (2019), UAVs combine ICTs, robots, AI, big data and IoT. Drones are interesting because of their versatility, both for monitoring and as an active part of the production process (harvesting of products, transport of materials and distribution of agrochemicals) (Roshanianfard et al., 2020). Furthermore, these technologies have been successfully employed in many applications for precision agriculture (e.g., herbicide applications, water deficiency identification, detection of diseases, etc.). Using the information obtained, several decisions can be made to handle the problem(s) detected and/or optimise harvesting by estimating the yield (Tsouros et al., 2019).

What is considered the highways on which information flows – communication technologies – are found as links in almost every digital technology. A wide set of communication technologies can be taken into consideration, from short-range (near field communication [NFC]) (Wan et al., 2019) to the newest 5G networks. 5G is well positioned to support Agri 4.0 practices by providing wide area coverage, low power consumption, low equipment cost and high spectrum efficiency (Tang et al., 2021).

The use of blockchain technology is less discussed in the literature. Here, the main application fields are (1) product traceability along the chain and (2) security and privacy issues (Gupta et al., 2020). This technology enables solutions that guarantee greater security in the traceability of raw materials, foodstuffs and the resources needed for production. Blockchain projects enable more effective and secure document management and increase security along the agri-food data supply chain (Bodkhe et al., 2020).

Finally, the least treated technologies for agricultural practices are AR & VR. Not surprisingly, these technologies are addressed by only two articles (Tang et al., (2021); Zhang et al., (2020), which explain how AR & VR can help farmers in many ways (e.g., crop, animal and machinery statistics; weather updates; soil and water conditions; disease detection with AI for both plants and farm animals; pest detection; soil examination, etc.) through wearable glasses and smartphones. Anyway, further analysis is needed to address their full potential in agriculture.

Figure 5 presents the list of encountered 4.0 technologies, cross-referenced with the identified application domains. The chart has been made to show a concise and clear representation of the digital technologies to which the literature has paid more attention. The main takeaway from the heatmap is that the studied literature focuses more on three technologies: IoT, data analytics, and AI and ML.

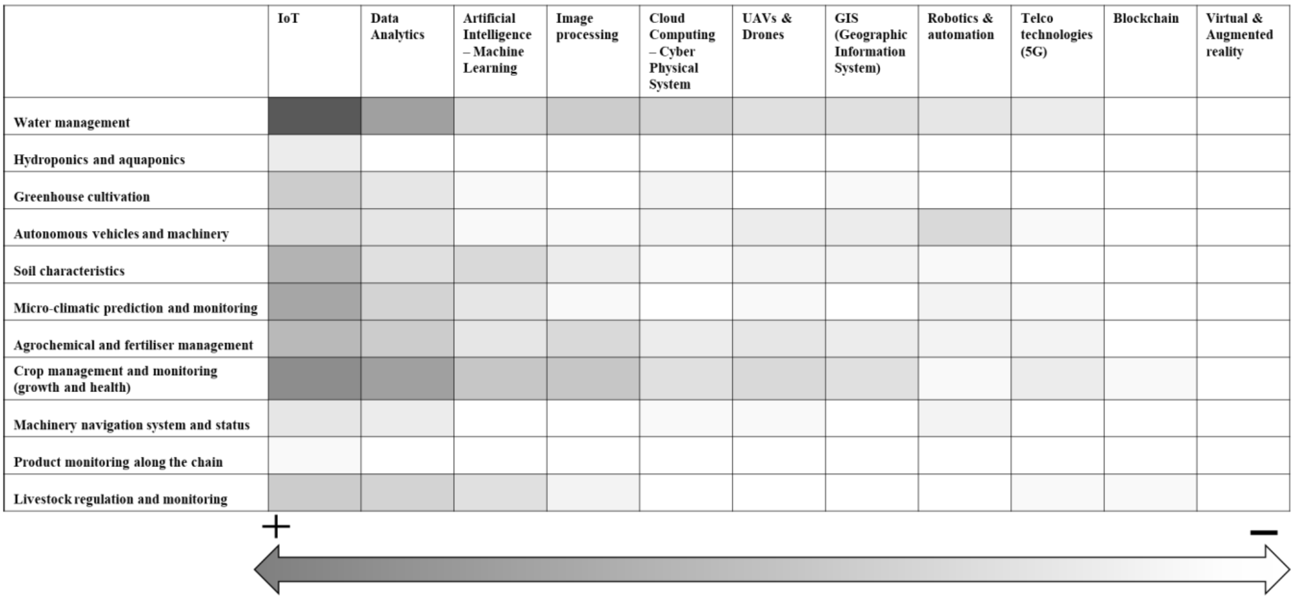

Figure 7. Heatmap of digital technologies and domains identified.

It is interesting to note how in two areas (water management and crop management, the most investigated in the body of literature), IoT and data analytics work in symbiosis. On one hand, the applications of IoT and data analytics in water management are the most studied and represented in the literature. Water efficiency is important, not only for input saving and environmental purposes, but crop quality and quantity are also affected when facing water shortage, as irregular irrigation leads to reduced soil nutrients and triggers different microbial infections (Ayaz et al., 2019). On the other hand, the applications in crop management are well investigated in Ray's (2017) paper, which explains how an IoT-based diagnosis and prevention system works to monitor and control wheat diseases, pests and weeds. Here, various sensors receive information about the environment and send the data to the collector module, which processes the information and transmits it through the gateway, the monitoring centre and the web server and is responsible for data storage and early warning release.

The last point that we want to emphasise is the application of AI and ML algorithms in agriculture. These technologies are intertwined with IoT and sensing, which act as sources that feed the decision-support algorithms in which the employed models can increase classification accuracy or reduce errors in regression problems, depending on the availability of adequately large datasets describing the determined problems (Kamilaris & Prenafeta-Boldú, 2018).

Summarising the messages emerging from Figure 5, we find that digital technologies are linked by data. Moreover, when introducing the topic of digital technologies, another important aspect is that they make data available, but it becomes essential to transform the data into information that can support users. The process of transforming the farm into an intelligent enterprise requires a software platform for Industry 4.0 that collects real-time data from machines, agricultural equipment and sensors distributed in the field and brings them to the management system to facilitate the analysis and decision support for farmers in a predictive way as well.

> *Finding 2: As noted in the literature analysis, there is not only evidence of 'verticality' in the studied contributions but also a general bias towards certain technologies, such as IoT and data analytics, and others that are mostly left uncovered (as represented in Figure 5), such as blockchain and VR & AR. Therefore, in future studies, it is important to understand why some technologies are more studied than others, whether it depends on their degree of application readiness or on their relevance within the Agri 4.0 paradigm.*

3.3 Benefits in the adoption of Agri 4.0 (RQ 3

Agri 4.0 has the potential to bring numerous benefits for all stakeholders. In this article, the description of benefits 4.0 is presented according to the principles of the triple bottom line (TBL), which is an accounting framework aimed at evaluating performance through three different lenses: people, planet and profits (Hacking & Guthrie, 2008). The benefits encountered include increased economic, environmental, and social sustainability, resulting from the use of digital technologies in agriculture (Figure 6).

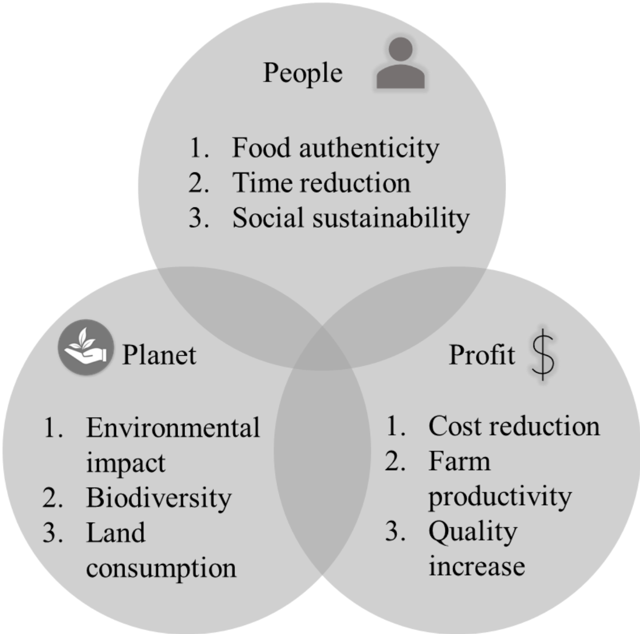

Figure 8. Agri 4.0 benefits identified.

(1) *People*

(a) Pursuing food authenticity. Increasing product quality and authenticity is not merely related to commercial purposes but also concerns food safety, where new technologies suitable for food traceability will be of great assistance (Sharma et al., 2020). Therefore, the Agri 4.0 paradigm plays an important role in reducing the number of agrochemicals and fertilisers to create ready-to-eat products after harvesting (Elijah et al., 2018), and higher product quality contributes to a better quality of life for consumers.

(b) Reduction in the time spent by farmers in carrying out operations (Khanna & Kaur, 2019; Tsouros et al., 2019). An example from the literature is Sri Heera and colleagues' (2019) paper, which emphasises irrigation as one of the most delicate and time-consuming activities and how automation can help reduce the time spent on this activity.

(c) Social sustainability. The adoption of Agri 4.0 techniques has the potential to increase farmers' quality of life. The controllable work environment in the plant factory is much more desirable than field cultivation, which requires a lot of physical energy to complete (Lezoche et al., 2020). Lastly, it is worth mentioning Chuang and colleagues' (2020) article, which presents how Agri 4.0 practices can attract young people, fighting the ageing of the sector.

(2) *Planet*

(a) Environmental impact. This is linked to the reduction in production inputs (especially polluting ones), which leads to a decrease in environmental impact (Kamienski et al., 2019). Agri 4.0 can have huge environmental impacts in the reduction of highly polluting inputs (e.g., agrochemicals and fertilisers), the efficiency in reducing water consumption, and the productivity increase in reducing the land area required for a certain amount of output (Hamuda et al., 2016).

(b) Biodiversity enhancement. Recently, we have observed a significant reduction in biodiversity (Lezoche et al., 2020), but due to Agri 4.0, it is possible to reverse the trend by using historical data and a database where farmers are supported in choosing the correct crop to plant in a given climate zone (Mohd Nizar et al., 2021) to support agricultural diversification.

(c) Reduction of land consumption: Soil degradation is a major problem, linked to various aspects, including pollution and climate change. It suffices to say that Africa is experiencing a 3% annual decrease in agricultural production due to soil erosion and land and environmental degradation (Magombeyi, 2018). In this respect, Agri 4.0 can help agriculture, to improve production performance per used area and leads to the mitigation of the problem of insufficient arable land (Madushanki et al., 2019).

(3) *Profit*

(a) Cost reduction. This is related to input reduction (e.g., water, fertilisers, agrochemicals, etc.) and process efficiency (the benefit that is most often found, in 59% of the articles in the analysed literature) (Hamuda et al., 2016; Ramin Shamshiri, Kalantari, et al., 2018). Delving deeper into this benefit, Shamshiri et al. (2018) provide a more specific view, reasoning in the case of vertical farming (a branch of greenhouse farming), whose economic benefits include reduced energy costs, lower food prices and an economic opportunity to secure land and return investments to investors by protecting against floods, droughts or damages caused by the sun.

(b) Enhancement of farm productivity. This means decreasing the time spent in operations, increasing the yield per square metre, and increasing the lifecycle of the cultivation system itself. Kim et al. (2018) cite a significant example of a real case, where a predictive disease monitoring system is applied to strawberries and how this support system has led to increased productivity.

(c) Quality improvement. An improvement in the quality of delivered products has the potential to increase farm sales because the use of smart techniques reduces the costs of managing different crops, making it economically advantageous to produce particular types of crops, thus enhancing revenues (S. Kim et al., 2018).

> Finding 3: *In addition to identifying and documenting the main benefits associated with the paradigm, we have realised how two of them are intertwined: economic and environmental benefits (profit and planet). Both benefits are mainly driven by the reduction of agricultural inputs, which consequently leads to a lower cost for agriculture and less pollution from its operations. Furthermore, it is unclear whether there is a model for assigning the levels of significance to various benefits; developing a key performance indicator (KPI) framework that compares metrics from Agri 4.0 examples and traditional farms is something to focus on. It is also important to investigate the achievable benefits by examining what occurs at three distinct levels: (1) farm, (2) supply chain and (3) systemic (country) levels.*

4. Discussion

The analysis of the application domains has made it possible to identify the two main subdomains of Agri 4.0. The first one is related to crop applications; the second is related to livestock applications. In this paper, 11 application domains of Agri 4.0 are identified. However, our analysis indicates that only one domain is directly related to livestock, a symptom that more attention is paid to crop applications. This is confirmed by the fact that even ambivalent domains (e.g., water management, precision microclimatic prediction and monitoring, autonomous vehicles and machinery, navigation system and product monitoring along the chain) are explored in the literature from the perspective of the crop-related domain rather than the livestock-related one. Although it may be considered a lesser priority issue, sustainability in livestock farming is also becoming increasingly important. The increased use of intensive livestock farming to feed an ever-growing world population is becoming a major issue, both from an ethical, economic and sustainability point of view. The development of scientific research must therefore also move on this front in order to ensure the greatest possible efficiency in the consumption of the planet's resources.

It is also very interesting to note that technologies lie at the core of the paradigm since they enable Agri 4.0. In the bulk of the literature, it has been possible to notice that most of the attention is paid to few technologies. Figure 5 highlights that only a few digital technologies have been extensively analysed in relation to Agri 4.0 application domains, predominantly

IoT and data analytics, while others, such as blockchain and AR & VR, are not stressed enough. This should be a cue for the providers of these technologies to exploit the opportunity to develop applications in the Agri 4.0 domain, to pursue both economic and sustainability benefits.

Another point to highlight is that in all articles that discuss one or more technologies is their missing framework or standard model to describe the readiness of various technologies in relation to Agri 4.0. In other words, it would be interesting to understand why some technologies are more studied than others, whether it depends on their degree of application readiness or on their relevance to the paradigm itself. As pointed out throughout this article, most research is aimed at understanding how digital technologies technically operate in agricultural processes. In Finding 3, we note the lack of a structured approach to the analysis of the benefits of Agri 4.0. Moreover, a quantitative vision for developing a KPI framework that compares metrics from Agri 4.0 examples and traditional farms is missing. In this case, further research should be directed to specific case studies to generate considerable statistics on the main aspects of benefits (economic, environmental, and social).

Table 4 Matrix of benefits depending on Technologies and Domains

	Infrastructure technology (Internet-of-Things, 5G; Edge computing; GIS)	**Communication technology (blockchain; AR/VR)**	**Automation technology (robotics and automation; drones)**	**Data processing technology (Data analytics; AI-ML; Image processing)**	**Collaboration technology (Cloud computing and cyber physical system)**
Environment and Product monitoring (Soil characteristics; Climate prediction and monitoring;	Quality Increase; Cost Reduction Biodiversity Impact	Quality Increase; Time Reduction;	Quality Increase; Social Sustainability Biodiversity Impact	Quality Increase; Farm Productivity; Cost Reduction	Time reduction; Social Sustainability; Farm Productivity

Crop/Livestock management and monitoring)	Land consumption			Land consumption	Biodiversity Enhancement
Input management (Water management; Agrochemical and fertilizer management)	Cost Reduction; Farm Productivity	Cost Reduction; Farm Productivity	Cost Reduction; Farm Productivity	Cost Reduction; Farm Productivity Quality Increase	Cost Reduction; Farm Productivity
Indoor farming (Hydroponics and aquaponics; Greenhouse cultivation)	Time reduction Farm productivity	Time reduction; Social Sustainability	Land Consumption; Time reduction; Environmental Impact	Time reduction; Cost reduction; Farm productivity Biodiversity Enhancement	Time reduction; Cost reduction; Biodiversity Enhancement
Value chain integration (Product monitoring along the chain	Time reduction;	Social Sustainability; Food Authenticity;		Social Sustainability; Food Authenticity	Time reduction
Instrumentation infrastructure (Autonomo	Environmental Impact Cost Reduction	Time reduction	Quality Increase; Time Reduction;	Quality Increase;	Time reduction Cost Reduction

us vehicle and machinery; Machinery navigation system and status)				Cost Reduction ; Time Reduction	

Based on the results of this study, Table 4 summarizes the main applications of the digital technologies examined for the 4.0 paradigm in agriculture. The technologies are grouped into five categories-infrastructure, communication, automation, data processing, and collaboration-following the classifications presented in Ivanov and Dolgui (2021b), and Dolgui and Ivanov (2021a), while the application domains were grouped into four main clusters. In each cell of the matrix, the benefits that can be pursued through different technologies in the various application domains have been identified. Analysing the proposed matrix, we notice that many benefits are repeated in the same way in different clusters of technologies, showing that very often the results are obtained through the joint application of different technologies.

Another aspect that emerges clearly from the matrix is that Agriculture 4.0 has great potential not only economically, by increasing productivity and lowering farm costs, but it can also play a very important role in preserving the environment and improving farmers' working conditions (Bersani et al., 2020). Therefore, the concept of responsible innovation can be introduced (Bronson, 2019), meaning innovation that is aimed at the quality of life. In particular, responsible innovation is a rubric for guiding innovation toward socially and ethically acceptable ends with links to European technology assessments as well as to corporate social responsibility. This brings the examination of smart technologies in terms of their potential to ensure productive and ecological efficiency in a socially responsible fashion (Klerkx et al., 2019). Future-oriented techniques such as foresight studies and scenario building will play a key role in this (Klerkx & Rose, 2020), helping the farmer by exploring alternatives of possible futures. This will make it possible to explore alternatives and to track and measure environmental and social goals improving the overall perception of agricultural activities, resulting in an integrated sustainability model (Fielke et al., 2019), enabling farms not only to pursue economic results but also to achieve and measure social and environmental objectives. These important elements of (in this case mainly digital) innovation in agriculture need to be discussed taking into account the ethical implications that emerge, such as (1) data ownership, (2) the distribution of bargaining power and, (3) more generally, the effects of digital innovation on human life and society (van der Burg et al., 2019). This specific issue was also studied by Bronson K. (2018), where the issue of rights holders is a key theme; the concern is to bring into play reasoned decisions on the technological needs and concerns of food system actors and policy makers.

In addition, Table 4 clearly indicates an existing research gap concerning the analysis of the benefits that automation technology can bring to agri-food supply chain integration (i.e. connecting all key players in the supply chain from farm to consumer), yet this technological cluster will play a fundamental role in the future in every sector and domain, so it would be interesting to investigate this direction to assess the potential of automation for value chain integration.

5. Research agenda

This study represents our attempt to consolidate the relevant research on Agri 4.0. Our analyses show that a limited number of studies have addressed the convergence between research on digital technologies and agriculture from a descriptive perspective regarding the paradigm itself. In our three main findings that summarise our thematic analyses, we identify possible future research directions, which are summarised in Table 5.

Table 5. Research directions emerging from the findings.

Findings	Research directions
Finding 1: Agri 4.0 application domains, less attention to livestock applications	1a) Study how to sort crop and livestock applications, identifying similarities and differences.
Finding 2: Digital technologies form the core of Agri 4.0, a missing readiness assessment	2a) Focus on how to assess different digital technologies' readiness in agriculture. 2b) Identify the relevance of different technologies, depending on the agricultural application domain.
Finding 3: The need for models and a framework to analyse benefits of Agri 4.0	3a) Catalogue the metrics to evaluate the benefits of Agri 4.0.

	3b) Research on how to sort different benefits' implications for three distinguished levels: enterprise, supply chain and systemic levels. 3c) Which role can automation technologies play in food supply chain integration? (The farm to fork concept)

The first finding leads us to think that there is less academic interest in breeding applications, and as a future direction of research, it becomes essential to understand how to unpack these two dimensions and understand their similarities and differences in detail.
The second finding is related to digital technologies. They lie at the core of digital revolution and in future research, scholars should concentrate on the entire set of technologies and on how the interactions among them are fundamental for the correct development of smart agriculture and for directing policy makers to the right prioritisation of emerging technologies in this field (Borch, 2007).

Lastly, it is crucial to pint out the importance of benefits for the achievement of full digital revolution in agriculture. The correct measurement and metrics to assess impact is fundamental. For future research, scholars should concentrate on the conceptual models and the hypotheses developed in case studies. Research is also required to support such processes, for instance, to quantitatively verify the organisational (e.g., capabilities, roles, technologies, and tools) prerequisites for correct implementation of Agri 4.0. The metrics for benchmarking have to be applied to the measure and the impacts at farm, supply chain and systemic levels. This is fundamental in understanding the real impacts at various levels, and it is also important to provide guidelines to decision makers and policy makers (Konrad & Böhle, 2019).

6. Conclusions

Agri 4.0 that is based on 'smart connected products' carries the potential to revolutionise the agricultural industry. Despite the growing popularity of and attention to the paradigm, there is plenty of space for new research in this area. To complete this SLR, we have applied the PRISMA methodology and have analysed 97 scientific papers. We have addressed the RQs regarding the categorisation and the definition of Agri 4.0 pillars: (1) identify its application domains, (2) determine the roles of enabling technologies of Agri 4.0, crossed with the application domains, and (3) cluster its main benefits. With this contribution, we intend to provide a systematic definition of Agri 4.0 pillars and direct the future of research based on the most relevant criticalities that have emerged. Many gaps appeared during the analysis; there is a lack of specific, quantitative analysis of technologies and benchmarking against traditional situations. This problem is also reflected at the systemic level, where no attention is paid to the positive effects that can be achieved, both economically and environmentally.

