Agriculture 4.0 paradigm: a preliminary systematic literature review

Maffezzoli F.*, Ardolino M.*, Bacchetti A.*, Renga F., Pavesi M.*****

** Department of Mechanical and Industrial Engineering, University of Brescia, Via Branze, 38 25123 - Brescia – Italy (f.maffezzoli@unibs.it; marco.ardolino@unibs.it; andrea.bacchetti@unibs.it)*

*** Department of Management Engineering, Politecnico di Milano, Via Lambruschini 4B 20156 – Milan – Italy (filippo.renga@polimi.it)*

**** Osservatori Digital Innovation, Politecnico di Milano, Via Lambruschini 4B 20156 – Milan – Italy (maria.pavesi@osservatori.net)*

Abstract: In recent years Agriculture 4.0 is gaining attention in literature. But even with a strong scientific background there is a lack of contributions that aim to define the meaning of the paradigm and systematise its pillars. The paper we propose investigates the enabling technologies describing the paradigm, its domain of application, benefits, and challenges, presenting a systematic review of the literature. So, 93 papers have been analysed with the aim at characterizing the phenomenon of "Agriculture 4.0" by examining how the literature describe the convergence of digital agriculture and digital technologies. During the analysis of the chosen literature set, we identify a set of 10 main application domains of digital technologies in agriculture, 11 characterising enabling technologies, 6 main benefits and 7 obstacles related to agriculture 4.0. Indeed, from the review, it emerges that there are significant areas of the phenomenon that are still unexplored and/or not fully addressed; this calls for future researchers to expand the area of investigation into smart agriculture (regarding the technologies covered and the effect achievable from the combinatorial effect among them) and to develop models and frameworks to support policy and decision making related to the agriculture 4.0 paradigm.

Keywords: Agriculture 4.0; Smart Agriculture; 4.0 Technologies; SLR; IoT; Data Analytics

1. Introduction:

Agriculture is a fundamental part of all economies in the world, with this paper we aim to analyse the new paradigm of 'agriculture 4.0' or 'smart agriculture'.

In the next decades, the world will face some important issues that will have massive effects also on the agricultural sector. Three main challenges are on the horizon: (1) world population is expected to increase, it is estimated that the human population will reach 9 billion people by 2050, increasing by 70% the food demand and the water consumption in agriculture should increase by 41% (the sector is already responsible for consumption of almost 70% of the planet's fresh drinking water) (Sott *et al.*, 2020); (2) in the medium-term climate change is going to deeply affect the extension of arable land across the world (Sott *et al.*, 2020); (3) ageing population in the developed economies brings the necessity to automate and digitalize the sector.

The concept of agriculture 4.0 includes a series of different scientific fields, where some of them are directly connected to land cultivation (water control, crop growing, harvesting, etc.), while some other are the expansion of the agricultural perimeter toward different disciplines, such as engineering, economics, management, etc. Advances in different areas of the Information and Communication Technologies (ICT) domain in combination with the need for improvement of agriculture productivity, both for food security issues and environmental impact, have created the field of smart agriculture. Therefore, it is possible to say that Agriculture 4.0 derives from the broader concept of Industry 4.0 (Lezoche et al, 2020), which aims to define the integration of different technologies (such as IoT, Artificial Intelligence and Cloud Computing, etc.) to automate cyber-physical tasks and processes, allowing better planning and control of agricultural systems. The relationship of this concept with that of Industry 4.0 paradigm, i.e., the adoption of digital technologies to support the processes of manufacturing companies, is clearly evident.

Although in literature, the reduction of input costs and the increase in productivity seems to be the driven force of this advance in agriculture, the importance of sustainability should not be neglected. Sustainability, as it is mentioned before, emerges as one of the major issues throughout the spectrum of human activity, thus one of the goals of smart agriculture is the minimization of the environmental impact of the agricultural activities (Lytos *et al.*, 2020).

The field that is considered as predecessor of smart farming is precision agriculture (Lytos *et al.*, 2020),Smart farming involves the digitalisation of agriculture, through the implementation of the so called "4.0" technologies (Lezoche *et al.*, 2020), while precision agriculture explicitly refers to the more efficient use of production inputs, minimising their use, for this reason the paradigm of precision agriculture is embedded within the broader theme of agriculture 4.0.

