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Bridging Industry 5.0 and Agriculture 5.0: Historical Perspectives, Opportunities, and Future Perspectives

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Abstract: The agricultural industry has undergone several significant changes over the past few centuries, influenced by the industrial revolutions that have occurred. These changes have progressed from Indigenous agriculture to mechanized farming and the current precision agriculture. While the industrial farming model has increased output, it has also faced various challenges in recent years. Industry 5.0 is expected to have a significant impact on the agriculture sector and potentially lead to a fifth agricultural revolution. In this paper, we examine the motivation behind the industrial and agricultural revolutions 4.0 and 5.0, review the phases of these revolutions that have occurred so far, and offer suggestions for the future. We also provide an overview of the concepts of Industry 4.0 and 5.0, as well as Agriculture 4.0 and 5.0, and discuss the smart strategies that are being implemented in different countries to advance these sectors. Additionally, we focus on the potential applications of Industry 5.0 technologies in the agriculture industry and the research challenges associated with them. Our goal is to provide industrial and agricultural professionals with new research opportunities.

Keywords: Industry 4.0; Industry 5.0; Agriculture 4.0; Agriculture 5.0

1. Introduction

The inception of Industry 4.0 (also referred to as the fourth industrial revolution) dates to 2011, when it was initiated as a high-tech strategy project by the German government [1]. The developed production systems are constantly improving to meet customer needs, foster innovation, and enhance competitiveness. Moreover, with the emergence of Industry 4.0, machines and computers are interconnected, enabling them to make autonomous decisions without human intervention. Therefore, companies have the chance to enhance their production capabilities and improve their international competitiveness [2]. The Industry 4.0 initiative enabled the construction of an environment where every company is seamlessly and continually interconnected. All the essential technologies and features are considered for services that are constantly communicating with one another, fulfilling a strong degree of coherence [3]. Consequently, the ability to synchronize operations is crucial for improving the supply chain network, as the optimization process necessitates the evaluation of multiple competing factors [4]. The autonomy and intelligence of production processes and supply chains in the industrial sector have increased. Consequently, the adoption of Industry 4.0 with farming affords the chance to evolve industrial agriculture to Agriculture 4.0, the fourth agricultural revolution [5]. In this scenario, intelligent and sustainable industrial agriculture would be realized through collecting and organizing in real-time and analyzing the spatiotemporal data in all phases of the farming system, including food production, processing, supply, and customer experience. Industrial agriculture ecosystems with real-time farm monitoring have a significant level of digitization

to enhance smart decision-making and significantly increase productivity, agri-food supply chain efficiency, food security, and natural resource consumption.

The advent of Industry 4.0 by corporations marked the onset of the Fifth Industrial Revolution [6]. It is believed that Industry 5.0 acknowledges the sector's capacity to surpass mere job creation and expansion to achieve dependable employment, leading to prosperity, by ensuring that production adheres to environmental boundaries and prioritizes worker health throughout the manufacturing process [6,7]. The inception of Industry 5.0 is predicated on the notion or anticipation that Industry 4.0 will place greater reliance on innovations propelled by AI and automation to enhance the efficiency and adaptability of production, while diminishing its reliance on original concepts such as social justice and sustainability. Hence, the concept of Industry 5.0 presents an exceptional viewpoint and underscores the importance of research and innovation in facilitating the industry's enduring impact on society while adhering to environmental constraints [6]. However, today, we are at the dawn of an innovative industry in agriculture, that of Agriculture 5.0 [8]. Agriculture 5.0 represents the trajectory that the farming industry will traverse in the years to come.