It is worth pointing out the synergy between economic and environmental benefits. Input reduction and better crop management not only lead to decreased operating costs for farmers but also have a strong environmental character by minimising the use of highly polluting products. Furthermore, Agri 4.0 will play a central role in reducing the use of soil by increasing the crop yield per square metre and decreasing the use of fresh water, which in the coming years will become an increasingly scarce resource. Moreover, the results indicate that the current body of literature focuses more on technologies (vertically). To let the Agri 4.0 paradigm take full root, it is necessary to be able to use multiple technologies and data sources, which need an open and horizontal environment. But it is also important to emphasise how the concept of responsible innovation finds fertile ground in the context of agriculture 4.0. Technological innovation and its subsequent use in the fields must be accompanied by the concept of responsibility, both at environmental and social level, as the use of digital technologies and 4.0 solutions in agriculture holds great potential in these areas.

This article also has some practical implications. As is the case with all literature reviews, ours is helpful for managers and practitioners who do not have the time to track down all the existing literature on their own. Practitioners can find in this paper a synthesis of the state of research on smart agriculture. The Results section, where we discuss the benefits and how digital technologies are present in different agricultural application domains, may also be useful for them. As shown in Section 0, Agri 4.0 is a topic that has gained steam in recent years, which is the reason why the previously mentioned stakeholders are potentially interested in the kind of article that we have proposed. It is our hope that the academic literature would provide even better advice as the field moves forward and could inspire more scholars to work on this topic.

Finally, it must be noted (as in any research) that this literature review has some limitations. First, we have focused only on academic journal papers written in English. We are aware that excluding studies written in other languages, as well as other types of publications (e.g., conference papers) might have limited our findings. Second, the findings of a literature review depend on the reviewers' experiences and educational backgrounds. Third, it is important to mention the fact that only one main source of literature has been considered (Scopus); even if it is well known for being highly populated, we might have omitted part of the important literature on Agri 4.0. The fourth limitation lies in the selection of the impact factor as a search filter, and it is possible that we have omitted a fraction of the relevant literature. The final limitation concerns the potential bias arising from the formulation of RQ3. In fact, this article focuses on the potential benefits of the application of digital technologies in the agri-food context, without considering the potential negative effects as well as the necessary challenges to be faced by practitioners. However, the analysis of this research does not aim to put the pros and cons of the application of the Agri 4.0 paradigm in the balance, leaving this potential research direction for future studies of this topic.

B. The Impact of the 4.0 Paradigm in the Italian Agricultural Sector: A Descriptive Survey

Title	The Impact of the 4.0 Paradigm in the Italian Agricultural Sector: A Descriptive Survey
Authors	Federico Maffezzoli, Marco Ardolino, Andrea Bacchetti
Outlet	Applied Sciences
Year	2022
Status	Published

Abstract.

This paper investigates how much Italian farms are involved in the so-called "Agri-culture 4.0" (Agri 4.0) journey. The paper focuses on analyzing the knowledge and adoption levels of specific 4.0-enabling technologies while also considering the main benefits and obstacles. A descriptive survey was carried out on a total of 670 respondents related to agricultural companies of different sizes. The findings from the survey demonstrate that Italian farms are in different positions in their journey toward the Agri 4.0 paradigm, mainly depending on their size in terms of revenues and land size. Furthermore, there are strong differences concerning both the benefits and obstacles related to the adoption of the Agri 4.0 paradigm, here depending on the technology adoption level. Regarding future research, it would be interesting to carry out the same study in other countries to make comparisons and suitable benchmark analyses. Although scholars have debated about the adoption of technologies and the benefits related to the Agri 4.0 paradigm, to the best of the authors' knowledge, no empirical surveys have been carried out on the adoption level of digital solutions in agriculture in specific countries.

Keywords: Agriculture 4.0; smart agriculture; digitalization; descriptive survey; digital technologies

1. Introduction

In the coming decades, the world will face major issues that will have massive effects on the agricultural sector. Three main challenges are on the horizon: (1) The world population is set to increase. It is estimated that the human population will reach 9 billion people by 2050, increasing the demand for food by 70%, and water consumption in agriculture is expected to increase by 41% (the sector is already responsible for the consumption of almost 70% of the fresh drinking water on the planet) [1]. (2) In the medium term, climate change will profoundly affect the extent of arable land worldwide [2]. (3) The aging population in developed economies will soon bring the need to automate and digitize the agriculture sector [3].

Agriculture is a fundamental part of all economies in the world and, like all key sectors, is involved in the Fourth Industrial Revolution. The evolution of the primary sector toward digitalization is not dictated by an overall trend but aims to address the main macro issues in the years and decades to come, such as the need to make crops more efficient and effective and to evolve in an environmentally sustainable way. The strong link between sustainability and digital innovation is not limited to the primary sector but involves all major economic ones. From this approach, the phenomenon of Agriculture 4.0 (from now on, Agri 4.0) derives from the broader theme of Industry 4.0, which is considered to have huge potential in providing digital solutions to address the main problems encountered by traditional agriculture, enabling support for farmers to make faster decisions, achieve higher process efficiency, and have the ability to take timely action to meet market demands [4]. The literature sometimes also refers to this emerging phenomenon as "smart agriculture," basically taking its cue from the concept of smart manufacturing, which is already widely used in industry [5]. In other cases, scholars have used the term "smart farming" [6], [7] or "digital farming" [8]. All these terms can be seen as synonyms, so for the current paper, the term Agri 4.0 will be used for simplicity purposes.

Scholars have focused on how digital technologies impact the agricultural sector [9], [10] and how the diffusion of the Agri 4.0 paradigm can transform production processes and business strategy [4].

Although this paradigm has been investigated in the literature, presenting concrete examples of categorization of the possible benefits, obstacles, and dedicated digital technologies, there is no pervasive study focusing on the knowledge of digital solutions in agriculture and their degree of utilization. Moreover, the scientific literature presents no contributions when it comes to surveying the state of knowledge of the solutions among farmers and their degree of use, as well as the impacts received in using these solutions, both in general terms and specifically in the Italian context. In addition, research on Agri 4.0 neglects the use of empirical methods, such as empirical surveys, to develop scientific results from information from farmer practitioners. The few empirical surveys carried out by scholars have tended to focus on other drivers or on a single aspect throughout the whole questionnaire, such as the ones by Bolfe [11] and Chuang [12].

In an attempt to fill the above-mentioned literature gaps, the following research questions have been formulated:

RQ1: What is the level of awareness of Agri 4.0 solutions among farm enterprises?

RQ2: What is the level of adoption of Agri 4.0 solutions?

RQ3: What are the main benefits perceived in adopting Agri 4.0 solutions?

RQ4: What are the main challenges perceived in adopting Agri 4.0 solutions?

The research questions were set based on a reference scheme developed by the authors, which is presented in Figure 1.

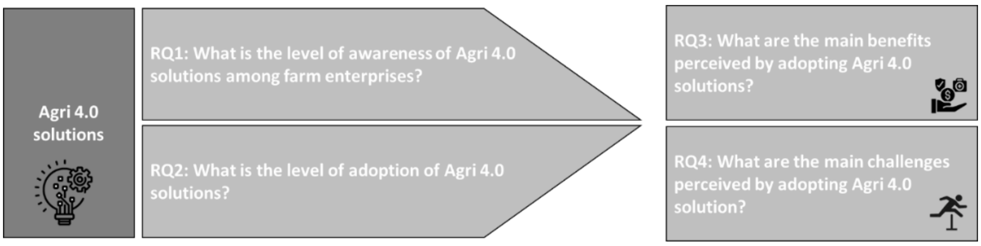

Figure 1. Reference scheme.

In particular, RQ1 and RQ2 aim at investigating the technological issues concerning Agri 4.0, while RQ3 and RQ4 investigate the effects in terms of the benefits and obstacles of the previous research questions.

Therefore, the present paper addresses the Agri 4.0 paradigm, aiming to gather evidence from the current state-of-the-art in the Italian agricultural context. Based on a descriptive survey completed by 670 respondents, the current paper aims to understand the degree of penetration of the phenomenon, covering many different open points of the paradigm and addressing these in multiple dimensions (distinctive solutions knowledge and utilization rate, benefits, and challenges).

The current paper concentrates on the Italian context. This choice was driven by the fact that, given the composition of the research group, the number of companies that could be involved was larger and because the Italian agriculture system is first in agriculture in Europe based on added value and third based on gross saleable production. Italy is also the world's leading producer of wine by volume and leading European producer of vegetables by value [13].

The present study also provides a systematization of the technological solutions adopted within the Agri 4.0 paradigm. Finally, the current paper provides a rationalization of the benefits and obstacles related to the implementation of the aforementioned digital technological solutions in the primary sector.

The current article is structured as follows: Section 2 gives an overview of the paradigm and presents the Agri 4.0 studied solutions. Section 3 describes the research methodology used, which is followed by Section 4, in which the four main thematic analyses are discussed. Next, Section 5 discusses the results, providing the research implications of the study and proposals for future research agendas in Agri 4.0.

2. Literature Review

2.1. Agri 4.0: Phenomenon and Paradigm Definition

The concept of Agri 4.0 encompasses several different scientific domains, some of which are directly related to land cultivation (water control, crop cultivation, harvesting, etc.), while others are an expansion of the agricultural area to different disciplines, such as engineering, economics, management, and so forth. Advances in different areas of the information and communication technology (ICT) domain, combined with the need to improve agricultural productivity, both for food safety and environmental impact issues, have determined the research area for Agri 4.0. Therefore, Agri 4.0 is derived from the broader concept of Industry 4.0 [9], which aims to define the integration of different technologies (such as Internet of Things (IoT), artificial intelligence, cloud computing, etc.) to automate cyber-physical tasks and processes, allowing for better planning and control of agricultural systems. The relationship of this concept with that of the Industry 4.0 paradigm, that is, the adoption of digital technologies to support the processes of manufacturing companies, is clear.

As reported in the literature, reducing input costs and increasing productivity seem to be the driving forces behind the progress in agriculture. However, the importance of sustainability should not be overlooked, a concept that has emerged as a major issue across the spectrum of human activities. Therefore, one of the goals of Agri 4.0 is to minimize the environmental impact of agricultural activities [14]. Thus, the implementation of Agri 4.0 solutions implies the possibility of farms achieving certain goals and benefits.

2.2. Enabling Digital Solutions for Agri 4.0

Taxonomies to group digital solutions in Agri 4.0 have already been presented in the literature. In particular, some interesting solutions are the ones presented by Lezoche et al. [9] and Liu et al. [10]; in both studies, the authors have presented an interesting categorization and description of the main technologies to be considered in Agri 4.0.

On the other hand, the current study focuses on solutions rather than technologies (i.e., different technologies can be part of the same type of solution); therefore, drawing on information and insights arising from the literature, five different clusters are presented: decision support system software; monitoring systems; systems for precision activities; mapping systems; and autonomous systems. The full list is presented in Table 1.

(a) **Decision support system software:** This type of software facilitates the decision-making process by helping prioritize goals, evaluate alternatives, and simulate outcomes. Within this category, there are two key reference solutions: (a) Business management software helps in automating the management processes within companies. In particular, this software is useful for various business functions, such as agricultural production, warehouse management, and accounting [15]. (b) Decision support systems (DSS) are computer tools that use data and mathematical models to support the decision maker, here being the farmer [16].

(b) **Monitoring systems:** Monitoring systems use different technologies, such as smart sensors and pervasive connectivity, to monitor different areas of a farm [17], [18]. The Agri 4.0 paradigm diffusion strongly relies on the development of innovative technologies such as sensors, the IoT, and Big Data [19]. Therefore, this cluster is divided into four different application areas that cover the main areas to be monitored within an agricultural company: agricultural machinery and equipment domain, crop and soils monitoring, enterprise infrastructure, and indoor cultivation.

(c) **Systems for precision activities:** The systems for precision activities enable the targeted use of various agricultural inputs [9], [20]. Specifically, in this cluster, it is possible to identify three solutions: precision irrigation systems, variable rate distribution systems, and on-field treatment with drones.

(d) **Mapping systems:** Land mapping is a fundamental activity of Agri 4.0. Thanks to the knowledge of the spatial variability of soil properties, farm potential in terms of quality, quantity, and yield can be optimized [18], [21]. In this regard, the three solutions refer to satellite technologies, mapping equipment installed on machinery, and mapping through drones.

(e) **Autonomous systems:** The use of increasingly advanced IT (information technology) and OT (operation technology) leads the agriculture industry to use autonomous systems both in terms of moving machines during operations and in terms of deciding on the activities to be performed within the fields [10], [22]. The main solutions of this cluster are robots for field activities and satellite guidance.

Table 1. List of the Agri 4.0 solutions considered.

Cluster of Technology Solutions	Solutions	References
Decision support system software	Business management software	[15], [16]
	Decision support system (DSS)	
Monitoring systems	Agricultural machinery and equipment	[17], [19]
	Crop and soil	
	Enterprise infrastructure	
	Indoor cultivation	
Systems for precision activities	Precision irrigation systems	[9], [20]
	Variable rate distribution system	
	On-field treatment with drones	
Mapping systems	Satellite technologies	[18], [21]
	Mapping equipment installed on machinery	
	Mapping drones	
Autonomous systems	Robot for field activities	[10], [22]
	Satellite guidance	

2.3. Agri 4.0: Benefits and Obstacles

A long list of potential benefits can be listed under different economic areas, as well as environmental benefits with a reduction of pollutants [23], [24] and social benefits with positive effects on the well-being of the workers involved and on society in general [25]. At the same time, there are also criticalities involved in implementing new systems, especially digital ones, in contexts such as the agricultural sector. For those who decide to implement innovative systems, there can be challenges of a technological, economic, and implementation nature, as well as those arising from corporate culture and organizational issues [26], [27].

The benefits investigated can be categorized into four clusters, which have been identified according to the triple bottom line (TBL; that is, people, planet, and profit) principles [28]. The first two clusters (effectiveness and efficiency) refer to the profit or bottom line. The next two are environmental and social benefits. From these four clusters, a set of 14 benefits was proposed. A full list of the benefits and references is presented in Table 2.

(a) **Effectiveness benefits:** The benefit cluster related to the economic part of the TBL. Operational effectiveness encompasses the practices employed to maximize resources and deliver high-quality results [24], [29]. Here, the authors investigated four different benefits related to effectiveness: higher product quality, yield increase, better soil quality, and an increase in the selling price of goods produced.

(b) **Efficiency benefits:** The benefit cluster related to the economic part of the TBL. Reducing the consumption of productive inputs and, thus, the associated costs is critical because it is known that a firm that has lower cumulative costs to perform all value-generating activities than its competitors has a cost advantage [30], [31]. Here, the authors investigated five different benefits related to efficiency: less water consumption, less technical input consumption, less machinery usage, simplification in the cultivation decision to be made, and general cost reduction.

(c) **Environmental benefits:** Sustainability from an environmental perspective is another benefit that can be achieved through the use of 4.0 solutions in agriculture [23]. Reducing the use of pollutants (such as agrochemicals and various fertilizers) increases soil quality, but from a purely environmental standpoint, there are real effects on air pollution decrease (CO, NO, etc.) and decreases in water pollution.

(d) **Social benefits:** The adoption of Agri 4.0 techniques has the potential to increase farmers' quality of life in terms of increased work safety and decreased work stress.

The controllable work environment in a plant factory is much more desirable than field cultivation, which requires a lot of physical energy to complete [32], [33]. Specifically, the benefits under this cluster are three: increase in work safety, reduced time spent in bureaucratic activities, and a reduction in physical labor. [25].

Table 2. List of benefits.

TBL Cluster	Cluster of Benefit	Benefits	References
Profit	Effectiveness	Product quality increase	[24], [29]
		Yield increase	
		Soil quality increase	
		Increase in selling price	
	Efficiency	Less water consumption	[30], [31]
		Less technical input consumption	
		Less machinery usage	
		Simplification in the cultivation decisions to be made	
		General cost reduction	
Planet	Environmental benefits	Air pollution (CO_2, N_2O, …) decrease	[23]
		Water pollution decrease	
People	Social Benefits	Work safety increase	[25], [32], [33]
		Reduced time spent on bureaucratic tasks	
		Physical labor reduction	

For 'obstacles,' four main clusters have been identified. The clusters cover the main areas of challenge when introducing a technological evolution in a certain environment:

(a) **Technological challenges:** This cluster refers to technical and technological issues related to the implementation of 4.0 solutions in agriculture [34]. Technical barriers can be limited or without interoperability (the data collected cannot be reused and different solutions do not work together) and lacking connectivity. However, it is also important to mention the limited or absent flexibility in the sense that the provided solution works only under optimal operating conditions (primarily weather) [27].

(b) **Economic challenge:** The implementation of innovative solutions and technologies in every field leads to a significant economic effort by the company that intends to adopt an innovative path. For this reason, it takes into consideration the economic return of the investment made in 4.0 solutions [35]. The challenge in question is the low investment return rate.

(c) **Implementation challenges:** The skills needed to properly implement 4.0 solutions, especially in companies in the primary sector, inevitably lead to the challenge of usage difficulty. Subsequently, the challenge connected to the first one is insufficient assistance because many companies can face obstacles that are difficult to overcome without an appropriate implementation assistance path [26].

(d) **Cultural and organizational challenge:** Because of the introduction of digitalization in agriculture, the 4.0 revolution in all economic sectors will require a new set of skills related to the introduction of digital solutions in companies [25]; for this reason, the challenge presented in the survey is the lack of key digital skills in the farm.

Out of these clusters, seven different obstacles could be derived. The full list of challenges and references is presented in Table 3.

Table 3. List of challenges.

Cluster of Challenges	Challenges	References
Technological challenge	Limited or absent interoperability	[27], [34]
	Limited or absent flexibility	
	Lack of connectivity	
Economic challenge	Low return of investment	[35]
Implementation challenge	Insufficient assistance	[26]
	Usage difficulty	
Cultural and organizational challenge	Lack of key digital skills in the farm	[25]

3. Methodology

Survey research is useful for obtaining information about a specific phenomenon concerning large populations, allowing for an adequate level of accuracy [36], [37]. The current research adopts descriptive survey research because the objective is to understand the significance of a phenomenon and describe its occurrence in a population [38], [39]. Indeed, descriptive surveys are highly valuable for gathering data from diverse populations because the researcher can extract the attitudes and features of respondents accurately [40]. Moreover, it is possible to provide an effective "picture" of the phenomenon being investigated from which evidence can be drawn. Thus, a descriptive survey is a convenient method when knowledge of a phenomenon is not too poorly underdeveloped, the variables and context can be described in detail, and the objective is to understand to what extent a given relationship is present. The intent of descriptive surveys is not necessarily to determine causal relationships, but they do provide an effective method for investigating a representative sample and enabling data regarding particular issues to be collected, which may be used to form the basis of decision-making activities in the future [41].

Therefore, the primary research objective is not theory development but rather the investigation of the impacts of the Agri 4.0 paradigm in the Italian primary sector by describing the knowledge levels, achieved benefits, and perceived challenges.

To obtain the above-mentioned objectives, a survey research process consisting of three steps was adopted: survey design, pilot testing, and data collection and analysis.

3.1. Survey Design and Pilot Testing

The questionnaire was characterized by 18 mixed open and closed questions, and it was structured into four sections. The first section aimed to collect general information and a registry about the company and respondents. The second section asked about the level of knowledge for each solution proposed; the description of each technological solution was provided through a "link" button to the respondents to provide the same interpretation of technology meaning and avoid bias related to ambiguous questions. The third section inquired about the company's perceptions of the benefits of Agri 4.0. Finally, the fourth section investigated the challenges and obstacles in adopting the Agri 4.0 paradigm.

To reach the highest number of respondents, a web survey was administered for conducting the research [42]. The trend of conducting surveys online has grown in recent times because they can offer many benefits over paper-based surveys. Indeed, with respect to face-to-face and e-mail surveys, web surveys do not require the manual transfer of responses into a database; the cost is minimal compared with other means of distribution, and greater anonymity is guaranteed, helping to avoid interviewer biases [42]. Online survey research can also allow researchers to isolate specific groups of participants who share common features [43].

Subsequently, to test possible question bias, translation accuracy, and the logical flow of the survey, pilot testing was performed before survey distribution [44]. In the first step, a group of colleagues was involved to check the readability and help pinpoint whether the questionnaire was within the study objectives. After refining the survey, the second step then involved sending the questionnaire to seven beta-tester companies to get feedback from them for further possible improvement. The pilot testing helped assess the content of the questionnaire and guaranteed the validity for the official launch.

Concerning the survey sample, the unit of analysis refers to Italian agricultural companies and farms. Moreover, this research involves all types of agricultural companies—except livestock farms—with no limits concerning their size and cultivation sector. The survey was carried out from January to October 2021, and repeated waves of reminders and recall activities were conducted with the support of the main Italian agricultural associations. The analysis started with a total number of 1273 responses before eliminating incomplete responses, duplicate responses, and test responses conducted internally by the team. As a result, a sample of 670 companies was validated. The survey respondent is the owner of the company to which the questionnaire was sent (or the decision maker in their place), who, therefore, has an overview of their farm.