This paper addresses the paradigm of agriculture 4.0 and aims to collect evidence from literature, which is quite sparse and diverse in the various related research fields. Based on a systematic review, the paper aims to systematise the scientific knowledge of the phenomenon and set directions for future research. This Systematic Literature Review (SLR) covers many different open points of the paradigm, we address it in multiple dimensions (distinctive technologies, agricultural domains, benefits, and challenges), our approach, therefore, differs from previously conducted literature reviews that tended to focus solely on one topic (a single technology, mainly Internet of Things) at the interface between digitalization and agriculture, or even broader reviews such as the one of *M. Lezoche, J.E. Hernandez, M.d.M.E. Alemany Díaz, H. Panetto and J. Kacprzyk (2020)* that reviews the set of smart technologies.

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

2. Research methodology

2.1 Search strategy and Research Questions (RQs)

To identify the relevant evidence that also fits pre-specified eligible criteria, this systematic literature review was conducted according to a specific methodology.

Preferred reporting items for systematic reviews and meta-analysis (PRISMA) approach was chosen (Moher et al., 2015) because it entails an evidence-based checklist linked to a four-phase flow diagram and ensures clarity and transparency when reporting systematic literature reviews. Thanks to PRISMA method bias is limited, chance effects are reduced, and the legitimacy of the analysed data is enhanced. (Moher et al., 2015)

In the first phase, the literature was analysed, in order to identify the macro-gaps and drafting our research questions. It has been noticed that most of literature is technology focused on one single topic or technology, not entirely analysing all the aspects characterising agriculture 4.0. Therefore, the research team formulated the following three research questions (RQs):

RQ 1. What is agriculture 4.0 and how it is commonly defined?

RQ 2. Which are the main application domains, benefits, and challenges of agriculture 4.0?

RQ 3. Which are the enabling technologies of agriculture 4.0?

2.2 Data collection

In principle, in order to identify the body of literature regarding the paradigm of agriculture 4.0, a set of preliminary keywords was identified, with the aim of covering the whole set of synonyms deriving from the agriculture 4.0 concept. The keywords used are the following: *"Smart Agrifood, Smart Agriculture, Smart Farming, Agrifood 4.0, Agriculture 4.0, Farming 4.0, Internet of Farming, Digital Agrifood, Digital Agriculture, Digital Farming, Precision Agriculture, Precision Farming, Agriculture 4.0 Platform* and *Smart Agriculture Platform".*

To ensure quality of literature and extracting the whole set of relevant articles, Scopus search engine was used, which is widely acknowledged as a world-leading source that provides comprehensive coverage for this research field. (Sott *et al.*, 2020). It is also important to specify the search criteria used: keywords were searched within the titles, abstracts, and paper keywords, in order to ensure total coverage of the sample. A database of 1259 studies was therefore retrieved.

At this stage, our objective was to identify the publications and apply practical screening. In this systematic literature review, only journal publications were included, while conference papers, books, company reports, etc., were excluded (12 papers excluded). In this way, it was ensured that only peer-reviewed articles were considered. In addition, only English-language papers were chosen (24 papers excluded) for analysis and included only studies at "final" publication stage, excluding 61 papers.

Two other important objective filters have been applied. Firstly, the time span of analysis starts from 2012 (30 papers excluded), this has been done for two reasons, the first concerns the fact that in this way the dated papers are isolated and the second, more technical, to exclude "false positives" regarding the 4.0 paradigm, since this concept is identified for the first time in 2011 (Lezoche *et al.*, 2020). Then, 581 studies were rejected, because they were published in journals outside the subject area of engineering, business management, economics, and computer science.

In this way we identified the set of papers eligible for screening, at this stage, 196 studies were excluded because they belonged to journals with impact factor lower than 1, did not present DOI and finally was made a clearance of double articles. This procedure is usual for systematic reviews since this process acts as a quality control mechanism that confirms the knowledge provided (Light and Pillemer, 1984)

The remaining 355 articles were eligible for full text screening. In this final step of analysis, an additional 262 papers were considered to be out of scope. Specifically, 184 of these were focused on IT and technical issues, 22 did not deal with issues related to agriculture and 23 were excluded because they were considered not very relevant to issues associated with the 4.0 paradigm. In sum, based on the predefined criteria, we selected and analysed 93 papers to systemise the knowledge in this research field and to identify possible knowledge gaps and future directions.

