Digitalization in the agri-food industry : the relationship between technology and sustainable development

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Digitalization in the agri-food industry: the relationship between technology and sustainable development

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Abstract

Purpose – Digitalization is becoming the subject of considerable interest in the literature. This is in view of its relevance in addressing social problems and contributing to the development of communities and societies. In the agri-food-industry, digitalization is also expected to contribute significantly to solve several challenges the sector is facing at this moment, such as the increasing food demand and resource use. However, the effects of advanced technologies are less a function of the technologies themselves than of how they are used by people. The study analyses the dominant challenges faced by firms in the agri-food industry in the usage and adoption of digital technology. Also, they show how these challenges impact on the sustainable development of digital technology for firms in the industry and provide avenues for future research.

Design/methodology/approach – The authors propose a structured literature review aiming to investigate the following research question: what are the main challenges faced by firms within the agri-food industry in the adoption of smart technologies?

Findings – Results illustrate the dominant challenges faced by firms in the agri-food industry in the usage and adoption of digital technology. Also, they show how these challenges impact on the sustainable development of digital technology for firms in the industry and provide avenues for future research.

Originality/value – So far, in the context of digitalization in the agri-food industry, various researchers have analysed different kinds of challenges to the adoption of smart technologies. This work reviews these contributions to create a clear reference framework of the challenges faced by agri-food firms while providing future avenues of research and implications at a policymaking, economic-managerial and socio-environmental level.

Keywords Sustainable development, Digitalization, Technology adoption, Agri-food, Technology usage

Paper type Research paper

Introduction

The "4.0 revolution", driven by digitalization, is leading firms towards deep business transformations, with radical changes to business models, strategies, processes, products and services (Teece and Linden, 2017). Within this revolution, smart technologies, by using the Internet of things (IoT), information and communication technologies (ICT) and other digital technologies, are requiring firms to revise their core competencies, complementing their skills and developing an ability to leverage knowledge into new expertise

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(Van Knippenberg *et al.*, 2015). The strong impact on core firm processes determined by smart technologies goes beyond driving mere increases in efficiency and efficacy. It creates new bases for both economic and social sustainability (Porter and Heppleman, 2014). Nonetheless, whilst the impact of smart technologies is not questioned, their adoption and diffusion appear to be challenged by several factors (Van Knippenberg *et al.*, 2015).

This calls for a wider analysis of the impact that such transformation can have on the agri-food industry. Thus, we explore the relationship between the usage of technology and the concept of sustainable development by collecting evidence that summarizes both the challenges faced by firms in adopting and developing digital technologies and the related economic, social and environmental impact. We focus on smart agriculture, representing the application of smart technologies to the agri-food industry. The growing number of functionalities unleashed by technologies that ease the interaction between machines, services and people is significantly challenging the agricultural and food industries. Smart agriculture uses the information technologies, the IoT and other digital tools and technologies to collect data from multiple sources in order to undertake decisions associated to crop, livestock or food production (Annosi *et al.*, 2019), with the purpose of maximizing returns and preserving the environment. Few studies have started to elaborate on the relation between smart technologies, digitalization and the agri-food industry, and more investigations are needed to explore the challenges that smart technologies may entail for organizations and their business models and to understand the related implications.

Indeed, while precision agriculture tools and technologies have been commercially available since the 1990s (Daberkow and Mcbride, 2003), the diffusion of such innovations has experienced a very modest pace. The reason for such delay is twofold. First, business models of both adopters and providers are not built to embrace such innovations (Long *et al.*, 2016a, b). This is because, on one side, adopters have not only to make financial investments but also to invest in creating new skills and competencies and, on the other side, providers must take into account the complexity of technologies in the light of the technological readiness of adopters that often requires complementarity between existing practices and new technologies (Adrian *et al.*, 2005). Second, different organizational challenges, especially on the adopters' side, may prevent the adoption of these technological innovations. Such characteristics range from experience, access to knowledge and technology (Daberkow and Mcbride, 2003), education (Hudson and Hite, 2003) and attitude towards the technologies (Cochrane, 1993).

In view of the heterogeneity of these organizational challenges and the importance they bear in enabling the adoption of smart technologies for firms in the agri-food industry, we perform a structured literature review (Tranfield *et al.*, 2003; Petticrew and Roberts, 2008) aiming to investigate the following research question: *what are the main challenges faced by firms within the agri-food industry in the adoption of smart technologies?*

Extant literature in the field has analysed the different kinds of challenges to the adoption of smart technologies (Adrian *et al.*, 2005; Cox, 2002; Tey and Brindal, 2012; Weersink *et al.*, 2018). However, also in view of shocks (e.g. COVID-19 emergency) additionally stressing the relevance and significance of the topic, we believe it may be useful to provide additional work that creates a clear reference framework of the challenges faced by agri-food firms in adopting smart technologies.

The paper is organized as follows: we first present our methodology. We then describe the sample of papers extracted and the results of our structured literature review. We finally discuss the related implications and potential future research avenues.

Methodology

We embraced a structured literature review approach in order to be able to identify the main challenges deriving from the adoption of digital technologies in the agri-food industry and the

relevant gaps and directions for future research (Petticrew and Roberts, 2008). Following Fink, (2019) and Tranfield *et al.* (2003), we describe the steps we took to select and examine extant studies with the aim to reduce biases and increase the level of transparency.

To understand the diversity of challenges emerging in the agri-food industry from the usage of new technologies, this study adopts a list of predefined set of selection criteria based on the guidelines and strategies reported in past approaches in executing structured reviews (Iden *et al.*, 2017; Massaro *et al.*, 2016; Crossan and Apaydin, 2010). Specifically, we follow Iden *et al.* (2017), using their theoretical and empirical classification and a development of research questions. By adopting such approach, our review ends up presenting the structured literature reporting about agri-food industry and the related application of new digital technologies. Particularly, the following sub-research questions are central in our study:

RQ1. What are the dominant challenges firms in agri-food industry face with the usage of digital technologies?