3.2. Sample Description

Table 4 shows the company size of the cluster. Because there is currently no specific classification for farm size in the primary sector, it was decided to develop five customized clusters. Indeed, it was considered misleading to use the classical criteria related to manufacturing enterprises because of the great diversity in terms of turnover between the sectors. It should be noted in the table that most of the sample, 70%, is below EUR 250,000 in turnover. Only the remaining 30% are above this threshold, of which 17% have a turnover of over half a million euros.

Table 4. Revenue clusters distribution in the sample.

		Number of farms	**(%)**
Revenue Cluster	A. < EUR 30,000	147	22

B. between EUR 30,000 and 100,000	194	28
C. between EUR 100,000 and 250,000	133	20
D. between EUR 250,000 and 500,000	84	13
E. > EUR 500,000	112	17
Total	670	100

For a more complete analysis and because of the peculiarities of the sector under study, an additional proxy for the size of the sample companies was used (Table 5), that is, cultivated hectares. In this case, there is no clear definition of the classes to be considered.

Table 5. Land size cluster distribution in the sample.

		Number of farms	**(%)**
Hectares Cluster	A. < 10	192	29%
	B. 10 – 20	112	17%
	C. 20 – 50	148	22%
	D. > 50	218	32%
	Total	670	100

Figure 2 represents the Italian distribution of farm locations; to have data with the correct granularity, the data are represented by province rather than by region. Here, the distribution of the sample subject ranges over the entire country, demonstrating a very important capillarity. In detail, there are 178 companies in Southern Italy, 96 in the center, and 396 belonging to Northern Italy.

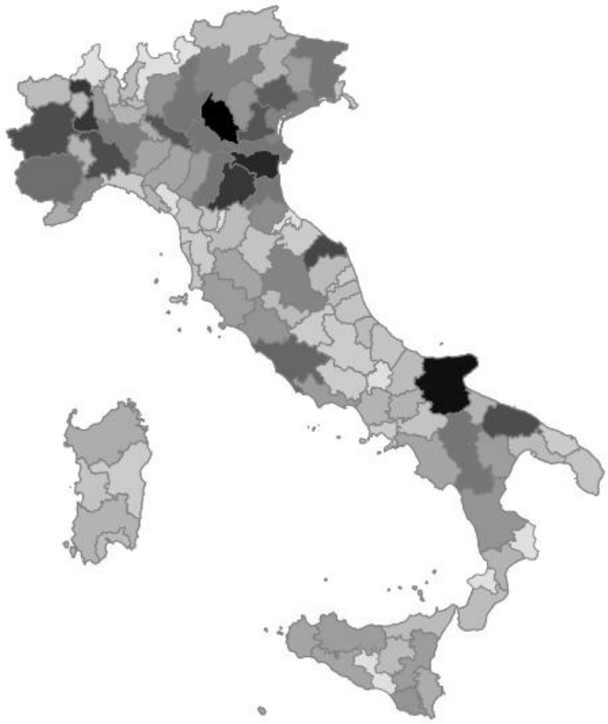

Figure 2. Geographical distribution of companies in the sample.

As a final representative analysis of the reference sample, Table 6 shows the distribution of prevalent cultivation. The classification method presented was developed following two interviews with experts in the field (agronomists), who indicated the categories listed in the table. The sample is highly heterogeneous in this respect as well, reinforcing the generalization of the analyses and considerations made in the current study.

Table 6. Pareto distribution of prevalent cultivation.

Prevalent Cultivation		Sample Pareto Distribution (%)
(a)	Cereals	37.4
(b)	Vineyards	19.7
(c)	Forage	8.2
(d)	Olive groves	7.9
(e)	Vegetables	5.5
(f)	Pome fruit trees	4.7
(g)	Stone fruit orchards	4.6
(h)	Industrial crops	3.3
(i)	Leguminous	2.1

(j)	Flowers and ornamental plants	1.6
(k)	Nursery tree	1.6
(l)	Other arboretums	1.4
(m)	Potatoes	1.3
(n)	Citrus groves	0.5
(o)	Other	0.3
Total		100

3.3. Variable Definition and Measure

Table 7 shows the variables used in the survey. The variable "Agri 4.0 solutions knowledge level" evaluates the degree of knowledge of the various solutions proposed. Four options are considered: "I have never used this solution, and I am not familiar with it," "I have never used this solution, but I know it," "I do not currently use this solution but have used it in the past," and "I currently use this solution." A variable implicitly connected to the one just described is "Agri 4.0 solutions adoption," in which the answer "I currently use this solution" was used to represent the results.

Table 7. Variable definition and criteria.

Variable	Type	Nr. of Levels/Clusters	Levels
Company size (revenues)	Ordinal	5	A. Less than EUR 30,000; B. between EUR 30,000 and 100,000; C. between EUR 100,000 and 250,000; D. between EUR 250,000 and 500,000; E. over EUR 500,000
Company size (land)	Ordinal	5	A. Lower than 10 hectares; B. Between 10 and 20 hectares; C. Between 20 and 50 hectares; D. Over 50 hectares
Agri 4.0 solutions knowledge level	Ordinal	4	I am not familiar with the solution; I am a little familiar with the solution; I am familiar with the solution at a

			theoretical level; I am familiar with the solution at a practical level
Agri 4.0 solution adoption	Ordinal	2	I use the solution; I do not use the solution
Benefits	Ordinal	5	Null; Low; Middle; High; Very High
Challenges	Ordinal	5	Null; Low; Middle; High; Very High

To identify the enabling solutions, benefits, and obstacles related to the Agri 4.0 paradigm, no systematic analysis was carried out, but a narrative literature review was conducted. This type of analysis, which is widely used in studies related to the medical sciences [45], does not involve following a strict protocol or specific standards but still allows for the identification of the main studies describing a problem of interest [46]. Concerning the identification of the articles to be analyzed, the Scopus and Web of Science databases were surveyed using strings formulated from the keywords related to agriculture and digitalization ("Smart Agrifood," "Smart Agriculture," "Smart Farming," "Agrifood 4.0," "Agriculture 4.0," "Farming 4.0," "Internet of Farming," "Digital Agrifood," "Digital Agriculture," "Digital Farming," "Precision Agriculture," and "Precision Farming"). The set of enabling solutions, benefits, and obstacles have already been presented in Section 2.

4. Results

4.1. RQ1: What Is the Level of Awareness of Agri 4.0 Solutions among Farm Enterprises?

The first highlight of the analysis derives from the investigation of the current degree of knowledge of Agri 4.0 solutions within the sample considered. Figure 3 summarizes the results. The level of awareness was measured using a 4-point scale, from a low to a high level of awareness of the solutions, specifically (a) I am not familiar with the solution, with no awareness of solutions existence; (b) I am a little familiar with the solution, meaning having only marginally heard of the solution; (c) I am familiar with the solution at a theoretical level, meaning having a good level of theoretical knowledge; and (d) I am familiar with the solution at a practical level, meaning knowing the solution and having knowledge of practical examples in the field.

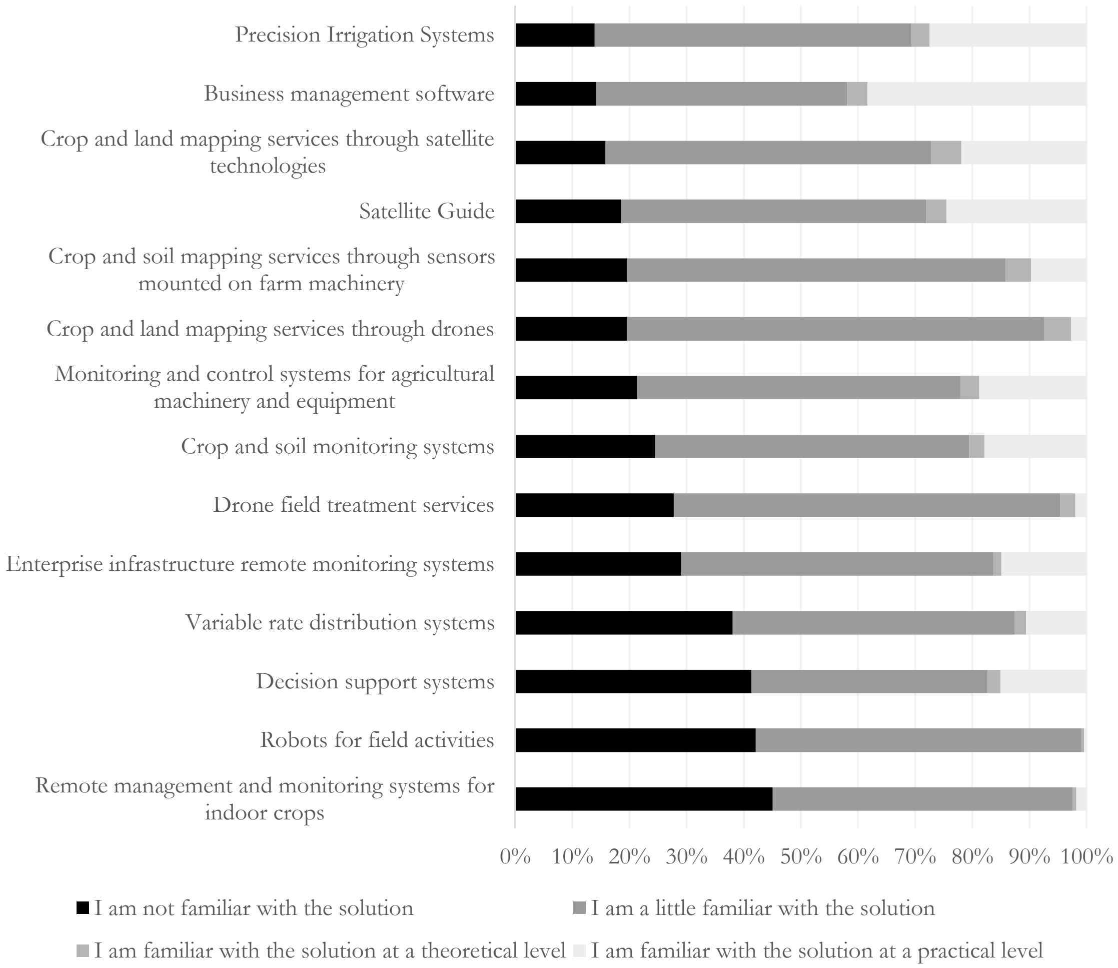

Figure 3. Agri 4.0 solutions awareness level.

Figure 3 shows all the solutions proposed within the questionnaire, ordering them from the most to least known. Another important aspect to consider is the statistical distribution of the number of solutions deeply known by the respondents (counting only answers in which the solution is familiar to the respondents). The distribution depicted in Table 8 represents the number of times a certain number of solutions is known at the same time, presenting the percentage over the entire sample and number of respondents.

Table 8. Statistical distribution of the number of digital solutions known.

Number of Digital Solutions Known Simultaneously	Respondents (%)	Respondents (Nr.)
0	28.4	190
1	17.3	116
2	13.7	92
3	11.2	75
4	9.6	64
5	7.5	50
6	4.2	28
7	3.4	23
8	2.1	14
9	1.3	9
10	0.7	5
11	0.3	2
12	0.3	2
Total:	100	670

The table clearly shows that the number of respondents claiming to know more solutions decreases as the number of known solutions increases.

The most well-known solutions within the given answer set are by far precision irrigation systems and business management software, followed by two technological solutions that share a similar technological basepoint, i.e., crop and land mapping services through satellite technologies and satellite guides. In this case, the management software solution is the most well known in practice, demonstrating that it is the solution most likely to be implemented by companies.

Crop and land mapping though drones deserve a separate discussion, which, despite being in the middle of the ranking for awareness, is one of the least known at the practical level, with only 3% of the respondents indicating that they had seen a practical example of this type of solution. A similar argument can be made for robots for field activities, of which not a single respondent claimed to have any practical knowledge, and remote management and monitoring for indoor crops, as the two least well-known solutions of the solution set.

The level of awareness of the solutions identified in the current study can be correlated with the descriptive variables of the analysis used as control variables to check for the presence of trends and patterns. To calculate the level of knowledge, scores were assigned from 0 to 3 in ascending order, here based on the answers given to the question about the level of awareness. To determine the level of awareness for each respondent, the sum of the level for each solution was divided by the maximum obtainable.

Figure 4 shows an increased pattern of awareness level related to hectare size of the farm, with the cluster of largest companies having a higher average (45%), median (45%), inferior quartile (33%) and major quartile (55%) than any other cluster. Furthermore, an increasing trend in the awareness of Agri 4.0 solutions is evident with respect to the size of the land worked.

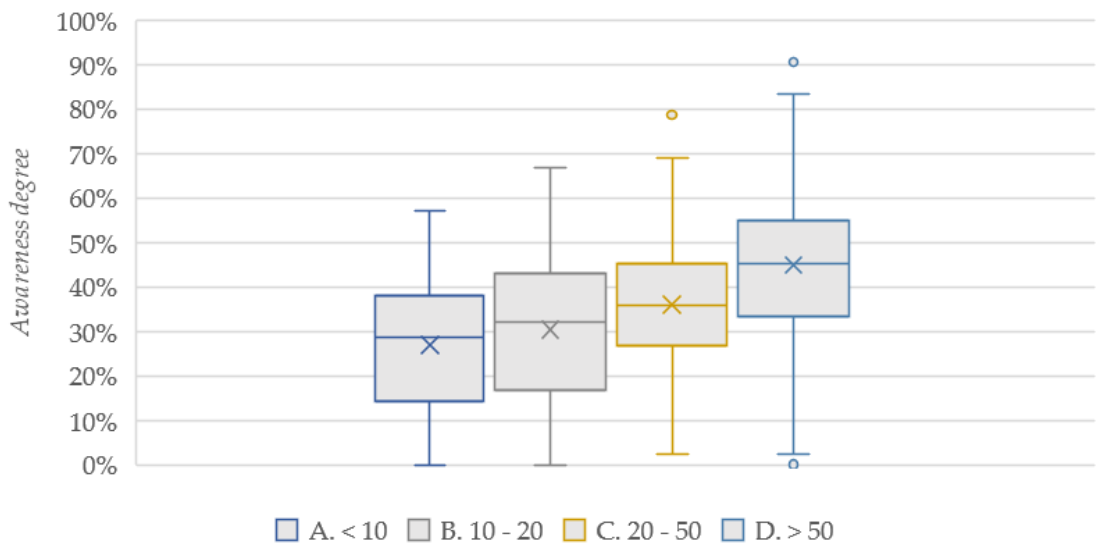

Figure 4. Boxplot graph of awareness level depending on the size of the company (land size).

This trend is further verified and reinforced by the analysis of the relationship between awareness level and turnover (Figure 5), in which it is possible to see how the level of awareness increases with an increase in the revenue cluster. The boxplot graph is particularly significant because each element (minimum, maximum, inferior quartile, major quartile, mean, and median) of the larger revenue class is greater than each element of the smaller revenue class. The boxplot shows that, on average, companies with a turnover of more than EUR 500,000 are currently using half (48%) of the solutions proposed in the survey.

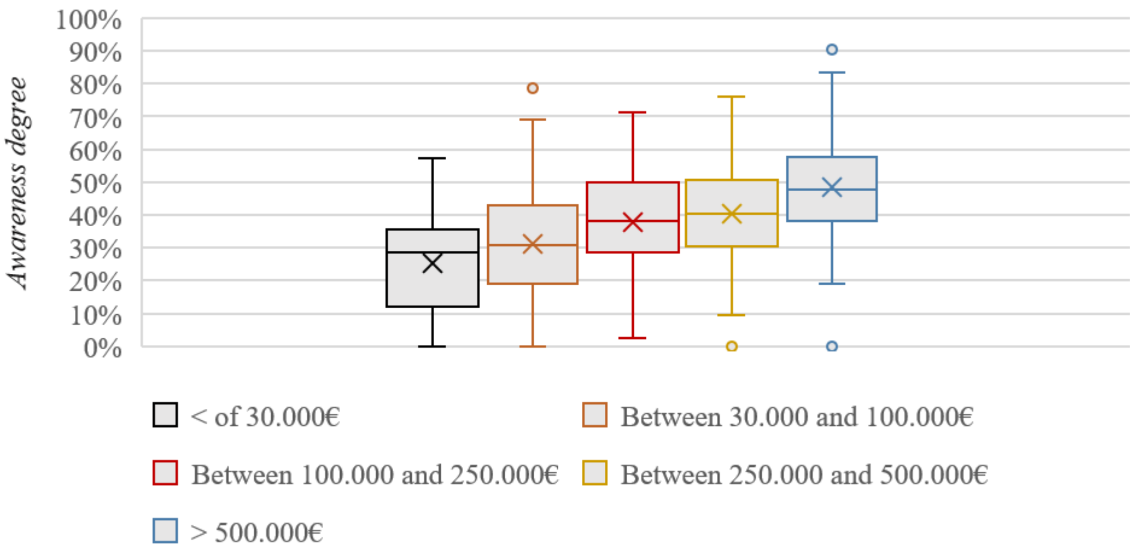

Figure 5. Boxplot graph of awareness level depending on company size (revenues).

4.2. RQ2: What Is the Level of Adoption of Agri 4.0 Solutions?

For each Agri 4.0 solution, the respondents were asked to specify whether they used the solution or not, allowing for the identification of adopters and nonusers.

Comparing the level of awareness versus the level of adoption, as expected, the rate of awareness increases for those using Agri 4.0 solutions compared with those who do not utilize any of the solutions. Figure 6 links the first two research questions, highlighting higher awareness of different Agri 4.0 solutions among the respondents who used at least one solution compared with those who did not use any.

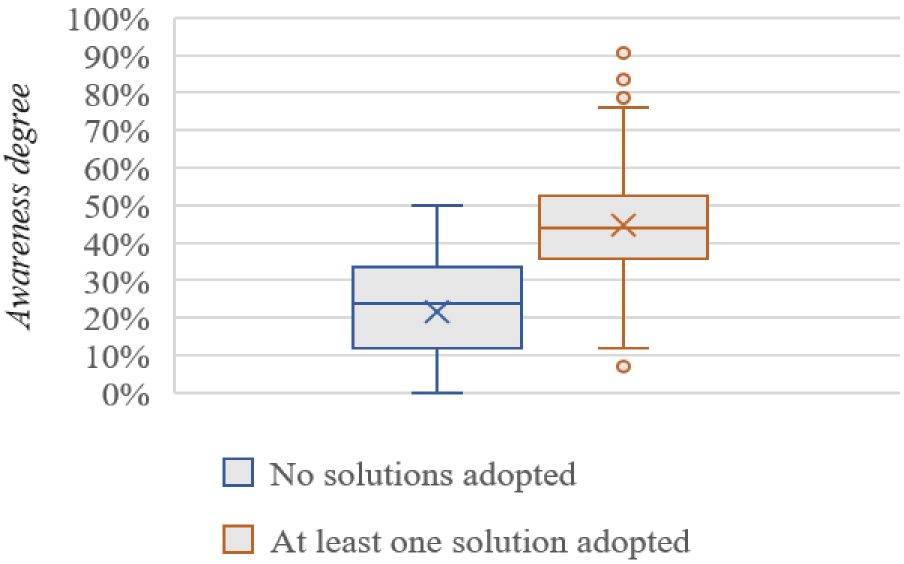

Figure 6. Boxplot graph of awareness level and utilization of 4.0 solutions.

The level of adoption can also be analyzed by comparing it against some control variables relative to the surveyed sample. First, it was examined whether there was a link between the size of companies and rate of utilization of technological solutions.

To assess whether the data and analyses had statistical significance or not, a chi-square test was performed, here measuring the *p*-value. Typically, its value is a very small number, close to zero. Here, the *p*-value is the assigned level of significance (i.e., a measure of evidence against the null hypothesis) and, to be statistically significant, this value must be less than 0.05. A significant association was found between revenue size cluster and utilization level of Agri 4.0 solutions (Table 9), in which the Pearson's χ^2 test *p*-value was very low ($3.48\ x\ 10^{-19}$, ensuring the significance of the analysis.

Table 9. Pearson's χ^2 test for adoption level and revenue clusters.

	Agri 4.0 Solution Adoption Level	**At Least One Solution Adopted**	**No Solutions Adopted**
Revenue Cluster	A. < EUR 30,000	47	100
	B. between EUR 30,000 and 100,000	98	96

C. between EUR 100,000 and 250,000	97	36
D. between EUR 250,000 and 500,000	63	21
E. > EUR 500,000	91	21

Pearson's χ^2 test: p-value = 3.48×10^{-19} (significant).

The growing trend in the level of adoption depends on the size (in terms of turnover) of the companies. This trend is further confirmed by the boxplot presented in Figure 7. To calculate the levels of adoption in the boxplot graphs, the sum of the usage responses for each respondent for the various solutions was analyzed and then divided by the total number of proposed solutions.

The association is clear in Figure 7, in which, from the lowest to the highest revenue class, all significant adoption-level metrics increase. The sample presents an average of 5% from the smallest class of revenue to an average of 27%, also taking into consideration the fact that the sample shows a maximum percentage of adoption level that goes from 14% to 71% for the most significant turnover class.

