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Review

Challenges and Opportunities of Agriculture Digitalization in Spain

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Abstract: Motivated by the ongoing debate on food security and the global trend of adopting new emerging technologies in the aftermath of COVID-19, this research focuses on the challenges and opportunities of agriculture digitalization in Spain. This process of digital transformation of the agricultural sector is expected to significantly affect productivity, product quality, production costs, sustainability and environmental protection. For this reason, our study reviews the legal, technical, infrastructural, educational, financial and market challenges that can hinder or impose barriers to the digitalization of agriculture in Spain. In addition, the opportunities that digitalization can bring are identified, with the intention of contributing to provide insights that helps strengthen the Spanish agricultural model and make the necessary decision so that professionals in the sector are prepared to adapt to this intense change.

Keywords: digitalization; agriculture; smart agriculture; innovation; productivity; business model

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1. Introduction

The COVID-19 pandemic has severely impacted the world economy due to lockdowns, mobility restrictions and the requirement to maintain personal distance, precipitating a change in production models and accelerating the digitalization process [1]. Indeed, since then, digital skills have become an essential requirement [1–3] and homeworking a common mode of operating in many businesses. While remote working has raised serious concerns due to the possible negative effects on work-life balance [4], it has also resulted in greater flexibility for workers, higher productivity and cost savings [5]. Therefore, the impacts of digitalization and remote working are reported to be perceived in different ways depending on age, gender and labor sector to which one belongs [2,3,6].

With the relaxation of the restrictive measures and the attempt to return to normality after the worst of the coronavirus pandemic, we are witnessing that the digital infrastructure and the labor regulations adopted are still in force. Therefore, a more widespread use of digital technologies is expected, as well as a greater acceptance of new solutions based on robotics, artificial intelligence, the Internet of things (IoT), and edge and cloud computing, further changing the landscape of digitalization. The application of these new technologies in the jobs will demand a higher level of digital skills from current employees and will change the portrait of economic competitiveness, so that people with greater digital literacy will have a better chance of gaining on the market [2,7,8]. This may lead to digital inequality in societies [7], since workers, depending on origin, gender or age, may not have the same opportunities in digital literacy [1,9]. This inequality may be accentuated when jobs in the primary sectors (which are often carried out by vulnerable people with low educational levels or by immigrants) are fully integrated into the digitalization process [10,11]. Therefore, it can be stated that the digitalization process has started to impact job recruitment opportunities [12,13].

Until now, agriculture was among the sectors that did not require a high level of education in a broad spectrum of their labor insertion [13–16]. For example, in the particular case of Spain, analyzing the latest available statistical data from 2013 showed that only 2% of farm owners had received higher education related to agriculture, (the interested readers on the statistical data of Spain is referred to Appendix A). As can be seen in Figure 1, this percentage is well below that of the main European agricultural countries [16]. Therefore, with digitalization, people working in these sectors may be more affected by inequalities [17,18]. The vulnerable workforce in this sector that lacks such digital qualification will take time to update their skills, fill digital gaps and remain competitive in the global market of their own sector.

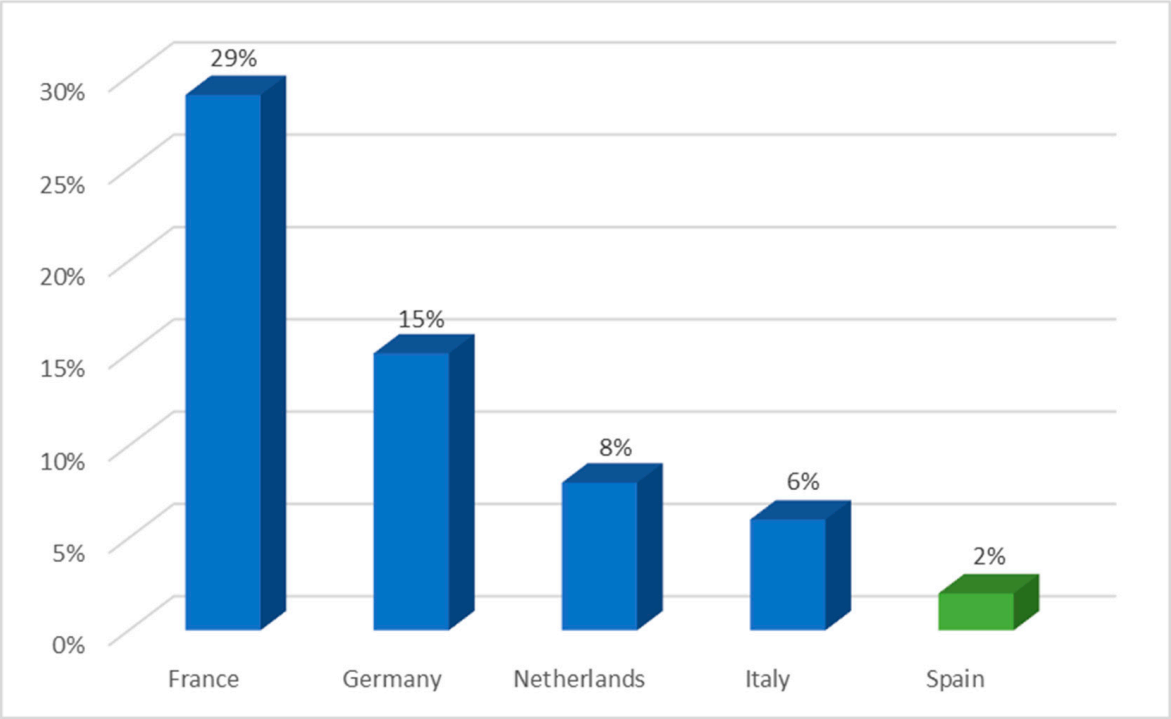


Figure 1. Percentage of farms in which their owners have completed higher education related to agriculture (2013) [16]. In this case, higher education is defined as any training cycle that has a duration equivalent to at least two full-time years after the end of compulsory schooling and that has been completed at university or any other agricultural training center.

Figure 2 shows the weight of agricultural GVA (Gross Value Added) on the economy as a whole in Spain in 2017, and compares it with five other large European countries, and with the European Union (EU) average [16]. As can be seen, Spain is the country that registers the highest percentage of GDP (Gross Domestic Product) from this sector, above Germany, Italy, the Netherlands or France. Furthermore, Figure 3 shows that in 2021 Spain was the fourth largest exporter of agricultural products in the European Union. However, the weight of agri-food exports over total goods was greater in Spain than in the rest of the countries analyzed, with 19%. Therefore, in a country like Spain, where agriculture is a strategic sector of the economy, the socio-economic concerns of digitalization are more pronounced. For this reason, in recent years, studies have begun to be published on the possible impact of digitalization in urban and rural areas of Spain [18–25]. Employment opportunities, gender equality and education in rural areas are among the development factors that can be greatly affected by the strengths and weaknesses of the country's agri-food industry, due to the importance of this sector in the Spanish economy [19,26].

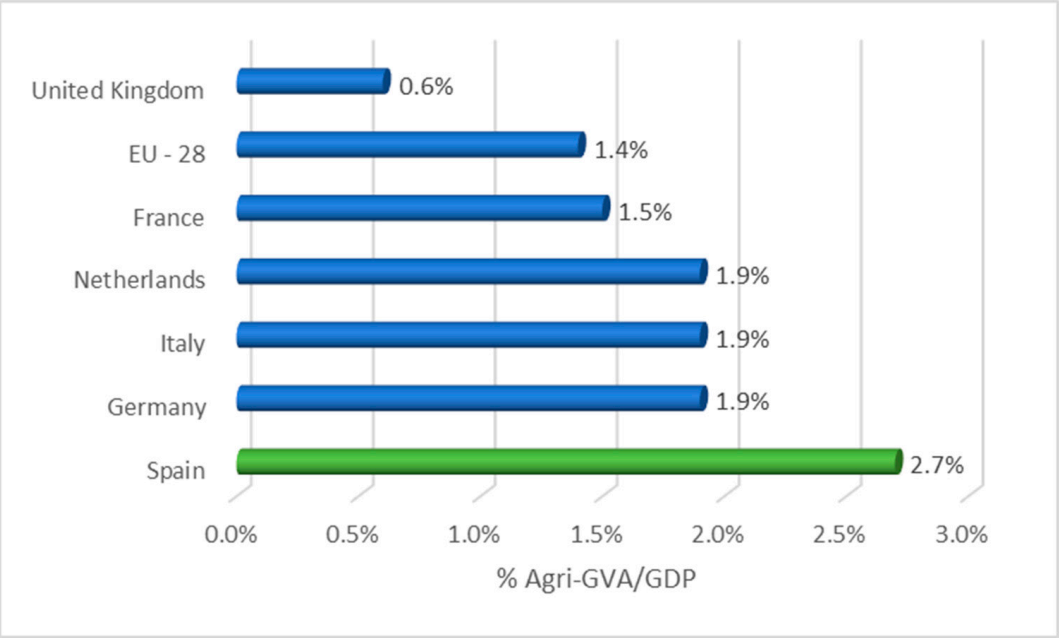


Figure 2. Direct contribution of agricultural GVA to the total GDP of the economy (2017) [16].