RQ2. How have the existing challenges impacted on the sustainable development of digital technology in agri-food sector?

RQ3. What are the relevant avenues for the future research on the identification of new sustainability paradigms related to the application of digital technology in agri-food sectors?

We use the procedure of planning, executing and reporting described by Tranfield *et al.* (2003). Within the first stage we clarified the main research objectives and identify the relevant database sources to use. To sustain our research goal, we selected objectives in a way to consent a large scan of articles allowing us to evaluate a large set of paradigms, definitions and operationalizations taking into consideration similarities and disparities.

The initial method of selection of articles follows Massaro *et al.* (2016) and Dumay and Cai (2014). To detect the main literature streams and focus on sources that are likely to provide highest level of impact (Podsakoff *et al.*, 2005), we searched for articles in Scopus (the main abstract and citation database of peer-reviewed literature). Falagas *et al.* (2008) and Gavel and Iselid (2008) confirm that Scopus has higher coverage in citation analysis than other databases.

We used the keywords of "challenges (and similar terms)", "digital*" and "agri-sector (and similar terms)" (i.e. digital AND agri-food AND challenges). Indeed, *challenge* was a term often used to refer to socio-economic impacts deriving from the usage of new digital technology (Shepherd *et al.*, 2018). We limited search to peer-reviewed journals focussing on sources with a high level of impact in the fields of organization and innovation management.

When performing this type of search, we focussed on the period from 2000 to 2020, with high citations and quality. We also included newer articles, taking into consideration their lower chance to report citations. We then refined the list examining titles, abstracts and full papers. Our criteria were to include research articles discussing about organizational challenges in the usage of new digital technologies in the agri-food sectors and new sustainability paradigms deriving from such usage.

This approach criteria corresponds to *tone* (Webster and Watson, 2002): it is objective, not limiting *a priori* the search and fulfils quality criteria. This procedure ended with a list of 22 papers.

Given the lack of explicit reference to sustainability paradigms within the text of selected papers, we decided to expand our set of data with second search for "sustainability" (and related terms). Therefore, in line with Massaro *et al.* (2015), an additional keyword query was performed in Scopus with the aim of executing a further control procedure and to check for articles we missed during the initial search.

To be able to include or exclude articles, we considered comparable terms in the keywords selection of this second search. We decided to include terms such as artificial intelligence, IoT, Internet of food, big data, digital, agri-tech or "smart" because of: (1) the observed trends in the application of new technology in agri-food sectors (Rose and Chilvers, 2018); (2) recent social-science reviews of articles related to agriculture 4.0 (Klerkx *et al.*, 2019). Thus, the final query is provided as follows:

> *TITLE-ABS-KEY* ((("*agri-food*" *OR* "*farm**" *OR* "*agri**") *AND* ("*4.0*" *OR* "*agritech*" OR "*agri-tech*" *OR* "*smart**" *OR* "*digit**" *OR* "*big data*" *OR* "*BDA*" *OR* "*iot*" *OR* "*iof*" *OR* "*cloud*" *OR* "*Internet of thing**" *OR* "*internet*" *OR* "*artificial intelligence*" *OR* "*ai*") *AND* ("*sustainab**"))) *AND* (*LIMIT-TO* (*DOCTYPE*, "*ar*")) *AND* (*LIMIT-TO* (*SUBJAREA*, "*BUSI*")) *AND* (*LIMIT-TO* (*LANGUAGE*,"*English*")) *AND* (*LIMIT-TO* (*SRCTYPE*, "*j*"))

By restricting the search to articles published in English, in the subject area of business and in peer-reviewed journals, we gathered a total of 94 articles in Scopus.

First, we scanned all the articles with an "Eye-balled approach": by doing so, we verified the reliability and the accurateness of the search, 17 studies were excluded for an inconsistency with the target topics. To identify relevant articles, we required that the topic of organizational challenges and sustainability issues be dealt with in an essential way. Then, one author reviewed all the abstracts of the selected articles. This step led to cut out ten additional articles in Scopus, for a lack of fit with the purpose of the review, reducing the sample to 34. In the third stage, the full text of the 34 articles selected was analysed, taking into consideration the emerging challenges for firms when engaging into the usage of new technology, different types of technologies adopted, new theoretical underpinning, new sustainability paradigms, unit of analysis and methodology considered. In total, 13 articles had to be excluded due the unavailability of full text access, revealing the final included body of knowledge comprising of 21 articles.

A combination of the search results between the first and the second search obtained a total of 43 papers, presented in Table 1 and analysed and discussed in the following section.

Results

The resulting data allows us to identify some initial sample descriptive elements. First, although the oldest article that is included in this literature review was published in 2003, considering the growing importance of these issues during the years, more relevant articles were published. Articles published after 2016 cover almost 75% of all included papers. Most articles were qualitative (40%) or quantitative (37%), and a smaller number comprised literature reviews (16%) or other methods.

