Assessing the impact of Industry 4.0 technologies on the social sustainability of agrifood companies

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Abstract

Industry 4.0 technologies present new opportunities for the sustainable development of companies in the agrifood industry. The extant literature on this topic suggests that innovative technologies can support agrifood companies in addressing environmental, economic, and social sustainability issues. While the environmental and economic benefits of technological innovations in the agrifood industry have been widely investigated, few studies sought to explore the impact of the adoption of Industry 4.0 technologies on long-standing social issues. This research addresses this knowledge gap, The data was gathered from 116 Italian agrifood companies that utilized Industry 4.0 technologies. The findings from structural equations modelling partial least squares (SEM-PLS) show that adopting Industry 4.0 technologies helps agrifood companies to improve human resources management, supply chain management, and stakeholder relationships. Finally, this contribution puts forward implications for practitioners, as it raises awareness on the benefits of using technological innovations to promote social sustainability outcomes.

Keywords: Industry 4.0, Technological skills, technological strategy, technological maturity, supply chain management, sustainable supply chain management.

1. Introduction

The adoption of Industry 4.0 (I4.0) technologies is driving innovation in the agrifood industry, leading to the definition of the Agriculture 4.0 paradigm. This represents a new approach to farm management, based on the use of real-time data and precision agriculture techniques (Maffezzoli et al., 2022; Sott et al., 2020). Over the years, this topic attracted considerable scientific interest, initiating the investigation of the implications of the adoption of I4.0 technologies in the agrifood industry (Bongomin et al., 2020; Cricelli et al., 2022; Lezoche et al., 2020). Scholars highlight how the adoption of I4.0 technologies presents agrifood companies with the opportunity to address long-standing sustainability issues. From this perspective, multiple studies focus on the connection between environmental and economic sustainability (Bandinelli et al., 2020; Clapp & Ruder, 2020; Forney & Epiney, 2022; Tang & Yang, 2016; Xie et al., 2022). These studies show how by using real-time and site-specific data, I4.0 technologies help agrifood companies improve resource management, productivity and efficiency.

A growing research stream focuses on the impact of I4.0 technologies on the sustainability of agrifood companies. This has its theoretical foundations in the well-known Triple Bottom Line framework, which considers environmental, economic, and social sustainability aspects equally (Elkington, 2017). However, while the environmental and economic benefits provided by I4.0 technologies are widely recognized, their impact on the social sustainability of agrifood companies is currently under-investigated. Several papers review I4.0 technological applications, offering a conceptual analysis of how technologies are set to disrupt the agrifood industry along the three dimensions of sustainability (dos Reis et al., 2020; Hassoun et al., 2022; Latino et al., 2023; Lezoche et al., 2020; Morella et al., 2021; Senturk et al., 2023).

While providing valuable contributions, these studies do not focus precisely on social sustainability issues and offer a mainly theoretical contribution. On a different note, some studies focus on the design and evaluation of technological solutions for specific agrifood applications (Mavridou et al., 2019; Shockley et al., 2019; Wolfert et al., 2017). Besides offering a thorough analysis of the potential of technologies, these papers provide a technical perspective, and overlook the social implications of technological innovation in the agrifood industry.

Indeed, studies focusing on investigating how I4.0 technologies affect the social sustainability of agrifood companies return a complex picture. One of the fundamental aspects of social sustainability in organizations concerns the quality of the working environment and the management of human resources. From this perspective, the prevailing idea in the literature is that the adoption of I4.0 technologies could help agrifood companies create safer and healthier working environments (Alves et al., 2023; Monteleone et al., 2020; Nawandar & Satpute, 2019). Multiple studies show how the dependence on uncontrollable environmental factors subjects agricultural workers to harsh working conditions (Martin et al., 2022; Rose et al., 2021). The use of I4.0 technologies enables the automation of the most physically demanding tasks, reducing operator workloads and increasing workplace security (Giannoccaro et al., 2020; Lioutas et al., 2021). However, some empirical studies present conflicting evidence. Weber et al. (2022) and Prause (2021) explain that the adoption of I4.0 technologies creates new forms of labour control, allowing farm owners to put pressure on workers to increase productivity.

Furthermore, while some scholars argue that the adoption of I4.0 technologies favours the development of new skills and the definition of new roles in agrifood companies (Martin et al., 2022; Neumann et al., 2021), others argue that the lack of technological skills is one of the main barriers to the adoption of I4.0 technologies in the agrifood industry and entails the risk of marginalizing workers with more traditional skills (Abbasi et al., 2022; Derakhti et al., 2023).

Beyond issues relating to labour management, several studies highlight how the development of global supply chains and the emergence of food scandals endangering consumers' health raised serious concerns regarding the security and accountability of agrifood supply chains (Milford et al., 2021; Smith & McElwee, 2020). The combination of modern ICTs and I4.0 technologies such as blockchain and IoT provides businesses with the opportunity to ensure transparency and respect for sustainability standards throughout the supply chain. This could also bring significant social benefits, improving relationships between supply chain partners and external stakeholders, including governments and consumers (Finger, 2023; Mukherjee et al., 2021; Vernier et al., 2021).

Despite this, relevant studies suggest that the effective use of I4.0 technologies requires an active commitment by companies (Brookbanks & Parry, 2022; Morella et al., 2021). In this scenario, the technological capability of the company plays a pivotal role. To derive social benefits from technological innovation, agrifood companies must ensure that they develop the necessary skills and integrate I4.0 technologies into their business activities effectively (Abbasi et al., 2022; Gaspar et al., 2021; Zeng & Lu, 2021).

Unfortunately, most of the literature on technological innovation in the agrifood industry failed to empirically investigate the connection between technological capability and the impact of I4.0 technologies on companies' social sustainability (Latino et al., 2023). This study aims to address this knowledge gap by answering the following research question:

RQ) How does the use of Industry 4.0 technologies affect the social sustainability of agrifood companies?

To answer the research question, we first analyse the available literature to identify metrics and indicators that explain how agrifood companies can use Industry 4.0 technologies to address key social sustainability issues. To model how firms acquire and integrate technologies into their business, we use the concept of technological capability (Annarelli et al., 2021; Arballo et al., 2019; Uddin et al., 2023; Wang et al., 2006). Specifically, we identify three key capabilities that the company must develop to effectively integrate Industry 4.0 technologies into the business, related to the development of I4.0 technological skills, the definition of an I4.0 technological strategy, and the I4.0 technological maturity of the firm. Then, we draw from the literature on companies' Corporate Social Responsibility (CSR) and supply chain social responsibility to identify the main issues in the agrifood industry, distinguishing between different aspects of social sustainability that involve multiple stakeholders throughout the supply chain (Lu et al., 2012; Mani et al., 2020; Pfajfar et al., 2022; Uddin et al., 2023). Specifically, we focus on the management of human resources, communication with supply chain partners, and relationships with consumers and society. Finally, we use data from a survey aimed at 1.320 Italian agrifood industry companies to validate a Structural Equation Modeling (SEM) model designed to assess the impact of I4.0 technologies on the social sustainability of agrifood companies.

Overall, this study provides two main theoretical contributions. First, it offers empirical evidence of the impact of I4.0 technologies on the social sustainability of agrifood companies. Second, it examines how the adoption of I4.0 technologies influences the social sustainability of agrifood companies. This advances the literature by explaining how technological innovation impacts social sustainability in the agrifood industry and by enabling the definition of a framework to assess the social impact of I4.0 technologies. This study also presents notable practical implications, which can help the management of agrifood companies reap the social benefits of adopting I4.0 technologies. The paper is organised as follows. The second section provides the theoretical background of the study, with an overview of how I4.0 technologies may impact social sustainability in the agrifood industry. Then, we develop our hypotheses and build the models. In this, we also present the main theories we used to model the concepts of I4.0 technological capability and social sustainability in the agrifood industry. In the next section, we describe the methodology, then we present the results. In the last two sections, we discuss the results and conclude, respectively.