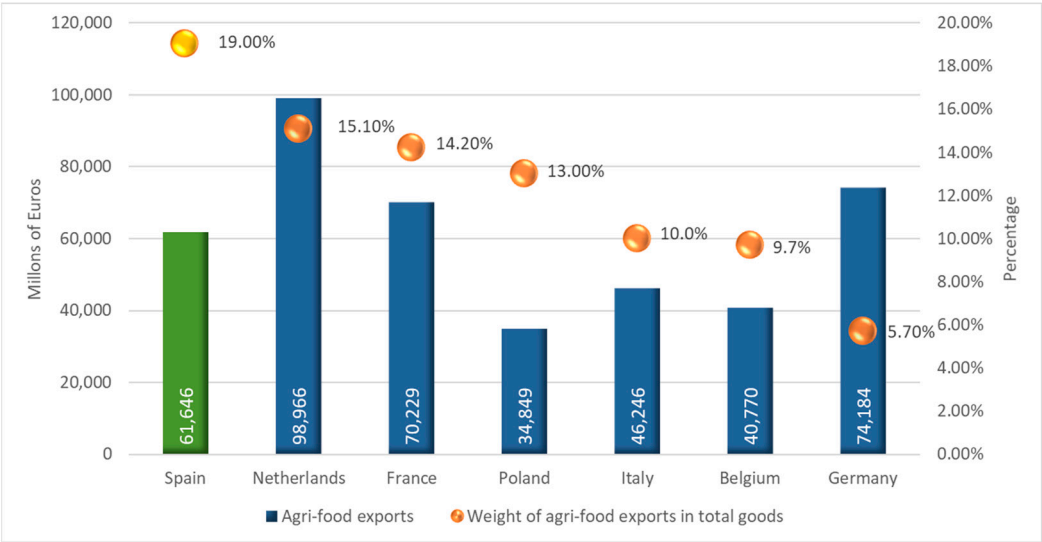


Figure 3. Agri-food exports (millions of euros) and the percentage that they represent over the total of goods of some of the EU-28 countries (2021) [25].

According to published data, technological progress could already empower countries like the Netherlands to achieve three times more productivity per square meter of tomato cultivation and seven times more productivity per square meter of cucumber compared to Almeria (in Spain) [16,27,28]. Hence, the Spanish government has called for the implementation of a plan for disruptive changes in the productivity of the agricultural industry based on digitalization.

To reach this ambition, farmers need to disruptively change their practices and improve their capabilities to keep themselves aligned with new technologies and innovative methods [29]. In the global panorama, digitalization has accelerated the industrial revolution and has given rise to new trends in the agricultural industry [30], incorporating the concepts of industry 4.0 [31], the new methods of cost reduction in the production, the welfare 4.0 [7], the new vertical and horizontal integration schemes of the value chain and the

environmental protection plans. Several reports of the achievement have been published in Australia [32], India [13], Spain [20,33,34], Maghreb [35], USA [36], among others.

Within the Multiannual Financial Framework 2021–2027, the European Union has launched the Digital Europe Programme focused on bringing digital technology closer to companies, citizens and public administrations [37]. Therefore, the acquisition of digital skills by EU citizens is one of the main bets of this programme, and fields such as high-performance computing, robotics, artificial intelligence and cybersecurity are among the educational objectives. Furthermore, within this programme, agriculture is presented as a prioritized application sector and the deployment and best use of these digital technologies are expected to have a profound impact on the socio-economic structure of Europe and the achievement of climate and biodiversity targets [20]. Therefore, during this transformation process, countries are expected to undergo a revolution towards higher productivity [38], ensuring sustainability, socio-economic demands [2,39,40], human rights [41,42] and contributing to the safety and inclusion of all [33].

The main contributions of this work are the following:

- The identification and review of the main challenges that may hinder or impose barriers to the digitalization of agriculture in Spain.
- The outline of the opportunities that the digitalization process can bring to the agri-food sector.
- The provision of insights that help prepare professionals in the sector to adapt to this digitalization process.

In the next section, Spanish socio-economic conditions are explored as a starting point for the analysis. Thereafter, Section 3 reviews the infrastructural, technical, legal, social, market, financial, and economic challenges related to the digitalization of agriculture in Spain. Section 4 addresses opportunities such as improved access to markets, the achievement of sustainable development goals, the promise of better education and health care systems in rural areas, greater territorial resilience, environmental protection, food security and openness to innovation, from which the sector could benefit. Section 5 highlights insights that could facilitate transit through this process of change and discusses the importance of correctly estimating the challenges and opportunities of agricultural digitalization in order to move in the right direction during implementation. Finally, Section 6 briefly summarizes the conclusions of the article.

2. Background

The study of the pre-industrial economy of Spain [14,15,43] demonstrates the relationship between inequality in labor income and education. Since the incorporation of Spain to the European Union, the agricultural sector has gone through different processes of modernization and reconstruction and an attempt has been made to fill the gap of socio-economic inequality due to globalization [44]. The tasks accomplished have had an impact on urbanization, rural social equalization and the reduction of precariousness and economic vulnerability. However, the modernization process that has been started recently with the divide-prevention target has become the division-production element. Recent studies show the impact of digital skills and internet access as the factor in expanding the socio-economic environment. Nevertheless, access to digital services such as cloud services and social networks are among the factors that no longer reduce inclusion gaps [33]. It is evident that from the moment in which we are to the point expected in 2050, there will be a great difference in the variation of purchasing power in the world, the process of urbanization at a global level, the variation of lifestyle, the use of new technologies, infrastructure, energy efficiency, employment opportunities, etc. While Spain has a moderate trend towards achieving goals in the Mediterranean region [17,20,35], income inequality, economic disparity, the digital divide and the gender gap are greater than the EU average [17].

In Spain, 14.2 percent of the population is active in agriculture and associated food industries [16]. In addition, a large part of Spain's foreign trade belongs to agricultural and food technology, which could reach 17,430 million euros in 2017 [16]. It is estimated that

the total accumulation of Spain for 30 years until the 2050 horizon reaches 17 million euros, three times more than the period ending in 2017 [16]. For this reason, the government has announced different packages to support biosecurity, sustainability and competitiveness in agriculture and livestock (for example, the economic plan published on 2 November 2021 by the Ministry of Agriculture, Fisheries and Food).

However, the sustainability and competitiveness of agriculture and livestock in the high-speed digitalization process in the world also requires a change in the human resource factors of the people involved in the agricultural sector, so that the use of digital technology in rural areas can be facilitated. A sufficient number of experts and technicians are needed in the digitalization of agriculture, a sufficient number of service providers for farmers and a market at scale to meet the requirements of the agricultural and food industry [21,29,45]. While government motivation packages will help defray the cost of machinery, software, and connectivity [45], recent studies show that resistance to new technologies is due in part to a lack of perceived benefit from adopting them [31,46].

Therefore, in addition to the investment required in the acquisition of internet coverage, software and connectivity, special investment must be made for the up-skilling and training of farmers, so that they become familiar with digital technology. Meanwhile, a high percentage of farmers still do not consider the investment of time, energy and money to digitize their activities to be a necessary act, and in the shadow of the financial damage caused by the COVID-19 pandemic, are unwilling to get involved in the process required for the adoption of technology.

Furthermore, most farmers are wary of the possible use and disclosure of their data and do not trust the possible acts of interoperability that could be performed with them. The last problem is the level of education of Spanish farmers to employ advanced digital gadgets on the farm [47].

Therefore, it is important that Spanish farmers know all the opportunities that the digitalization process can bring. Digital agriculture will provide farmers with IT-based infrastructures for a higher level of market participation. Using the precise information about the product and the production process, a direct link between the producer and the consumer will be created. Therefore, production waste within the distribution chain will be lower and the value chain will have higher efficiency. With the higher level of data and information in the value chain, the decision-making process will be optimized and administrative processes will be improved. With optimized decisions, the quality of the products will be higher and green production regulations will be better-respected [45].