2.3 Data synthesis and analysis

All articles were analysed both descriptively and thematically. In the descriptive analysis, a deductive approach was adopted, focusing on classifying the articles according to the year and journal of publication, the number of citations and the methodology applied. On the other hand, the thematic analysis was more inductive in nature and aimed at characterizing agriculture 4.0 paradigm. Specifically, as previously specified, we aim to (1) conceptualize smart agriculture by providing a more comprehensive definition, (2) understand its application domains, benefits, and challenges, and (3) identify which digital technologies define the adoption of smart agriculture practices.

2.4 Sample descriptive analysis

The 93 selected articles are analysed descriptively in this section for year of publication, number of citations per year, journal, type of study, and citations per journal in order to identify trends within this body of literature.

Figure 1 illustrates the time distribution of the papers and the number of citations per year. The sample was retrieved in December 2020; therefore 2021 numbers are incomplete. So, with the notable exception of *Banhazi M., Lehr H. et al.* (*2012*) and the two contribution of *Tang Y., Dananjayan S. et al.* and *Mohd Nizar N.M. and Jahanshiri E.* (*2021*), the papers analysed were all published between 2016 and 2020. In particular, a significant increase of literature streams emerged only from 2018 onwards. More specifically, 83 articles (i.e., 90% of the 93 scrutinised papers) were published between 2018 and 2020, pointing to an increased scholarly interest in the field of smart agriculture in recent years, both in terms of articles published and number of citations.

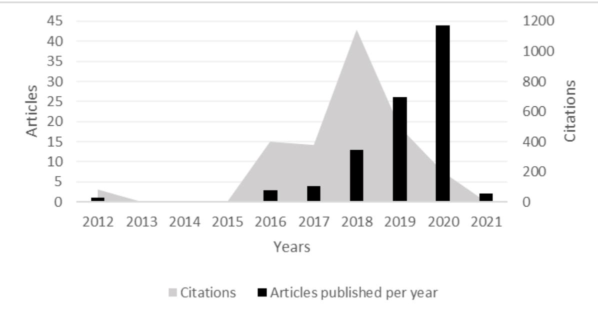

Figure 1: Publication volume and citations

To determine the knowledge stocks and flows among scholars, we analysed how the literature set was spread across different journals. Our 93 articles appeared in a total of 37 Journals. Out of these Journals, only 15 published two or more papers. It seems there is a high degree of fragmentation, with the exception of three Journals: *Sensors (Switzerland), Computers and Electronics in Agriculture* and *IEEE Access*. Publishing 14, 14 and 12 studies, respectively.

Indeed, the papers were classified according to the methodological approach as either 'theoretical' or 'empirical'. The theoretical papers were further divided into three subcategories: a) literature reviews, b) systematic literature reviews, and c) Concept research. Papers in the first category present a thorough review of the studies of a given topic; those in the second category show a defined methodology for their review of the literature for their given topic; while the articles published in the third category assume a specific position regarding the selected issue regarding how it is grounded in theory. We also used three sub-categories to further classify the empirical papers: a) case studies, which employ empirical research methods, b) surveys, which employ interviews to real enterprises, public institutions and experts, c) simulations, or other model-based analyses, and d) which represent agricultural projects demonstration.