2. Theoretical background

The concept of Agriculture 4.0 entails a new paradigm in which I4.0 technologies are seamlessly integrated into agricultural practices. Over the years, multiple studies reviewed the applications of I4.0 technologies in the agrifood industry (Abbasi et al., 2022; J. Miranda et al., 2019;

Sott et al., 2020). Prominent technologies include IoT, Big Data, Artificial Intelligence, and blockchain (Candiago et al., 2015; dos Reis et al., 2020; Lezoche et al., 2020; Wolfert et al., 2017). In most applications, these are used for the processing of real-time data and the execution of precision agriculture interventions (Giannoccaro et al., 2020; Latino et al., 2023). Furthermore, the data provided by I4.0 technologies can be fed to decision support systems to assist agrifood companies in planning activities and achieving key performance targets.

The adoption of I4.0 technologies offers agrifood companies the opportunity to promote the conscious use of resources, while increasing productivity and efficiency. Most of the literature on the impact of I4.0 technologies in the agrifood industry stresses the relationship between environmental and economic sustainability (Annosi et al., 2020; Khanna et al., 2022; Luzzani et al., 2021; Ruiz-Garcia & Lunadei, 2011). Yadav et al. (2022) identify five main research areas, i.e. food safety, information management, food waste, control and monitoring, decision-making and miscellaneous applications. Furthermore, in their systematic review of the literature on Agriculture 4.0, Maffezzoli et al. (2022) highlight how application domains include water management, crop management, prediction of climate conditions and soil monitoring. However, while the economic and environmental benefits guaranteed by I4.0 technologies are well documented, the social implications of technological innovation are currently under investigated. Recent studies suggest that the adoption of I4.0 technologies in the agrifood industry may have significant social implications, in terms of human resource management, security and accountability of supply chains, and impact on society (Janker & Mann, 2020; Luzzani et al., 2021; Rijswijk et al., 2021).

The peculiar working conditions and the dependence on uncontrollable natural factors entail unique challenges relating to labour management. Many activities and field operations can only be executed when specific environmental conditions are met. This implies that during critical periods, such as sowing or harvesting, farmers have to contend with work overload, lack of breaks and days off, and a general deterioration of working conditions (Weber et al., 2022). Also, during these periods, many companies rely heavily on temporary employment contracts, hiring workers who may suffer harsh working conditions (Christiaensen et al., 2021; Janker & Mann, 2020). The adoption of I4.0 technologies presents an opportunity to mitigate these negative effects. Real-time analysis of environmental conditions allows for better planning of activities and better management of human resources. Furthermore, the use of smart IoT systems for continuous crop monitoring enables companies to reduce human interventions and alleviate workloads. Finally, the automation of the most physically demanding tasks can help reduce the pressure on field operators and contribute to the creation of safer work environments (Hrustek, 2020; Lioutas et al., 2021)

At the same time, recent studies warn about the potential unintended consequences of technology development. Prause (2021) analyses the implications of digitalization on the social sustainability of agrifood labour, with mixed evidence. Results suggest that technologies assist farm owners in acquiring technological and managerial skills and improve activity planning. In some instances, however, field operators lamented a significant increase in workloads. By enabling real-time monitoring of the pace of activities in the fields, smart technologies allow owners to exert pressure on the workers, who are pushed to increase productivity. Furthermore, the authors question whether rapid technological innovation can lead to job losses and the marginalization of workers with low technological skills. From this perspective, several studies find that one of the main challenges to the diffusion of I4.0 technologies in industry agrifood is the lack of technological skills and an innovation-oriented strategy (Derakhti et al., 2023; Silvestri et al., 2023). Mahdad et al. (2022) show how farmers' unfamiliarity with technologies generates scepticism and resistance among workers. Several studies emphasize the importance of top management in the definition of a technological strategy (Ghobakhloo et al., 2023; Rijswijk et al., 2021). Thus, the development of the company's technological capability is key to enabling innovation in agrifood companies.

Generally, scholars agree that the adoption of I4.0 technologies can significantly affect the relationships among partners in agrifood supply chains. This may have notable implications from a social sustainability standpoint (Clapp & Ruder, 2020; Glavee-Geo et al., 2022). Mahdad et al. (2022) observe how modern information technologies can improve information sharing and strengthen interdependencies between actors in agrifood supply chains. Indeed, many successful applications of I4.0 technologies in the agrifood industry stem from the collaboration between agrifood companies and external technology providers (Brookbanks & Parry, 2022; Motta et al., 2020). This can help agrifood companies circumvent skill gaps and develop their technological capability, eliciting collaboration and a more equitable distribution of value (Glavee-Geo et al., 2022; Muller et al., 2021). Furthermore, by increasing transparency and promoting communication between partners, I4.0 technologies can help agrifood companies disseminate sustainability standards throughout the supply chain (León-Bravo et al., 2017; Mani et al., 2018; Sharma et al., 2022). This can lead to significant environmental and social benefits, as companies can select reliable partners, and ensure compliance with ethical standards regarding sourcing, production processes, and product quality.

It is important to emphasize the social responsibilities of the agrifood industry towards society. From this perspective, key issues are the control and accountability of agrifood supply chains. Ensuring product safety is not only mandatory to access markets and comply with regulations but is also key to providing consumers with reliable information (Dos Santos et al., 2021; Majdalawieh et al., 2021; Rao et al., 2021). Brooks et al. (2021) highlight how the emergence of security issues and fraudulent practices undermined consumers' trust in agrifood supply chains. As a result, consumers place greater emphasis on product authenticity (Menon & Jain, 2021).

Furthermore, governments and national authorities exert pressure on agrifood supply chains by enacting stricter regulations (Swinnen et al., 2021), and standards are used to reduce information asymmetries throughout agrifood supply chains. As for the role that I4.0 technologies can play, recent studies analyse how the adoption of IoT systems and blockchain technology allows companies to track products "from farm to fork" (Camilleri, 2020). This can help create safer and more transparent supply chains (David et al., 2022; Rana et al., 2021; Senturk et al., 2023). Also, the adoption of effective traceability systems can shield consumers and producers from fraud and counterfeiting. However, the lack of technological skills and companies' limited awareness seem to hinder the adoption of advanced tracking solutions in the agrifood industry (Galati et al., 2021; Silvestri et al., 2023).

Overall, the contribution that I4.0 technologies can provide to the social sustainability of agrifood businesses is currently little investigated. Several authors, including Costa et al. (2023) and Maffezzoli et al. (2022) highlight the need for quantitative studies to investigate the impact of innovative technologies on the social sustainability of agrifood companies. The authors emphasize the need to identify reliable measures to assess how I4.0 technologies affect the multifaceted dimensions of social sustainability within the agrifood industry. Finally, in light of the potential of I4.0 technologies to support socially sustainable innovation in the agrifood industry, it is important to analyse how the development of companies' technological capability influences the achievement of social sustainability objectives both within and outside the firm.

3. Hypothesis development

This paper aims to assess how the adoption of I4.0 technologies impacts the social sustainability of agrifood companies. The next paragraphs illustrate the hypotheses underlying the study. To model how companies can effectively integrate I4.0 technologies into business activities we use the concept of technological capability. Also, we refer to the literature on CSR companies to identify the main social benefits that I4.0 technologies may provide to agrifood companies.