Since digitalization is a complicated process, it is highly important that this path is carried out following the guidelines of the Digital European Programme [37] and the associated laws [48] so that Spanish farmers and livestock producer can catch up with farmers from other EU countries (such as France and the Netherlands). Making weak progress in the digitalization process would have the consequence that Spanish farmers would lose their position in the market and their competitiveness [16]. Hence the importance of this process being carried out successfully, involving the greatest possible number of actors.

3. Challenges

According to the objectives of the European Commission (declared on 20 December 2021), [48–50], rural areas throughout Europe should have the same capacity for connection, resilience and prosperity by 2040. These rural areas are expected to become benefit from digital infrastructure in a wide range of services, be resilient to climate change and economic crises, and improve the added value of farming and agri-food activities.

Following the EU declaration, societies must work together to balance inclusion, sustainability, competitiveness, resilience, quality of life and well-being. The Commission's Gender Equality Strategy 2020–25 has also paid attention to the inclusion of women and vulnerable groups in rural areas in terms of quality of work and education. Therefore, the digitalization process must be carried out together with the implementation of policies that help achieve the objectives of improving social equity in urban and rural areas.

Cluster 4 of the Horizon European Programme is dedicated to Digital, Industry and Space, developing world-class technologies to serve the needs of all types of European Industries, including agriculture. Therefore, the actions supported under this destination aim to provide high-performance solutions that business will trust and adopt to maintain their competitiveness and maximize their contribution to environmental sustainability [49]. These solutions include IoT, Artificial Intelligence (AI), robotics, block-chain and edge computing. On the other hand, the Horizon Europe mandate for Cluster 6 (Food, Bioeconomy, Natural Resources, Agriculture and Environment) is to provide opportunities to enhance and balance environmental, social and economic goals and direct economic activities toward sustainability. Innovation and digitalization in agriculture are key to achieving these goals [50].

Thus, it is obvious that digital technologies, such as AI, cloud and edge computing, satellite sensitive services, robotics, drones, block-chain, IoT, 4G and 5G internet service and digital transportation, have the potential to enhance the agriculture efficiency, achieve greater sustainability, improve the quality of life in rural areas, and secure food production. Hence, the declaration of the future of agriculture in the EU is defined along the Horizon European Programme [37,49,50] with the following objectives:

- Achieve intelligent and resilient agriculture
- Provide enhanced added value
- Reinforcement of environment protection and climate change issues
- Strengthen socio-economic growth in rural areas
- Achieve the expected results in the area of sustainable food production, considering both the branches of human and animal nutrition
- Provide greater attention to small and medium farmers and producers.

In Spain, recent studies [51] show that inequality and the difficulty of the market is more pronounced towards the self-employed and small entrepreneurs. Therefore, a series of different processes have been initiated to support the progress of the self-employed and small businesses with special attention to the process of digitalization of companies [52]. In this way, the strategic project for the recovery and economic transformation (PERTE) of the agri-food sector has received the green light, launching actions aimed at supporting the digitalization and reducing the skills gap through the establishment and provision of advice on digitalization, and the training and updating of knowledge of advisors [53]. Taking into account the impact of family businesses and SMEs on the Spanish economy, the policies and support packages encourage reaching the digitalization standard and generate opportunities for the collaboration of SMEs. Thus, for example, the Digital Kit programme is a Government initiative that aims to subsidize the implementation of digital solutions specifically adapted to small businesses, micro-businesses and the self-employed in the agri-food sector in order to achieve significant progress in the level of digital maturity.

However, given the nature of the agri-food sector, the implementation of the digitalization process is not without its challenges. The main challenges identified that may hinder or impose barriers to the digitalization of agriculture in Spain are described below.

3.1. Infrastructure Challenges

To successfully implement the digitalization process in the agricultural sector, three network layers must be considered: (i) The backbone connectivity to the internet; (ii) the regional network infrastructure, which is the wireless transfer of data from the farm to the nearest backbone (private 4G LTE, 5G, or cellular hotspot); and (iii) the local sensor network (low-power wide-area networks or LPWANs, such as LoRaWAN) for collecting the data of interest [54].

Having this type of infrastructure will facilitate a greater application of digital technology in agriculture, such as mobile apps, digital platforms, and the use of decision support systems in various tasks [45].

However, if there is a lack of Internet access at the bottom layer of digitalization, inequality in Internet access will translate to the highest level of the digitalization pro-

cess, impacting not only usage and consumption, but also other aspects such as digital literacy [2].

In Spain, the digital divide at more than 100 Mbps between rural and urban areas has been reduced to 20 percentage points in 2021. With the projects underway, in December 2023 this difference will be below 10 percentage points. The rural coverage of networks of more than 100 Mbps reached 68.13% as of 30 June 2021 (see Figure 4), with populations of less than 500 inhabitants generally being below said penetration (see Figure 5) [55]. In relation to mobile networks, the aggregate rural coverage of 5G has gone from 0% to 26.1% in 2021 (see Figure 6) [55]. Therefore, the future challenges of mobile network coverage are focused on improving 4G coverage and accelerating the deployment of 5G mobile networks in urban and rural areas. Greater coordination is also desirable between Ministry of Agriculture, Fisheries and Food and Secretary of State for Digital Progress, the municipalities and the operators in order to bring about coverage in the territory beyond the population hubs, taking into account the different technologies available: Fibre optics, satellite access and other radio-communication technologies that together may help mitigate the effects of low connectivity perceived by the sector in rural areas [53].

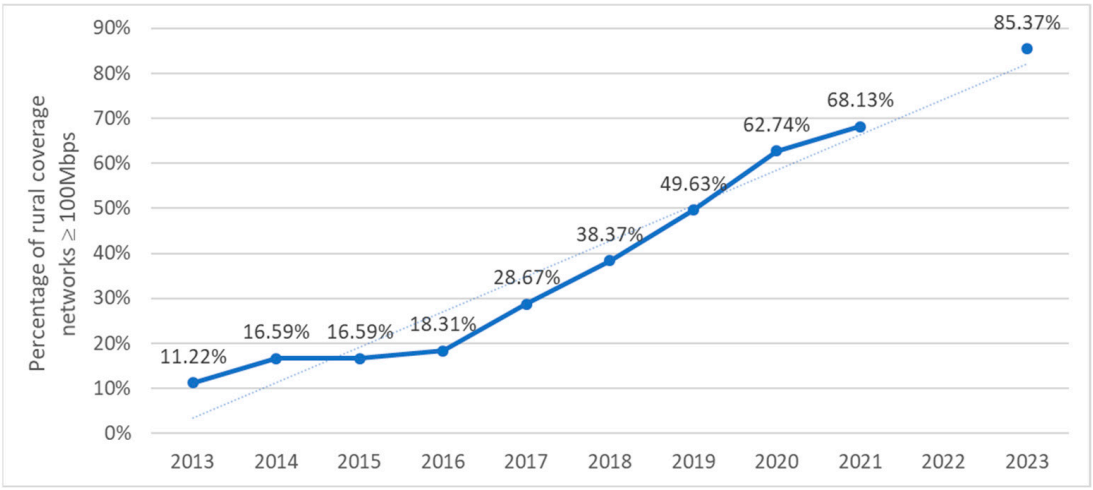


Figure 4. Evolution of coverage at 100 Mbps [55].

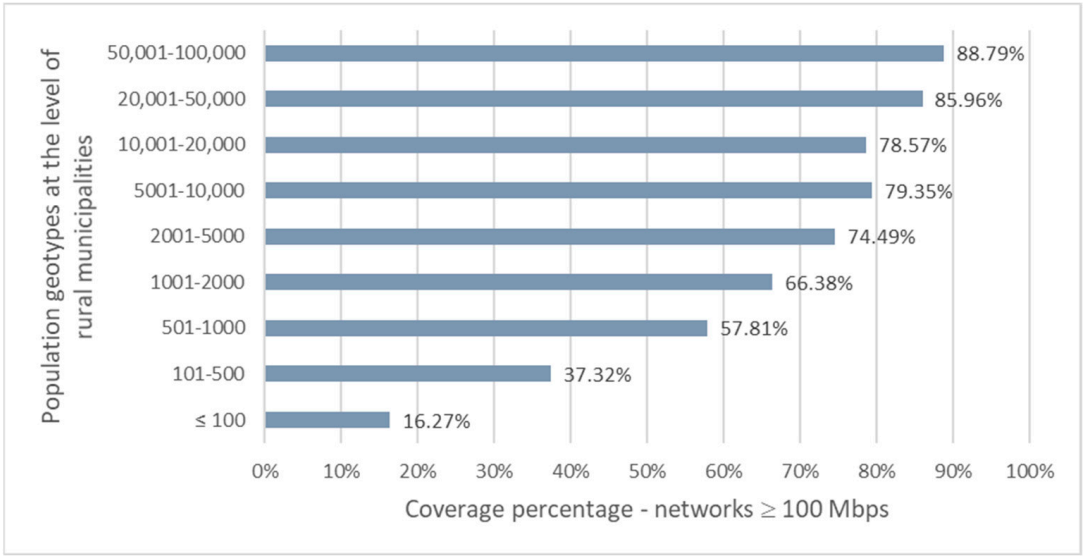


Figure 5. Coverage at speeds ≥ 100 Mbps by population geotypes (30 June 2021) [55].