We were able to identify all challenges described in the articles and to build, accordingly, three core categories. These categories are related to: (1) the challenges in the usage of digitalization (e.g. how to work with digital technologies facing their complexity); (2) challenges related to sustainable development of digital technology in agri-food industry (e.g. high costs incurred in the adoption and management of big data); (3) identification of research avenues able to incorporate new sustainability paradigms. More specifically, the challenges linked to the usage of digitalization were related to the barriers that people face in the use of digitalization. For instance, how to work with digital technologies facing their complexity. Second, the challenges linked to sustainable development of digital technology in agri-food industry are related to the challenges that farmers and firms face in order to adopt digitalization. For example, high costs incurred in the adoption and management of big data. Third, we highlighted the relevant avenues for the future development of research on the identification of new sustainability paradigms. These were specifically related to the application of digital technology in agri-food sectors and emerged from the implications and

N		Authors	Year	Title	Methods	Unit of analysis
1	1.1	Cecchini and Scott	2003	Can information and communications technology applications contribute to poverty reduction? Lessons from rural India	Qualitative	Farms
2	1.2	Mulauzi and Albright	2008	Information and Communication Technologies (ICTs) and development information for professional women in Zambia	Quantitative	Farms
3	1.3	Richards *et al.*	2009	Seed systems for African food security: Linking molecular genetic analysis and cultivator knowledge in West Africa	Qualitative	Farmer groups
4	1.4	Mokotjo and Kalusopa	2010	Evaluation of the Agricultural Information Service (AIS) in Lesotho	Qualitative	Farms
5	1.5	Boyd and Jardine	2011	Did public risk perspectives of mad cow disease reflect media representations and actual outcomes?	Quantitative	Farms
6	1.6	Islam and Grönlund	2011	Bangladesh calling: Farmers' technology use practices as a driver for development	Quantitative	Farms
7	1.7	Soomai *et al.*	2011	Multi-stakeholder perspectives on the use and influence of "grey" scientific information in fisheries management	Quantitative	Fisheries
8	1.8	Hay and Pearce	2014	Technology adoption by rural women in Queensland, Australia: Women driving technology from the homestead for the paddock	Mixed methods	Farms
9	1.9	Abdullah	2015	Digital Divide and Caste in Rural Pakistan	Quantitative	Farms
10	1.10	Tanure *et al.*	2015	Bioeconomic Model of Decision Support System for Farm Management Proposal of a Mathematical Model	Quantitative	Agricultural firms in general
11	1.11	Hennessy *et al.*	2016	The digital divide in farming: A problem of access or engagement?	Qualitative	Farms
12	1.12	Akoumianakis and Ktistakis	2017	Digital calendars for flexible organizational routines	Design Science	Farmer groups
13	1.13	Chandra *et al.*	2017	A Study of Climate–Smart Farming Practices and Climate–resiliency Field Schools in Mindanao, the Philippines	Qualitative	Farms

(*continued*)

Table 1. Summary of the articles

N		Authors	Year	Title	Methods	Unit of analysis
14	1.14	Panagiotopoulos *et al.*	2017	The value of social media data: Integrating crowd capabilities in evidence-based policy	Qualitative	Farms
15	1.15	Pant and Hambly Odame	2017	Broadband for a sustainable digital future of rural communities: A reflexive interactive assessment	Qualitative	Farms
16	1.16	Coble *et al.*	2018	Big data in agriculture: A challenge for the future	Quantitative	Whole agricultural value chain
17	1.17	Saggi and Jain	2018	A survey towards an integration of big data analytics to big insights for value-creation	Literature Review	Agricultural firms in general
18	1.18	Bauwens and Pantazis	2018	The ecosystem of commons-based peer production and its transformative dynamics	Qualitative	Farms
19	1.19	Bello-Bravo *et al.*	2018	An assessment of learning gains from educational animated videos versus traditional extension presentations among farmers in Benin	Quantitative	Farms
20	1.20	Khanna *et al.*	2018	Sustaining our natural resources in the face of increasing societal demands on agriculture: Directions for future research	Literature Review	Farms
21	1.21	Shepherd *et al.*	2018	Priorities for science to overcome hurdles thwarting the full promise of the "digital agriculture" revolution	Literature Review	Agricultural firms in general
22	1.22	Rotz *et al.*	2019	Automated pastures and the digital divide: How agricultural technologies are shaping labour and rural communities?	Qualitative	Agricultural firms in general
23	2.1	Storer *et al.*	2014	Strategic supply chain management factors influencing agribusiness innovation utilization	Quantitative	Whole agricultural value chain
24	2.2	Sanders and Masri	2016	The energy–water agriculture nexus: The past present and future of holistic resource management via remote sensing technologies	Literature Review	Agricultural firms in general

Table 1. (*continued*)

N		Authors	Year	Title	Methods	Unit of analysis
25	2.3	Long *et al.*	2016a	Barriers to the adoption and diffusion of technological innovations for climate–smart agriculture in Europe: Evidence from the Netherlands France Switzerland and Italy	Qualitative	Agricultural firms in general
26	2.4	Long *et al.*	2016b	Business models for maximizing the diffusion of technological innovations for climate-smart agriculture	Qualitative	Agricultural firms in general
27	2.5	Rao *et al.*	2018	Improving competitiveness through performance evaluation using the APC model: A case in micro-irrigation	Qualitative	Agricultural firms in general
28	2.6	Long and Blok	2018	Integrating the management of socio-ethical factors into industry innovation Towards a concept of Open Innovation 2.0	Quantitative	Agricultural firms in general
29	2.7	Kheyfets and Chernova	2019	Sustainable agriculture in Russia: Research on the dynamics of innovation activity and labour productivity	Quantitative	Agricultural firms in general
30	2.8	Goh *et al.*	2019	Integration precision and unmanned aerial vehicles technology in oil palm management system development	Literature Review	Farms
31	2.9	Long *et al.*	2019	The diffusion of climate–smart agricultural innovations: Systems-level factors that inhibit sustainable entrepreneurial action	Qualitative	Farms
32	2.10	Greenland *et al.*	2018	Sustainable innovation adoption barriers: water sustainability food production and drip irrigation in Australia	Qualitative	Farms
33	2.11	Allaoui *et al.*	2019	Decision support for collaboration planning in sustainable supply chains	Qualitative	Whole agricultural value chain
34	2.12	Murugesan and Sudarsanam	2020	Transdisciplinary approach for sustainable rural development	Qualitative	Farms
35	2.13	Kaur	2019	Modelling Internet of things driven sustainable food security system	Quantitative	Agricultural firms in general

(*continued*)

Table 1.