3.1 Technological capability

The concept of technological capability is widely used by scholars to analyse the problem of technology management in organizations (Annarelli et al., 2021; Arballo et al., 2019; Keinz & Marhold, 2021; Valdez-Juárez & Castillo-Vergara, 2021; Xu & Tao, 2024). As shown by Coombs & Bierly (2006) and Wang et al. (2006), the concept of technological capability has its roots in the resource-based view (RBV), in the theory of dynamic capabilities and the knowledge-based view

(KBV) of the firm. Following the RBV, companies' main source of competitive advantages is the ability to leverage unique, distinctive and difficult-to-imitate resources (Barney, 1991).

Accordingly, Altuntas (2023) highlights how a firm's technological capability is intrinsically linked to the definition of a technological strategy, through which the management plans investments, processes, and organizational changes so that the company can take advantage of the technologies to drive innovation efforts. Consistently, Taghizadeh et al. (2020) demonstrate how SMEs' performance in open innovation initiatives is influenced by technological capability, which goes far beyond the use of technologies and implies a strong strategic orientation towards innovation and R&D activities.

The theory of dynamic capabilities posits that to sustain a competitive advantage, companies must develop the ability to analyse the external environment, seize opportunities, and reconfigure (Teece et al., 1997). Thus, the concept of technological capability takes on a dynamic quality, related to the company's ability to effectively integrate technologies into business processes, and develop technological maturity. Al-Mamary et al. (2022) identify four fundamental aspects of technological capability, encompassing the ability to integrate the technologies into business processes, to use technologies to improve products, and the ability to upgrade technologies.

The KBV theory suggests how firms require adequate knowledge management systems to benefit from resources and create a competitive advantage (Grant, 1996). Given the importance of technological assets for companies in modern industries, it naturally follows that knowledge management plays a crucial role in assessing the organization's technological capability. Drawing on the classic distinction between explicit and tacit knowledge, Peerally et al. (2022) and Lin & Lai (2021) highlight the role of human resources in developing the technological capability of the firm. Thus, a comprehensive evaluation of technological capability requires considering the company's ability to develop employees' technological skills. In this paper we ground our understanding of a company's technological capability on the above-mentioned theories, distinguishing three key aspects related to the definition of an I4.0 technological strategy, the development of I4.0 technological skills, and the assessment of the level of I4.0 technological maturity of the firm, respectively. Then, we use the concept of technological capability to assess how the adoption of I4.0 technologies affects social sustainability in agrifood companies.

3.2 Social sustainability

Given the lack of established metrics to evaluate social sustainability in the agrifood industry, we draw from the literature on Corporate Social Responsibility and stakeholders theory to investigate its multiple facets. We moved from the popular definition provided by the Brundtland Commission (1987), which describes sustainable development as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*", encompassing social equity, inclusion, participation, cohesion, and resilience. Then, we focus on defining social sustainability for business. To this end, we refer to the well-established concept of CSR, which originated from Carroll's seminal work on the economic, legal, ethical and discretionary responsibilities of companies (Carroll, 1979).

Indeed, companies' social responsibilities extend beyond the firm's boundaries, affecting the relationships with supply chain partners, communities and the environment in which it operates (Esposito & Ricci, 2021; Fatima & Elbanna, 2023; Mani et al., 2016). Thus, in accordance with the main theoretical developments, we ground the concept of social sustainability for agrifood companies on CSR, sustainable supply chain management and the stakeholders' theory (Al-Shammari et al., 2022; ElAlfy et al., 2020; López-Concepción et al., 2022; Mani et al., 2018; Mosca & Civera, 2020; Pfajfar et al., 2022; Waheed & Zhang, 2022). Specifically, we identify three fundamental dimensions of business social sustainability, pertaining to sustainable supply chain management, responsibilities to society and external stakeholders, and human resources management, and discuss how the development of the firm's technological capability associated with the adoption of I4.0 technologies might affect each.

3.2.1 Sustainable supply chain management

We start with the analysis of sustainability at the supply chain level, referring to the well-established literature on sustainable supply chain management (Carter et al., 2020; Fernando et al., 2022; Marshall et al., 2015; Uddin et al., 2023). This requires companies to focus not only on internal sustainability targets but also to transfer their sustainability standards to supply chain partners. This entails supporting partners' initiatives and ensuring that partners implement sustainability practices throughout the supply chain (Dubey et al., 2019; Ebinger & Omondi, 2020). While most studies consider environmental and social sustainability aspects together, Marshall et al. (2015) observe that in practice, companies tend to treat these two concepts distinctly, sometimes making trade-offs between environmental and social sustainability initiatives. This can be a particularly serious concern for agrifood companies, which are pressured to reduce the environmental impact of cultivation (Borsellino et al., 2020; El Bilali et al., 2021), but are also affected by serious issues regarding labour management and supply chain accountability.

By adopting modern information systems, agrifood companies to make their business models more socially sustainable, improving information sharing and coordination among supply chain partners. Additionally, I4.0 technologies could help businesses to better monitor the supply chain, enabling them to effectively implement CSR initiatives and build trust relationships with partners. Consequently, I4.0 technological capabilities are essential for businesses to effectively use I4.0 technologies to impact supply chain social sustainability. Thus, we aim to test the following hypothesis:

H1.a) I4.0 technological skills positively influence the social sustainability of agrifood companies in terms of supply chain management.

H1.b) I4.0 technological strategy positively influences the social sustainability of agrifood companies in terms of supply chain management.

H1.c) I4.0 technological maturity positively influences the social sustainability of agrifood companies in terms of supply chain management.

3.2.2 Sustainable stakeholders' management

Agrifood companies have the responsibility to ensure the quality of production processes and product safety. Despite this, the occurrence of food safety scandals repeatedly endangered consumer health and undermined trust in agrifood supply chains (Chandan et al., 2023; Smith & McElwee, 2020). Furthermore, the prevalence of fraud and counterfeiting poses serious concerns regarding firms' accountability and supply chain transparency (Adamashvili et al., 2021; Dos Santos et al., 2021; Ebinger & Omondi, 2020). In recent years, agrifood companies shifted their focus towards implementing more ethical production practices to regain consumer trust and comply with regulations (Bandinelli et al., 2020; Majdalawieh et al., 2021). International standards have also been developed to help consumers make informed decisions (Dos Santos et al., 2021; Muller et al., 2021; Ostfeld et al., 2019).

However, certifications and regulations have shown weaknesses, and agrifood companies require new tools to substantiate their claims. The development of advanced product tracking systems based on the combination of I4.0 technologies such as blockchain and IoT offers companies the opportunity to prove their commitment to environmental and social sustainability. Furthermore, the use of such technologies could improve the transparency and security of supply chains, enabling agrifood companies to build relationships of trust with consumers and governments. The literature suggests, however, that integrating these solutions into business processes requires advanced I4.0 technological capabilities and developing the skills and maturity necessary to change the management of information and business processes. Therefore, we aim to test the following hypothesis:

H2.a) I4.0 technological skills positively influence the social sustainability of agrifood companies in terms of stakeholders' management.

H2.b) I4.0 technological strategy positively influences the social sustainability of agrifood companies in terms of stakeholders' management.

H2.c) I4.0 technological maturity positively influences the social sustainability of agrifood companies in terms of stakeholders' management.