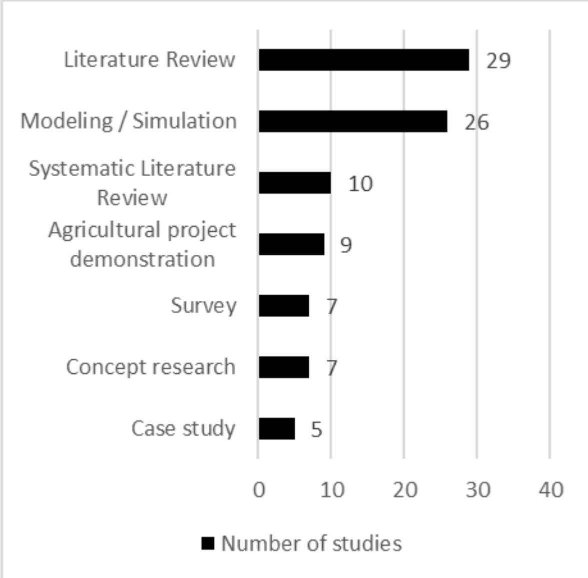

Figure 2: Categorisation of papers

In Figure 2, the above-mentioned categories are represented in a descending order. In terms of number of papers proposed it is possible to see a balance. 50.5% of the studies were classified as empirical and 49.5% classified as theoretical. From the empirical point of view modelling and simulation research is the most prevalent in the category (26 papers, 28%). The high number of papers categorized as modelling and simulation refers to technological aspects, where the focus is primarily on the technical viability of a given model and/or solution. This kind of aspect is clearly evident in some of the most representative articles of the sample, such as the study of *Partel V., Charan Kakarla S., Ampatzidis Y.* (*2019*) and *Kiani F., Seyyedabbasi A.* (*2018*).

On the other hand, there are 46 theoretical papers, which account for the other half of papers identified, the prevalent category is literature reviews (29 articles, 31%), followed by systematic literature reviews (9 papers, 10%). The high number of literature reviews and systematic literature reviews required a more in-depth analysis. From Figure 3 it can be noticed that the literature reviews are focused on giving a technological overview related to the 4.0 paradigm. It is also important to note that one paper aims to define the 4.0 paradigm in agriculture, it is the study of *M. Lezoche, J.E. Hernandez, M.d.M.E. Alemany Díaz et al.* published in 2020, which, as previously written, it is not a SLR and pays particular attention to the enabling technologies of the paradigm. For this reason, we believe that a paper like this one is needed, that not only performs a SLR, but that does it adopting a holistic approach, adopting a systemic vision that goes beyond tech-centric papers.

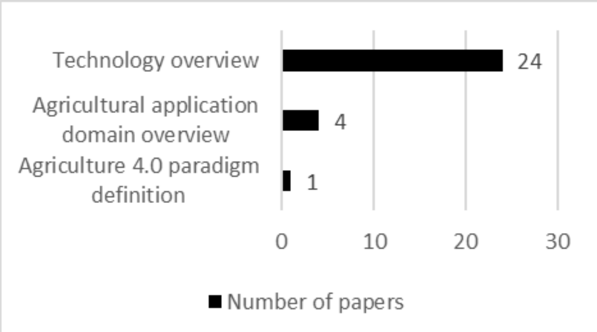

Figure 3: Literature reviews studies overview

3. Results

3.1 Conceptualization of agriculture 4.0 (RQ1)

Concepts and definitions are the starting point for all research. Comprehensively defining the concept of Agriculture 4.0 is one of the main goals of this paper (RQ 1), a common element across the concepts mentioned in table 1 is the pervasive role that technology will have in agriculture.

Table 1: Definitions of agriculture 4.0

Author(s)	Definition
(Munz, Gindele and Doluschitz, 2020)	""systems of systems", different systems communicate with each other. In addition, external data, such as weather data, soil data or breeding value estimates, are also included, and linked to the farm's data."
(Escamilla-García *et al.*, 2020)	"Agriculture 4.0 is the integration of technologies (IoT, PA, artificial intelligence (AI), cloud computing (CC), among others) through the cloud to automate cyber physical tasks and systems, allowing the planning and control of production."
(Monteleone *et al.*, 2020)	"Smart farming represents the use of smart, data-rich ICT-services and applications, in combination with advanced hardware (in tractors, greenhouses, etc.). Smart farming extends the precision agriculture concept since the existing tasks for management and decision-making based on data are enhanced by context, situation, and location awareness."
(Sott *et al.*, 2020)	"A4.0 refers to the technological adoption to create a value chain that integrates the organization, customers, and other stakeholders. In this sense, A4.0 refers to the use of information and communication technologies such as Big Data and Analytics and ML to explore the variability of data and use it to deal with changes in the agricultural scenario."