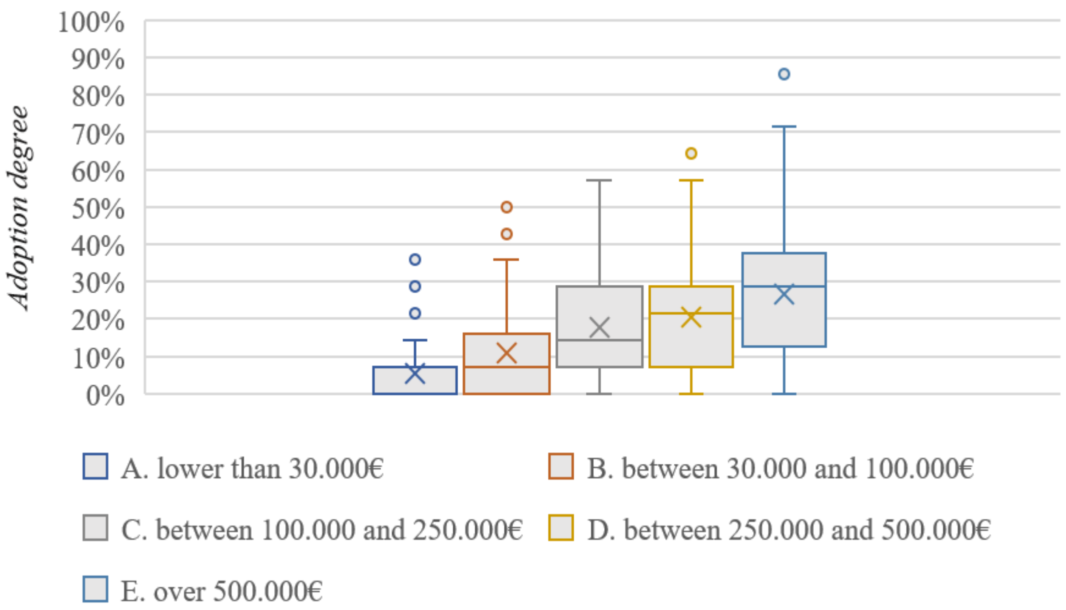

Figure 7. Boxplot graph of the adoption rate depending on company size (revenue).

The analysis represented in Figure 7 indicates that companies with higher turnover not only have more knowledge of the available solutions, but also a higher degree of use, perhaps because of the greater capacity to spend resources on these solutions.

The trend shown above is also confirmed when using the size of the cultivated area as a proxy for farm size. This can be proved by the strong association between these two variables (utilization rate–size in hectares) with a Pearson's χ^2 test *p*-value equal to $4.618 \, x \, 10^{-15}$ (significant).

Table 10 shows the increase of utilizers as the farm's size increases. At the same time, the number of farms not using 4.0 solutions drops, resulting in a strong relationship between these two variables. Moreover, from a visual perspective (Figure 8), the boxplot graph helps in seeing the main message of this analysis: the utilization values increase as the number of hectares increases, but it is interesting to note the strong increase from 50 hectares onwards.

Table 10. Pearson's χ^2 test for adoption level and land size cluster.

	Agri 4.0 Solution Adoption Level	**At Least One Solution Adopted**	**No Solutions Adopted**
Hectares	A. < 10	57	53
Cluster	B. 10 – 20	26	56
	C. 20 – 50	46	66
	D. > 50	94	54

Pearson's χ^2 test: *p*-value = $4.618 \, x \, 10^{-15}$ (significant).

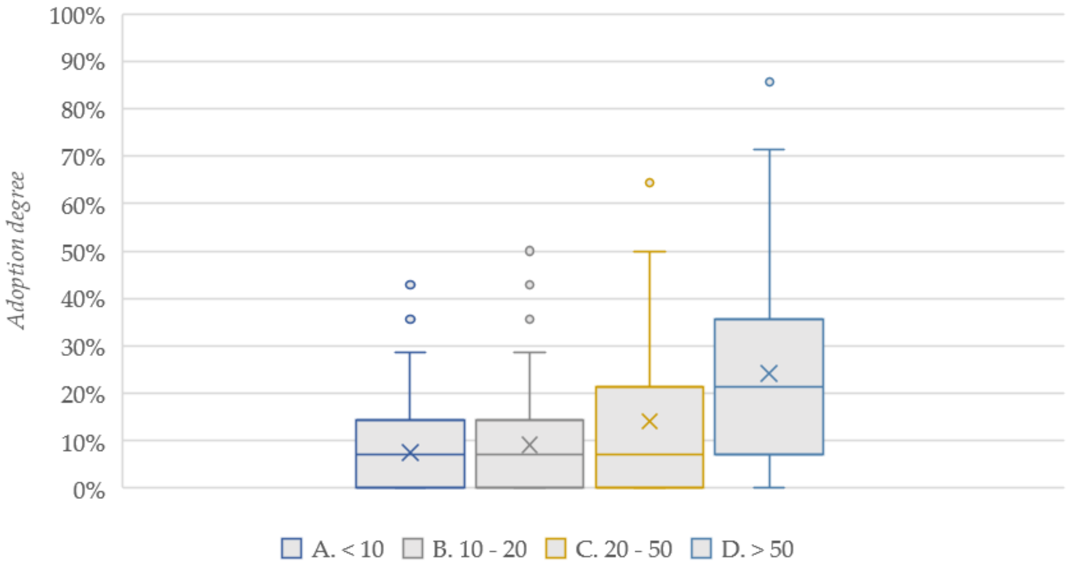

Figure 8. Boxplot graph of the utilization rate depending on company size (land size).

Subsequently, the focus of the analysis shifted to another important control variable in the questionnaire: the respondent's educational qualification (whether agricultural or not).

In Table 11, it is possible to see the strong relationships between the degree of utilization and type of education received by the business owner. The Pearson's chi-square test *p*-value results in a very small value, ensuring the statistical significance of the analysis.

Table 11. Pearson's χ^2 test for adoption level and type of education.

	Agri 4.0 Solutions Adoption Level	At Least One Solution Adopted	No Solutions Adopted
Agricultural	A. No	205	194
education	B. Yes	191	80

Pearson's χ^2 test: *p*-value = $7.98 \ x \ 10^{-7}$ (significant).

The graphical relationship of the effect that the control variable has on the degree of adoption is depicted in Figure 9. The subgroup of respondents with an educational background in agriculture presents a greater degree of adoption of Agri 4.0 solutions than the subgroup without this type of background. This can be seen in all aspects of the boxplot, from the minimum to the maximum, as well as for the interquartile range (0 – 21% vs. 7 – 29%), the mean (13% vs. 18%), and the median (7% vs. 14%).

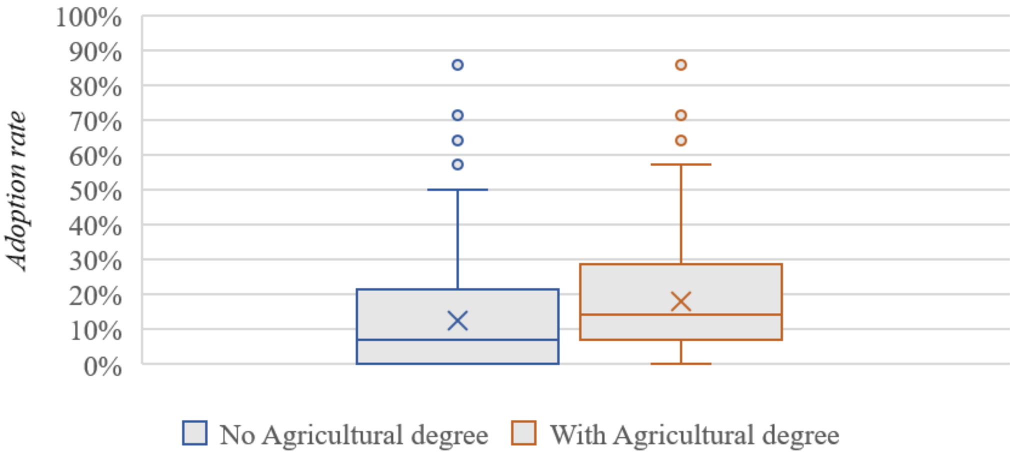

Figure 9. Boxplot graph of adoption level and type of education.

4.3. RQ3: What Are the Main Benefits Perceived in Adopting Agri 4.0 Solutions?

Figure 10 shows a boxplot that compares the benefit (divided into 14 different classes of benefit) obtained from the implementation of 4.0 solutions by users with the expected benefit by those who are not currently using any of the 4.0 solutions proposed in the questionnaire. This analysis highlights how the expectations of nonusers exceed the reality of users in terms of the level of benefit.

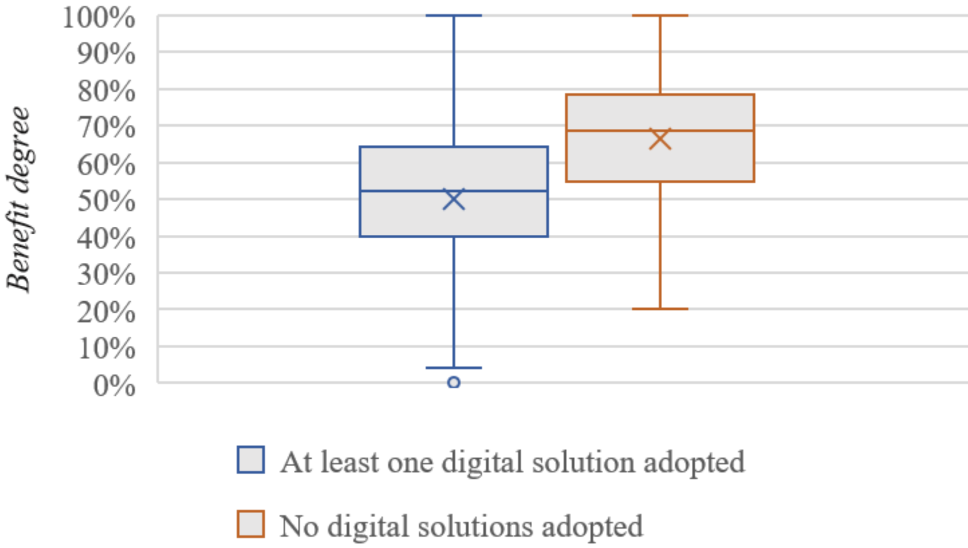

Figure 10. Boxplot graph of the level of benefit between users and nonusers.

This result deserves a more specific analysis; in Figure 10, the average of the benefit obtained and that expected from the two types of different actors, here unpacked in the 14 different obtainable benefits, is visualized. Figure 10 also represents the average benefit perceived by large users, which means those users who are currently operating many solutions (above eight different solutions).

Figure 11 represents what was previously summarized in Figure 10, providing more detail regarding each benefit presented to the respondents. It is interesting to note that, for all benefits (except for the benefit of reducing water consumption), the respondents who are users of 4.0 solutions present an average level of benefit lower than the average benefit that nonusers expect. In particular, it is possible to see how this gap is wider for "increase in sales price," which reports a rather low value (1.7 average value) for users while showing a potentially higher benefit for nonusers. In general, the benefits that have brought the most benefit to the sample under analysis are "lower consumption of technical inputs," "lower water consumption," and "soil quality improvement." However, it is also interesting to notice an upward trend. As previously stated, the average of the users is clearly lower than the expected benefit of the nonusers, but it is also true that the average of the large users (in this case, those respondents declaring that they use eight or more different solutions) increases considerably to the level of the expectations. A takeaway from this trend is that to reach (at least at the level of the average) the level of benefit expectation, it is necessary to use several solutions in parallel to exploit the joint work to achieve the desired benefits.

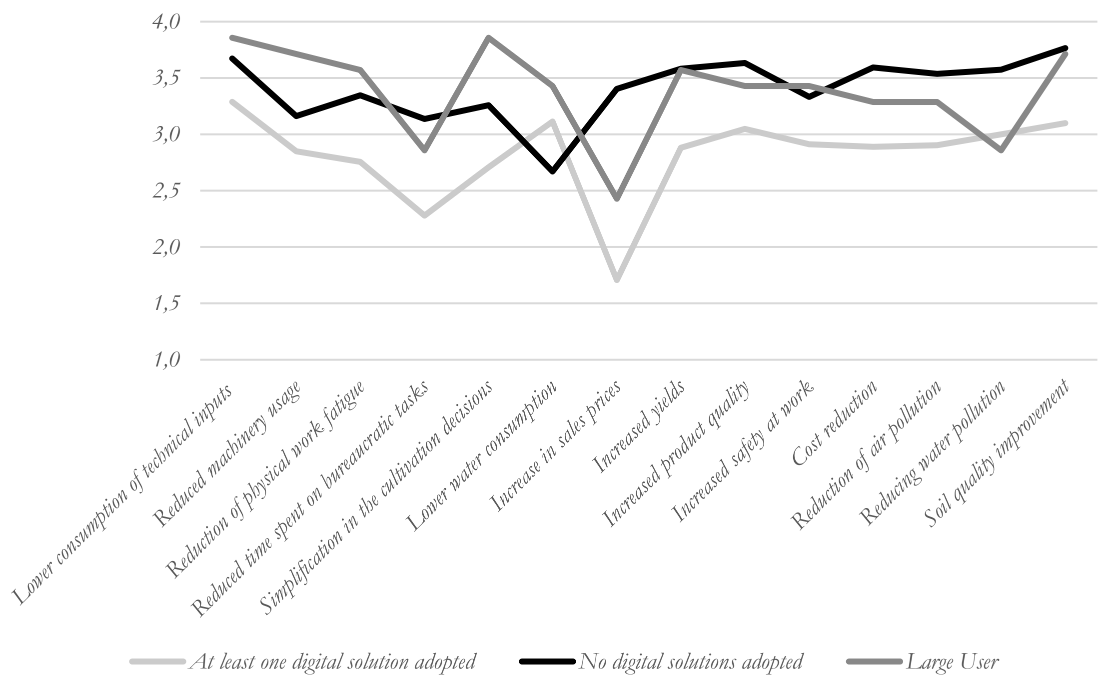

Figure 11. Benefits of Agri 4.0 solutions.

To gain a better understanding of the differences between users and nonusers, a ranking of benefit levels for users and expectations for nonusers was drawn up in descending order to identify the relative position of each benefit in these two lists. The results are shown in Table 12. The columns of "position" represent the relative position for users' benefits, and, in brackets, the position difference for nonusers' expected benefits is given.

Table 12. Relative position of benefits.

Benefit	Position: Users	Position: Nonusers
Lower consumption of technical inputs	1	2 (−1)
Lower water consumption	2	14 (−12)
Soil quality improvement	3	1 (+2)
Increased product quality	4	3 (+1)
Reducing water pollution	5	6 (−1)
Increased safety at work	6	10 (−4)
Reduction of air pollution (CO_2, N_2O,…)	7	7 (-)
Cost reduction	8	4 (+4)
Increased yields	9	5 (+4)
Reduced machinery usage	10	12 (−2)
Reduction of physical work fatigue	11	9 (+2)
Simplification in the cultivation decisions to be made	12	11 (+1)
Reduced time spent on bureaucratic tasks	13	13 (-)
Increase in sales prices	14	8 (+6)

The message that emerges from Table 12 is indicative of whether the various benefits perceived by users are in line (at least from the point of view of relative position) with expectations or not. Maintaining this approach but aggregating the benefits by cluster, we find interesting results.

As depicted in Figure 12, it is possible to notice that the "people" and "planet" clusters have an average position in line between the two samples. The "profit" cluster is a different matter. In this case, the analysis should be divided into subclusters of efficiency and effectiveness. In the first one, the perceived benefit is higher than the expected one, demonstrating the usefulness of 4.0 solutions in this area, while the relative position of the effectiveness subcluster is lower than expected (on average 2.2 positions lower in the ranking).

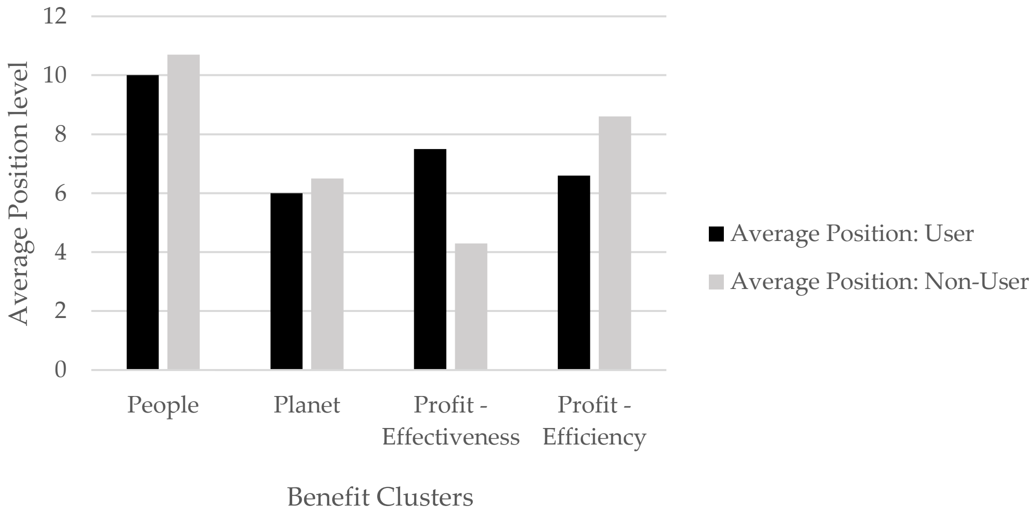

Figure 12. Aggregate positioning of benefits.

4.4. RQ4: What Are the Main Challenges Perceived in Adopting Agri 4.0 Solutions?

The analysis aimed to describe the barriers to implementing 4.0 systems in agriculture and expected difficulty in overcoming these barriers. In this paragraph, the aim is to replicate the structure of analysis presented in the previous research question, replicating the same type of analysis to identify analogies between the two research questions.

As a first analysis, Figure 13 represents the level of challenge declared by respondents, dividing the sample between users and nonusers, with users defining their perceived level and nonusers defining their expectations of the proposed challenge. The analysis of the boxplot depicted in Figure 13 contrasts with the analysis seen for benefits. In this case, on average, users experience a lower level of obstacles than nonusers. However, the analysis is at an aggregate level, and one cannot see the obstacles one by one. For this reason, the analysis of the level per obstacle has also been replicated (Figure 14).

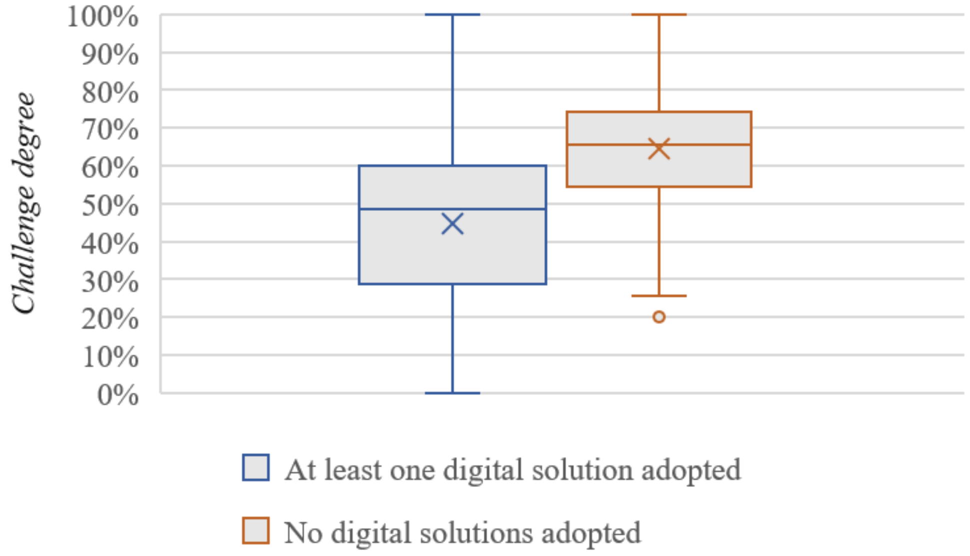

Figure 13. Boxplot graph of level of challenge between users and nonusers.