3.2.3 Sustainable human resources management

An essential aspect of social sustainability in businesses is the organization of work and the management of human resources (Gàlvez et al., 2020; Grybauskas et al., 2022). Companies must guarantee the health, safety, and well-being of workers. Additionally, firms must ensure fair wages and balanced workloads. Furthermore, companies must take into account the needs of the employees, supporting their training and professional growth (Amrutha & Geetha, 2020; Pinzone et al., 2020). From this perspective, agrifood companies present unique challenges. Dependence on uncontrollable environmental factors affects labour management, negatively affecting human resources. Agrifood workers face cyclical work peaks and may operate in harsh environmental conditions for prolonged periods. Furthermore, cultivation activities require the execution of repetitive and physically demanding tasks, which negatively impact workloads and operators' health. Thus, responsible labour management is a key aspect of the social sustainability of agrifood companies, which includes organizational issues, and important aspects related to workers' conditions and the quality of the working environment.

The adoption of I4.0 technologies and the development of I4.0 technological capability could help mitigate the effects of unpredictable factors, reduce work overloads and help agrifood companies create safer and healthier work environments. For example, automation can be used to support and alleviate the workload of field operators. Additionally, predictive models can be used to improve activity planning and reduce the impact of environmental factors on labour management. Finally, the adoption of I4.0 technologies could lead to the empowerment of workers, who may develop new managerial and high-level skills (Martin et al., 2022; Neumann et al., 2021). Thus, we aim to test the following hypothesis:

H3.a) I4.0 technological skills positively influence the social sustainability of agrifood companies in terms of human resources management.

H3.b) I4.0 technological strategy positively influences the social sustainability of agrifood companies in terms of human resources management.

H3.c) I4.0 technological maturity positively influences the social sustainability of agrifood companies in terms of human resources management.

Figure 1 illustrates the model underlying the hypotheses.

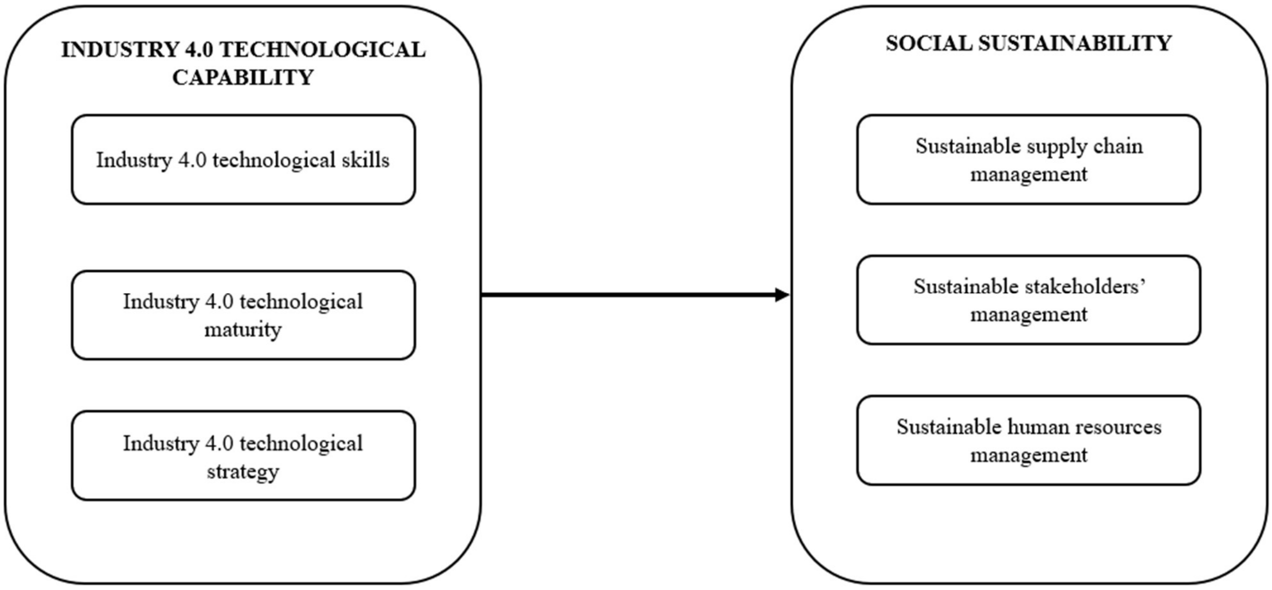

Figure 1 Theoretical model.

4. Methodology

To assess the impact of Industry 4.0 technologies on the social sustainability of agrifood companies, we adopted a quantitative approach based on the analysis of data obtained from a survey aimed at Italian agrifood companies. The following sections provide a detailed overview of the data collection process, survey structure, and data analysis techniques.

4.1 Data collection and sampling

The data were collected between December 2023 and February 2024 through a survey targeting 1.320 Italian agrifood companies. We chose to focus on Italian companies for two reasons. First, the Italian agrifood industry is characterized by the quality and variety of its products, as well as intense international trade. By focusing on companies supplying different categories of agricultural products, we are able to enhance the generalizability of the results, which relate well to all firms performing cultivation activities, regardless of the crop typology. Second, Italy is a highly industrialized country, which is a favourable condition to assess the impact of I4.0 technologies on agrifood production. The survey is based on a questionnaire that we pre-tested on a small sample of agrifood firms. The results of the pre-test allowed us to assess the completion time and the clarity of the questionnaire, implementing small improvements in the wording and presentation of the question. We carefully selected companies to meet two criteria.

Firstly, we focused on agrifood companies involved in the cultivation, harvesting, and preparation of agrifood products for processing. We also included companies engaged in processing activities, provided they also carried out cultivation activities. We excluded firms that only perform processing activities, as a key goal of the study was to evaluate the impact of I4.0 technologies on the social sustainability of cultivation-related activities, encompassing field operations and labour management. We also excluded companies in the meat industry. Although the literature suggests that I4.0 technologies can have a significant impact on livestock activities, these pose unique social sustainability issues, such as those related to animal conditions, which fall outside the scope of this study.

Regarding the second criterion, we chose to include only companies with a revenue exceeding €500.000. Thus, while maintaining the distinction between small, medium, and large companies, we excluded small-scale businesses, as they are less likely to rely on I4.0 technologies.

To ensure that the selected companies met the criteria, we consulted an online database, classifying firms based on their primary ATECO code and revenue. The ATECO code is a designation used by the Italian government to identify the main activity of a firm. Specifically, we chose only companies falling under the ATECO code 01, which includes businesses engaged in the "Cultivation of crops, animal production, hunting, and related services," excluding sub-codes related to livestock and hunting activities. Table 1 shows the ATECO codes considered.

Table 1 ATECO codes of the companies

ATECO code	Description
01.10	Cultivation of non-permanent crops, namely plants that do not last more than two seasons. This includes rice and pulses.
01.13	Cultivation of vegetables (including melons) with leaf, stem, fruit, root, bulbs, and tubers (excluding sugar beets and potatoes).
01.20	Cultivation of permanent crops, namely plants that persist in the soil for more than two years, which, despite wilting, regenerate consistently. This includes citrus and oil-bearing fruits.
1.21	Grape farming. Wine production activities from grapes primarily not of own production are excluded.

Following weekly reminders, we gathered responses from 118 companies. Next, we discarded two answers due to incoherent responses and collected the final sample comprising 116 observations.

4.2 Questionnaire structure

We divided the questionnaire into 3 main sections. The first focuses on technological capability and aims to assess the technological skills, technological strategy and technological maturity of the company. To measure technological skills we used three items, adapted from Dubey et al. (2019) and Wang et al. (2006). These measure the technology skills of the company's employees, investments in training, and the company's ability to attract staff with advanced technology skills. We used three items to evaluate the company's technological strategy. Items are adapted from Ghobakhloo et al. (2023), Taghizadeh et al. (2020) and Wang et al. (2006) and measure the company's ability to set new technological standards, use technologies to solve problems, and drive innovation in the industry.