In analysing the papers mentioned in table 1 and the other contributions present in the literature set we found that the term agriculture 4.0 is associated with: 1) a change in the nature of agricultural processes that become digital and 'smart' 2) shifts in the farms business models from traditional to digital; 3) the development of new strategic capabilities and skills related to 4.0 technologies; 4) the centrality of data in the new paradigm, in the way those are extracted and analysed, interconnecting different systems and actors along the whole agricultural supply chain. So, it is possible to synthesize the various viewpoints, defining the Agriculture 4.0 paradigm as follows:

"Agriculture 4.0 is the evolution of Precision Farming, realized through the automated collection, integration and analysis of data coming from the field, equipment sensors and other third-party sources, enabled by the use of smart and digital technologies of Industry 4.0 (for details see (Zheng *et al.*, 2020)). In this way it makes possible the generation of knowledge, to support the farmer in the decision-making process and, therefore breaking the boundaries of the single farm enterprise. The new paradigm will require the evolution from a traditional system to a digital one, bringing with it the need for operators in the sector to develop a series of strategic skills related to 4.0 technologies. The final aim is to enhance cost reduction, profitability and environmental-social sustainability of agriculture." (adapted from: *Sponchioni G., Vezzoni M., Bacchetti A., Pavesi M. and Renga F.* of *2019*).

3.2 The main application domains, benefits, and challenges (RQ2)

Entering into the themes of agriculture 4.0 in this paragraph we have investigated and analysed the papers in order to find an answer to the second research question (RQ 2).

Within the literature reviewed, the main domains of application of the 4.0 paradigm in agriculture were identified. Ten different domains are identified: (1) product monitoring along the chain; (2) hydroponic and aquaponic; (3) autonomous vehicles and machinery navigation systems; (4) greenhouse cultivation; (5) livestock regulation and monitoring of growth and health status; (6) land and soil monitoring; (7) agrochemical and fertilizer management; (8) precision microclimatic prediction and monitoring; (9) crop management and monitoring (growth and health); (10) water management.

Specifically, four of the domains (7, 8, 9, 10) are addressed in most of the studies analysed (63%). In literature, particular emphasis is given to processes at farm-enterprise level, giving peculiar attention to issues that have a strong link with the field, while little emphasis is given to broader issues that take into account the entire supply chain.

This fact is reflected in the analysis of the benefits associated with agriculture 4.0. We identified six main benefits: (1) Cost reduction, mainly related to input reduction and process efficiency (this is the benefit found more often, in 59% of the articles in the analysed literature); (2) increase in farm productivity and therefore yield increase; (3) environmental benefits, also related to benefit 1 through input reduction; (4) increase in the quality of the product itself; (5) reduction in the time spent by farmers; and finally (6) the increase in social sustainability related to the use of 4.0 practices in agriculture.

Another key element of our research was to investigate what challenges smart farming is facing with. This topic receives a lot of attention in literature as both studies classified as empirical and theoretical address the issue.