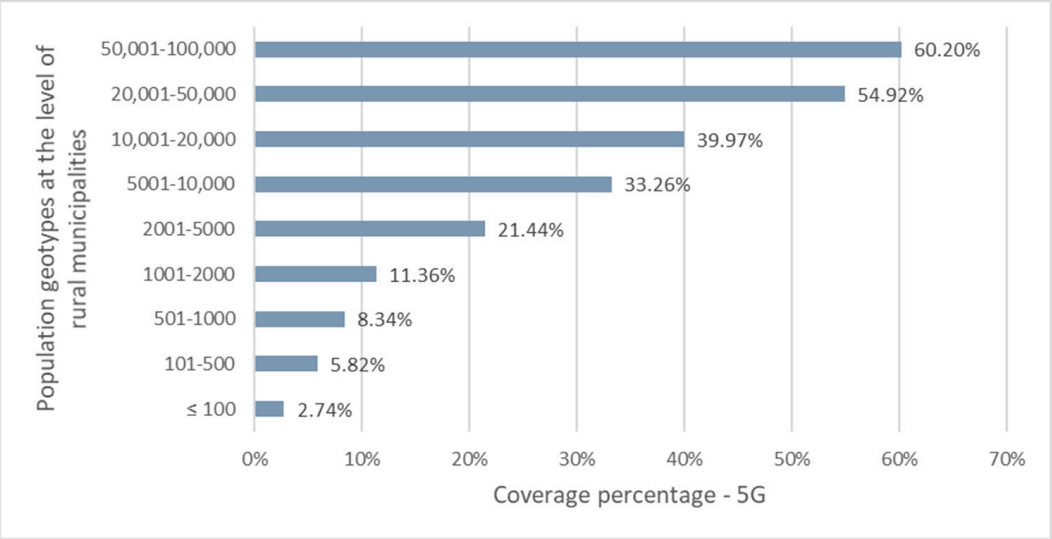


Figure 6. Aggregate 5G coverage (New Radio + Dynamic Spectrum Sharing) by population geotype (30 June 2021) [55].

However, the data infrastructure is also essential for the process of digitalization of agriculture. The data infrastructure is the system that enables and governs the collection, access, transfer, storage and analysis of data to produce knowledge and advice to stakeholders in the agricultural sector [56]. Currently, different architectures of central cloud and distributed cloud, collaborative computing strategies and new trends, such as data lakes and data houses for data storage and processing are being proposed for agricultural 4.0 applications. Data analysis has also been shown to be more efficient through artificial intelligence systems after placing it on cloud-based servers. However, an important prerequisite for the effective operation of cloud computing is a high-speed Internet connection. Therefore, telecommunications companies that can provide these services as close as possible to the users will play a key role in the digitalization process.

3.2. Technical Challenges

According to the McKinsey COTEC report [57], the agricultural sector in Spain has a technical automation potential of 57% (see Figure 7). However, while part of the territory is connecting to 5G networks, others are still waiting to enjoy the benefits of broadband, as we have discussed in the previous section. If the digital gap between rural and urban areas is not closed first in terms of coverage or connectivity to the telephone network and the Internet, everything that is wanted to be done in the field of digitalization and data processing will be up in the air. The Spain Digital Agenda has set the goal that 100% of the population has 100 Mbps coverage in 2025 [58].

In addition to improving connectivity, the use of technology and the service in rural areas mentioned above, it is also necessary to improve the compatibility of the data and the flow thereof to facilitate interoperability.

Clusters 4 and 6 of the Horizon European Programme envisage different data coming from farmers, livestock holders, and other agents related to the food production industries, such as transport, IT-based companies, machinery manufacturing/service companies, public administration, universities and research centers, etc., as well as different digital technologies such as remote sensing, IoT, Artificial Intelligence, robotics, block-chain and cloud and edge computing [59].

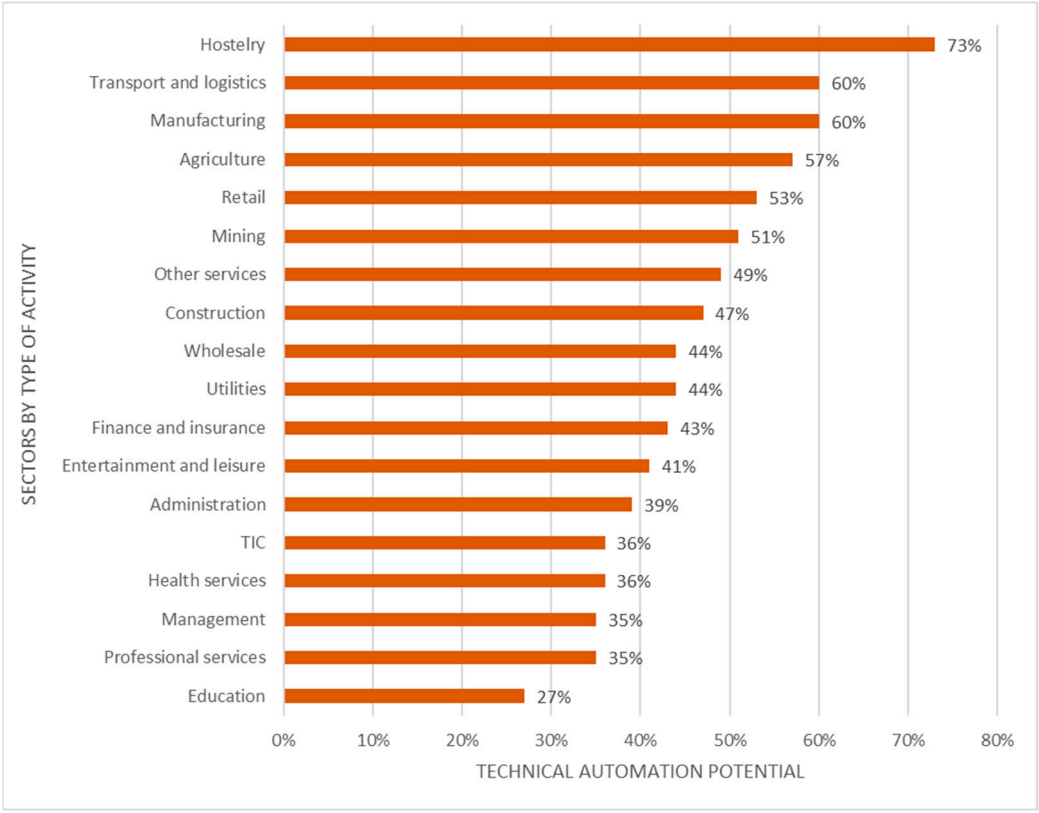


Figure 7. Technical automation potential by type of activity (2017) [57].

Therefore, from a technical point of view, it would be advantageous to use the same language and ontology in the stream of data. In case of having a platform to share the data, the best service and product provided could attract the consumer in a free and dynamic market. Hence, in the free market, small and medium-sized companies can develop through access to the same platform and through the same platform, search for possible technology for their businesses. Therefore, the compatibility and interoperability of the data will give the possibility of a better incorporation of technology and advanced solutions to small and medium farmers and producers [47].

Risks in Technology Development

From a general agricultural point of view, with the use of data and with the advances in the digitalization process, there will be a risk of losing the independence of operations between the agents of the value chain. Therefore, this could reduce the reliability of the data by being vulnerable to possible manipulations, and lead to asymmetric information, democratization and the loss of the possibility of using the full capacity of the farm with the digital standards [30]. Farmers' reliance on data providers and the risks of cyberattacks, in turn, could lead to data being used illegally, forcing farmers to practice growing crops that are not in their interest. The other possibility will be small farmers' dependence on service providers and loss of their sustainability and independence, inequity and inequality in access to technology or access to data among farmers [10,18]. The additional reliance on self-employed workers and small business owners will lead to farmers losing control over vital decision-making processes. Digital inequality can lead to associative interventions and make it difficult for vulnerable subgroups (such as refugees or immigrants) to access data and market opportunities, leading to the potential for negative consequences such as exploitation, surveillance, algorithmic bias, etc. [11,60].