We used two items to measure the technological maturity of the company. These measure the firm's ability to integrate and rely on multiple I4.0 technologies. Items were adapted from Ghobakhloo et al. (2023) and Wang et al. (2006). The second part of the questionnaire investigates how I4.0 technologies affect the social sustainability of agrifood companies. We distinguish three aspects of social sustainability, relating to the management of the supply chain, relations with external stakeholders, and human resources. Specifically, we used three items to assess how technologies influence sustainable supply chain management. Items are adapted from Lu et al. (2012) and Mani et al. (2018) and evaluate if I4.0 technologies help companies establish trust relationships with partners, promote and assess partners' CSR performance.

Sustainable stakeholder management was measured with three items, adapted from Mani et al. (2016) and Marshall et al. (2015). These investigate whether I4.0 technologies help the company to consider stakeholders' needs, address consumers' demands, and foster the development of the communities in which the company operates.

Finally, we utilized three items to assess the impact of I4.0 technologies on the sustainable management of human resources. Items are adapted from Gorgenyi-Hegyes et al. (2021) and Mani et al. (2020) and relate to the ability to enhance the healthiness of the workplace, ensure employees' work-life balance, and address workers' needs.

Each variable was measured using a 5-point multi-item Likert scale, ranging from "Strongly disagree" to "Strongly agree." Scales and items are available in the Appendix. The last section of the questionnaire includes socio-demographic information about the respondents and inquiries regarding the company's business activity.

4.3 Data analysis

In this paper, we use SEM methodology to analyse data and test hypotheses. We made this choice for 3 main reasons. First, SEM is a popular methodology in business management research and is suitable to investigate technological innovation and adoption issues (Henseler et al., 2016).

Several recent studies use SEM to analyse the impact of the adoption of innovative technologies on different aspects of business management, including human resources, knowledge management, and sustainability (Amouei et al., 2023; Dubey et al., 2019; Ghobakhloo et al., 2023; Raut et al., 2019; Sony et al., 2023) Second, SEM enables the evaluation of the effects of latent variables, defined by Rigdon (2016) as conceptual variables that affect the behaviour of other variables in a theoretical model.

Consistently, we used SEM to investigate how I4.0 technological capability influences different aspects of the social sustainability of agrifood companies. Third, SEM can be used effectively in exploratory empirical research, provided that the latent variables are framed in an appropriate theoretical context (Rigdon, 2016). Given the lack of empirical studies investigating the impact of I4.0 technologies on the social sustainability of agrifood companies, we referred to the RVB and KBV theories to define technological capability, and to the concept of CSR to identify agrifood companies' social responsibilities.

As for determining the appropriate sample size, this depends on the complexity of the model and the number of factors. In general, SEM can perform well even with small sample sizes in the analysis of relatively simple models, with reliable and distinct variables (Iacobucci, 2010). Furthermore, if the core population is limited and homogeneous, and if the sample adequately represents the target population, SEM can perform well also with relatively small samples (Rigdon, 2016). Under these assumptions, general rules of thumb suggest that even samples between 50 and 100 observations can prove adequate (Molwus et al., 2013). In this study, we focus on specific segments of Italian agrifood companies and select the companies so that they meet rigorous criteria. Considering the low number of factors and the limited target population, the final sample comprising 116 observations proves sufficient. In line with previous studies, we perform the model evaluation in two phases, using the AMOS 29 (Gerbing & Anderson, 1988) software.

Firstly, we use a Confirmatory Factor Analysis (CFA) to test the reliability, validity and fit of the measurement model, which focuses on the relationships between factors and latent variables. In the second we assess the goodness of fit of the structural model, which represents the hypothesized relationships between the latent variables. In this, the literature does not provide a single indicator but suggests evaluating and reporting several measures of model fit (Hair et al., 2019; Henseler et al., 2016; Richter et al., 2017).

Consistent with the hypotheses, in this study we test three different models. In the first model, we test the impact of I4.0 technological capability variables on sustainable supply chain management. In the second model, we test the impact of I4.0 technological capability variables on sustainable stakeholder management. Finally, in the last model, we test the impact of I4.0 technological capability variables on sustainable human resource management. Despite its advantages, SEM presents some weaknesses. Specifically, the definition of the model entails the risk of omitting significant variables or including redundant variables. Both circumstances affect parameter estimation and could bias the results (Tomarken & Waller, 2005). To mitigate these risks, it is important to develop SEM models starting from robust theoretical frameworks (Hair et al., 2019). In this study, we address this weakness by referring to well-established theories and measures.

Furthermore, because of the previous issue, the validation of the model does not provide information on potential alternatives. In fact, several equally valid or even superior models might be developed considering different variables and relationships (Tarka, 2018; Tomarken & Waller, 2005). From this perspective, an additional limitation of SEM concerns model respecification. All changes to the model must be justified by theory, to prevent the inclusion of variables and relationships designed to increase the level of fit, sacrificing coherence and common sense (Tarka, 2018). Finally, SEM cannot account for poor study design, which could lead to incorrect or biased measurements (Rigdon, 2016).

5. Results

We present the results in three sections, addressing descriptive analysis, measurement model, and structural model evaluation respectively.

5.1 Descriptive analysis

The distribution of responses related to socio-demographic variables and companies' characteristics is shown in tables 2 and 3. Regarding the respondents, 74.1% are male, 23.2% are female, and 2.7% prefer not to disclose. Furthermore, 52.6% of the interviewees are top managers in their companies, 24.1% work in production, while the remaining 23.8% are distributed among human resources, R&D, marketing, logistics, and information services. Furthermore, approximately 72% of respondents have at least 10 years of experience in the agrifood industry.

As for the companies, we note that all industrial activities included in the study are adequately represented in the sample. Most of the companies are headquartered in the northern regions of Italy, and while most firms serve the domestic market, the share of companies primarily targeting foreign markets is significant. Moreover, the majority are small businesses, with fewer than 50 employees and a revenue of less than 10 million euros. These data align with the characteristics of companies within the Italian agrifood industry, suggesting a good representativeness of the sample.

Table 2 distribution of socio-demographic variables (individuals).

Variable (individuals)	Distribution
Gender	
Male	74.1%
Female	23.2%
Division	
Top management	52.6%
Production	24.1%
R&D	6.0%
Human resources	4.3%

Marketing	6.9%
Logistics	4.3%
ICTs	0.8%
Years of experience	
1 – 5	14.6%
6 – 10	12.9%
11 – 20	27.5%
More than 20	44.8%

Table 3 distribution of variables related to companies' characteristics.

Variable (companies)	Distribution
ATECO code	
1.10	14.6%
1.13	17.2%
1.20	15.5%
1.21	52.5%
Headquarters (Italy)	
North	42.2%
Central Italy	22.3%
South	21.5%
Islands	12.9%
Primary market	
Italy	66.4%
Europe	23.3%
North and South America	10.3%
Total revenue	
Less than 10 million €	64.7%

Between 10 and 50 million €	25.9%
Over 50 million €	9.5%
Number of employees	
Less than 50 employees	62.1%
Between 50 and 250 employees	31.0%
Over 250 employees	6.9%
Years of activity in the agrifood industry	
Less than 10 years	10.3%
Between 10 and 20 years	12.9%
More than 20 years	76.7%

5.2 Measurement models

To test the measurement models, we conducted a Confirmatory Factor Analysis (CFA) for each model, following the recommendations of Hair et al. (2019). The fit indices for the first model show a good model fit (Cmin/df = 1.198 [df = 38] (p = 0.000), CFI = 0.988, IFI = 0.988, TLI = 0.982, RMSEA = 0.041, SRMR = 0.05). The fit indices also show good model fit for the second model (Cmin/df = 1.281 [df = 38] (p = 0.000), CFI = 0.979, IFI = 0.980, TLI = 0.970, RMSEA = 0.049, SRMR = 0.05), and for the third model (Cmin/df = 1.609 [df = 38] (p = 0.000), CFI = 0.963, IFI = 0.964, TLI = 0.946, RMSEA = 0.073, SRMR = 0.05) (Byrne, 2001; Hair et al., 2006).