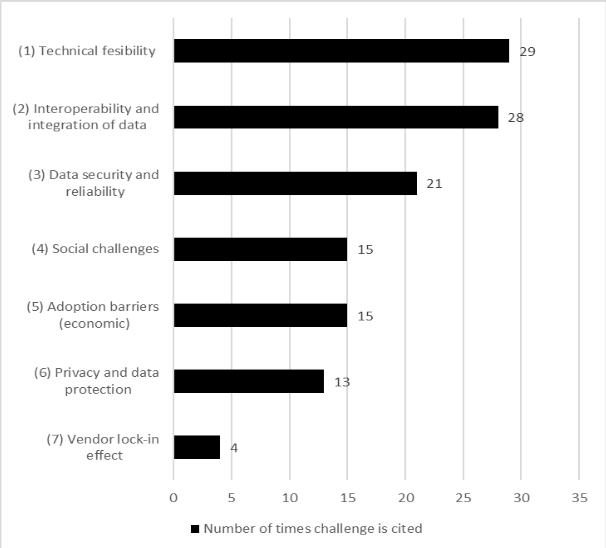

Figure 4: Challenges

In Figure 4 are represented, in a descending order, the challenges that agriculture 4.0 is facing: (1) Technical feasibility seems to be the main challenge faced to implement the solutions, still difficult to implement in large scale projects, the problems encountered regards the hardware in use (Farooq *et al.*, 2019) as well as the problem of connectivity due to the disconnected and inaccessible territory (Lezoche *et al.*, 2020) (Tang *et al.*, 2021). (2) Data integration and interoperability appear to be one of the biggest challenges to face, this peculiar category is linked to the concept of platform (that will be discussed in the next paragraph) and it is mainly to Internet of Things (IoT). Currently there is still lack of interoperable solutions within farm boundaries (Madushanki *et al.*, 2019), but even greater problem is faced from a supply chain point of view. (3) Data plays a central role in the paradigm, and with it also brings its own challenges, such as data security and reliability, due to difficulties related to dataset evaluation and analysis (Gupta *et al.*, 2020). (4) Social challenges cannot be neglected neither, it is true it can help farmers on one side (reduction of physical effort) but it can increase social divide (knowledge expertise on technologies) as well (Klerkx, 2020) (Monteleone *et al.*, 2020). (5) Economic barriers refer to the fact that digital solutions and 4.0 technologies require high investment that are a big hurdle for most of small farms (Long, Blok and Coninx, 2016). (6) The ability to transmit large amounts of data carries the challenge of privacy and data protection (Demestichas, Peppes and Alexakis, 2020). (7) Lastly, the lock-in effect is taken into account with regard to the supply of digital solutions, which, given the verticality of knowledge, could become the domain of a few large incumbents (Kamilaris, Kartakoullis and Prenafeta-Boldú, 2017).

3.3 Enabling technologies of agriculture 4.0 (RQ3)

The last thematic analysis covered in this working paper concerns the enabling technologies of the 4.0 paradigm in agriculture (RQ 3). The identified technologies that enable agriculture 4.0 are the following.

IoT: Most frequent example includes the use of advanced technologies in fertilisers and irrigation systems. Some farmers use monitoring systems on animal feed distribution, milk production, etc., in order to identify changes in health, performance and reproductive status (Elijah *et al.*, 2018).

Data analytics and Big data: Thanks to big data, the large data sets collected will allow farmers to monitor their farming activities and the state of their fields in real time. In this way, it will be possible to gather essential information and increase yields significantly (Pham and Stack, 2018).

Artificial Intelligence (AI) and Machine learning (ML): Maximising the outcome is the order of the day for any machine learning model, and model evaluation metrics are useful for analysing the obtained results, which in the agricultural domain means optimizing the usage of inputs or also pest's identifications and correct treating methods (Lezoche *et al.*, 2020).

Cloud Computing (Cyber-Physical System); the virtualization of physical assets and the possibility to compute data in the cloud gives an opportunity to increase flexibility for implementing digital processes (Zamora-Izquierdo *et al.*, 2019).

Image processing: gathering of data through multimedia sensors employed in intelligent systems to optimise the automatic and unsupervised production processes. This technology is a specific part of data analytics that plays a very big role in agriculture, with image analysis is possible to monitor crop growth and their health (Hamuda, Glavin and Jones, 2016).

Geographic Information System and analytics: Geographic Information System (GIS) and analytics includes the ability to collect large amounts of data, map entire areas and monitor the position of various machines is highly relevant in this context (Shashikala S V, 2019) (Kim *et al.*, 2019).

Robotics and automation: Applications of robots in smart agriculture have shown a growing interest towards automation due to the fact that robots are now capable of performing various farming operations, including crop scouting, pest and weed control, harvesting, targeted spraying, pruning, milking, Phenotyping, and sorting (Ramin Shamshiri *et al.*, 2018).

UAVs (Unmanned Aerial Vehicles): UAV technologies have been successfully employed in a variety of applications for precision agriculture such as herbicide applications, water deficiency identification, detection of diseases, etc. Using the information acquired by the UAVs several decisions can be made to handle the problem(s) detected and/or optimize harvesting by estimating the yield (Tsouros, Bibi and Sarigiannidis, 2019).

Communication technologies: represents the 'highway' on which data is transported. The latest 5G network is well positioned to support agriculture 4.0 practices by providing wide area coverage, low power consumption, low-cost equipment and high spectrum efficiency (Tang *et al.*, 2021).

Blockchain: this technology enables solutions that guarantee greater security in the traceability of raw materials, foodstuffs and the resources needed for production. Blockchain projects enable more effective and secure document management and increase security along the agri-food data supply chain (Bodkhe *et al.*, 2020).

Augmented and Virtual reality: AR and VR can help farmers in many ways, such as crop, animal, machinery statistics, weather updates, soil and water conditions, disease detection with AI for both plants and farm animals, pest detection, soil examination, etc. through wearable glasses and smartphones (Zhang, Cao and Dong, 2020).

In the following figure (Figure 5), the list and relative frequency with which we encountered the technologies described above is represented. As you can see, the 4.0 technologies we focus on the most are those related to the Internet of Things and Data analytics.