N		Authors	Year	Title	Methods	Unit of analysis
36	2.14	Umar *et al.*	2019	Underlying structure of job competency scale in climate–smart agricultural extension service	Quantitative	Farms
37	2.15	de Zegher *et al.*	2019	Designing contracts and sourcing channels to create shared value	Quantitative	Whole agricultural value chain
38	2.16	Kulikov *et al.*	2020	Challenges of enterprise resource planning (ERP) implementation in agriculture	Quantitative	Agricultural firms in general
39	2.17	Aydin and Aydin	2020	A sustainable multi-layered open data processing model for agriculture: IoT-based case study using semantic web for hazelnut fields	Quantitative	Farms
40	2.18	Lakshmi and Bahli	2020	Understanding the robotization landscape transformation: A centring resonance analysis	Literature Review	Agricultural firms in general
41	2.19	Aryal *et al.*	2020	Agricultural sustainability under emerging climatic variability: The role of climate–smart agriculture and relevant policies in India	Conceptual	Agricultural firms in general
42	2.20	Cane and Parra	2020	Digital platforms: mapping the territory of new technologies to fight food waste	Qualitative	Whole agricultural value chain
43	2.21	Sarker *et al.*	2020	Role of big data on digital farming	Literature Review	Farms

Table 1.

future avenues of research highlighted in the studies. Many papers included a mixture of two or all the aforementioned core categories.

We also aimed to analyse where those challenges take place within the agricultural supply chain. Overall, most of the challenges take place at the farm level (49%), agricultural firms in general (33%) and the whole agricultural value chain (10%).

Discussion of results

We screened literature perspectives and theories related to such issues and challenges. This resulted in an overview, which is presented in synthesis in Tables 1 to 3 and detailed in the following paragraph.

Challenges to the usage of new technologies

Through the review, we identified seven challenges in the usage of digitalization for agri-food firms:

Data complexity. When digital technologies are successfully adopted within a company, a great amount of data is generated. This big data can be used by policymakers and decision-makers in order to make punctual and efficient decisions. Big data propose a holistic support

Challenges to the usage of digitalization	Challenges to the sustainable development of digital technology in agri-food sector	Relevant avenues for the future development of research on the identification of new sustainability paradigms related to the application of digital technology in agri-food sectors
(1) Data complexity	(1) Access	(1) Collaboration
(2) Lack of essential improvements	(2) Missing institution	(2) Looking beyond economic benefits and towards social/long term benefits
(3) Gender differences	(3) Lack of appropriate incentives	(3) Automatization vs transformation
(4) Lack of modernity	(4) Age	(4) Role of policies, incentives and institutions
(5) Farm business characteristics	(5) Lack of involvement	
(6) Lack of services	(6) High costs	
(7) Hurdles in evaluating benefits	(7) Education	
	(8) Knowledge	
	(9) Quality	
	(10) Internet usage	
	(11) Language	
	(12) Business models	

Table 2.
Theories of the challenges

to cope with the complexities related to farming (e.g. farmer's and consumer's needs, efficiency, predictive analytics, supply chain integration). According to Sarker *et al.* (2020) while the adoption of big data analytics could potentially bare huge opportunities and benefits, the applicability to agriculture is still debated, due to the complex structure of this technology which can be hard to implement without a support from institutions and services and a strong initiative. Saggi and Jain (2018) underline that data can be very complex to be managed due to structure, as confirmed by Aydin and Aydin (2020) that analyse the need to coordinate the efforts of diverse stakeholders to provide relevant data gathered from heterogeneous sources. In this light, Shepherd *et al.* (2018) suggest that data governance should be designed to enable an equal share of the benefits of digital agriculture. Soomai *et al.* (2011) support these argumentations, noticing that the high technical content of information and data hinder the potential usefulness.

These problems can lead to difficulties for policymakers to process data, especially in lack of formal systems that help managing big data. Finally, Tanure *et al.* (2015) explore these issues for managers aiming at finding and selecting relevant information, providing as a solution a generalized mathematical bioeconomic model which managers can use for livestock production systems.

Lack of essential improvements. Another challenge that is influencing the use of digital technologies is the lack of essential improvements. Literature refers to these in two ways. First of all, Bauwens and Pantazis (2018) in their investigation conclude that higher-level forms of organizations need to make several adjustments in order to realize the profits promised by the digital technologies. Another type of improvement lays within the technology itself, as described by Akoumianakis and Ktistakis (2017) looking at online calendar services or – more in general – at the degree of improvement at the technological levels. For example, Kheyfets and Chernova (2019), looking at the Russian agricultural industry, show that significant investments in fixed assets and growth of physical capital did not create long-term growth in labour productivity. This is in view of a relation to a weak innovation activity at the country level and low technological competitiveness with respect to the international arena.

Gender differences. Studies of gender within agri-food industry have pointed some interesting results for decision-makers. According to Hay and Pearce (2014), grazier women