However, the diversification of the technology in use and the low level of standardization and compatibility of software (for example, to share information) can considerably hinder the digitalization of agriculture among rural areas [47].

The adaptability of the technology can be a great problem, and in some cases, it will not be possible to integrate the devices of the different brands. Thus, farmers will have to decide initially which brand they should invest in to buy. Therefore, a kind of independent consultancy service would also be required to help farmers to make such decisions [31,45].

3.3. Legal Challenges

The digitalization of agriculture makes it necessary to develop a balanced regulatory framework that allows the takeoff of the use of new technologies and digital services in an inclusive way [11,41]. At the same time, this regulatory framework must avoid situations of dominance or abuse of a dominant market position by a few operators.

However, the negotiation of contracts is necessary for the successful development of agro-digital services and products. Users of these products must be able to identify who will be responsible in case of non-compliance and the duties of each party. In addition, it is necessary to guarantee the reliability of the digital tools through adequate certifications and periodic audits. This type of contract also offers a greater guarantee and more incentive to investors.

Data privacy and security is also vital. Digital agriculture by nature requires high-speed and high-volume data exchange. Therefore, attention to digital rights, data privacy, data protection, intellectual property, data preservation and storage are of great importance [60] since the extensive use of data will put the farmers' privacy at risk [47]. The EU agricultural sector has predicted that the level of participation can lead to power imbalances and considers digital rights in line with fundamental rights [41,42].

Agricultural data are diverse and include different parameters. Applications can deal with animal data, terrain data, weather data, machinery data, and financial data. Much of this information is private data of companies and individuals and the website's acceptance of cookies has the potential for breach of trust of companies' private data. Therefore, due to the immaterial nature of the data, it is difficult to control what part of the data are private, what data are shared, and what use has been made of the shared data. In this sense, the farmer has no control over the data share after the data leaves the farm gates, which should be considered prior to the data exchange. Loss of personal data can lead to data breach notification obligations under data protection laws and endanger businesses from a confidentiality standpoint. In any case, a digitized agriculture needs adequate safeguards for their data sets, which must be treated as a real asset by every agribusiness company.

From a business point of view, it is important to consider how data ownership can be protected. Intellectual property law protects the exclusive rights over intangible assets and regulates the granting of the right of use and license to third parties. However, the data itself cannot be protected yet. That is why it is very important to include intellectual protection clauses in contracts related to new agricultural services or technologies.

In July 2018, the law on integrated farm statistics and repealing regulations of interchange of agricultural data (EU 2018/1091) was ratified by the European Parliament. The law is applied to the different actors in the value chain to put light on the relationship between the different partners and the contractual normative between them [30,48].

The data in question mentioned in EU 2018/1091 are mainly related to non-personal data. Therefore, the aim is to assist in the use and sharing of data in the agricultural industry. The body sharing the data must be assured that it will be processed securely to prevent misappropriation, alienation, and information asymmetry [41,42,48].

In Spain, the Ministry of Agriculture, Fisheries and Food, in its Strategy for the Digitalization of the Agri-Food and Forestry Sector and Rural Areas, indicates that it will support the self-regulation initiative of the sector for the use and valorization of data [53]. This initiative will consist of the establishment of a Code of Conduct for the exchange and use of agri-food data for the different agents in the chain (agricultural organizations, cooperatives, agri-food industries, input suppliers, agricultural machinery companies, technological companies and other agents in the chain). In this way, the different agents will be able to sign their own code of good practices for the use of agricultural data or

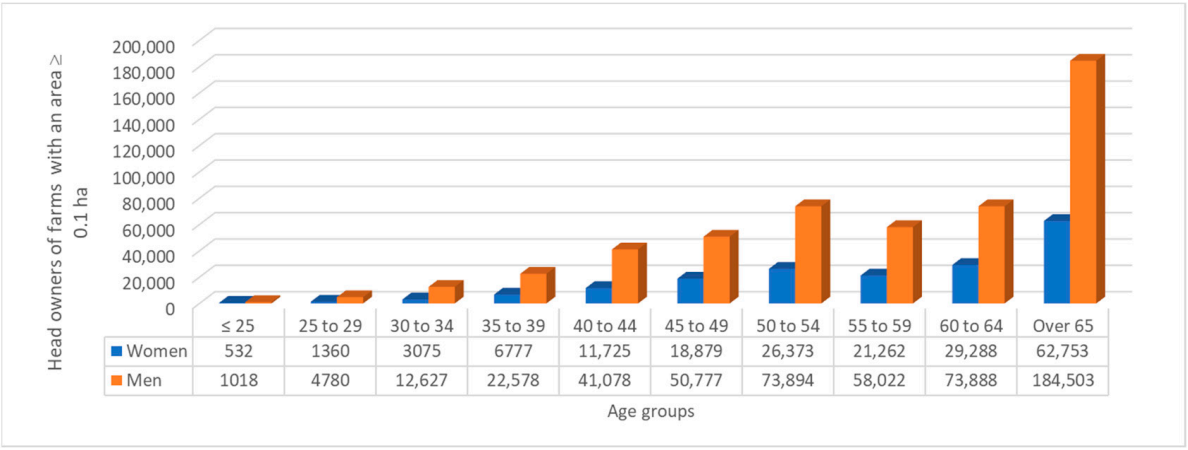
promote adherence to the code recently adopted at the European level by Copa-Cogeca, CEMA and other operators [61] (For more information, see Appendix A).

3.4. Social Challenges

According to the literature, three requirements are considered for the promotion of digitalization: Internet access, digital literacy, culture and attitude towards digital agribusiness [21].

There is a risk of depopulation of rural areas due to the lack of investment in the service and infrastructure. The studies in [62] show that half of the Spanish municipalities are threatened by the loss of inhabitants and the immigration of the young talents. Migration from rural areas also increases social inequality and generates negative impacts on the risk of entry and entrepreneurship of new players and small farmers in the region, leading to low progress and productivity of the region's market [6,20].

However, the lack of knowledge and skills (digital literacy) and the low ability to define and solve problems are identified in [39] as the main patterns of inequality in digital agriculture. The lack of digital literacy can have a severe impact on the Spanish agricultural sector if mitigation measures are not taken in advance. On the other hand, it can also increase gender inequality [22], since women in Spain traditionally have less presence in the digital domain and in the agricultural sector [21,63]. Figure 8 shows the distribution of head owners of farms with an area greater than or equal to 0.1 ha, according to age groups and sex in Spain in 2016. Usually, head owners of farms are the ones who make daily decisions on productive, financial and organizational management. Therefore, the gender data describe an unbalanced scenario, where 74% of farm decision makers are men and 26% women. This can lead to lower income in certain vulnerable subgroups, despite the fact that the digitalization process aims to reduce discrimination and bias in Spanish society [12]. There are many recent movements in Spain to encourage the application of ICT among subgroups that have traditionally had less access. The authors in [64] mention rural women's associations in Galicia to increase digital literacy through educational and recreational activities. They also provide training for the use of social networks and other new technologies to harmonize work and family. According to the authors, the main focus of women in the region is on agricultural and livestock activities and the activities of the association have also impacted the older ones.



	≤ 25	25 to 29	30 to 34	35 to 39	40 to 44	45 to 49	50 to 54	55 to 59	60 to 64	Over 65
Women	532	1360	3075	6777	11,725	18,879	26,373	21,262	29,288	62,753
Men	1018	4780	12,627	22,578	41,078	50,777	73,894	58,022	73,888	184,503

Figure 8. Distribution of head owners of farms with an area greater than or equal to 0.1 ha, according to age groups and sex in Spain (2016) [63].

Together with the digitalization of agri-food, an improvement in the qualification and skills of workers is expected as they use the new machinery and technological equipment. Therefore, the educational challenge in the digitalization era will be key to satisfying the labor market demand in agri-food occupations, and in turn will contribute to reducing the existing inequality gaps [8,18,52,65].

The other challenge for the digitalization of the agri-food sector in Spain is the correlation between age and digital skills. In Spain, the majority of active farmers are older than the average European farmer. According to published data [16], only 4% of the population in agriculture is under 35 years of age (this compares to 7% in Germany and 8% in France), and 31% of the population in the agricultural sector is over 65 years of age (compared to 8% in Germany and 15% in France), as shown in Figure 9 [16]. Furthermore, if we consider the distribution by sex and age, the percentage of women under 35 years of age in the agricultural sector represents only 0.7% (see Figure 8). Therefore, overcoming educational challenges not only requires training in digital skills, but also needs further associated intervention to try to address inequalities and make agricultural activity more attractive and accessible for youth and women [1,3,9–11].