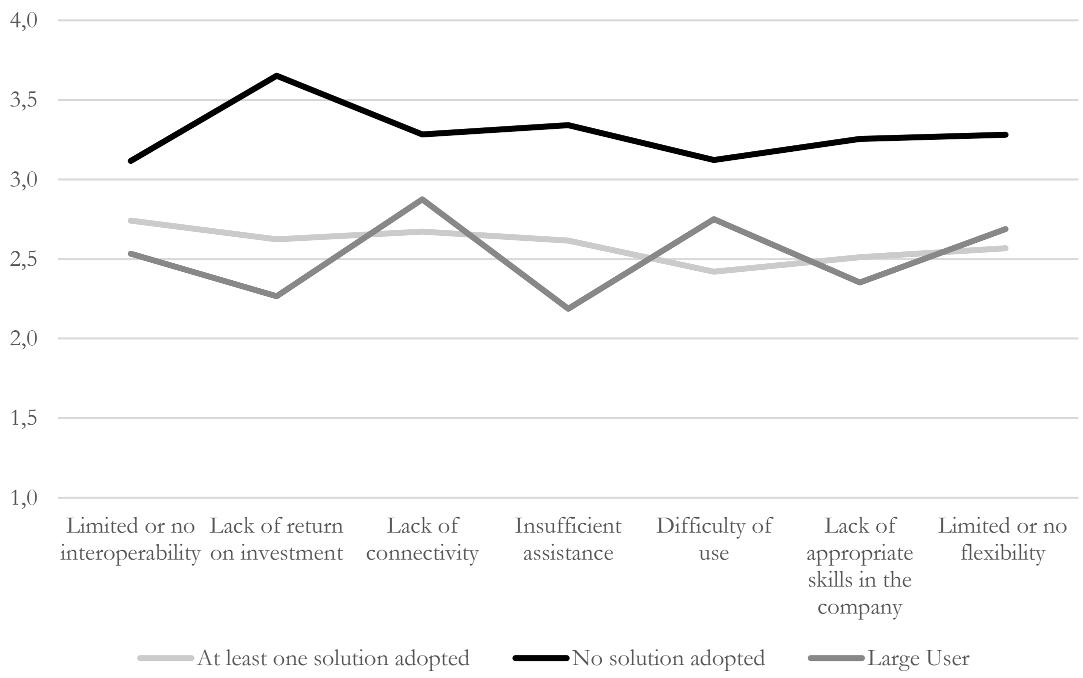

Figure 14. Challenges with Agri 4.0 solutions.

In this case, unlike the analysis carried out for the benefits, there is not the same trend, and the analysis depicted in Figure 14 contrasts with the findings of the previous research question. In this case, it is significant that each of the barriers has a lower challenge level found by users compared with the expectations of nonusers. In addition, the trend for those who use many different solutions in parallel does not lead to a particular increase or decrease in the challenge level for each obstacle proposed, thus identifying a constant trend in the challenge level as the number of solutions used increases but with an increase in the variability of the level per item, as can be seen in Figure 14.

To better understand the challenge level and relationship for each item in the list between users and nonusers, a ranking of the items from the highest level of perceived challenge to the lowest level was again drawn up (Table 13).

Table 13. Relative position of challenges.

Challenge	**Position: Users**	**Position: Nonusers**
Limited or no interoperability	1	1 (-)
Lack of connectivity	2	5 (−3)
Lack of return on investment	3	7 (−4)
Insufficient assistance	4	6 (−2)
Limited or no flexibility	5	4 (+1)
Lack of appropriate skills in the company	6	3 (+3)
Difficulty of use	7	2 (+5)

In contrast to the same table presented for benefits, in this case, a higher position corresponds to a more serious problem for respondents. The first important consideration that is possible to see from Table 13 is that limited or no interoperability is at the top of both the problems encountered by users and expectations of respondents who do not use any Agriculture 4.0 solution, demonstrating the centrality of the issue for Agri 4.0 and, more generally, in the 4.0 paradigm. Furthermore, in this case, it is interesting to compare the clusters, as carried out in the benefits, and compare the relative position in the case of user response and expectations of nonusers.

As presented in Figure 15, in this case, economic obstacles hold a higher position, so the perceived problem is greater than the expectations of nonusers; here, even four positions differ between the two types of respondents. As far as the technology category is concerned, the position is relatively stable between the two samples. It is also interesting to note that technological challenges rank first among the problems encountered by users. Less serious than expected are cultural and organizational challenges and implementation problems, both of which have a lower relative position than expected for these clusters.

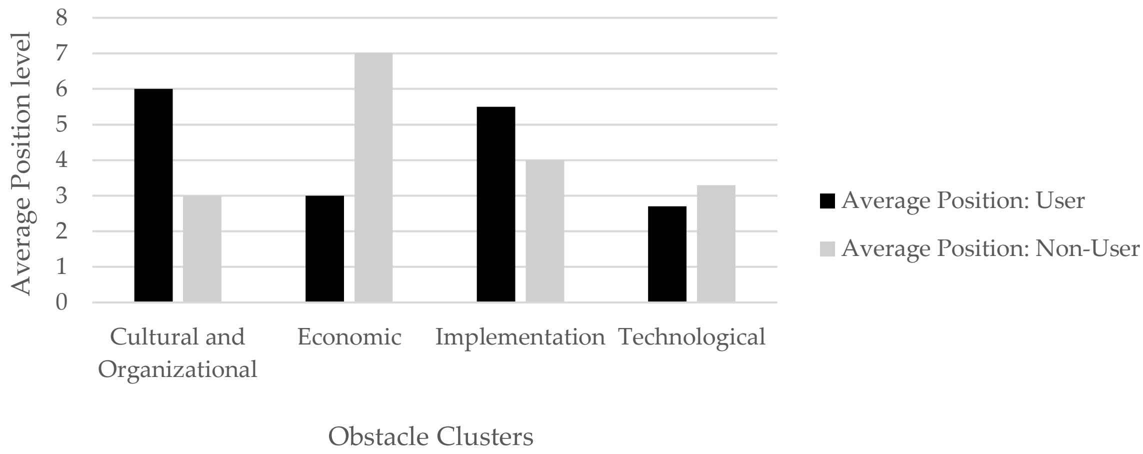

Figure 15. Aggregate positioning of obstacles.

5. Discussion and Conclusions

The current study aimed to map the state-of-the-art in Agri 4.0 within Italian farms through a descriptive survey, here adopting the perspectives of the awareness and adoption level, understanding which benefits users value the most and the differences between nonuser clusters, as well as identifying the critical factors and challenges that impact a company's adoption level regarding Agri 4.0 solutions. A large sample of 670 agricultural companies in Italy was analyzed. In particular, the digital solutions presented to respondents refer to five different clusters: DSS software, monitoring systems, systems for precision activities, mapping systems, and autonomous systems. In addition, this study considered the benefits by clustering the specific items by referring to the TBL, that is, economic, social, and environmental benefits, while analyzing several kinds of challenges: technological, economic, implementation, and cultural and organizational.

At a general level, our study shows that Italian farms display a heterogeneously distributed level of knowledge of the proposed solutions, but few farms know more than one solution in depth. Moreover, the current study shows that some control variables influence the level of awareness more than others; as turnover and cultivable area increase, an increase in the average level of awareness of Agri 4.0 solutions can be seen. The first is the level of awareness of each digital solution, which is still not pervasive over all the different solutions identified. Extensive knowledge of the solutions is still far from common. Above all, it is possible to see that the percentage of those who claim to know examples of practical implementation is low for each solution. The other important point is the degree of adoption. Here, the key message is that the average level of adoption increases as the turnover and size of the arable land increase. The level of maturity, therefore, is still low on average, and the market is not very dynamic if smaller companies are more out of the change process. In fact, smaller companies have less capacity to invest, and in line with the result of the barriers to adoption (which puts the economic problem at the top), this leads to a greater shift in adoption toward larger companies. At the same time, a similar increasing trend can be noticed in the degree of adoption. Although the average penetration rate is not particularly high, companies that have embarked on the journey to Agri 4.0 transformation have generally perceived lower barriers than companies that have yet to begin this journey. Finally, the present article has also investigated the benefits and potential obstacles to implementing Agri 4.0 solutions. The analysis shows that the main benefits perceived by the user are the reduction of technical inputs and water, which, in turn, benefit the entrepreneur economically but can also be said to have a positive impact on the environment. It is also interesting to note that the main problem encountered is the limited, even lack of, interoperability between 4.0 systems in the field. This obstacle is the point at which the actors and technology providers of the Agri 4.0 value chain must focus on to extract the maximum value from the digitalization of agricultural systems.

5.1. Research and Managerial Implications

For the current study, there are several implications, both for scholars and for practitioners.

The first aim of the proposed study was to provide evidence in a developed economy market of the state of adoption of Agri 4.0, here trying to define through concrete numbers the state of adoption of the paradigm in Italy, which can be representative also of other European economies. As defined above, there is no study analyzing the state of penetration of Agri 4.0 in Italy or Europe. Hence, the current study paves the way for scholars to pursue empirical research regarding the paradigm and state of the art. Some of the key insights of the proposed study are that Agri 4.0 is gaining more momentum, mainly because of the continuing need to be more sustainable, efficient, and using increasingly circular means while using digital leverage. However, within the main applicable solutions, it appears there are different levels of awareness that make up the digital solutions because some solutions are probably not yet mature enough to fit the needs of farmers.

The same applies even more so to the level of adoption because, on paper, the expected benefits are far greater than those perceived. This seems to me an important implication, and there is probably a mismatch between practical application and theory. A further implication is that the more solutions are used simultaneously, the more there is an alignment between expected and actual benefits.

The results of the exploratory survey presented in the current article provide several insights that can be useful for professionals working in the agricultural sector, technological suppliers of Agri 4.0 solutions, and public administration decision makers. First, it is clear that the approach to the digitalization of agricultural processes is currently possible for all companies, regardless of size, here in terms of revenue and arable land, even though an increasing trend is noticed in Figures 7 and 8.

The identification of the most known solutions within the sample leads to two possible implications for practitioners: (1) from the point of view of public institutions, it helps us to understand which solutions or clusters of solutions should be invested in from a communication and knowledge point of view as a way to inform potential users of the potential of these solutions; (2) it helps the companies providing the different solutions to identify the most well-known ones and, ultimately, which solutions can be used the most (at least in the short term).

In addition, the benefit analysis has shown that the average benefit among users is lower than the expectations of nonusers, but that, for those who use a large number of solutions in parallel, the average benefit per solution is similar to the level of expectations. At the same time, challenge expectations are higher than the challenges experienced by users. Furthermore, the results highlight that, for both nonuser and user expectations, the technological obstacle (particularly from the point of view of interoperability between different systems and lack of connectivity in the fields) is the worst and, therefore, the most important to pay attention to, particularly from the point of view of policy-makers, who must focus on these aspects to entice and channel investment from farms that have not yet invested in Agri 4.0. In fact, one of the main difficulties that can undermine the success of a digitalization strategy in agriculture is the risk of not being able to connect the new technologies with the infrastructure already in place on the farm or even with other solutions in parallel. To overcome this constraint, it is important to develop an integration strategy plan that allows for effectively linking not only the solutions to each other, but also the people who must be properly trained and whose skills must be properly aligned. In this way, it is possible to properly implement Agri 4.0.

5.2. Limitations and Future Research Directions

As with any other research, the current study also comes with limitations. First, the sample investigated in the present study is not perfectly aligned with the current Italian agricultural context in terms of revenues and land size. Indeed, the sample differs from the Italian landscape, which is smaller in terms of the size of arable land and turnover [47]. Thus, there is still extensive room for improvement. Moreover, the current study focused only on Italian agricultural companies, which may limit the generalization of the results. Despite this, however, it is necessary to specify that the Italian agricultural sector is one of the best performers in the Italian economy, with one of the highest added value to the gross domestic product (GDP) in Europe.

A possible limitation lies in comparing the benefits and barriers from two "parallel" clusters, potentially creating bias. To overcome this problem, it would be interesting to perform a longitudinal study as a follow-up. Here, the current survey could be repeated in a few years, comparing the cluster that is not currently adopting any solution and evaluating their evolution over time; this can be done mainly to compare the evolution from the point of view of adoption and analyze what the new users see as the benefits and barriers compared with initial expectations.

Another interesting future direction of work could be to compare the level of awareness and adoption with other countries, both with a similar sector structure (such as Spain or France) and others that are among the early adopters of Agri 4.0 and precision farming (such as the Netherlands), to carry out specific benchmark analyses. Further areas of research can be derived from adopting the same research also in companies from another sector, such as breeders of livestock for meat production and meat, eventually comparing the differences between the internal branches of the agricultural sector.

Author Contributions: Conceptualization, F. Maffezzoli, M. Ardolino and A. Bacchetti, methodology, M. Ardolino and F. Maffezzoli; validation, F. Maffezzoli, M. Ardolino and A. Bacchetti; formal analysis, F. Maffezzoli; investigation, F. Maffezzoli, A. Bacchetti; data curation, F. Maffezzoli; writing—original draft preparation, F. Maffezzoli; writing—review and editing, F. Maffezzoli, M. Ardolino and A. Bacchetti; supervision, A. Bacchetti. All authors have read and agreed to the published version of the manuscript.

C. Unlocking the Potential of Agriculture 4.0: A Comparative Study on Italian Farms' Technological Evolution, Business Demands, and Perceived Benefits

Title	Unlocking the Potential of Agriculture 4.0: A Comparative Study on Italian Farms' Technological Evolution, Business Demands, and Perceived Benefits
Authors	Maffezzoli Federico, Ardolino Marco, Bacchetti Andrea, Perona Marco
Outlet	XXVIII Summer School "Francesco Turco" – Industrial Systems Engineering
Year	2023
Status	Accepted for publication

Abstract.

This paper aims to investigate the state-of-the-art of Agri 4.0 adoption in Italian agricultural companies and to understand variations in business needs, technologies implemented, and benefits perceived. The study utilizes a descriptive approach with longitudinal features, examining 543 Italian agricultural companies through a survey and comparing the responses of 168 sub-samples in common with a similar survey launched two years prior. The results show that Italian agricultural companies still have limited awareness of Agri 4.0 technologies, with company size (in terms of hectares and revenues) influencing technology adoption. Knowledge and adoption of Agri 4.0 technologies increase over a two-year interval. Companies are primarily seeking Agri 4.0 solutions to improve environmental sustainability and product quality, and the perceived benefits are related to the number of Agri 4.0 technologies used. The paper acknowledges some limitations, such as the limited number of subjects involved in the longitudinal study and the focus on a limited geographical area (Italy) and suggests incorporating additional Agri 4.0 technologies in future surveys to gain further insights into Agri 4.0 development. This study provides one of the first attempts to assess variations in Agri 4.0 implementation concerning technology adoption, business need expressed by farmers, and the alteration of benefits, filling a gap in the literature of longitudinal studies investigating the development of the Agri 4.0 paradigm in a specific agricultural context.

Keywords: Agriculture 4.0, Smart Farming, Survey, Longitudinal Study

1. Introduction

In near future the world will face some major challenges, such as (1) climate change: with major effects of agriculture and earth arable surface, (2) freshwater shortage due to overall utilisation increase (also in agriculture), (3) demographic changes, with less people in rural areas and ageing workforce [1], and (4) geopolitical instability with subsequent potential fluctuations of process for fundamental agricultural inputs. A fundamental help in addressing these challenges comes from the so-called Agriculture 4.0 (Agri 4.0). [2]

Agri 4.0 encompasses various scientific domains, with some directly focused on land cultivation (such as water control, crop cultivation, harvesting, etc.), while others extend into different disciplines like engineering, economics, and management [3]. The development of Agri 4.0 is driven by advancements in information and communication technology (ICT) and the need to enhance agricultural productivity for food safety and environmental concerns. Agri 4.0 is a derivative of the broader concept of Industry 4.0, which aims to integrate technologies like Internet of Things (IoT), artificial intelligence, and cloud computing to automate cyber-physical tasks in agriculture, enabling better planning and control of agricultural systems. In fact, there are many other areas where the 4.0 paradigm is being applied, such as logistics processes [4]. This concept aligns with the adoption of digital technologies to support manufacturing processes in Industry 4.0 paradigm [5].

According to literature, the motivation behind agricultural progress lies in reducing input costs and increasing productivity. However, sustainability should not be disregarded, as it has emerged as a crucial aspect across various human activities. Hence, one of the objectives of Agri 4.0 is to minimize the environmental impact of agricultural practices, even though this research showcases interesting highlights related to this specific aspect. Implementing Agri 4.0 solutions offers farms the potential to achieve specific goals and benefits. Thus, while the existing literature has explored this concept, providing specific instances of classifying the potential advantages, and investigating in the enabling digital technologies, there is a lack of comprehensive study that primarily focuses on understanding the awareness and adoption of digital solutions in agriculture. Furthermore, scientific research has not made significant contributions in terms of examining the business needs that lie behind the willingness among farmers to invest in such technologies, along with the overall impact of their implementation, both in a broader sense and specifically within the context of the Italian market. Moreover, the present article empirical research methods, proposes a further point of view (lacking in the relevant literature), presenting a longitudinal analysis of such factors, leading to a gap in the generation of scientific findings based on practical insights from those directly involved in agricultural practices.

In an attempt to fill the above-mentioned literature gaps, the following research questions have been formulated:

RQ1: What is the state-of-of the-art of Agri 4.0 adoption in the Italian farms?

RQ2: Which business needs bring farmers to invest in Agri 4.0 and which benefits perceived?

RQ3: What are the main Agri 4.0 evolutions regarding technologies implemented, business needs and perceived benefits?

The article is structured as follows: Section 2 describes the research methodology used, that is followed by Section 3 in which results on three main thematic analysis have been discussed. Thereafter, Section 4 discusses the main findings and present the proposal for future research agenda.

2. Research methodology

2.1 Research design

This research has two primary objectives focused on the implementation of Agri 4.0 (A4.0) in the agricultural sector of Italy. Firstly, it seeks to assess the current state of A4.0 adoption in Italy, emphasizing technological advancements related to core enabling technologies [6], identifying business motivations driving farmers to invest in these technologies, and analysing the benefits resulting from their implementation [7]. Secondly, the study aims to evaluate the evolution of A4.0 in the Italian agricultural sector by comparing responses from a sub-sample of two surveys, as depicted in Figure 9.

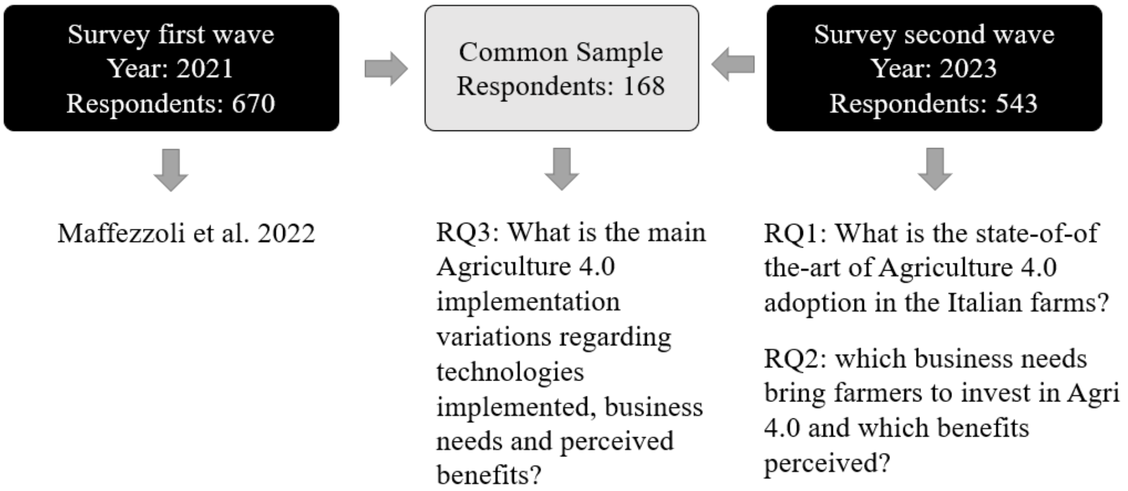

Figure 9 Research design

To achieve the first objective, the researchers analysed survey results conducted between the end of 2022 and February 2023. For the second objective, they employed a longitudinal study design, comparing responses from a sub-sample that participated in both the current survey and a previous survey conducted in 2021. Longitudinal studies, commonly used in medical and social sciences, observe the changes in a phenomenon over time within a specific sample. The survey design used in this research follows a similar approach to a previous study conducted in 2021, as discussed by Maffezzoli et al. [8]. During the research we have employed a two-wave fixed panel design with a two-year interval between the surveys. The data collection process and management were consistent for both surveys. This methodology has been utilized in other scientific literature [9], such as the study by Zheng et al. [10], which also employed a longitudinal design with similar characteristics.

The survey was conducted online using the web survey mode as it was deemed cost-effective and feasible in terms of time and resources. Utilizing web surveys eliminated the need for manual data transfer and minimized interviewer biases [11]. The researchers chose "Qualtrics" as the web survey tool, which provides an open platform for designing, launching, and collecting online surveys. The tool also facilitated mail recording and tracking to monitor response statuses, while the questionnaire served as the primary data collection tool. Each farm's reference person completed and archived the questionnaire. Data collection occurred between the end of 2022 and the first two months of 2023, with regular reminder mailings every two weeks and follow-up telephone calls to ensure respondent participation. The questionnaire consisted of four sections: the first section gathered basic information about the company and the respondent, the second section focused on the extent of the company's existing A4.0 enabling technology knowledge, and the third section explored business needs and benefits achieved.

2.2 Sample description and data collection

Sample description is shown from two perspectives. First, the complete 2023 sample (S1), then the common subsample (S2). In order to show the data concisely, we have represented in each table both the full sample data and the sub-sample in common.

Table 5 shows the company size by cluster. Due to the absence of a dedicated classification for farm size in the primary sector, a decision was made to create five tailored clusters. This approach was chosen to avoid confusion caused by using traditional criteria associated with manufacturing businesses, as there is significant variation in turnover across different sectors, and it is the same presented in first wave survey (Maffezzoli et al., 2022).