Type of challenges	Theories	Authors
Usage of digitalization	Data complexity	(Aydin and Aydin, 2020) (Saggi and Jain, 2018) (Sarker *et al.*, 2020) (Shepherd *et al.*, 2018) (Soomai *et al.*, 2011) (Tanure *et al.*, 2015)
	Lack of essential improvements	(Akoumianakis and Ktistakis, 2017) (Bauwens and Pantazis, 2018) (Kheyfets and Chernova, 2019)
	Gender differences	(Hay and Pearce, 2014) (Mulauzi and Albright, 2008)
	Lack of modernity	(Islam and Grönlund, 2011)
	Farm business characteristics	(Hennessy *et al.*, 2016)
	Lack of services	(Mokotjo and Kalusopa, 2010) (Sarker *et al.*, 2020)
	Hurdles in evaluating benefits	(Kulikov *et al.*, 2020) (Lakshmi and Bahli, 2020) (Storer *et al.*, 2014)
Challenges to the sustainable development of digital technology in agri-food sector	Access	(Abdullah, 2015) (Bello-Bravo *et al.*, 2018) (Cecchini and Scott, 2003) (Chandra *et al.*, 2017) (Coble *et al.*, 2018) (Hay and Pearce, 2014) (Mokotjo and Kalusopa, 2010) (Mulauzi and Albright, 2008) (Pant and Hambly Odame, 2017)
	Missing institutions	(Aryal *et al.*, 2020) (Kaur, 2019) (Khanna *et al.*, 2018) (Murugesan and Sudarsanam, 2020) (Richards *et al.*, 2009)
	Lack of appropriate incentives	(Cecchini and Scott, 2003) (de Zegher *et al.*, 2019) (Khanna *et al.*, 2018)
	Age	(Hay and Pearce, 2014)
	Lack of involvement	(Cecchini and Scott, 2003) (Greenland *et al.*, 2018) (Kulikov *et al.*, 2020) (Long *et al.*, 2019) (Sanders and Masri, 2016)
	High costs	(Coble *et al.*, 2018) (Greenland *et al.*, 2018) (Khanna *et al.*, 2018) (Rotz *et al.*, 2019)
	Education	(Abdullah, 2015) (Bello-Bravo *et al.*, 2018) (Hay and Pearce, 2014)

Table 3.
Summary of the analysis

(*continued*)

Type of challenges	Theories	Authors
	Knowledge	(Abdullah, 2015) (Bello-Bravo *et al.*, 2018) (Chandra *et al.*, 2017) (Mulauzi and Albright, 2008) (Murugesan and Sudarsanam, 2020) (Umar *et al.*, 2019)
	Quality	(Abdullah, 2015)
	Internet usage	(Abdullah, 2015)
	Language	(Mulauzi and Albright, 2008)
	Business models	(Long *et al.*, 2016a) (Long *et al.*, 2016b) (Long and Block, 2018) (Shepherd *et al.*, 2018)
Relevant avenues for the future development of research on the identification of new sustainability paradigms related to the application of digital technology in agri-food sectors	Collaboration	(Allaoui *et al.*, 2019) (de Zegher *et al.*, 2019) (Long and Block, 2018) (Long *et al.*, 2016a) (Long *et al.*, 2016b) (Rao *et al.*, 2018) (Sarker *et al.*, 2020)
	Looking beyond economic benefits and towards social/ long-term benefits	(Aryal *et al.*, 2020) (Cane and Parra, 2020) (Goh *et al.*, 2019) (Kulikov *et al.*, 2020) (Rao *et al.*, 2018)
	Automation vs transformation	(Boyd and Jardine, 2011) (Lakshmi and Bahli, 2020) (Rotz *et al.*, 2019)
	Role of policies, incentives and institutions	(Boyd and Jardine, 2011) (Coble *et al.*, 2018) (Long *et al.*, 2019) (Panagiotopoulos *et al.*, 2017) (Rotz *et al.*, 2019)

Table 3.

are using digital technologies three times more often than men. Despite the fact that gender divisions still exist, the increasing use of digital technologies in rural areas is bridging this gap. Mulauzi and Albright (2008) found that the access and use of digital technologies are hindered by marginalization of gender, but that other variables, such as a language barrier, high costs and limited skills and knowledge, are playing a bigger role in this context.

Lack of modernity. Research into the technology use of farmers in Bangladesh argued that neither education nor income is a real barrier in the use of digital technologies, but that being modern (i.e. having children or being young) is very important (Islam and Grönlund, 2011). This means that when farmers have children or are from a younger generation, they are more likely to use digital technology within their businesses, because this "modern generation" uses it more often and thus faces less barriers in its usage.

Farm business characteristics. According to Hennessy *et al.* (2016), the usage of digital technology may depend on the business characteristics of farms and not on the access of digital technologies. In their study, farmers who had access to computers and used them in their household did not always use them in their business. Also, dairy farmers were more likely to use computers for their business twice more often than tillage farmers (Hennessy *et al.*, 2016), suggesting the relevance of the business characteristics of the farm.

Lack of services. The usage of technologies for a sustainable development is also related to the presence of dedicated services, at the institution, private firm or consultancy level. However, several authors report a lack of services, hindering the usage of digitalization.

Sarker *et al.* (2020) highlight the need to support government initiatives, private sector's involvement and public–private partnerships, to aim for a large-scale development of big data technology and the implementation of sustainable business models. According to Mokotjo and Kalusopa (2010), farms seem to limit their usage of agricultural information services as a consequence of a lack of promotion and training.

Hurdles in evaluating benefits. It is fundamental that decision-makers properly assess technology implementation and benefits of its usage. Lakshmi and Bahli (2020) underline how decision-makers should be focussed on assessing the long-term benefits of robotic agriculture, especially when evaluating costs and investment decisions. Awareness and expectations both play a role in defining this capability (Kulikov *et al.*, 2020), together with the skills and competencies by vendors, which may hinder the process of benefit assessment by users (Kulikov *et al.*, 2020).

Looking at a different unit of analysis, that of the whole value chain, Storer *et al.* (2014) highlight the need to focus on the understanding of the benefits of the development of strategic supply chain management coordination, especially with respect to innovation adoption, highlighting a paradox in between the benefits achieved by partners and their level of investment in industry-led innovation.

Challenges to the sustainable development of digital technology in agri-food sector. We identified 12 challenges that can hinder the sustainable development of digital technology in agri-food. We explain them as follows.

Access. Access seems also to be a challenge to the sustainable development of digital technology due to the high costs of equipment, maintenance and connectivity (Mulauzi and Albright, 2008). Farmers are, indeed, complaining about the fact that they do not have access to a better broadband connection or access overall (as confirmed by Pant and Hambly Odame, 2017, in their study of Canadian farms). Additional, in supply chains the infrastructure seems to work as a critical bridge between small and big data and therefore needs to rely on access (Coble *et al.*, 2018).