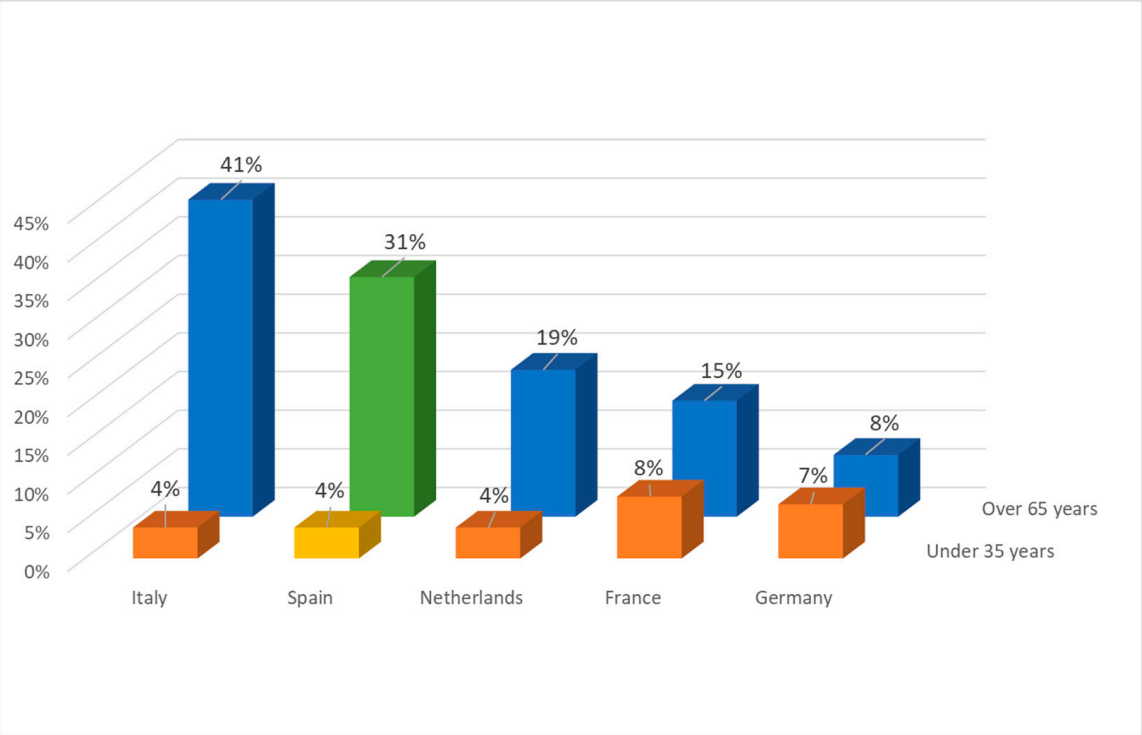


Figure 9. Distribution of farms by age range of the owners in European countries with relevant agricultural activity (2016) [16].

In addition, the type of Internet use largely corresponds to the level of education. Therefore, the group with the highest level of education uses the Internet for more advanced applications, such as financial services, while the group with the lowest level of education uses it for simpler visualization applications [66]. With the incorporation of younger and more qualified people, advances in the development of more innovative platforms and in the digitalization process will be facilitated, and the resilience index in rural areas will also be improved [20].

3.5. Market Challenges

Given the complexity of the ecosystem that supports digital agriculture, the collaboration of the different operators of the agricultural value chain, food industry, administration, regulatory body, economic agents and social activists, is required to integrate the entire market system. Taking into account the different forms of collaboration between the agents of the value chain, we can identify challenges both in the horizontal framework and in the vertical framework.

Horizontal framework: Farmers collaborate horizontally in the production phase and collect data for the development of their activities, data that they later combine with

knowledge and experience to make the best decisions. Data may include soil samples, fertilizer characteristics, plant parameters, frequency and amount of irrigation, and crop yield [47]. Market data, entry prices and logistics data can also be included in the data exchange framework. Therefore, the modality, volume and quality of data can be a barrier when it comes to transferring, integrating, and sharing the digital flow of information to generate applications based on agronomic macro-data.

Vertical framework: However, farmers are collaborating with the other agents in the value chain of the agricultural sector vertically to provide services and goods to consumers. Vertical collaboration requires data sharing, data processing, data management, data annotation and digital warehouse management to improve productivity [47]. The vertical collaboration framework includes the collaboration of people active in the agri-food sector with market players, such as food processors, retailers, CPG companies, certifiers, IT-based start-ups, research institutes, and software developers [59]. Therefore, a major challenge is to ensure that the exchange of data among the agents of the value chain generates an added value that is distributed equitably among all of them. Therefore, to reach a point of equality and symmetrical dissemination of information in the value chain and avoid surveillance, discrimination and bias [11,26], appropriate laws and regulations are required. The adjustment of the regulations will allow small and medium farmers to maintain their independence in the value chain and the consequent socio-economic impacts [10].

With the appearance of new collaboration methods, and in particular, after the involvement of technology companies such as Microsoft and IBM in the agri-food value chain, it seems absolutely necessary to develop new business models that take into account new players and roles [29,51]. It can shape the accelerated speed of technology adoption and form new alliances between the actors involved in the value chain. It is worth remembering that, even if most farmers have the digital literacy to clearly articulate demand, the risk margin for self-employed and small businesses is narrow. Therefore, only if they see an immediate profit and short-term return from technology adoption, then they will invest in it [21,29].

3.6. Financial Challenges

The dilemma of digitalization in agriculture has been accentuated in the period of the coronavirus pandemic, in which most of the self-employed and small and medium-sized companies have found themselves in difficult financial conditions. The reports show that, in the pandemic period, the reduction in financial resources would have had a negative impact on business activity and as a result of the widening of the income gap during the economic crisis, the self-employed and small entrepreneurs would not have been interested in investing in the digitalization process [20,51]. Therefore, according to the surveys, the acquisition costs of the machinery, equipment and applications have been the main obstacle, and then, the contracting of the specialized service provider has been the second obstacle in the digitalization process [45]. Thus, the Government of Spain has announced a line of credit in July 2021 to promote digitalization in the agri-food sector, within the strategic action plan for the period 2021–2023 [53]. Such government support could generate new opportunities for entrepreneurial activities in Spain, especially for young people, considering that the socio-economic factors of digital skills in the Spanish population are highly correlated with age and educational level [67].

3.7. Economic Challenges

In the economic field, there is a legal conflict over the ownership and profitability of the data. The dominance of a subgroup over the data and having priority (dominance) of access to the hardware and digital infrastructure will lead to the challenge in the distribution of the benefits of digital technologies [39]. This problem can be solved by establishing laws and regulations that make it easier to establish who has the right to exploit the data, how it should be exploited and how the benefits of its exploitation should be shared. However, information asymmetry has always been a problem in the market. As inequality is consid-

ered a legacy in the information age [2,7,43], operating models and new business models need to be developed to increase traceability of data usage [29]. By trying to implement proper regulations and offering a wide range of funding and motivational investment to support farmers, the return on investments (time and energy) for digitalization and the veracity of feasibility plans for data utilization are the main issues of concern for farmers. It should always be clear how the data should be used and by whom, the ownership and profitability of the data should be clear, and how much the farmers' share will be in the benefits obtained as a result of the use of the data. The answer to the above questions will solve the economic challenges and the impact on technology adoption [21].

4. Opportunities for the Future

The digitalization of agriculture will mean the transformation of the existing ecosystem and will lead to the creation of new companies and technology-based start-ups. The farm-to-table strategy launched in 2020 by the European Union foresees the use of digital technology to improve business operations, innovation in the business model and new interaction channels for value chain agents with the aim of achieving a comprehensive transition towards the sustainability of the agri-food sector in Europe [29]. The new collaboration schemes could supply the technological service in response to the demand of the primary activities of the sector. However, by transforming activities and actors, the digitalization of agriculture will also drive social changes that must be evaluated. Next, we will study the benefits and new opportunities that the digitalization of agriculture can bring according to the socio-economic conditions of Spain.

4.1. Social Opportunities

The digitalization process of agriculture can impact various aspects of life in rural areas, improving work-life balance [6] and lifestyle [6,68], reducing mental stress and musculoskeletal disorders [65,69], and reducing environmental and climatic impacts [42,70]. The creation of quality employment in the agri-food sector, together with the development of new business models through digital technology, are key factors in making rural areas more attractive places to live and work. On the other hand, solving the challenge of education, in addition to the direct impact on the digitalization of agri-food, will have an indirect impact on the day-to-day of the active people in the sector and will provide a higher index of sustainability. With the deployment of high-speed Internet in all rural areas, there will also be higher levels of digital interaction, which in turn will provide better access to education, public services and the labor market [10,21,71]. Hence, connectivity and the ability to use digital technologies will be essential elements of sustainable development and the reduction of inequality [22,42].