Construct convergent validity and reliability were assessed using Cronbach's α, Spearman-Brown's coefficient, Composite Reliability (CR) and Average Variance Extracted (AVE) (Chang & Fong, 2010; Fornell & Larcker, 1981; Ghobakhloo et al., 2023; Gleim et al., 2013; Hair et al., 2006; Hair et al., 2019; Iacobucci, 2010; Lewandowska et al., 2023). All factor loadings are greater than 0.5, all the constructs have a Cronbach's α and CR value exceeding the suggested threshold of 0.70 as well the AVE is above the cut-off 0.50, thus, all constructs reached the minimum threshold for a good convergent validity and reliability (table 4; table 5; table 6). Then, to assess discriminant validity, we used the Fornell and Larcker criterion, making sure that the square root of the AVE is greater than the correlation between constructs (Fornell & Larcker, 1981) (table 7; table 8; table 9).

Table 4 factor loadings and reliability measures for the model testing the impact of technological capability on sustainable supply chain management.

Construct	Factors	Factor loadings	Cronbach's α / Spearman-Brown's coefficient	CR
Technological skills (TSK)	TSK_1	0.729	0.788	0.792
	TSK_2	0.791		
	TSK_3	0.722		
Technological strategy (TST)	TST_1	0.815	0.812	0.822
	TST_2	0.676		
	TST_3	0.838		
Technological maturity (TMT)	TMT_1	0.844	0.766*	0.769
	TMT_2	0.735		
Sustainable supply chain management (SSC)	SSC_1	0.851	0.892	0.894
	SSC_2	0.892		
	SSC_3	0.831		

***Spearman-Brown's coefficient value for the two-item scale**

Note. N = 116; Model fit (Cmin/df = 1.198 [df = 38] (p = 0.000), CFI = 0.988, IFI = 0.988, TLI = 0.982, RMSEA = 0.041, SRMR = 0.05).

Table 5 factor loadings and reliability measures for the model testing the impact of technological capability on sustainable stakeholders' management.

Construct	Factors	Factor loadings	Cronbach's α / Spearman-Browns' coefficient	CR
Technological skill (TSK)	TSK_1	0.700	0.788	0.791
	TSK_2	0.807		
	TSK_3	0.730		
Technological strategy (TST)	TST_1	0.815	0.812	0.822
	TST_2	0.671		
	TST_3	0.842		
Technological maturity (TMT)	TMT_1	0.836	0.766*	0.768
	TMT_2	0.742		
Sustainable stakeholders' management (SST)	SST_1	0.805	0.788	0.784
	SST_2	0.693		
	SST_3	0.718		

***Spearman-Brown's coefficient value for the two-item scale.**

Note. N = 116; Model fit (Cmin/df = 1.281 [df = 38] (p = 0.000), CFI = 0.979, IFI = 0.980, TLI = 0.970, RMSEA = 0.049, SRMR = 0.05).

Table 6 factor loadings and reliability measures for the model testing the impact of technological capability on sustainable human resources management.

Construct	**Factors**	**Factor loadings**	**Cronbach's α / Spearman-Brown's coefficient**	**CR**
Technological skills (TSK)	TSK_1	0.715	0.788	0.791
	TSK_2	0.781		
	TSK_3	0.744		
Technological strategy (TST)	TST_1	0.818	0.812	0.822
	TST_2	0.676		
	TST_3	0.835		
Technological maturity (TMT)	TMT_1	0.822	0.766*	0.767
	TMT_2	0.755		
Sustainable human resources management (SHR)	SHR_1	0.820	0.893	0.896
	SHR_2	0.872		
	SHR_3	0.889		

***Spearman-Brown's coefficient value for the two-items scale.**

Note. N = 116; Model fit (Cmin/df = 1.609 [df = 38] (p = 0.000), CFI = 0.963, IFI = 0.964, TLI = 0.946, RMSEA = 0.073, SRMR = 0.05).

Table 7 validity measures for the model testing the impact of technological capability on sustainable supply chain management.

AVE is displayed on the main diagonal. Squared correlations between constructs off-diagonal.				
Construct	TSK	TST	TMT	SSC
TSK	**0.608**			
TST	0.295	**0.559**		
TMT	0.581	0.117	**0.626**	
SSC	0.108	0.510	0.062	**0.737**

Abbreviations: SSC: sustainable supply chain management, TSK: technological skills, TST: technological strategy, TMT: technological maturity.

Table 8 validity measures for the model testing the impact of technological capability on sustainable stakeholders' management.

AVE is displayed on the main diagonal. Squared correlations between constructs off-diagonal.				
Construct	TSK	TST	TMT	SST
TSK	**0.608**			
TST	0.291	**0.558**		
TMT	0.582	0.111	**0.625**	
SST	0.028	0.549	0.028	**0.548**

Abbreviations: SST: sustainable stakeholders' management, TSK: technological skills, TST: technological strategy, TMT: technological maturity.

Table 9 validity measures for the model testing the impact of technological capability on sustainable human resources management.

AVE is displayed on the main diagonal. Squared correlations between constructs off-diagonal.				
Construct	TSK	TST	TMT	SHR
TSK	**0.608**			
TST	0.296	**0.558**		
TMT	0.588	0.117	**0.623**	
SHR	0.097	0.370	0.127	**0.741**

Abbreviations: SHR: sustainable human resources management, TSK: technological skills, TST: technological strategy, TMT: technological maturity.

5.3 Structural models

The structural model tests the hypothesized relationships between latent variables. To test the structural models, we drew the paths representing the hypothesized relationships between the variables. The fit indices confirm good model fit for the first model (Cmin/df = 1.198 [df = 38] (p = 0.000), CFI = 0.988, IFI = 0.988, TLI = 0.982, RMSEA = 0.041, SRMR = 0.05), as well as for the second model (Cmin/df = 1.281 [df = 38] (p = 0.000), CFI = 0.979, IFI = 0.980, TLI = 0.970, RMSEA = 0.049, SRMR = 0.05), and the third model (Cmin/df = 1.609 [df = 38] (p = 0.000), CFI = 0.963, IFI = 0.964, TLI = 0.946, RMSEA = 0.073, SRMR = 0.05) (Byrne, 2001; Hair et al., 2006). Tables 10, 11 and 12 show the results of the assessment of the structural models, and table 13 provides an overview of the hypotheses.

The results allow us to support hypotheses H1.a, H2.a and H3.a, confirming the positive effect of I4.0 technological skills on all three dimensions of social sustainability. Results also don't support hypotheses H1.b, and H3.b while at the same time confuting hypothesis H2.b, which suggests a significant negative relationship between I4.0 technological strategy and sustainable stakeholder management. Finally, hypotheses H1.c and H2.c, are not supported, while hypothesis H3.c is supported, suggesting a positive relationship between I4.0 technological maturity and sustainable human resources management.

Table 10 structural equation model coefficients for the first model (sustainable supply chain management)

Paths	Standardized coefficients
TSK → SSC	0.773**
TST → SSC	-0.191
TMT → SSC	0.131

Note. N = 116; Model fit (Cmin/df = 1.198 [df = 38] (p = 0.000), CFI = 0.988, IFI = 0.988, TLI = 0.982, RMSEA = 0.41, SRMR = 0.05).