Table 5 Revenue cluster distribution (total & common sample)

Revenue Cluster	**Nr. of farms – S1**	**(%) S1**	**Nr. of farms – S2**	**(%) S2**
A. < EUR 30,000	*107*	*20*	*32*	*19*
B. between EUR 30,000 and 100,000	*148*	*27*	*52*	*31*
C. between EUR 100,000 and 250,000	*100*	*18*	*31*	*18*
D. between EUR 250,000 and 500,000	*59*	*11*	*20*	*12*
E. > EUR 500,000	*129*	*24*	*33*	*20*
Total	**543**	**100**	**168**	**100**

In the table, it is important to highlight that the majority of the sample, accounting for 65% (slightly higher in comm sub-sample with 68%), falls below a turnover of EUR 250,000. Conversely, the remaining 35% (32% in sub-sample) surpass this threshold, with 24% (20% in sub-sample) of them having a turnover exceeding half a million euros.

Due to the unique characteristics of the sector being examined, and in order to conduct a more comprehensive analysis, an extra indicator of sample company size was employed (Table 6), namely, the number of cultivated hectares. However, it is worth noting that there is no definitive classification for the categories to be considered in this case.

Table 6 Land size distribution (total & common sample)

Hectares Cluster	Nr. of farms S1	(%) S1	Nr. of farms S2	(%) S2
A. < 10	*139*	*26*	*49*	*29*
B. between 10 and 20	*75*	*14*	*35*	*21*
D. between 20 and 50	*111*	*20*	*32*	*19*
E. > 50	*218*	*40*	*52*	*31*
Total	**543**	**100**	**168**	**100**

In this case sub-sample is slightly smaller compared to the total sample, 69% of farms are below 50 hectares while it is 60% in total sample.

3. Results

3.1 Agri 4.0 Technology adoption.

The initial finding of the analysis focuses on examining the current level of knowledge of Agri 4.0 solutions among the survey's participants (S1). Figure 2 provides a summary of the results. To gauge the awareness, a 4-point scale was utilized, ranging from low to high familiarity with the solutions. These levels include: (a) *Unknown*, which means lack of familiarity, indicating no awareness of the existence of the solutions; (b) *Known but do not use*, that means limited familiarity, implying having heard of the solutions to a small extent; (c) *Used in the past, not anymore*, meaning the respondent has a theoretical familiarity, indicating a good understanding of the solution; and (d) *In use*, or in other words there is practical familiarity, signifying knowledge of the solutions and practical examples in the field.

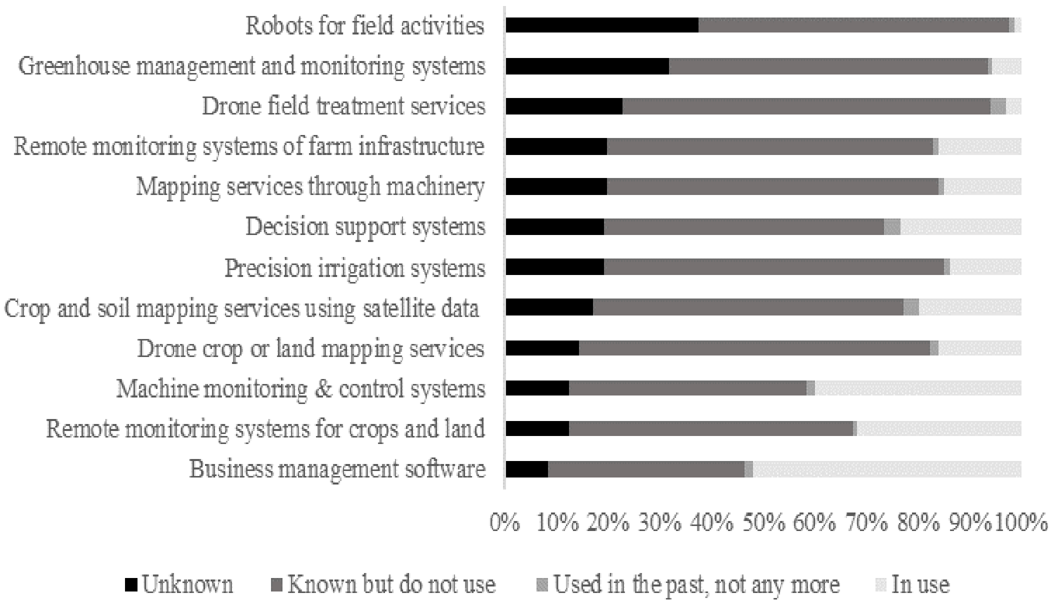

Figure 10 Agri 4.0 solutions awareness level.

The data reveals varying levels of adoption and awareness among the surveyed participants for different Agri 4.0 solutions. Overall, it is evident that certain solutions have gained higher traction and acceptance compared to others, hereby some of the highlights of the analysis depicted in Figure 2.

First of all, it is important to point out that approximately 52% of respondents reported using *business management software*, indicating a substantial adoption rate. However, 38% were aware of this solution but had not yet incorporated it into their operations.

Remote monitoring systems for crops and land, which demonstrated relatively high levels of awareness (55%) and adoption (32%), indicating a considerable interest in leveraging technology for monitoring and managing crops and land remotely.

Similar to remote monitoring systems, *machine monitoring and control systems* exhibited notable awareness (46%) and adoption (40%) rates, implying their perceived value in optimizing farm machinery operations.

Drone-based mapping services for crops and land showed significant awareness (68%), indicating a widespread recognition of their potential benefits. However, adoption levels were relatively lower (16%), possibly due to various factors such as cost, regulatory challenges, or limited integration capabilities.

Precision irrigation systems (enabled by digital technologies) demonstrated relatively high level of awareness (66%), indicating the recognition of their potential in optimizing water usage. However, adoption levels were reported at 14%, suggesting potential barriers to implementation.

Similar to precision irrigation systems, *decision support systems* were familiar to 54% of the respondents, while adoption levels were reported at 23%. This indicates a moderate uptake, potentially due to the complexity of integrating such systems into existing agricultural practices.

The use of *drones for field treatment services* exhibited relatively lower adoption levels (3%) despite a significant awareness rate (71%). Suggesting that practical challenges hinder their widespread use. At last, we find that *robots for field activities* demonstrated the lowest adoption rate (1%) among the surveyed solutions, despite a relatively high awareness level (60%). Practical limitations, cost factors, or technological challenges might contribute to this low adoption rate.

3.2 Agricultural Business needs and benefits perceived.

Combining the information about business needs and perceived benefits in a single paragraph provides a clear and concise overview of the relationship between the two. The identified needs directly align with the perceived benefits and how addressing those needs with specific Agri 4.0 solutions mentioned above can lead to positive outcomes.

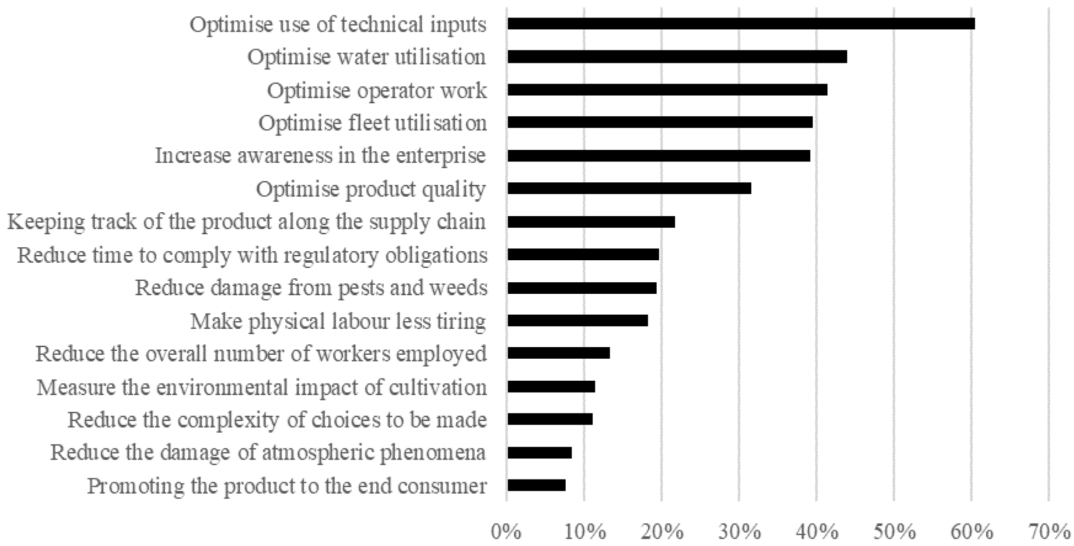

Figure 3 presents the farmers identified business needs, along with the corresponding percentages indicating their relative importance. The key findings reveal a diverse range of priorities requiring attention and optimization. At the top of the list, optimizing the use of technical inputs emerged as the highest priority, emphasizing the significance of efficiently utilizing resources such as fertilizers, pesticides, and machinery. Other important areas include optimizing operator work, fleet utilization, and water utilization. These factors highlight the importance of streamlining tasks, leveraging technology, and implementing sustainable irrigation practices to enhance operational efficiency and conserve valuable resources. The findings also emphasize the importance of reducing complexity in decision-making processes, promoting consumer engagement, optimizing supply chain management, and increasing awareness of enterprise operations.

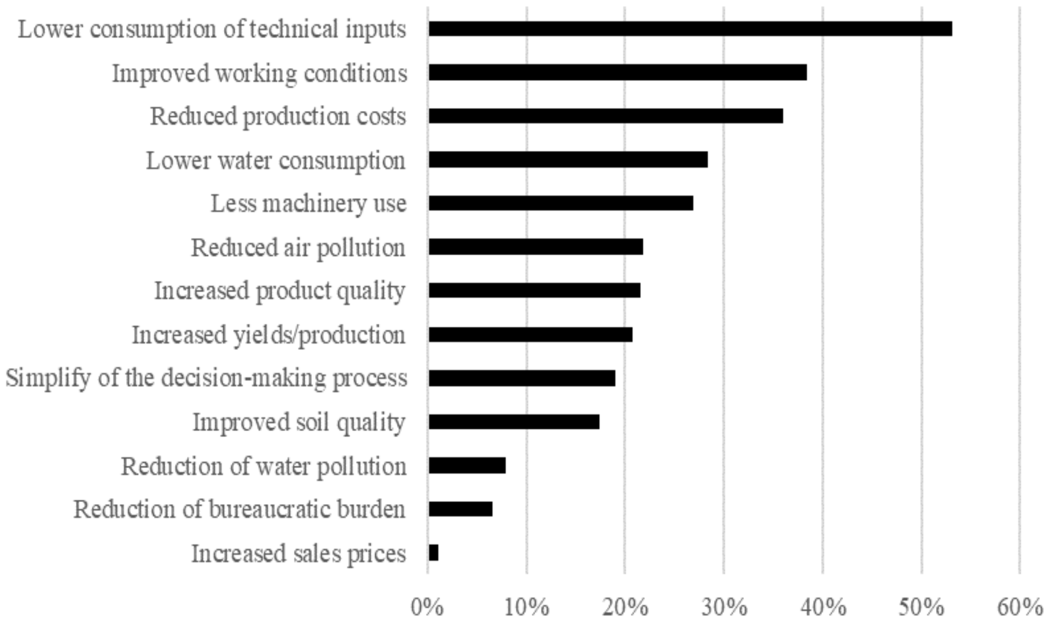

Figure 12 Benefits perceived.

Figure 4 presents the perceived benefits of adopting Agri 4.0 solutions. It showcases the benefits in descending order. At the top, with 53%, is the lower consumption of technical inputs, highlighting the desire to reduce resource dependency [12]. Improved working conditions follow closely at 38%, emphasizing the importance placed on enhancing the welfare of agricultural workers. Reduced production costs rank third at 36%, indicating that Agri 4.0 is meeting the expectation of cost savings. Resource efficiency is recognized through lower water consumption (28%) and reduced machinery use (27%), showing strong connection with business needs expressed. It is important to highlight that reduction of water pollution (8%) and reduction of bureaucratic burden (7%) are perceived as relatively minor benefits. Last but not least, increased sales prices are viewed as the least significant, with only 1% of farmers perceiving it as a positive outcome.

3.3 Variations in technologies implemented, business needs and benefits.

As previously depicted, the sub-sample of common companies is constituted of 168 farms. But, in the analysis that will be shortly presented, only the "utilizer" sample has been analysed. The first notable result is the increase in users within the sample, from 114 in the first survey to 121 in the second, a growth of 6.1%.

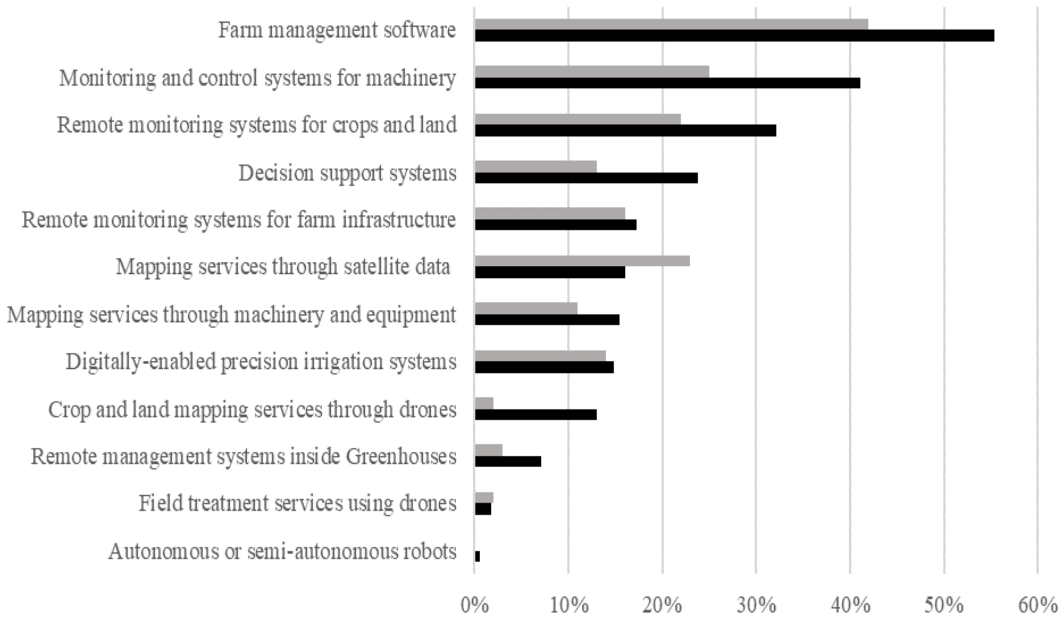

Figure 13 Agri 4.0 solutions utilization comparison

Monitoring and control systems for machinery exhibits the largest positive delta of 16%. The significant increase suggests a growing interest in implementing monitoring and control systems to enhance the efficiency and productivity of agricultural machinery [13]. Decision support systems also show a large positive delta of 11%. It indicates a significant increase in adoption and interest in decision support systems, which provide valuable insights and recommendations for agricultural decision-making [14]. With a positive delta of 10%, there has been an increase in the utilization of remote monitoring systems for crop and land monitoring. This technology allows farmers to remotely monitor and assess the condition of their crops and land [15], leading to more informed decision-making. Also farm management software shows a positive delta of 13%. On the other hand, the only negative delta is observed in mapping services through satellite data, which shows a negative delta of -7%. Taking a closer look at the graph, we can see that it could be due to alternative mapping services, such as Drone mapping, which is gaining traction within the sample.

Table 7 Business Needs Comparison

Business Needs	**(%) 2023**	**(%) 2021**	**(%) Delta**
Optimise use of technical inputs	*66*	*56*	*10*
Optimise water use	*49*	*38*	*11*
Optimise operator work	*40*	*30*	*10*
Increase awareness of what is happening in the business	*39*	*31*	*8*
Optimise fleet utilisation	*35*	*35*	*0*
Optimise product quality	*27*	*27*	*0*
Keeping track of the product along the supply chain	*25*	*41*	*-16*
Reduce pest and weed damage	*21*	*19*	*2*
Reduce the time required to fulfil regulatory obligations	*20*	*20*	*0*
Make physical labour less tiring	*18*	*20*	*-2*
Reduce the overall number of workers employed	*12*	*16*	*-4*
Reduce the complexity of the choices to be made	*10*	*20*	*-10*
Reducing the damage of atmospheric phenomena	*9*	*9*	*0*
Measure the environmental impact of cultivation	*9*	*34*	*-25*
Promoting the product to the end consumer	*7*	*27*	*-20*

Positive and negative deltas reflect the changing priorities and focus areas within the surveyed companies. Table 7 shows that, while there is an increasing emphasis on optimizing technical inputs (such as technical inputs and water usage) and operator work. Although, it shows that there has been a decline in the importance given to measuring environmental impact and promoting products directly to consumers. It would be interesting to study the reasons for this and possibly the correlation with main external factors.

Table 8 Benefits Perceived Comparison

Benefits	(%) 2023	(%) 2021	(%) Delta
Lower consumption of technical inputs	*54*	*39*	*15*
Improved working conditions	*43*	*20*	*23*
Reduced production costs	*38*	*23*	*15*
Lower water consumption	*30*	*35*	*-5*
Less machinery use	*25*	*22*	*3*
Increased product quality	*24*	*34*	*-10*
Reduction in air pollution	*21*	*22*	*-1*
Simplify the decision-making process	*17*	*18*	*-1*
Increased yields/production	*17*	*22*	*-5*
Improved soil quality	*13*	*31*	*-18*
Reduction of water pollution	*12*	*27*	*-15*
Reduction of bureaucratic burden	*7*	*13*	*-6*
Increased sales prices	*2*	*2*	*0*

Table 8 highlights the evolving perception of benefits achieved, with some benefits showing significant positive deltas and others experiencing negative deltas. Table 8 highlights the fact that higher perceived benefits are efficiency related, even though larger delta (23%) is related to improving working conditions (physical fatigue). On the other hand, larger negative delta belongs to soil quality and water pollution (-18% and -15%, respectively), reflecting an interesting reduction in environmental attention.

Business needs expressed and perceived benefits show an interesting relationship. Farms articulate their specific requirements, such as reducing production costs, optimizing resource utilization, and increase awareness of farm operations. Correspondingly, perceived benefits encompass lower input consumption, lower machinery utilization, and enhanced working conditions. The alignment between farm needs and perceived benefits indicates the industry's adaptability to changing market dynamics, technological advancements, and sustainability considerations. Understanding this relationship is fundamental in developing targeted agricultural solutions that address the evolving demands of farms, leading to sustainable and efficient farming practices.

4. Discussion and conclusion

This paper presents analysis and provides valuable insights into the adoption and awareness levels of various Agri 4.0 solutions. It highlights the varying degrees of acceptance and utilization across different technologies. Understanding the adoption patterns, but also needs that bring farmers to invest in 4.0 solutions and related perceived benefits can assist policymakers, researchers, and industry stakeholders in identifying barriers and devising strategies to facilitate the wider integration of Agri 4.0 solutions in the agricultural sector, thereby unlocking the potential benefits of enhanced productivity, efficiency, and sustainability in farming practices. The results of the study demonstrate varying levels of adoption and awareness of Agri 4.0 technologies among farmers. Certain solutions, such as business management software and remote monitoring systems, have gained higher traction and acceptance compared to others. We identified a diverse range of business needs expressed by farmers, focusing on resource optimization, operational efficiency, and awareness of farm operations.

Another significant result of this study is that the perceived benefits of adopting Agri 4.0 solutions align closely with these needs, emphasizing lower consumption of technical inputs, improved working conditions, and reduced production costs. However, there were variations in the perceived benefits over time, with a decline in the importance given to environmental impact and consumer engagement. Regarding technologies implemented, the study revealed changing priorities within the surveyed companies. Monitoring and control systems for machinery and decision support systems experienced significant increases in adoption, indicating a growing interest in efficiency and decision-making processes.

Nonetheless this study presents some limitations. Although the focus of the study was precisely on the comparison of technology utilisation and the 'needs vs. benefits' nexus, a key part related to the obstacles encountered by user companies towards 4.0 technologies is absent. Second, the study primarily presents descriptive statistics. Statistical tests, such as chi-square tests or regression analysis, could provide insights into the significance of the observed differences and associations. The absence of statistical analysis limits the strength of the conclusions that can be drawn from the findings. For this reason, the focus of the research team following this preliminary study, will be precisely to strengthen the results with the appropriate analyses.

Last but not least, further investigation will deepen contextual information about the specific agricultural settings or regions where the study was conducted, because the adoption and awareness of Agri 4.0 technologies can be influenced by various factors, such as socio-economic conditions, infrastructure availability, or regulatory frameworks. Without understanding the context, it is challenging to fully interpret and generalize the findings.

Overall, this study underscores the importance of aligning Agri 4.0 solutions with farmers' specific needs and priorities. Understanding the relationship between business needs and perceived benefits is crucial for developing targeted agricultural solutions that address evolving demands and promote sustainable and efficient farming practices.

REFERENCES

2.1 References Part I

J. Becker, R. Knackstedt, and J. Pöppelbuß, "Developing Maturity Models for IT Management: A Procedure Model and its Application," Business & Information Systems Engineering, vol. 1, no. 3, pp. 213–222, Jun. 2009.