Since access to infrastructure represents a comparative advantage for firms, firms within rural areas that do not have access may be disadvantaged. Hay and Pearce (2014) found that access to technology has changed the farming lifestyle and farming practices of rural women.

Technology adoption results in less isolation within the rural areas that come to be more connected to each other through social media and emails (Hay and Pearce, 2014). Another study investigated the access of professional women in Zambia to ICT (Mulauzi and Albright, 2008). According to the authors, ICT can be useful to develop women's growth as it provides them with knowledge about health, education, environment, good governance (Mulauzi and Albright, 2008). Another benefit from adopting digital technologies in rural areas is that those firms now have access to educational videos and niche markets (Bello-Bravo *et al.*, 2018; Pant and Hambly Odame, 2017). Echoing these studies, Cecchini and Scott (2003) investigate how access to technology may trigger poverty reduction. Specifically, they argue that ICT can give poor people and farmers access to education, health and other services but that this access may be prevented in view of its high costs. Abdullah (2015) shows how also in the Pakistan region, access is still not optimal, and the infrastructure has to be improved to foster network development within the country and for its population. Within the Philippines region, key challenges to improve infrastructure are access to communication, transportation and water resources (Chandra *et al.*, 2017). Finally, also access to professional support plays a role (Hay and Pearce, 2014).

Mokotjo and Kalusopa (2010) support this view, claiming that most farmers in Lesotho still do not have access to agricultural information systems.

Missing institutions. A lack of supporting institutions creates additional challenges for farmers (Khanna *et al.*, 2018), especially in developing countries. Several works in the Indian context are contributing to this stream of research. Aryal *et al.* (2020) highlight that this is an issue both for the farmers and for the system level, since technologies and practices such as the climate–smart agriculture could support both environmental and economic sustainability.

Murugesan and Sudarsanam (2020) confirm the same relationship, in the even more specific field of sustainable rural development. Nonetheless, to do so, institutions should support the upscaling and outscaling of technologies through investment, policy and institutional framework at the micro (the farmer), meso (industry) and macro (system) levels and both nationally and locally. Kaur (2019) confirms that Indian policymakers should explore technologies to maximize their outreach and extend the benefits to a larger set of population, improving food security. Richards *et al.* (2009) show that the African countries face challenges in how to integrate new sources of knowledge within their farm to improve food security.

Lack of appropriate incentives. Cecchini and Scott (2003) state that the implementation of digital projects must be executed by firms and individuals who have the appropriate incentives to work with groups. Also, Khanna *et al.* (2018) claim that the adoption rates are often low due to behavioural factors and that those factors can be solved by appropriate incentives. Another issue is related to the fact that, within complex supply chains, the sustainable development of digital technology can be limited by a perception of diverse incentives by different players, since benefits and costs do not always accrue in an equitable manner (de Zegher *et al.*, 2019). Thus, the adoption may critically depend on relationships and incentives. Within their study, de Zegher *et al.* (2019) suggest solutions such as contract designing and sourcing channel to set mutual benefits, in order to create that "shared value", which stands at the basis of sustainable development.

Age. Age seems to be an important aspect in the adoption of technology (Daberkow and Mcbride, 2003). The older a farmer is, the less likely is that this person is going to adopt digital technologies within his or her business. However, according to the results of Hay and Pearce (2014), this is not the case for grazier women in Queensland as, in that context, other factors, such as attitude and lower education, were more likely to hinder the implementation of digitalization technologies.

Lack of involvement. Our review has highlighted three barriers related to the lack of involvement, at three different levels: (1) the lack of user involvement, or even the *user resistance*, related to a lack of an entrepreneurial mindset of farmers, which impacts on the demand growth rate, limiting the diffusion of knowledge related to the innovation and enhancing the adoption and diffusion costs for sustainable entrepreneurs (Long *et al.*, 2019); (2) partner involvement and commitment, meant as their propensity to adopt or to bear costs and risk of the new technologies (Greenland *et al.*, 2018); (3) the involvement of community, which seems to play a relevant role, especially when searching for solutions to ensure the needs of the poorest classes of people, such as access to technologies, education and knowledge (Cecchini and Scott, 2003). Community involvement, but of a different type – integrated resource management communities – is also at the core of the study by Sanders and Masri (2016), focussing on the energy–water agriculture nexus.

High costs. An additional challenge is that of high costs. Many regions and firms cannot afford to improve their infrastructure as most of the time they lack financial resources to do so. To improve the infrastructure, decision-makers must consider the acquiring, installing and maintaining costs (Rotz *et al.*, 2019). Farmers do also face high costs in the extension of learning presentations since those are costly in terms of resources (also in terms of travel time) and distance for extension agencies. Hidden costs do also play a role in the adoption of digital technologies (Khanna *et al.*, 2018). Another relevant element is the switching cost from

lower cost and higher diffusion of alternative technologies, which is particularly relevant when significant financial investment is required to adopt technology, even in the light of higher potential sustainability (Greenland *et al.*, 2018). For example, in terms of adoption of big data within the whole agricultural value chain, Coble *et al.* (2018) argue that, although there are high volume costs, the adoption of big data will eventually result in reducing operational and processing costs.

Education. Abdullah (2015) examines the difference between castes in rural Pakistan and their use of digital technologies, concluding that the use of ICT is dependent on the literacy of the people. Castes of farmers should be much more educated in order to make use of the technologies. Hay and Pearce (2014) state that the position of women in the agriculture will be diminished when they are not educated, but they also mention that lack of education is a barrier in adoption. Bello-Bravo *et al.* (2018) investigated in which way farmers can be educated better, concluding that the use of animated videos among farmers can be very effective, showing greater learning gains than farmers who were using traditional technology.