4.2. Open Innovation System

New players in the process of digitizing agriculture can bring new business models for marketing, as well as new ideas for seeking financing and incubating start-ups. Start-ups will be more interested in young entrepreneurial graduates and young talent generated at universities [21,29]. Therefore, the digitalization of agriculture has the capacity to revolutionize the structure of the market and also the nature of work. With the redefinition of the functions of farmers and the modification of the digital spirit in the agricultural sector, the sense of work on how and where the agents of the value chain can work will be changed. Therefore, the development of agriculture and the definition of agricultural business in rural areas will undergo a revolution in the near future [29].

4.3. Reaching the Sustainable Development Goals

The United Nations defined, in 2015, a roadmap towards equity and sustainable development with a horizon set at 2030 [72]. These are the so-called Sustainable Development Goals (SDGs). Digitalization is presented as a key process to achieve a more sustainable agriculture and to strategically address the challenges associated with the SDGs. Digital-

ization can help improve real-time monitoring of crops, providing early detection of pest infestations and disease outbreaks. It can also help to optimize yields and resources, and to obtain higher quality and healthier products. With the adoption of digital technologies across the broader spectrum of the economy, greater participation in the economy and labor market by women, the youth generation, and vulnerable social groups can also be achieved. In this way, the country will move towards greater equity and accelerate the achievement of the ambitions of the SDGs [22].

4.4. Higher Health Conditions

Working in the agriculture sector is known to be a physically and mentally demanding job. Farmers may be exposed to infectious material, vibrations and noise, pesticides and other chemical substances, high or low temperatures, painful postures, and repetitive hand or arm movements. In addition, work intensity, long working hours, isolation or financial uncertainty are some of the psychosocial factors that can affect the physical and mental health of farmers in rural areas of Spain [73–75]. The adoption of digital agriculture can help reduce farmer fatigue, as well as the risk of injury [76]. It also has the potential to provide better work-life balance [18,46,52] and improve family conditions, reducing stress and associated psychological problems. All this will have a positive impact on health conditions in Spain in a general panorama [6,17,66].

4.5. Territorial Resilience

In the sustainable rural economy, the percentage of young people, the percentage of the aged population and the number of business and professional activities in the agri-food sector weighted by population are the key indicators of territorial resilience. The resilience index is positively correlated with the percentage of young people and the number of business and professional activities in agri-food, while it is negatively correlated with the percentage of the aged population. The presence of young people will promote generational renewal, a greater ability to adapt to change, as well as greater openness to innovation and technological incorporation. Studies also show that, in the context of economic crisis, agriculture and the agri-food sector play an essential role in sustaining rural economies [9,20]. Therefore, the digitalization of agriculture must be one of the elements to be considered in the processes of change and territorial resilience. With the financial packages announced by the Spanish government to support digitalization and the strategic plan for the development of rural areas, a greater presence of young people and an increase in agricultural activities are expected, which will impact territorial resilience and sustainable rural development [18,66].

4.6. Environment Protection

The use of technology for the fusion of data and information will impact the decisions of farmers for better planning of the production process. It will also facilitate the notification of the health status of the animals and will integrate, in real time, other data of interest such as information on the atmosphere, soil data, fertilizers. The software will facilitate the integration of global information, so that the data can be used safely and accurately. Therefore, it is important that the software that is developed is compatible with the data system available in the different countries. These advances represent an opportunity to improve food security, animal safety, environmental protection and reduce the effects of climate change [42].

Digital technologies will also enable better utilization of available resources. Thus, for example, the use of drones and autonomous robots will allow for a more precise mapping and control of water and the application of nutrients. In addition, from the point of view of the use of fuels, the deployment of robotic systems that comply with the policies of respect for the environment and climate change mitigation will be promoted. In addition, robots and drones can play a very important role in reducing the use of fertilizers in the

cultivation of products and in the use of pesticides for the elimination of weeds, which will have a significant impact on the protection of the environment [77].

4.7. Food Security

Recent technological advances highlight the potential of digital technologies to play a critical role in food security. Thus, for example, various smart platforms have been developed to assess the sleep, temperature and feeding patterns of cattle to estimate their health status. With this type of intelligent platform, it will be possible to prevent diseases and infections among animals. These technological methods reduce the possibility of errors by human agents and raise the level of safety in food protection [16].

Similar technology has also been developed to detect contamination of fruits and vegetables easily and quickly. The method works on the analysis of the data taken by the farmers. In addition, the data can be used to inform the consumer about the origin of the product or for the detection and elimination of low-quality fruits. It will also help in the protection against diseases, it will facilitate the distribution processes and it will guarantee the quality of organic fruits [16]. Therefore, the digitalization of the agriculture could open up new opportunities for gathering, integrating and analyzing data to predict, assess and manage food safety risks.

However, digital traceability and certification technologies will allow agro-industries to document and guarantee farm compliance with quality, environmental and social commitment standards, tracking products from the point of origin to the consumer. These digital tools will also provide information on how agricultural products flow through value chains.

4.8. Improved Market Access

Digitalization of agriculture can facilitate market connections between different actors in the value chain, such as small farmers, cooperatives, producers and distributors of agricultural inputs, service providers, processors, buyers and traders of agricultural products, as well as national wholesalers and international exporters. It can also make it easier for farmers to share information, leading to more transparency about market locations and prices. Thus, digitalization can help increase consumer confidence, improve transparency, and reduce costs, time to market, and lost revenue due to a lack of accurate and timely market information, all of which translates in better market access conditions for farmers [78].

4.9. Production Model Transformation

One of the lessons that the humanitarian crisis caused by the coronavirus has left us is that the most digitized countries, companies and societies have been able to react better and faster to these eventualities.

In this context, the Spanish economy will not recover to pre-crisis levels until at least mid-2023, according to various estimates [79,80]. Therefore, reindustrializing the country's agricultural sector could contribute to increasing the weight and relevance of an economic sector that is less volatile and dependent on tourism, and would also guarantee the local supply of essential goods and services in critical situations.

The applications that may have greater market penetration, and therefore could contribute more effectively to the transformation of the production model would include precision irrigation, field monitoring, precision spraying, weed removal, precision fertilizer, precision planting, precision harvesting and data management. Edge and cloud computing, IoT, robotics, artificial intelligence and augmented reality are among the most promising enabling technologies to drive the required transformation.

IoT technologies allow monitoring in real time, if necessary, all the parameters involved in production: use of resources, state of plant growth, behavior of animals, soil fertility, appearance of pests and diseases. The combination of sensorized data with agronomic models allows optimal actions to be carried out throughout the entire production process,

thanks to decision-making algorithms. This translates into higher levels of automation, reducing the use of inputs and increasing productivity in a sustainable way [81,82].

However, the most recent advances in robotics, artificial vision and artificial intelligence are enabling the automation of tasks that until very recently were reserved for human operators due to their difficulty or the need for very high precision. Today there are mobile robots that automate the processes of plowing, planting, weeding, fertilizer application and harvesting, while generating a huge amount of data that can later be analyzed and integrated into decision-making, not only about the production process, but also for maintenance machinery prediction. There is also great expectation for the development of agricultural robot prototypes, capable of accurately harvesting high-value crops, analyzing the state of the crops in real time and harvesting only those products with the optimum degree of maturity [83].

Therefore, it is very important to foster collaboration between research centers, digital innovation hubs, startups, technology companies, and companies in the sector. The collaboration between all these actors will improve the flow of knowledge and innovation, and will reduce the fragmentation of results and the lack of advice, which will contribute to advancing in the transformation of the production model [53].

5. Discussion

Table 1 summarizes the key topics considered to identify the challenges and opportunities for the digitalization of agriculture in Spain, presented in Sections 2 and 3, respectively, as well as the sources used in this study.

Table 1. Key topics considered in this study.

Key Topics Studied	References
Impact of COVID-19	[1,3–5,10,46,66]
Digital inequalities	[2,8,10,18,19,32,33,39,43,68,71]
Health and welfare	[5–7,40,43,66,67,69,73–76]
Gender issues	[6,21,22,35,52,63,64,67]
Education	[8,9,14,52]
Urban-rural gaps	[11,18,20,28,34,62]
Social inequality	[12,14,15,17,18,20,34,38,40,46,51,62,66]
Economic and financial aspects	[27,51,65,70,79,80]
Sustainable development goals	[72]
Regulation and legal aspects	[12,18,41,44,47,48,56,59–61]
Digitalization	[37,49,50,57,58,65]
Digital infrastructure	[19,36,54,55]
Key technology enablers	[30,31,45,47,59,76,77,81,83,84]
Agriculture digitalization	[16,23–26,29,42,45,47,53,54,59,78,82,85]
Data sharing	[60,61]

After identifying and analyzing the main challenges and opportunities for the digitalization of agriculture in Spain, summarized in Figure 10, a series of insights are provided below to take into account during the implementation process.