Bolfe, É.L.; Jorge, L.A. de C.; Sanches, I.D.; Luchiari Júnior, A.; da Costa, C.C.; Victoria, D. de C.; Inamasu, R.Y.; Grego, C.R.; Ferreira, V.R.; Ramirez, A.R. Precision and Digital Agriculture: Adoption of Technologies and Perception of Brazilian Farmers. Agriculture 2020, 10, 653.

Chuang, J.-H.; Wang, J.-H.; Liang, C. Implementation of Internet of Things depends on intention: Young farmers' willingness to accept innovative technology. Int. Food Agribus. Manag. Rev. 2020, 23, 253–266.

A. R. Hevner, T. M. Salvatore, J. Park, and S. Ram, "Design Science in Information Systems Research," MIS Research Center, pp. 75 – 105, 2004.

Klingenberg, C.O., Borges, M.A.V. and Antunes Jr, J.A.V. (2019), "Industry 4.0 as a data-driven paradigm: a systematic literature review on technologies", *Journal of Manufacturing Technology Management*, No. 88881, p. JMTM-09-2018-0325.

M. Lezoche, J. E. Hernandez, M. del M. E. Alemany Díaz, H. Panetto, e J. Kacprzyk, «Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture», Computers in Industry, vol. 117, p. 103187, mag. 2020.

Morrar, R., Arman, H. and Mousa, S. (2017), "The fourth industrial revolution (Industry 4.0): A social innovation perspective", *Technology Innovation Management Review*, Talent First Network, Vol. 7 No. 11, pp. 12–20.

Andreas Schumacher, Selim Erol, Wilfried Sihn, A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises, Procedia CIRP, Volume 52, 2016, Pages 161-166, ISSN 2212-8271.

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-

Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, *14*(3), 207–222.

2.2 References Paper A

Alonso, R. S., Sittón-Candanedo, I., García, Ó., Prieto, J., & Rodríguez-González, S. (2020). An intelligent Edge-IoT platform for monitoring livestock and crops in a dairy farming scenario. Ad Hoc Networks, 98, 102047.b https://doi.org/10.1016/j.adhoc.2019.102047

Alreshidi, E. (2019). Smart Sustainable Agriculture (SSA) Solution Underpinned by Internet of Things (IoT) and Artificial Intelligence (AI). International Journal of Advanced Computer Science and Applications, 10(5). https://doi.org/10.14569/IJACSA.2019.0100513

AlZu'bi, S., Hawashin, B., Mujahed, M., Jararweh, Y., & Gupta, B. B. (2019). An efficient employment of internet of multimedia things in smart and future agriculture. Multimedia Tools and Applications, 78(20), 29581–29605. https://doi.org/10.1007/s11042-019-7367-0

Angelopoulos, C. M., Filios, G., Nikoletseas, S., & Raptis, T. P. (2020). Keeping data at the edge of smart irrigation networks: A case study in strawberry greenhouses. Computer Networks, 167, 107039. https://doi.org/10.1016/j.comnet.2019.107039

Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A., & Aggoune, E.-H. M. (2019). Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk. IEEE Access, 7, 129551–129583. https://doi.org/10.1109/ACCESS.2019.2932609

Barbedo, J. G. A. (2019). Detection of nutrition deficiencies in plants using proximal images and machine learning: A review. Computers and Electronics in Agriculture, 162, 482–492. https://doi.org/10.1016/j.compag.2019.04.035

Bersani, C., Ouammi, A., Sacile, R., & Zero, E. (2020). Model Predictive Control of Smart Greenhouses as the Path towards Near Zero Energy Consumption. Energies, 13(14), 3647. https://doi.org/10.3390/en13143647

Bodkhe, U., Tanwar, S., Parekh, K., Khanpara, P., Tyagi, S., Kumar, N., & Alazab, M. (2020). Blockchain for Industry 4.0: A Comprehensive Review. IEEE Access, 8, 79764–79800. https://doi.org/10.1109/ACCESS.2020.2988579

Borch, K. (2007). Emerging technologies in favour of sustainable agriculture. Futures, 22. https://doi.org/10.1016/j.futures.2007.03.016

Bronson, K. (2018). Smart Farming: Including Rights Holders for Responsible Agricultural Innovation. Technology Innovation Management Review, 8(2), 7–14. https://doi.org/10.22215/timreview/1135

Bronson, K. (2019). Looking through a responsible innovation lens at uneven engagements with digital farming. NJAS - Wageningen Journal of Life Sciences, 90–91, 100294. https://doi.org/10.1016/j.njas.2019.03.001

Chen, J., & Yang, A. (2019). Intelligent Agriculture and Its Key Technologies Based on Internet of Things Architecture. IEEE Access, 7, 77134–77141. https://doi.org/10.1109/ACCESS.2019.2921391

Chuang, J.-H., Wang, J.-H., & Liang, C. (2020). Implementation of Internet of Things depends on intention: Young farmers' willingness to accept innovative technology. International Food and Agribusiness Management Review, 23(2), 253–266. https://doi.org/10.22434/IFAMR2019.0121

Da Silva, V. L., Kovaleski, J. L., Pagani, R. N., Silva, J. D. M., & Corsi, A. (2020). Implementation of Industry 4.0 concept in companies: Empirical evidences. International Journal of Computer Integrated Manufacturing, 33(4), 325–342. https://doi.org/10.1080/0951192X.2019.1699258

Ding, Y., Wang, L., Li, Y., & Li, D. (2018). Model predictive control and its application in agriculture: A review. Computers and Electronics in Agriculture, 151, 104–117. https://doi.org/10.1016/j.compag.2018.06.004

Dolgui, A., & Ivanov, D. (2021a). Ripple effect and supply chain disruption management: New trends and research directions. International Journal of Production Research, 59(1), 102–109. https://doi.org/10.1080/00207543.2021.1840148

Dolgui, A., & Ivanov, D. (2021b). 5G in digital supply chain and operations management: Fostering flexibility, end-to-end connectivity and real-time visibility through internet-of-everything. International Journal of Production Research, 1–10. https://doi.org/10.1080/00207543.2021.2002969

Dufva, T., & Dufva, M. (2019). Grasping the future of the digital society. Futures, 107, 17–28. https://doi.org/10.1016/j.futures.2018.11.001

Elijah, O., Rahman, T. A., Orikumhi, I., Leow, C. Y., & Hindia, M. H. D. N. (2018). An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges. IEEE Internet of Things Journal, 5(5), 3758–3773. https://doi.org/10.1109/JIOT.2018.2844296

Erukala B., & Mekala R. (2019). Smart Agriculture: Automated Controlled Monitoring System using Internet of Things. International Journal of Recent Technology and Engineering, 8(3), 8778–8784. https://doi.org/10.35940/ijrte.C6538.098319

Escamilla-García, A., Soto-Zarazúa, G. M., Toledano-Ayala, M., Rivas-Araiza, E., & Gastélum-Barrios, A. (2020). Applications of Artificial Neural Networks in Greenhouse Technology and Overview for Smart Agriculture Development. Applied Sciences, 10(11), 3835. https://doi.org/10.3390/app10113835

Farooq, M. S., Riaz, S., Abid, A., Abid, K., & Naeem, M. A. (2019). A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming. IEEE Access, 7, 156237–156271. https://doi.org/10.1109/ACCESS.2019.2949703

Ferrag, M. A., Shu, L., Yang, X., Derhab, A., & Maglaras, L. (2020). Security and Privacy for Green IoT-Based Agriculture: Review, Blockchain Solutions, and Challenges. IEEE Access, 8, 32031–32053. https://doi.org/10.1109/ACCESS.2020.2973178

Fielke, S. J., Garrard, R., Jakku, E., Fleming, A., Wiseman, L., & Taylor, B. M. (2019). Conceptualising the DAIS: Implications of the 'Digitalisation of Agricultural Innovation Systems' on technology and policy at multiple levels. NJAS - Wageningen Journal of Life Sciences, 90–91, 100296. https://doi.org/10.1016/j.njas.2019.04.002

Fosso Wamba, S., Akter, S., Edwards, A., Chopin, G., & Gnanzou, D. (2015). How 'big data' can make big impact: Findings from a systematic review and a longitudinal case study. International Journal of Production Economics, 165, 234–246. https://doi.org/10.1016/j.ijpe.2014.12.031

Guo, G., Wen, Q., & Zhu, J. (2015). The Impact of Aging Agricultural Labor Population on Farmland Output: From the Perspective of Farmer Preferences. Mathematical Problems in Engineering, 2015, 1–7. https://doi.org/10.1155/2015/730618

Gupta, M., Abdelsalam, M., Khorsandroo, S., & Mittal, S. (2020). Security and Privacy in Smart Farming:

Challenges and Opportunities. IEEE Access, 8, 34564–34584. https://doi.org/10.1109/ACCESS.2020.2975142

Hacking, T., & Guthrie, P. (2008). A framework for clarifying the meaning of Triple Bottom-Line, Integrated, and Sustainability Assessment. Environmental Impact Assessment Review, 28(2–3), 73–89. https://doi.org/10.1016/j.eiar.2007.03.002

Hamuda, E., Glavin, M., & Jones, E. (2016). A survey of image processing techniques for plant extraction and segmentation in the field. Computers and Electronics in Agriculture, 125, 184–199. https://doi.org/10.1016/j.compag.2016.04.024

Horng, G.-J., Liu, M.-X., & Chen, C.-C. (2020). The Smart Image Recognition Mechanism for Crop Harvesting System in Intelligent Agriculture. IEEE Sensors Journal, 20(5), 2766–2781. https://doi.org/10.1109/JSEN.2019.2954287

Jayaraman, P., Yavari, A., Georgakopoulos, D., Morshed, A., & Zaslavsky, A. (2016). Internet of Things Platform for Smart Farming: Experiences and Lessons Learnt. Sensors, 16(11), 1884. https://doi.org/10.3390/s16111884

Jukan, A., Masip-Bruin, X., & Amla, N. (2017). Smart Computing and Sensing Technologies for Animal Welfare: A Systematic Review. ACM Computing Surveys, 50(1), 1–27. https://doi.org/10.1145/3041960

Kamienski, C., Soininen, J.-P., Taumberger, M., Dantas, R., Toscano, A., Salmon Cinotti, T., Filev Maia, R., & Torre Neto, A. (2019). Smart Water Management Platform: IoT-Based Precision Irrigation for Agriculture. Sensors, 19(2), 276. https://doi.org/10.3390/s19020276

Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2017). A review on the practice of big data analysis in agriculture. Computers and Electronics in Agriculture, 143, 23–37. https://doi.org/10.1016/j.compag.2017.09.037

Kamilaris, A., & Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. Computers and Electronics in Agriculture, 147, 70–90. https://doi.org/10.1016/j.compag.2018.02.016

Khanna, A., & Kaur, S. (2019). Evolution of Internet of Things (IoT) and its significant impact in the field of Precision Agriculture. Computers and Electronics in Agriculture, 157, 218–231. https://doi.org/10.1016/j.compag.2018.12.039

Kiani, F., & Seyyedabbasi, A. (2018). Wireless Sensor Network and Internet of Things in Precision Agriculture. International Journal of Advanced Computer Science and Applications, 9(6). https://doi.org/10.14569/IJACSA.2018.090614

Kim, J., Kim, S., Ju, C., & Son, H. I. (2019). Unmanned Aerial Vehicles in Agriculture: A Review of Perspective of Platform, Control, and Applications. IEEE Access, 7, 105100–105115. https://doi.org/10.1109/ACCESS.2019.2932119

Kim, S., Lee, M., & Shin, C. (2018). IoT-Based Strawberry Disease Prediction System for Smart Farming. Sensors, 18(11), 4051. https://doi.org/10.3390/s18114051

Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. NJAS - Wageningen Journal of Life Sciences, 90–91, 100315. https://doi.org/10.1016/j.njas.2019.100315

Klerkx, L., & Rose, D. (2020). Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways? Global Food Security, 24, 100347. https://doi.org/10.1016/j.gfs.2019.100347

Kolipaka, V. R. R. (2020). Predictive analytics using cross media features in precision farming. International Journal of Speech Technology, 23(1), 57–69. https://doi.org/10.1007/s10772-020-09669-z

Konrad, K., & Böhle, K. (2019). Socio-technical futures and the governance of innovation processes—An introduction to the special issue. Futures, 109, 101–107. https://doi.org/10.1016/j.futures.2019.03.003

Lee, J., Bagheri, B., & Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001

Lezoche, M., Hernandez, J. E., Alemany Díaz, M. del M. E., Panetto, H., & Kacprzyk, J. (2020). Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture. Computers in Industry, 117, 103187. https://doi.org/10.1016/j.compind.2020.103187

Light, R. J., & Pillemer, D. B. (1984). Summing up: The science of reviewing research. Cambridge, Mass. : Harvard University Press. http://archive.org/details/summingupscience00ligh

Liu, Y., Ma, X., Shu, L., Hancke, G. P., & Abu-Mahfouz, A. M. (2021). From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges. IEEE Transactions on Industrial Informatics, 17(6), 4322–4334. https://doi.org/10.1109/TII.2020.3003910

Long, T. B., Blok, V., & Coninx, I. (2016). Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: Evidence from the Netherlands, France, Switzerland and Italy. Journal of Cleaner Production, 112, 9–21. https://doi.org/10.1016/j.jclepro.2015.06.044

Madushanki, A. A. R., N, M., A., W., & Syed, A. (2019). Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review. International Journal of Advanced Computer Science and Applications, 10(4). https://doi.org/10.14569/IJACSA.2019.0100402

Magombeyi, M. S. (2018). Effectiveness of agricultural water management technologies on rainfed cereals crop yield and runoff. INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY, 25.

Mohd Nizar, N. M., Jahanshiri, E., Tharmandram, A. S., Salama, A., Mohd Sinin, S. S., Abdullah, N. J., Zolkepli, H., Wimalasiri, E. M., Mohd Suhairi, T. A. S. T., Hussin, H., Gregory, P. J., & Azam-Ali, S. N. (2021). Underutilised crops database for supporting agricultural diversification. Computers and Electronics in Agriculture, 180, 105920. https://doi.org/10.1016/j.compag.2020.105920

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic Reviews, 4(1), 1. https://doi.org/10.1186/2046-4053-4-1

Monostori, L. (2003). AI and machine learning techniques for managing complexity, changes and uncertainties in manufacturing. Engineering Applications of Artificial Intelligence, 16(4), 277–291.

https://doi.org/10.1016/S0952-1976(03)00078-2

Monteleone, S., Moraes, E. A. de, Tondato de Faria, B., Aquino Junior, P. T., Maia, R. F., Neto, A. T., & Toscano, A. (2020). Exploring the Adoption of Precision Agriculture for Irrigation in the Context of Agriculture 4.0: The Key Role of Internet of Things. Sensors, 20(24), 7091. https://doi.org/10.3390/s20247091

Navarro, E., Costa, N., & Pereira, A. (2020). A Systematic Review of IoT Solutions for Smart Farming. Sensors, 20(15), 4231. https://doi.org/10.3390/s20154231

Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. Journal of Intelligent Manufacturing, 31(1), 127–182. https://doi.org/10.1007/s10845-018-1433-8

Pagani, R. N., Kovaleski, J. L., & Resende, L. M. (2015). Methodi Ordinatio: A proposed methodology to select and rank relevant scientific papers encompassing the impact factor, number of citation, and year of publication. Scientometrics, 105(3), 2109–2135. https://doi.org/10.1007/s11192-015-1744-x

Partel, V., Charan Kakarla, S., & Ampatzidis, Y. (2019). Development and evaluation of a low-cost and smart technology for precision weed management utilizing artificial intelligence. Computers and Electronics in Agriculture, 157, 339–350. https://doi.org/10.1016/j.compag.2018.12.048

Petticrew, M., & Roberts, H. (A c. Di). (2006). Frontmatter. In Systematic Reviews in the Social Sciences (pagg. i–xv). Blackwell Publishing Ltd. https://doi.org/10.1002/9780470754887.fmatter

Pham, X., & Stack, M. (2018). How data analytics is transforming agriculture. Business Horizons, 61(1), 125–133. https://doi.org/10.1016/j.bushor.2017.09.011

Ramin Shamshiri, R., Kalantari, F., C. Ting, K., R. Thorp, K., A. Hameed, I., Weltzien, C., Ahmad, D., Mojgan Shad, Z., 1. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. International Journal of Agricultural and Biological Engineering, 11(1), 1–22. https://doi.org/10.25165/j.ijabe.20181101.3210

Ramin Shamshiri, R., Weltzien, C., A. Hameed, I., J. Yule, I., E. Grift, T., K. Balasundram, S., Pitonakova, L., Ahmad, D., Chowdhary, G., (2018). Research and development in agricultural robotics: A perspective of digital farming. International Journal of Agricultural and Biological Engineering, 11(4), 1–11. https://doi.org/10.25165/j.ijabe.20181104.4278

Ray, P. P. (2017). Internet of things for smart agriculture: Technologies, practices and future direction. Journal of Ambient Intelligence and Smart Environments, 9(4), 395–420. https://doi.org/10.3233/AIS-170440

Reif, R., & Walch, D. (2008). Augmented & Virtual Reality applications in the field of logistics. The Visual Computer, 24(11), 987–994. https://doi.org/10.1007/s00371-008-0271-7

Roopaei, M., Rad, P., & Choo, K.-K. R. (2017). Cloud of Things in Smart Agriculture: Intelligent Irrigation Monitoring by Thermal Imaging. IEEE Cloud Computing, 4(1), 10–15. https://doi.org/10.1109/MCC.2017.5

Roshanianfard, A., Noguchi, N., Okamoto, H., & Ishii, K. (2020). A review of autonomous agricultural vehicles (The experience of Hokkaido University). Journal of Terramechanics, 91, 155–183. https://doi.org/10.1016/j.jterra.2020.06.006

Saad, A., Benyamina, A. E. H., & Gamatie, A. (2020). Water Management in Agriculture: A Survey on Current Challenges and Technological Solutions. IEEE Access, 8, 38082–38097. https://doi.org/10.1109/ACCESS.2020.2974977

Saggi, M. K., & Jain, S. (2018). A survey towards an integration of big data analytics to big insights for value-creation. Information Processing & Management, 54(5), 758–790. https://doi.org/10.1016/j.ipm.2018.01.010

Seuring, S., & Gold, S. (2012). Conducting content-analysis based literature reviews in supply chain management. Supply Chain Management: An International Journal, 17(5), 544–555. https://doi.org/10.1108/13598541211258609

Shafi, U., Mumtaz, R., García-Nieto, J., Hassan, S. A., Zaidi, S. A. R., & Iqbal, N. (2019). Precision Agriculture Techniques and Practices: From Considerations to Applications. Sensors, 19(17), 3796. https://doi.org/10.3390/s19173796

Sharma, R., Kamble, S. S., Gunasekaran, A., Kumar, V., & Kumar, A. (2020). A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. Computers & Operations Research, 119, 104926. https://doi.org/10.1016/j.cor.2020.104926

Sikorski, J. J., Haughton, J., & Kraft, M. (2017). Blockchain technology in the chemical industry: Machine-to-machine electricity market. Applied Energy, 195, 234–246. https://doi.org/10.1016/j.apenergy.2017.03.039

Sott, M. K., Furstenau, L. B., Kipper, L. M., Giraldo, F. D., Lopez-Robles, J. R., Cobo, M. J., Zahid, A., Abbasi, Q. H., & Imran, M. A. (2020). Precision Techniques and Agriculture 4.0 Technologies to Promote Sustainability in the Coffee Sector: State of the Art, Challenges and Future Trends. IEEE Access, 8, 149854–149867. https://doi.org/10.1109/ACCESS.2020.3016325

Sri Heera S., S. P., Athreya S.S., N. S. S., & Rakesh M. (2019). Automated Irrigation and Smart Farming. International Journal of Engineering and Advanced Technology, 8(6S3), 1450–1452. https://doi.org/10.35940/ijeat.F1258.0986S319

Tang, Y., Dananjayan, S., Hou, C., Guo, Q., Luo, S., & He, Y. (2021). A survey on the 5G network and its impact on agriculture: Challenges and opportunities. Computers and Electronics in Agriculture, 180, 105895. https://doi.org/10.1016/j.compag.2020.105895

Terence, S., & Purushothaman, G. (2020). Systematic review of Internet of Things in smart farming. Transactions on Emerging Telecommunications Technologies, 31(6). https://doi.org/10.1002/ett.3958

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. British Journal of Management, 14(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Trappey, A. J. C., Trappey, C. V., Govindarajan, U. H., Sun, J. J., & Chuang, A. C. (2016). A Review of Technology Standards and Patent Portfolios for Enabling Cyber-Physical Systems in Advanced Manufacturing. IEEE Access, 4, 7356–7382. https://doi.org/10.1109/ACCESS.2016.2619360

Tsouros, D. C., Bibi, S., & Sarigiannidis, P. G. (2019). A Review on UAV-Based Applications for Precision Agriculture. Information, 10(11), 349. https://doi.org/10.3390/info10110349

Ülgen, Björklund, Simm, & Forslund. (2019). Inter-Organizational Supply Chain Interaction for Sustainability: A Systematic Literature Review. Sustainability, 11(19), 5488. https://doi.org/10.3390/su11195488

van der Burg, S., Bogaardt, M.-J., & Wolfert, S. (2019). Ethics of smart farming: Current questions and directions for responsible innovation towards the future. NJAS - Wageningen Journal of Life Sciences, 90–91, 100289. https://doi.org/10.1016/j.njas.2019.01.001