Knowledge. Limited knowledge and skills for using ICT by farmers contribute to the challenges (Abdullah, 2015; Mulauzi and Albright, 2008) or in delayed development (Murugesan and Sudarsanam, 2020). Kulikov *et al.* (2020) in their survey found this to be a major issue, especially with respect to the lack of knowledgeable, trained and skilled workers capable of operating digital technologies and systems. This is also supported by the study of Chandra *et al.* (2017), who performed research about climate smart farming. They find that climate–resiliency field schools can serve as a platform where farmers can gain information in order to improve their farm planning. However, they also mention that climate–smart interventions involve knowledge-intensive processes.

In this direction, to face the lack of informative platforms, Bello-Bravo *et al.* (2018) suggest farmers to share their knowledge through videos. Still related to knowledge and competencies, the work by Umar *et al.* (2019) recalls the role of competence and knowledge related to advisors, consultants and services, proposing a scale for its measurement.

Knowledge, training and capacity of advisors and consultants are of crucial relevance and shall be considered to make sure that technologies are correctly delivered, and their benefits are transmitted to farmers and entrepreneurs and could be enhanced by designing trainings and initiatives (Umar *et al.*, 2019).

Quality and Internet usage. The quality is linked to the quality of access to Internet by farmers. According to Abdullah (2015), the connection speed of broadband seems to play a role in the adoption of digital technology. Besides, the usage of Internet among farmers is also an indicator that farmers who do not use Internet are often less likely to adopt ICT as well.

Language. Languages within a country can differ a lot, because countries may use a main common language while also having many local languages. For example, in Zambia, the development information is accessed in eight languages (Mulauzi and Albright, 2008). It requires a lot of effort to translate knowledge and informative knowledge in order to serve every local group. When different groups of farmers cannot access the information in their language, this can result in a lack of usage of ICT by these groups.

Business models. Long *et al.* (2016b), Long and Block (2018) and Shepherd *et al.* (2018) highlight that the successful sustainable development of digital technology in agri-food sector is partially dependent on the business models that providers adopt, especially for the successful adoption and diffusion. If those are not designed to embrace such innovations (Long *et al.*, 2016a, b), both financial investments and in the development of skills will not take place. Providers must consider the complexity of technologies and the technological readiness of adopters. In this light, the proposed value proposition, as well as the design of revenue and cost model to deliver such proposition is of critical importance.

Relevant avenues for the future development of research

The challenges highlighted are – to different extent – inhibiting sustainable business models and action. To overcome them, both coordination and involvement of institutional actors, two elements that we account for in this paragraph, are needed (Long *et al.*, 2019). Indeed, for sustainable advances to be made, an institutional change needs to occur, and collective action and coordination often play an important role in such processes.

Collaboration: To foster a sustainable development, the adoption and usage of innovations are needed and so is the capability to integrate, through them, economical and socio-ethical issues. Long and Blok (2018) define responsible innovation as the ideal approach to integrate these aspects, bridging entrepreneurial needs with the pursuit of an innovation conducted for – and with the engagement of – society. Nonetheless, in many studies, the trade-off between dominant business logics, resource constraints, unequal contribution and stakeholder engagement (Long *et al.*, 2016b; Long and Block, 2018; Rao *et al.*, 2018) poses serious challenges to such target. Long and Blok (2018) suggest the need for open innovation approaches, to foster collaborations and provide incentives to the reach of both economical and societal objectives, thus towards the definition of sustainable models. Also, many studies highlight the need to develop collaborative – or coopetitive – mechanisms to support the technology adoption, usage and the reach for sustainable paradigms. According to Sarker *et al.* (2020), a strong initiative as well as networks and public–private partnerships are necessary to scale-up the usage of technology and to solve the challenges such as the lack of expertise and the complexity of context-specific technologies. Such competencies might reside in a network of partners and not in a focal firm alone. On the same line, other authors, such as Allaoui *et al.* (2019), recall the importance of collaborative decision support systems to support choices of sustainability paradigms.

Another crucial element is the one recalled by de Zegher *et al.* (2019) with respect to the need to find equitable division of the benefits and costs of technological innovation within complex supply chain, to ensure the creation of a "shared value" that could lead to the definition of new sustainability paradigms.

Looking beyond economic benefits and towards social/long-term benefits. In their work, Cane and Parra (2020) analyse technological solutions to surplus and food waste, taking into consideration the collective and environmental outcomes, the entrepreneurial needs and the consumer requirements. Their aim is to suggest how to better cope with estimates of the impact of technologies to support both the entrepreneurial mindset and environmental issues of food waste reduction. As highlighted by Kulikov *et al.* (2020), a potential way to address this issue could lay in setting specific criteria to measure benefits and efficiency post-implementation, in order to support the evaluation of adoption, usage and feasibility of technologies. Rao *et al.* (2018) describe similar needs and dynamics in the context of micro-irrigation. Additionally, for small farms, where the trade-off between costs and benefits could not be large enough to stimulate adoption and usage of technology, the role of institutions is particularly crucial (Aryal *et al.*, 2020).

Indeed, Goh *et al.* (2019) highlight that stakeholders are aware of the need to pursue sustainability and to relate it to an issue of necessary competitiveness in the industry, provided the strict constraints imposed by institutions, customer pressures and benchmarking towards sustainable organizations.

Automation versus transformation. Lakshimi and Bahli (2020) recognize that automation and robotization change the workforce composition, with routinized work being replaced by automation solutions, while highly specialized jobs and those involving abstract skills are being created. While automation is optimal for farmers who can afford the technology and creates new employment opportunities, it may also create a process of exclusion and inequality (Rotz *et al.*, 2019). This confirms a trend towards a cultural change, rather than a simple issue of technology adoption, which will need to be addressed

in the future, especially since automation within the agri-food industry is currently focussed on environmental and sustainability issues, and it is also key to productivity, efficiency and safety issues. Thus, the implications to be addressed by policymakers and educators are those of preventing job insecurity and inequality, while decision-makers shall focus on strategic change.