- Digital agriculture has the potential to generate significant socio-economic changes. In Spain, digitalization is expected to help create new jobs, boost the innovation ecosystem, and reduce social barriers to hiring, especially those related to gender and age inequality.
- Thanks to digitalization, the increase in technology and innovations in the agricultural sector can represent an opportunity to attract young and educated workers, as well as facilitate greater participation of women in the activity. The presence of young people,

in turn, will promote generational renewal, a greater ability to adapt to change, as well as greater openness to innovation and technological incorporation.

- The complete digital transformation of the agri-food sector is conditioned by the internet connection of the different devices that are involved throughout the entire information transfer process. Therefore, it is essential to first close the existing digital gap between rural and urban areas in terms of network coverage or connectivity in order to materialize the transformation of the agricultural sector.
- Once connectivity is assured, key technologies will come into play to carry out a first upward process from the physical to the digital. Robotics, AI, IoT, edge computing, cloud computing, and blockchain have been initially identified as key technology enablers for the digitalization of agriculture and the agri-food sector [84]. These technologies provide a framework not only for creating new ideas, giving rise to new high-quality products, and finding new ways of doing business, but are also expected to have a major impact on the efficiency and functioning of food and agricultural systems [85].
- With the increase in the level of support through motivational packages from the Government of Spain, the creation of agro-technological ecosystems that attract private investment, and the coordination of all the agents involved in this digital transformation, the Spanish agri-food sector will be able to continue being in the lead in terms of productivity, competitiveness, profitability and sustainability at the European and global level.
- In order to use the full potential of digitalization in the agri-food sector, governments must provide the trusted environment to put protective laws and regulations in place. The design and management of digitalization programs require a high level of administrative capacity. In addition, digitalization must become the political priority. Therefore, they should support investors in the digitalization of agriculture towards the establishment of new companies and start-ups with the capacity to recruit the young and talented generation.
- Agricultural policies have the challenging task of ensuring that digitalization occurs in an ethical, equitable and inclusive manner. New codes of ethics are needed to protect farmers' rights to their own data and prevent concentration of power with technology providers.
- The development of business models designed especially for self-employed and small and medium-sized farmers, and the creation of new types of activities, scaling up the size of the market, will facilitate the entry of new players and the young generation into the domain of digital agriculture. The interested reader is referred to [86,87] for more study on the business models design.
- Research centers play a fundamental role in the design and implementation of new solutions. For this reason, collaboration between research centers, digital innovation hubs, startups and technology companies should be encouraged, with the aim of improving the flow of knowledge and innovation and reducing the fragmentation of results and the lack of advice. All of this will contribute to advancing in the transformation of the production model.
- The indices of sustainable development and resilience have a direct correlation with the entrepreneurial culture of the country and the educational level of the society. Therefore, the favorable conditions of agriculture development, future climate change and future socio-economic development should be taken into consideration for the country's budget planning to ensure the success of the digitalization process and the equality of all.
- The mistake of overestimating or underestimating the challenges and opportunities of agricultural digitalization can lead to wrong decisions that could be difficult to correct.

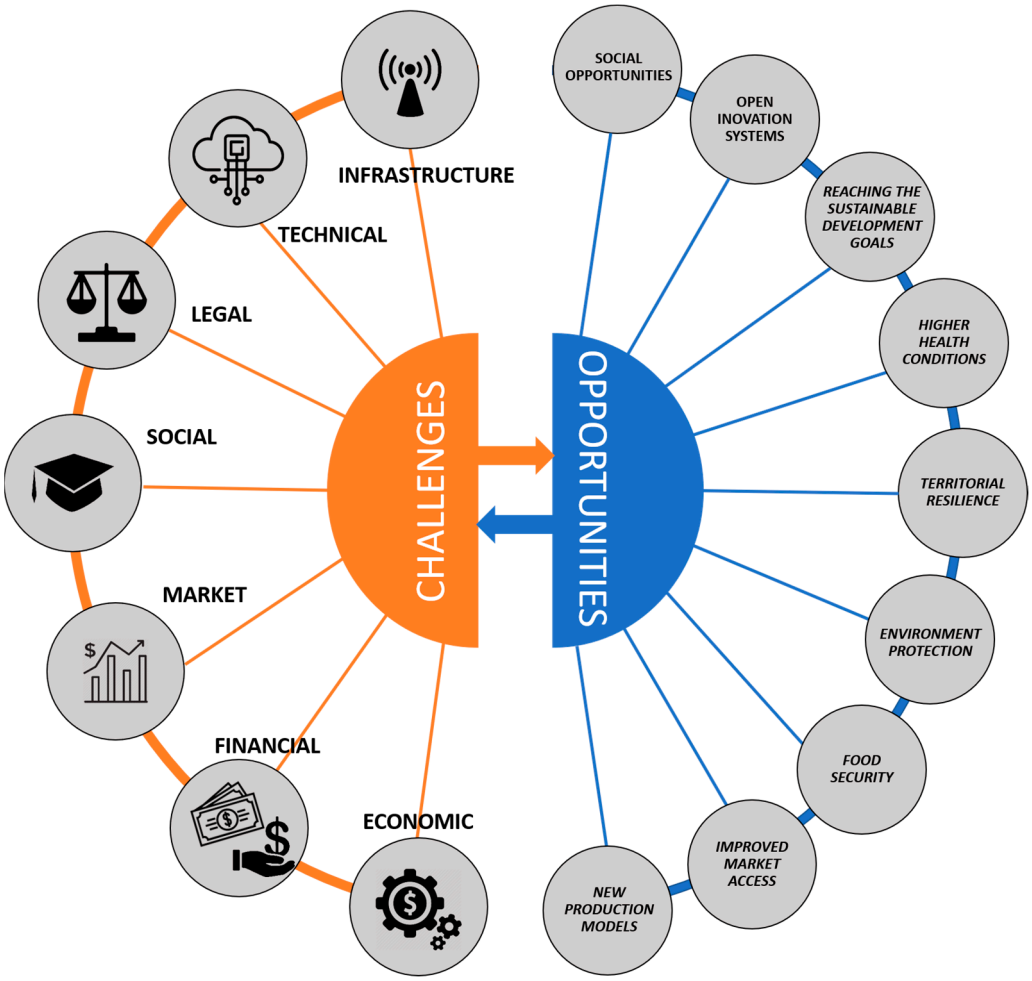


Figure 10. Challenges and opportunities of Spanish agriculture digitalization.

6. Conclusions

In the last decade, the agri-food sector has begun a transformation process, generating and introducing innovations in order to satisfy the growing demand for food of a population that continues to increase. With the outbreak of the COVID-19 pandemic in 2020 [88], a change in production models was precipitated and the digitalization process that was underway accelerated. The future of the economy, in general, goes through digitalization, and in the case of agriculture, it is configured as a key action to be able to respond to the environmental challenges of adaptation to climate change, food security, depopulation of rural areas, consumer demands in a globalized market, and the challenge of guaranteeing the competitiveness of the actors involved throughout the entire chain. Given the weight that the agricultural sector has in the Spanish economy and the importance that Spain has in the supply of food and agricultural products to Europe, it is essential that the main agents are able to understand how this process will affect them and what challenges and opportunities lie ahead. In this way, they will be able to face the process with a greater chance of success. Therefore, this article has focused on the Spanish socio-economic conditions and has explored the legal, technical, infrastructure, educational, financial and market challenges related to the digitalization of agriculture in Spain. In addition, it has identified the opportunities that this digitalization process can bring to the sector and its workers, such as improved access to markets, the achievement of sustainable development goals, the promise of better education and health care systems in rural areas, as well as greater territorial resilience, environmental protection, food security and openness to innovation. The expected impacts of agricultural digitalization in reducing socioeconomic inequalities have also been addressed. Finally, the article has provided some insights

to take into account so that actions that favor adaptation to this intense process can be correctly implemented.

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Appendix A

- The reader interested in the Statistics of agriculture in Spain is referred to the Monthly Bulletin of Statistics of the Ministry of Agriculture, Fisheries and Food of Spain.
- The reader interested in the Spanish law on integrated agricultural statistics and repealing regulations for the exchange of agricultural data is referred to the website of the Spanish Ministry of Agriculture, Fisheries and Food.

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