Vera-Baquero, A., Colomo-Palacios, R., & Molloy, O. (2014). Towards a Process to Guide Big Data Based Decision Support Systems for Business Processes. Procedia Technology, 16, 11–21. https://doi.org/10.1016/j.protcy.2014.10.063

Vidyashree A L, & Shashikala S V. (2019). Agribusiness Innovation Utilizing Gis with Machine Learning. International Journal of Engineering and Advanced Technology, 8(6), 2442–2444. https://doi.org/10.35940/ijeat.F8539.088619

Villa-Henriksen, A., Edwards, G. T. C., Pesonen, L. A., Green, O., & Sørensen, C. A. G. (2020). Internet of Things in arable farming: Implementation, applications, challenges and potential. Biosystems Engineering, 191, 60–84. https://doi.org/10.1016/j.biosystemseng.2019.12.013

Vincent, D. R., Deepa, N., Elavarasan, D., Srinivasan, K., Chauhdary, S. H., & Iwendi, C. (2019). Sensors Driven AI-Based Agriculture Recommendation Model for Assessing Land Suitability. Sensors, 19(17), 3667. https://doi.org/10.3390/s19173667

Viriyasitavat, W., Da Xu, L., Bi, Z., & Sapsomboon, A. (2020). Blockchain-based business process management (BPM) framework for service composition in industry 4.0. Journal of Intelligent Manufacturing, 31(7), 1737–1748. https://doi.org/10.1007/s10845-018-1422-y

Wan, X., Zheng, T., Cui, J., Zhang, F., Ma, Z., & Yang, Y. (2019). Near Field Communication-based Agricultural Management Service Systems for Family Farms. Sensors, 19(20), 4406. https://doi.org/10.3390/s19204406

Wang, X., Ong, S. K., & Nee, A. Y. C. (2016). A comprehensive survey of augmented reality assembly research. Advances in Manufacturing, 4(1), 1–22. https://doi.org/10.1007/s40436-015-0131-4

Xu, X. (2012). From cloud computing to cloud manufacturing. Robotics and Computer-Integrated Manufacturing, 28(1), 75–86. https://doi.org/10.1016/j.rcim.2011.07.002

Yanes, A. R., Martinez, P., & Ahmad, R. (2020). Towards automated aquaponics: A review on monitoring, IoT, and smart systems. Journal of Cleaner Production, 263, 121571. https://doi.org/10.1016/j.jclepro.2020.121571

Zamora-Izquierdo, M. A., Santa, J., Martínez, J. A., Martínez, V., & Skarmeta, A. F. (2019). Smart farming IoT platform based on edge and cloud computing. Biosystems Engineering, 177, 4–17. https://doi.org/10.1016/j.biosystemseng.2018.10.014

Zhai, Z., Martínez, J. F., Beltran, V., & Martínez, N. L. (2020). Decision support systems for agriculture 4.0: Survey and challenges. Computers and Electronics in Agriculture, 170, 105256. https://doi.org/10.1016/j.compag.2020.105256

Zhang, X., Cao, Z., & Dong, W. (2020). Overview of Edge Computing in the Agricultural Internet of Things: Key Technologies, Applications, Challenges. IEEE Access, 8, 141748–141761. https://doi.org/10.1109/ACCESS.2020.3013005

Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M. (2020). The applications of Industry 4.0 technologies in manufacturing context: A systematic literature review. International Journal of Production Research, 34. https://doi.org/10.1080/00207543.2020.1824085

Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M. (2021). The road towards industry 4.0: A comparative study of the state-of-the-art in the Italian manufacturing industry. Benchmarking: An International Journal, ahead-of-print(ahead-of-print). https://doi.org/10.1108/BIJ-01-2021-0056

2.3 References Paper B

1. Mohammad Fakhrul Islam, S.; Karim, Z. World's Demand for Food and Water: The Consequences of Climate Change. In *Desalination—Challenges and Opportunities*; Hossein Davood Abadi Farahani, M., Vatanpour, V., Hooshang Taheri, A., Eds.; IntechOpen, 2020 ISBN 978-1-78984-738-3.

2. Sott, M.K.; Furstenau, L.B.; Kipper, L.M.; Giraldo, F.D.; Lopez-Robles, J.R.; Cobo, M.J.; Zahid, A.; Abbasi, Q.H.; Imran, M.A. Precision Techniques and Agriculture 4.0 Technologies to Promote Sustainability in the Coffee Sector: State of the Art, Challenges and Future Trends. *IEEE Access* 2020, *8*, 149854–149867. https://doi.org/10.1109/ACCESS.2020.3016325.

3. Abeliansky, A.; Prettner, K. Automation and Demographic Change. *SSRN Electron. J.* 2017. https://doi.org/10.2139/ssrn.2959977.

4. Yadav, V.S.; Singh, A.R.; Raut, R.D.; Mangla, S.K.; Luthra, S.; Kumar, A. Exploring the application of Industry 4.0 technologies in the agricultural food supply chain: A systematic literature review. *Comput. Ind. Eng.* 2022, *169*, 108304. https://doi.org/10.1016/j.cie.2022.108304.

5. Mazzetto, F.; Gallo, R.; Sacco, P. Reflections and Methodological Proposals to Treat the Concept of "Information Precision" in Smart Agriculture Practices. *Sensors* 2020, *20*, 2847. https://doi.org/10.3390/s20102847.

6. Jayaraman, P.; Yavari, A.; Georgakopoulos, D.; Morshed, A.; Zaslavsky, A. Internet of Things Platform for Smart Farming: Experiences and Lessons Learnt. *Sensors* 2016, *16*, 1884. https://doi.org/10.3390/s16111884.

7. Pivoto, D.; Waquil, P.D.; Talamini, E.; Finocchio, C.P.S.; Dalla Corte, V.F.; de Vargas Mores, G. Scientific development of smart farming technologies and their application in Brazil. *Inf. Process. Agric.* 2018, *5*, 21–32. https://doi.org/10.1016/j.inpa.2017.12.002.

8. Shang, L.; Heckelei, T.; Gerullis, M.K.; Börner, J.; Rasch, S. Adoption and diffusion of digital farming technologies—Integrating farm-level evidence and system interaction. *Agric. Syst.* 2021, *190*, 103074. https://doi.org/10.1016/j.agsy.2021.103074.

9. Lezoche, M.; Hernandez, J.E.; Alemany Díaz, M. del M.E.; Panetto, H.; Kacprzyk, J. Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture. *Comput. Ind.* 2020, *117*, 103187. https://doi.org/10.1016/j.compind.2020.103187.

10. Liu, Y.; Ma, X.; Shu, L.; Hancke, G.P.; Abu-Mahfouz, A.M. From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges. *IEEE Trans. Ind. Inform.* 2021, *17*, 4322–4334. https://doi.org/10.1109/TII.2020.3003910.

11. Bolfe, É.L.; Jorge, L.A. de C.; Sanches, I.D.; Luchiari Júnior, A.; da Costa, C.C.; Victoria, D. de C.; Inamasu, R.Y.; Grego, C.R.; Ferreira, V.R.; Ramirez, A.R. Precision and Digital Agriculture: Adoption of Technologies and Perception of Brazilian Farmers. *Agriculture* 2020, *10*, 653. https://doi.org/10.3390/agriculture10120653.

12. Chuang, J.-H.; Wang, J.-H.; Liang, C. Implementation of Internet of Things depends on intention: Young farmers' willingness to accept innovative technology. *Int. Food Agribus. Manag. Rev.* 2020, *23*, 253–266. https://doi.org/10.22434/IFAMR2019.0121.

13. CREA: L'agro-alimentare italiano settore chiave dell'economia Leader in Europa per valore aggiunto agricolo—CREA Available online: https://www.crea.gov.it/-/crea-l-agro-alimentare-italiano-settore-chiave-dell-economia-leader-in-europa-per-valore-aggiunto-agricolo-1 (accessed on 15 July 2022).

14. Lytos, A.; Lagkas, T.; Sarigiannidis, P.; Zervakis, M.; Livanos, G. Towards smart farming: Systems, frameworks and exploitation of multiple sources. *Comput. Netw.* 2020, *172*, 107147. https://doi.org/10.1016/j.comnet.2020.107147.

15. Nikkilä, R.; Seilonen, I.; Koskinen, K. Software architecture for farm management information systems in precision agriculture. *Comput. Electron. Agric.* 2010, *70*, 328–336. https://doi.org/10.1016/j.compag.2009.08.013.

16. Zhai, Z.; Martínez, J.F.; Beltran, V.; Martínez, N.L. Decision support systems for agriculture 4.0: Survey and challenges. *Comput. Electron. Agric.* 2020, *170*, 105256. https://doi.org/10.1016/j.compag.2020.105256.

17. Khujamatov, Kh.E.; Toshtemirov, T.K. Wireless sensor networks-based Agriculture 4.0: Challenges and apportions. In Proceedings of the 2020 International Conference on Information Science and Communications Technologies (ICISCT), Karachi, Pakistan, 8–9 Febuary 2020; IEEE: Tashkent, Uzbekistan, 2020; pp. 1–5.

18. Raj, M.; Gupta, S.; Chamola, V.; Elhence, A.; Garg, T.; Atiquzzaman, M.; Niyato, D. A survey on the role of Internet of Things for adopting and promoting Agriculture 4.0. *J. Netw. Comput. Appl.* 2021, *187*, 103107. https://doi.org/10.1016/j.jnca.2021.103107.

19. Quy, V.K.; Hau, N.V.; Anh, D.V.; Quy, N.M.; Ban, N.T.; Lanza, S.; Randazzo, G.; Muzirafuti, A. IoT-Enabled Smart Agriculture: Architecture, Applications, and Challenges. *Appl. Sci.* 2022, *12*, 3396. https://doi.org/10.3390/app12073396.

20. Radoglou-Grammatikis, P.; Sarigiannidis, P.; Lagkas, T.; Moscholios, I. A compilation of UAV applications for precision agriculture. *Comput. Netw.* 2020, *172*, 107148. https://doi.org/10.1016/j.comnet.2020.107148.

21. Araújo, S.O.; Peres, R.S.; Barata, J.; Lidon, F.; Ramalho, J.C. Characterising the Agriculture 4.0 Landscape—Emerging Trends, Challenges and Opportunities. *Agronomy* 2021, *11*, 667. https://doi.org/10.3390/agronomy11040667.

22. Ramin Shamshiri, R.; Weltzien, C.; Hameed, A.I.; Yule, J.I.; Grift, E.T.; Balasundram, S.K.; Pitonakova, L.; Ahmad, D.; Chowdhary, G.; 1. Department of Agriculture Technology, Faculty of Agriculture, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia; et al. Research and

development in agricultural robotics: A perspective of digital farming. *Int. J. Agric. Biol. Eng.* 2018, *11*, 1–11. https://doi.org/10.25165/j.ijabe.20181104.4278.

23. Agrimonti, C.; Lauro, M.; Visioli, G. Smart agriculture for food quality: Facing climate change in the 21st century. *Crit. Rev. Food Sci. Nutr.* 2021, *61*, 971–981. https://doi.org/10.1080/10408398.2020.1749555.

24. Branca, G.; Arslan, A.; Paolantonio, A.; Grewer, U.; Cattaneo, A.; Cavatassi, R.; Lipper, L.; Hillier, J.; Vetter, S. Assessing the economic and mitigation benefits of climate-smart agriculture and its implications for political economy: A case study in Southern Africa. *J. Clean. Prod.* 2021, *285*, 125161. https://doi.org/10.1016/j.jclepro.2020.125161.

25. Klerkx, L.; Jakku, E.; Labarthe, P. A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS—Wageningen. J. Life Sci.* 2019, *90–91*, 100315. https://doi.org/10.1016/j.njas.2019.100315.

26. Schneider, P. Managerial challenges of Industry 4.0: An empirically backed research agenda for a nascent field. *Rev. Manag. Sci.* 2018, *12*, 803–848. https://doi.org/10.1007/s11846-018-0283-2.

27. Zambon, I.; Cecchini, M.; Egidi, G.; Saporito, M.G.; Colantoni, A. Revolution 4.0: Industry vs. Agriculture in a Future Development for SMEs. *Processes* 2019, *7*, 36. https://doi.org/10.3390/pr7010036.

28. Norman, W.; MacDonald, C. Getting to the Bottom of "Triple Bottom Line." *Bus. Ethics Q.* 2004, *14*, 243–262. https://doi.org/10.5840/beq200414211.

29. Rose, D.C.; Wheeler, R.; Winter, M.; Lobley, M.; Chivers, C.-A. Agriculture 4.0: Making it work for people, production, and the planet. *Land Use Policy* 2021, *100*, 104933. https://doi.org/10.1016/j.landusepol.2020.104933.

30. Porter, M.E. Technology and competitive advantage. *J. Bus. Strategy* 1985, *5*, 60–78. https://doi.org/10.1108/eb039075.

31. Prathibha, S.R.; Hongal, A.; Jyothi, M.P. IOT Based Monitoring System in Smart Agriculture. In Proceedings of the 2017 International Conference on Recent Advances in Electronics and Communication Technology (ICRAECT), Bangalore, India, 16–17 March 2017; pp. 81–84.

32. Marinoudi, V.; Sørensen, C.G.; Pearson, S.; Bochtis, D. Robotics and labour in agriculture. A context consideration. *Biosyst. Eng.* 2019, *184*, 111–121. https://doi.org/10.1016/j.biosystemseng.2019.06.013.

33. Santiteerakul, S.; Sopadang, A.; Yaibuathet Tippayawong, K.; Tamvimol, K. The Role of Smart Technology in Sustainable Agriculture: A Case Study of Wangree Plant Factory. *Sustainability* 2020, *12*, 4640. https://doi.org/10.3390/su12114640.

34. da Silveira, F.; Lermen, F.H.; Amaral, F.G. An overview of agriculture 4.0 development: Systematic review of descriptions, technologies, barriers, advantages, and disadvantages. *Comput. Electron. Agric.* 2021, *189*, 106405. https://doi.org/10.1016/j.compag.2021.106405.

35. Petrillo, A.; Felice, F.D.; Cioffi, R.; Federico Zomparelli Fourth Industrial Revolution: Current Practices, Challenges, and Opportunities. In *Digital Transformation in Smart Manufacturing*; Petrillo, A., Cioffi, R., Felice, F.D., Eds.; IntechOpen: Rijeka, Croatia, 2018.

36. Rea, L. M.; Parker, R. A. *Designing and Conducting Survey Research*; Jossey-Boss: San Francisco, CA, USA, 1992.

37. Rossi, P. H.; Wright, J. D.; Anderson, A.B. *Handbook of Survey Research*; Academic Press: New York, NY, USA, 2013.

38. Malhotra, M.K.; Grover, V. An assessment of survey research in POM: From constructs to theory. *J. Oper. Manag.* 1998, *16*, 407–425. https://doi.org/10.1016/S0272-6963(98)00021-7.

39. Wacker, J. G. A Definition of Theory: Research Guidelines for Different Theory-Building Research Methods in Operations Management. *J. Oper. Manag.* 1998, *16*, 361–385. https://doi.org/10.1016/S0272-6963(98)00019-9.

40. McMurray, A. *Research: A Commonsense Approach*; Cengage Learning Australia, 2004;.

41. Oppenheim, A.N.; Oppenheim, A.N. *Questionnaire Design, Interviewing, and Attitude Measurement*; New ed.; Pinter Publishers; Distributed exclusively in the USA and Canada by St. Martin's Press: London, UK ; New York , NY, USA, 1992; ISBN 978-1-85567-043-3.

42. Dillman, D.A.; Phelps, G.; Tortora, R.; Swift, K.; Kohrell, J.; Berck, J.; Messer, B.L. Response rate and measurement differences in mixed-mode surveys using mail, telephone, interactive voice response (IVR) and the Internet. *Soc. Sci. Res.* 2009, *38*, 1–18. https://doi.org/10.1016/j.ssresearch.2008.03.007.

43. Yun, G.W.; Trumbo, C.W. Comparative Response to a Survey Executed by Post, E-mail, & Web Form. *J. Comput.-Mediat. Commun.* 2000, *6*, JCMC613. https://doi.org/10.1111/j.1083-6101.2000.tb00112.x.

44. Forza, C. Survey research in operations management: A process-based perspective. *Int. J. Oper. Prod. Manag.* 2002, *22*, 152–194. https://doi.org/10.1108/01443570210414310.

45. Series Foreword: Critical Specialities in Treating Autism and Other Behavioral Challenges. In *A Practical Guide to Finding Treatments That Work for People with Autism*; Wilczynski, S.M., Ed.; Critical Specialties-Treating Autism&Behavioral Challenge; Academic Press: San Diego, CA, USA, 2017; pp. vii–viii, ISBN 978-0-12-809480-8.

46. Chaney, M.A. So You Want to Write a Narrative Review Article? *J. Cardiothorac. Vasc. Anesth.* 2021, *35*, 3045–3049. https://doi.org/10.1053/j.jvca.2021.06.017.

47. Struttura Delle Aziende Agricole. Available online: http://dati.istat.it/Index.aspx?DataSetCode=DCSP_SPA (accessed on 15 July 2022).

2.4 References Paper C

1. S. O. Araújo, R. S. Peres, J. Barata, F. Lidon, e J. C. Ramalho, «Characterising the Agriculture 4.0 Landscape—Emerging Trends, Challenges and Opportunities», *Agronomy*, vol. 11, fasc. 4, Art. fasc. 4, apr. 2021, doi: 10.3390/agronomy11040667.

2. G. Branca *et al.*, «Assessing the economic and mitigation benefits of climate-smart agriculture and its implications for political economy: A case study in Southern Africa», *Journal of Cleaner Production*, vol. 285, p. 125161, feb. 2021, doi: 10.1016/j.jclepro.2020.125161.

3. F. Maffezzoli, M. Ardolino, A. Bacchetti, M. Perona, e F. Renga, «Agriculture 4.0: A systematic literature review on the paradigm, technologies and benefits», *Futures*, vol. 142, p. 102998, set. 2022, doi: 10.1016/j.futures.2022.102998.

4. Ardolino M., Bacchetti A., Perona M., Zheng T., e Adrodegari F., «An exploratory survey on the impacts of logistics 4.0 on italian manufacturing companies», *International Journal of Integrated Supply Management*, vol. 15, pp. 121–150, 2022, doi: 10.1504/IJISM.2022.121909.

5. M. Lezoche, J. E. Hernandez, M. del M. E. Alemany Díaz, H. Panetto, e J. Kacprzyk, «Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture», *Computers in Industry*, vol. 117, p. 103187, mag. 2020, doi: 10.1016/j.compind.2020.103187.

6. J. Chen e A. Yang, «Intelligent Agriculture and Its Key Technologies Based on Internet of Things Architecture», *IEEE Access*, vol. 7, pp. 77134–77141, 2019, doi: 10.1109/ACCESS.2019.2921391.

7. M. S. Magombeyi, «Effectiveness of agricultural water management technologies on rainfed cereals crop yield and runoff», *INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY*, p. 25, 2018.

8. F. A. Maffezzoli, M. Ardolino, e A. Bacchetti, «The Impact of the 4.0 Paradigm in the Italian Agricultural Sector: A Descriptive Survey», *Applied Sciences*, vol. 12, fasc. 18, p. 9215, set. 2022, doi: 10.3390/app12189215.

9. R. Filippini, «Operations management research: some reflections on evolution, models and empirical studies in OM», *International Journal of Operations & Production Management*, vol. 17, fasc. 7, Art. fasc. 7, gen. 1997, doi: 10.1108/01443579710175583.

10. T. Zheng, M. Ardolino, A. Bacchetti, e M. Perona, «The road towards industry 4.0: a comparative study of the state-of-the-art in the Italian manufacturing industry», *BIJ*, vol. 30, fasc. 1, pp. 307–332, gen. 2021, doi: 10.1108/BIJ-01-2021-0056.

11. C. Forza, «Survey research in operations management: a process-based perspective», *International Journal of Operations & Production Management*, vol. 22, fasc. 2, Art. fasc. 2, feb. 2002, doi: 10.1108/01443570210414310.

12. E. Navarro, N. Costa, e A. Pereira, «A Systematic Review of IoT Solutions for Smart Farming», *Sensors*, vol. 20, fasc. 15, p. 4231, lug. 2020, doi: 10.3390/s20154231.

13. Y. Liu, X. Ma, L. Shu, G. P. Hancke, e A. M. Abu-Mahfouz, «From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges», *IEEE Trans. Ind. Inf.*, vol. 17, fasc. 6, pp. 4322–4334, giu. 2021, doi: 10.1109/TII.2020.3003910.

14. Z. Zhai, J. F. Martínez, V. Beltran, e N. L. Martínez, «Decision support systems for agriculture 4.0: Survey and challenges», *Computers and Electronics in Agriculture*, vol. 170, p. 105256, mar. 2020, doi: 10.1016/j.compag.2020.105256.

15. I. Zambon, M. Cecchini, G. Egidi, M. G. Saporito, e A. Colantoni, «Revolution 4.0: Industry vs. Agriculture in a Future Development for SMEs», *Processes*, vol. 7, fasc. 1, Art. fasc. 1, gen. 2019, doi: 10.3390/pr7010036.