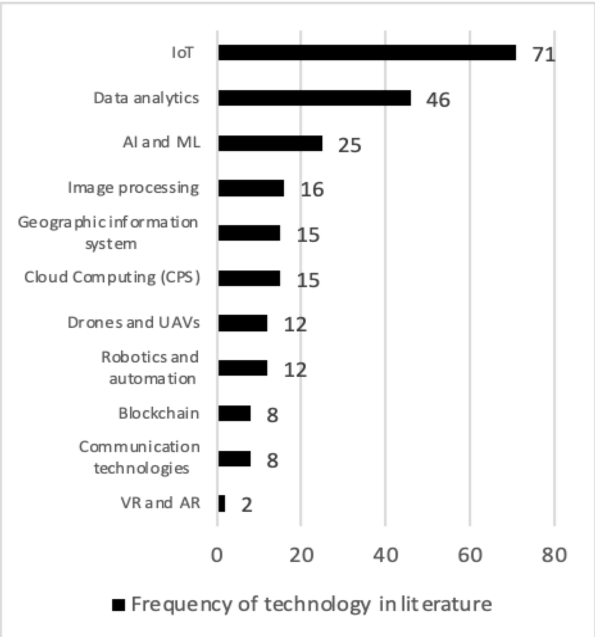

Figure 5: List of technologies and frequency in literature

Summarizing the message arising from the enabling technologies, we find that digital technologies are linked by data. Digital technologies make data available, but it becomes essential to transform data into information that can support users. Therefore, the existence of a common environment in which data can be hosted and translated into a common language becomes fundamental to provide farmers a useful decision support system. It is therefore important to focus on platforms, which must be open and cross-sector in the supply chain perspective.

Within the body of literature, the topic of platforms emerges in only 26% of cases and within these articles, two different categories of platforms emerge. The first, and most common (80% of cases), concept revolves around 'vertical' platforms in the sense that they aim to integrate data from multiple sources but are closely tied to a single process at the farm level. While the second category, 'horizontal' development (20% of cases), focuses on a system view in which the farm is the epicentre of a larger network and involves the integration of multiple sources and multiple systems.

4. Discussion and conclusions

Digital agriculture based on 'smart connected products' carries the potential to revolutionise the agricultural industry, but despite the growing popularity and attention for the paradigm there is plenty of space for new research in the area. For this SLR contribution, 93 scientific papers have been analysed. From this reviews and analysis, we were able to answer to all initial research questions, addressing the definition of agriculture 4.0 paradigm, identifying the application domains, its main benefits and the several challenges agriculture 4.0 is facing and will face even more in future. During the analysis, it was noted that the current body of literature focuses more on technologies (vertically) and relatively little attention is paid to the topic of platforms (even less to horizontal solutions). In order to let the paradigm take full root, it is necessary to be able to use multiple technologies and multiple data sources in parallel, which, for proper use, need an open and horizontal environment. With this contribution we intend to give a complete definition of agriculture 4.0 and direct the future of research based on the most relevant criticalities that have emerged. Many gaps arose during the analysis, there is a lack of specific, quantitative analysis of technologies, benchmarking against traditional situations. This problem is also reflected at the systemic level, where no attention is given to the effects that can be achieved at the country level economically, environmentally, and socially. In future research, it will be therefore important a quantitative analysis on the paradigm and its scalability and to study toward the missing framework or standard model that describe the readiness of various technologies in relation with agriculture 4.0. Finally, the study conducted has limitations. First, we focused only on academic journal papers written in English. We are aware that excluding studies written in other languages as well as other types of publications might have limited our findings. Second, it is important to mention the fact that only one source of literature has been considered (Scopus), this could have omitted part of important literature. Another limitation lays in the selection of the Impact Factor as a filter for search and there is the possibility that we may have missed a fraction of relevant literature.

References

Bodkhe, U. *et al.* (2020) 'Blockchain for Industry 4.0: A Comprehensive Review', *IEEE Access*, 8, pp. 79764–79800.

Demestichas, K., Peppes, N. and Alexakis, T. (2020) 'Survey on Security Threats in Agricultural IoT and Smart Farming', *Sensors*, 20(22), p. 6458.

Elijah, O. *et al.* (2018) 'An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges', *IEEE Internet of Things Journal*, 5(5), pp. 3758–3773.