**** p < .01**

Abbreviations: SSC: sustainable supply chain management, TSK: technological skills, TST: technological strategy, TMT: technological maturity.

Table 11 structural equation model coefficients for the second model (sustainable stakeholders' management)

Paths	Standardized coefficients
TSK → SST	0.946**
TST → SST	-0.551*
TMT → SST	0.273

Note. N = 116; Model fit (Cmin/df = 1.281 [df = 38] (p = 0.000), CFI = 0.979, IFI = 0.980, TLI = 0.970, RMSEA = 0.049, SRMR = 0.05).

**** p < .01; *p < .05**

Abbreviations: SST: sustainable stakeholders' management, TSK: technological skills, TST: technological strategy, TMT: technological maturity.

Table 12 structural equation model for the third model (sustainable human resources management).

Paths	Standardized coefficients
TSK → SHR	0.667**
TST → SHR	-0.365
TMT → SHR	0.409*

Note. N = 116; Model fit (Cmin/df = 1.609 [df = 38] (p = 0.000), CFI = 0.963, IFI = 0.964, TLI = 0.946, RMSEA = 0.073, SRMR = 0.05).

**** p < .01; *p < .05**

Abbreviations: SHR: sustainable human resources management, TSK: technological skills, TST: technological strategy, TMT: technological maturity.

Table 13 summary of hypotheses and results.

Hypothesis	Results
H1.a: technological skills positively influence sustainable supply chain management	Supported
H1.b: technological strategy positively influences sustainable supply chain management	Not supported
H1.c: technological maturity positively influences sustainable supply chain management	Not supported

H2.a: technological skills positively influence sustainable stakeholders' management	Supported
H2.b: technological strategy positively influences sustainable stakeholders' management	Not supported
H2.c: technological maturity positively influences sustainable stakeholders' management	Not supported
H3.a: technological skills positively influence sustainable human resources management	Supported
H3.b: technological strategy positively influences sustainable human resources management	Not supported
H3.c: technological maturity positively influences sustainable human resources management	Supported

6. Discussion

The results provide mixed evidence and prompt reflection on the complex relationship between the adoption of I4.0 technologies and social sustainability in agrifood companies. Firstly, we observe how results support hypotheses H1.a, H2.a, and H3.a, emphasizing the positive impact of I4.0 technological skills on all three dimensions of sustainability. In line with previous contributions, training is key not only to ensuring the effective integration of new solutions into business but also to creating healthier work environments (Caputo et al., 2019; Neumann et al., 2021; Sony & Mekoth, 2022). As shown by Cannas (2023) and Rijswijk et al. (2021), this could be particularly important for companies performing cultivation activities, where traditional business practices often prevail. Several studies suggest that one of the main obstacles to the adoption of I4.0 technologies in the agrifood industry is the lack of familiarity of agrifood workers with innovative solutions. This generates scepticism and resistance, stressing the importance of investing in the development of technological skills. Furthermore, investing in employee training may promote an innovation-oriented culture, eliciting the adoption of I4.0 technologies (Mahdad et al., 2022). Finally, the development of technological skills can contribute to the creation of healthier work environments, empowering employees to manage and supervise processes, and shifting from executors to decision-makers (Martin et al., 2022; Neumann et al., 2021). Again, this may be especially relevant for companies performing cultivation activities, that may leverage I4.0 technologies to reduce manual labour and revolutionize the execution of field activities (Arvanitis & Symeonaki, 2020).

Secondly, the results also suggest that the development of I4.0 technological skills enhances the social sustainability of agrifood companies in terms of supply chain management and relationships with stakeholders. However, this issue is currently under-investigated. Our results highlight that I4.0 technologies might raise awareness among workers in the agrifood industry regarding supply chain issues and external stakeholders' demands by favouring the development of transversal skills and reducing the time dedicated to cultivation activities. Also, several studies explain how the adoption of blockchain and IoT systems requires agrifood companies to develop not only technological expertise but also managerial skills, enabling them to significantly affect supply chain dynamics, potentially helping companies build trust relationships with partners and increase security and accountability (Blanka et al., 2022; David et al., 2022). This can help companies upstream of the agrifood supply chain develop a better understanding of the dynamics of the industry, increasing coordination between partners and tightening links between supply chain actors and external stakeholders (Clapp & Ruder, 2020; Glavee-Geo et al., 2022).

Thirdly, the findings also shed light on the complexity of the relationship between technological strategy and social sustainability. Surprisingly, the results confute hypothesis H2.b, highlighting a significant, yet negative relationship between I4.0 technological strategy and sustainable stakeholders' management. One possible explanation is that, by favouring automation, the adoption of I4.0 technologies could reduce human involvement in business operations. This could lead to a reduction in interactions with stakeholders and consequently reduce the firm's ability to address stakeholders' demands. Furthermore, the process of integrating advanced technologies could require considerable economic and organizational resources, which could otherwise be used by management to improve relations with stakeholders and implement activities aimed at satisfying their needs.

However, it is important to stress how this explanation might contradict some findings in the literature, which suggest that the adoption of I4.0 technologies is an important step for agrifood companies to address some long-standing social sustainability issues. For example, according to Rijswijk et al. (2021), technological innovation may provide significant opportunities for the development of rural communities, whereas several studies argue that the use of advanced tracking systems could help agrifood companies regain consumers' trust and effectively enhance the transparency and accountability of the supply chain (Dal Mas et al., 2023; Majdalawieh et al., 2021; Motta et al., 2020).

Regarding I4.0 technological maturity, the results provide mixed evidence, and support only hypothesis H3.c, suggesting a significant positive relationship between I4.0 technological maturity and sustainable human resources management. This finding proves that the seamless integration of different I4.0 technologies has a positive effect on the quality of the working environment. This aligns with recent studies suggesting that the greatest benefits of adopting I4.0 technologies emerge when companies leverage the synergies of different technological solutions (Annosi et al., 2020). Mazzetto et al. (2019) and Mahdad et al. (2022) demonstrate how the combination of IoT and farm management systems allows agrifood companies to access real-time data on weather conditions and crop health, enabling the development of predictive models to support activity planning. This reduces the dependence of activities on uncontrollable natural factors, improving labour management and reducing operator workloads. Similarly, Sam et al. (2022) show how the combination of smart information systems and Big Data analytics enables the automation of traditionally manual tasks, significantly improving the working conditions of horticultural workers. Furthermore, the results suggest that the integration of I4.0 technologies into business processes represents an opportunity for human resources empowerment in an industry characterized by traditional working practices. This also contrasts previous findings that technological innovation in the agrifood industry could have negative social implications in terms of labour management, leading to job losses and the exclusion of workers with low technological skills (Prause, 2021).

Finally, the results do not support hypotheses H1.c and H2.c, suggesting that the relationship between I4.0 technological maturity and the improvement of social performance in agrifood companies in terms of supply chain and stakeholders' management is not significant. This conflicts with previous studies suggesting that the adoption of I4.0 technologies is one of the main drivers through which agrifood companies can address stakeholders' demands and build more transparent and accountable supply chains (Majdalawieh et al., 2021; Sander et al., 2018). Analysing this result, we hypothesize an influence of the characteristics of the companies in the sample, which focuses on companies performing cultivation activities. However, literature investigating the impact of I4.0 technologies on the security of agrifood supply chains often focuses on the processing and transportation issues (Corallo et al., 2020; Kamble et al., 2019). Furthermore, several studies assessing the impact of product tracking systems on the sustainability of agrifood supply chains focus on specific product categories, suggesting how this outcome may vary depending on unique product, or market characteristics (Danese et al., 2021; Salah et al., 2019). Therefore, we emphasize the need for studies that focus on investigating how different I4.0 technologies and applications can promote social sustainability in the agrifood industry at multiple supply chain levels beyond the cultivation stage and taking into account the specificities of different product categories.