Role of policies, incentives and institutions. Policies, rules and institutions play an important role in creating demand and, therefore, markets (Long *et al.*, 2019). Social contexts can also play a mediating role, preventing, reducing or emphasizing public understanding, with economic impacts on actors, as found by Boyd and Jardine (2011) in their study on the effects of mad cow disease. Panagiotopoulos *et al.* (2017) also suggest that farmers can use digital platforms in order to influence policymakers. So, an avenue of research that has commonly emerged in the review is a deeper understanding of policy effect. Authors have especially recalled the role of those policies that: (1) by providing substitute solutions might hinder demand for technologies (Long *et al.*, 2019); (2) are aimed at fostering development of the rural areas that is found to be driven by increases in farming income (Murugesan and Sudarsanam, 2020); and (3) target both environmental and economic issues (Khanna *et al.*, 2018) Additionally, scholars (Coble *et al.*, 2018) recall the importance of analysing issues of data security, data sharing and data infrastructure, since these elements stand at the basis of comparative advantages to certain areas.

Implications

Our review revealed several challenges that may prevent the usage and development of digital technologies in agri-food firms. These barriers range from the difficulty people may find in accessing the tools that enable its implementation to the ability to manage data complexity, from the lack of appropriate institutions and incentives to digitalization to the need to craft new, more technologically sustainable, business models. Taken together, these barriers draw a challenging context for firms and individuals that will be engaged in this industry in the years to come and thus trace important implications at a policymaking, economic-managerial and socio-environmental level.

Policymaking level

The results of our review show that policymakers can help overcome several of these challenges. When institutions and incentives are missing in the usage and development of sustainable digital technologies, policymakers can adopt strategies that promote digital entrepreneurship, financing investments for farmers and workers in the industry. Such an approach implies providing funds to individuals that either lack access to infrastructure or lack appropriate knowledge about how to efficiently leverage the digital tools to make their farms examples of sustainable business model within the industry. Also, we believe government initiatives able to sponsor a cultural change, a shift from a logic of innovation that is individualistic and single-minded to one that is collectivistic, focussed on the community and open-minded are key to the development of sustainable business models in the agri-food industry. This is in line with the future avenues of research that some scholars have already started walking, avenues marked – among others – by the need to incorporate institutional changes and implement collaboration and coopetition in the usage and development of digital technologies.

Economic and managerial level

Our results identify key implications also at an economic level. Indeed, following extant research (Lakshimi and Bahli, 2020; Rotz *et al.*, 2019), we acknowledged that one of the future avenues of research in this field is automation and robotization. Such direction suggests

that the economy will experience significant transformation in the workforce, seeing, on one hand, the replacement of more routinized jobs by robots or similar technologies and, on the other, the creation of more sophisticated, software-related jobs. This implies that the labour market is going to completely change its configuration, entailing important impacts not only on countries' economy but also on strategic decisions firms may make in terms of offshoring and outsourcing and, eventually, on the structure of global trade. Indeed, changes in labour composition may trigger a completely new geography of labour costs, with firms in the industry deciding to strategize around locations where automation can be more efficient and production costs may be reduced, eventually shifting the balance of payments between developing and developed countries and triggering new trade dynamics between them.

Also, building on extant literature, our review has acknowledged that an entrepreneurship that is sustainable may play a key role in overcoming several challenges to the usage and adoption of digital technologies (Long *et al.*, 2019). This suggests the need for managers to incorporate, within their business models, a logic that is not of short-term efficiency and profitability, rather of long-term, shared, creation of value. To do so, managers within the industry may need to sponsor the development of training programmes for farmers and employees, in the direction to overcome the barriers of education and knowledge that still represent a key challenge for many agri-food businesses.

Socio-environmental level

Finally, our review has highlighted the need to embrace, as a future avenue for research that may help overcome some of the identified barriers to the usage and adoption of digital technologies in the agri-food industry, a long-term vision that focusses not only on economic but also on social impact. This means that firms have to completely rethink themselves, developing strategies that are not at all business-as-usual and build digital business models that are sustainable from both an economic and a social side. For example, firms may need to restructure their supply chains, envision different relationships with employees and clients, interact with the diverse partners that compose the outside ecosystem and do so in a perspective of value creation for the society as a whole rather than value appropriation for the firm itself.

Embracing a social vision means for firms in the agri-food industry to acknowledge that the shift towards such digitalized, sustainable business models translates into benefits not only for themselves but also for the society as a whole. For example, incorporating digital technologies may help control the effect that farms' production and distribution have on air and soil conditions and help minimizing the usage of pollutants and release of CO_2 gases within the atmosphere. In this perspective, firms within the agri-food industry may generate long-term benefits for the environment, becoming also more able to embrace the quest to deal with climate change and contribute to prevent the dangerous consequences of rising temperatures on the ecosystem.

Conclusions

Our review has aimed at capturing in a structured way the state of the art regarding digitalization in the agri-food industry. Building on extant literature, we have identified the challenges that prevent firms in the industry to use and adopt digital technologies, also drawing related implications at a policymaking, economic-managerial and socio-environmental level.

Results have pointed to several barriers, ranging from lack of adequate infrastructures, incentives, knowledge to issues of costs, language, quality of Internet access available for farmers. Whereas some of these difficulties may be overcome by promoting specific government interventions or investment by private actors, some other challenges require

more profound, deep shifts for firms in the industry. We concluded that such shifts entail not only a perspective that is long-term, rather one that is collaborative and sustainable in both an economic and social sense. Firms in the agri-food industry need to change the logic around which, up to now, they have built their business models, embracing an approach able to involve several actors and to benefit both players in the industry and in the environment in general.

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