Escamilla-García, A. *et al.* (2020) 'Applications of Artificial Neural Networks in Greenhouse Technology and Overview for Smart Agriculture Development', *Applied Sciences*, 10(11), p. 3835.

Farooq, M. S. *et al.* (2019) 'A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming', *IEEE Access*, 7, pp. 156237–156271.

Gupta, M. *et al.* (2020) 'Security and Privacy in Smart Farming: Challenges and Opportunities', *IEEE Access*, 8, pp. 34564–34584.

Hamuda, E., Glavin, M. and Jones, E. (2016) 'A survey of image processing techniques for plant extraction and segmentation in the field', *Computers and Electronics in Agriculture*, 125, pp. 184–199.

Kamilaris, A., Kartakoullis, A. and Prenafeta-Boldú, F. X. (2017) 'A review on the practice of big data analysis in agriculture', *Computers and Electronics in Agriculture*, 143, pp. 23–37.

Kim, J. *et al.* (2019) 'Unmanned Aerial Vehicles in Agriculture: A Review of Perspective of Platform, Control, and Applications', *IEEE Access*, 7, pp. 105100–105115.

Klerkx, L. (2020) 'Dealing with the game-changing technologies of Agriculture 4.0_ How do we manage diversity and responsibility in food system transition pathways?', *Global Food Security*, 24, p. 7.

Lezoche, M. *et al.* (2020) 'Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture', *Computers in Industry*, 117, p. 103187.

Light, R. J. and Pillemer, D. B. (1984) *Summing up: the science of reviewing research*. Cambridge, Mass.: Harvard University Press. Available at: http://archive.org/details/summingupscience00ligh (Accessed: 14 May 2021).

Long, T. B., Blok, V. and Coninx, I. (2016) 'Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy', *Journal of Cleaner Production*, 112, pp. 9–21.

Lytos, A. *et al.* (2020) 'Towards smart farming: Systems, frameworks and exploitation of multiple sources', *Computer Networks*, 172, p. 107147.

Madushanki, A. A. R. *et al.* (2019) 'Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review', *International Journal of Advanced Computer Science and Applications*, 10(4), 14-28.

Monteleone, S. *et al.* (2020) 'Exploring the Adoption of Precision Agriculture for Irrigation in the Context of Agriculture 4.0: The Key Role of Internet of Things', *Sensors*, 20(24), p. 7091.

Munz, J., Gindele, N. and Doluschitz, R. (2020) 'Exploring the characteristics and utilisation of Farm Management Information Systems (FMIS) in Germany', *Computers and Electronics in Agriculture*, 170, p. 105246.

Pham, X. and Stack, M. (2018) 'How data analytics is transforming agriculture', *Business Horizons*, 61(1), pp. 125–133.

Ramin Shamshiri, R. *et al.* (2018) 'Research and development in agricultural robotics: A perspective of digital farming', *International Journal of Agricultural and Biological Engineering*, 11(4), pp. 1–11.

Sott, M. K. *et al.* (2020) 'Precision Techniques and Agriculture 4.0 Technologies to Promote Sustainability in the Coffee Sector: State of the Art, Challenges and Future Trends', *IEEE Access*, 8, pp. 149854–149867.

Tang, Y. *et al.* (2021) 'A survey on the 5G network and its impact on agriculture: Challenges and opportunities', *Computers and Electronics in Agriculture*, 180, p. 105895.

Tsouros, D. C., Bibi, S. and Sarigiannidis, P. G. (2019) 'A Review on UAV-Based Applications for Precision Agriculture', *Information*, 10(11), p. 349.

Vidyashree A L, and Shashikala S V (2019) 'Agribusiness Innovation Utilizing Gis with Machine Learning', *International Journal of Engineering and Advanced Technology*, 8(6), pp. 2442–2444.

Zamora-Izquierdo, M. A. *et al.* (2019) 'Smart farming IoT platform based on edge and cloud computing', *Biosystems Engineering*, 177, pp. 4–17.

Zhang, X., Cao, Z. and Dong, W. (2020) 'Overview of Edge Computing in the Agricultural Internet of Things: Key Technologies, Applications, Challenges', *IEEE Access*, 8, pp. 141748–141761.

Zheng, T. *et al.* (2020) 'The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review', *International Journal of Production Research*, 59, p. 1922-1954.