7. Conclusions

The adoption of I4.0 technologies is one of the main drivers of the sustainable development of the agrifood industry (Lezoche et al., 2020; B. S. Miranda et al., 2019). However, the effects of technological innovation on the social sustainability of agrifood companies remain unclear. Indeed, recent studies suggest that the adoption of I.40 technologies may have significant social implications for agrifood companies, affecting labour management, supply chain accountability, and relationships with key stakeholders, including governments and consumers (Chandan et al., 2023; Prause, 2021; Rijswijk et al., 2021). Despite this, available literature focuses on the relationship between environmental and economic benefits, while social sustainability implications are currently under-investigated, especially from an empirical perspective.

This study aimed to help bridge this gap by providing evidence of the impact of I4.0 technologies on the social sustainability of companies in the agrifood industry. To this end, we use data from 116 Italian agrifood companies to validate a theoretical model explaining how the adoption of I4.0 technologies influences the social sustainability of agrifood companies. Specifically, this study focuses on agrifood companies performing cultivation activities, which face unique and relevant social sustainability challenges related to labour, supply chain, and stakeholders' management. Also, by including companies cultivating a variety of product categories, this study provides some valuable theoretical and practical contributions.

From a theoretical perspective, this study offers two main contributions. First, it validates a conceptual model assessing the impact of I4.0 technologies on the social sustainability of agrifood companies. This advances the literature by providing a framework that can guide future studies on the social implications of technological innovation in the agrifood industry. Second, this study is one of the few to provide empirical evidence of the impact of I4.0 technologies on different aspects of the social sustainability of agrifood companies. This helps explain how technological innovation may influence social sustainability in the agrifood industry and identify further research opportunities. Results show that the development of I4.0 technological skills has a positive impact on all three dimensions of social sustainability. This is consistent with recent literature suggesting that the adoption of I4.0 technologies promotes the development of managerial skills, shifting the role of agricultural workers from executors to decision-makers. Furthermore, the development of I4.0 technological skills enables the use of advanced solutions, which can support operators in the execution of physically demanding tasks (Alves et al., 2023; Lioutas et al., 2021). I4.0 technological skills also positively affect the sustainable management of the supply chain and stakeholder relations, although the reasons are currently under-investigated.

Finally, the results highlight the complexity of the relationship between I4.0 technological strategy and social sustainability. The results reveal a negative relationship between I4.0 technological strategy and sustainable stakeholders' management, somewhat contradicting recent studies suggesting that an adequate technological innovation strategy is a crucial stepping stone in assisting agrifood companies regain the trust of consumers and society. Advancing an explanation, we hypothesize that the adoption of I4.0 absorbs resources and attention that could have been otherwise directed to address stakeholders' demands. Finally, a positive relationship was found between I4.0 technological maturity and human resources management, confirming that I4.0 technologies may help companies create healthier work environments, in combination with the development of I4.0 technological skills.

As for practical implications, this study can help managers of these companies analyse and reap the social benefits of adopting I4.0 technologies. Findings show that the introduction of innovative technologies represents a significant opportunity to develop employees' skills and improve the quality of working conditions, balancing the workloads of field operators.

Automation could effectively support cultivation activities, while the use of predictive models could reduce the impact of unpredictable natural factors. Moreover, acquiring advanced and transversal technological skills could provide benefits that go beyond the management of cultivation activities. The use of data provided by modern information systems could simplify communication and coordination with partners and enhance supply chain security, with positive effects on the relationships with stakeholders, including governments and consumers. Finally, the results suggest managers carefully assess how the company's I4.0 technological strategy and maturity affect the various dimensions of social sustainability. The findings warn about the risk of focusing exclusively on the company's needs and losing sight of the interests of supply chain partners and external stakeholders.

Despite its contributions, this work is not exempt from limitations. Concerning the sample, this study is based on data obtained from companies operating in specific stages of the Italian agrifood industry. In particular, the study focuses on companies performing cultivation activities in a highly industrialized context. Thus, while adequate to the scope of the study, the sample has limitations. First, it does not include companies that perform product processing and distribution activities. Companies in the meat industry are also excluded. This affects the generalizability of the results, as the study does not provide information on the advantages that I4.0 technologies can offer to such companies.

Furthermore, by focusing on a single country, the study does not account for socioeconomic factors that might affect the results. Future studies can extend the analysis by carrying out cross-country investigations or by focusing on different geographic areas. Another limitation of the study concerns the use of sociodemographic variables. While providing useful information to outline the profile of the respondents and validate the information sources, the available observations prevented us from capturing any differences in the perceptions of respondents based on variables such as gender or age. Future contributions could focus on assessing how sociodemographic variables mediate individuals' perception of the impact of I4.0 technologies on the social sustainability of agrifood companies.

In conclusion, we reflect on possible limitations in the theoretical model. Specifically, the absence of previous studies investigating the impact of I4.0 technologies on the social sustainability of agrifood leads to a lack of established metrics and indicators. In this study, we address this shortcoming by referencing established theories such as the RBV to model the technological capability of the company, and the literature on CSR to investigate the multiple facets of social sustainability in the agrifood industry. Despite our efforts to identify all relevant variables, this may have caused us to overlook some important factors. Thus, we elicit future research to extend the analysis and provide additional elements to our framework. Lastly, we point out that this study investigates the impact of I4.0 technologies on the social sustainability of agrifood companies holistically. Therefore, future contributions could obtain different results by focusing on individual technologies or specific applications.

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Appendix

Table A.1 provides a summary of the scales used to measure the latent constructs of technological capability and social sustainability The table also presents items used to measure each indicator, along with a brief description.

Table A.1 latent variables, factors, and items.

Construct	Factor	Items
Industry 4.0 technological skills	TSK_1	The employees of the company possess advanced Industry 4.0 technological skills.
	TSK_2	The company invests heavily in the development of employees' Industry 4.0 technological skills.
	TSK_3	The company hires employees with advanced Industry 4.0 technological skills.
Industry 4.0 technological strategy	TST_1	The company can establish new technological standards.
	TST_2	The company is one of the leaders in the agrifood industry in terms of technological innovation.
	TST_3	The company can leverage the technologies to solve problems.
Industry 4.0 technological maturity	TMT_1	The company can integrate many Industry 4.0 technologies in business processes
	TMT_2	The company regularly uses Industry 4.0 technologies in business processes.
Sustainable supply chain management	SSC_1	Industry 4.0 technologies help the company establish trust relationships with partners.
	SSC_2	Industry 4.0 technologies help the company inform the partners about the CSR requirements to comply with.
	SSC_3	Industry 4.0 technologies help the company define and implement formal procedures to assess partners' CSR performance.
	SSM_1	Industry 4.0 technologies help the company involve and consider the interests of the stakeholders in business decisions.

Sustainable stakeholder management	SSM_2	Industry 4.0 technologies help company consider and address consumers' needs in business decisions.
	SSM_3	Industry 4.0 technologies enable the company to promote economic development in the communities where it operates.
Sustainable human resources management	SHR_1	Industry 4.0 technologies help the company ensure work-life balance for its employees.
	SHR_2	Industry 4.0 technologies help the company improve workplace healthiness through the dissemination of shared codes of conduct.
	SHR_3	Industry 4.0 technologies help the management to address workers' needs.