Improving agricultural efficiency is the primary means of ensuring worldwide food security in the 21st century. Agriculture 5.0 involves the development of smart innovations that will allow farmers to raise their production while lowering agriculture's environmental effect and resolving significant political and social issues of food production systems [9]. This article explores advancements in agricultural technologies, including the development of individualized human–machine interaction solutions that harness the combined capabilities of humans and machines. It also delves into bio-inspired innovations and smart materials that have the potential to enhance recycling efforts and incorporate embedded sensors for improved functionality [10]. Nonetheless, it is not restricted to that. To remain focused, this work makes a reflection on the 4.0 and 5.0 eras for agriculture and industry, concentrating primarily on their descriptions, historical perspectives, and different countries' strategic plans. The challenge presented by the fourth agricultural revolution is to integrate the current paradigm of smart technologies in the different sectors and processes that can be managed by global food systems. Moreover, industry 4.0 strategies can be enhanced and applied to the agricultural sector; nevertheless, the industry is evolving quicker than agriculture, as experts are already discussing Industry 5.0. On the other hand, the 5.0 future revolution in agriculture is still a new and smart concept for farmers. For this reason, this review deals with how the industrial revolution affected the agricultural revolution. This article is organized into eight different sections, besides this initial introduction. Section 2 provides an overview of the paper's main contribution and outlines its structure. Section 3 provides the rationale for the revolution in industry and agriculture, specifically focusing on the 4.0–5.0 era. Section 4 provides a comprehensive overview of the historical context surrounding the industrial and agricultural revolutions. In Section 5, there is a detailed discussion about the various descriptions put forth by authors in the fields of industry and agriculture, ranging from 4.0 to 5.0. Section 6 discusses the strategic plans of various countries in the field of smart industry and agriculture. Section 7 presents a novel architecture that combines the latest advancements in smart industry and smart farming. Additionally, Section 8 provides an overview of the essential technologies used in smart agriculture applications within the context of Industry 4.0 and 5.0. Finally, Section 9 explores the constraints and potential future impacts of the study.

2. Contributions and Structure

Several researchers have provided extensive literature studies and detailed discussions on the potential utilization of developing technologies to revolutionize manufacturing, production, and supply chain management in the contemporary industrial sector [11–13]. Notably, the utilization of Industry 4.0 technology in combatting the coronavirus (COVID-19) pandemic was introduced in reference [14]. In contrast to the works, the objective of this study is to present analyses on the implementation of Industry 4.0 and 5.0 technologies in

the farming sector. In recent years, numerous surveys have been conducted on exploring the utilization of innovative technologies in the agriculture industry [13]. These surveys investigate the roles of emerging technologies such as IoT, big data analytics, robotics, and AI in the field of smart agriculture. The agricultural industry can be broadly categorized into two main sectors: agri-food production and agri-food supply chain management.

This paper provides readers with a unique perspective by presenting the current state and insights gained from the Industrial Agriculture Revolution. This work is the first to attempt the connection between 4.0 and 5.0 for the industrial and agricultural revolutions. It focuses on the motivations behind the 4.0–5.0 industrial and agricultural revolutions. It provides a thorough and precise explanation of the concepts of Agriculture 4.0 and 5.0, as well as Industry 4.0 and 5.0. It presents historical perspectives on the industrial and agricultural revolutions. It has an origin in the architecture between smart industry technologies and their applications in the agriculture sector. Furthermore, our objective is to furnish readers with essential applications and technological obstacles that may arise in future research when Industry 5.0 intersects with agriculture. As shown in Table 1, the agricultural industry has yet to be studied, considering 4.0 and 5.0 revolutions. The current paper addresses this research gap. The methodology adopted in this paper is illustrated in Figure 1.

Table 1. Summary of the surveys related To I4.0 and I5.0, A4.0 and A5.0.

Reference	Target Industry Revolution		Target Agriculture Revolution		Focused Technology						
	4.0	5.0	4.0	5.0	Big Data	AI	Robotics	Bio-Inspired	Digital Twins	6G and beyond	Others
Lu [15]	√				√						√
Elijah et al. [13]	√		√		√						
Aceto et al. [16]											√
Zhai et al. [17]	√		√			√					
Ayaz et al. [18]	√		√				√				√
Polymeni et al. [19]				√						√	√
Juwono et al. [20]				√		√					√
Zhang [21]		√		√							√
Araújo et al. [22]		√		√	√	√	√				√
Liu et al. [11]	√	√		√	√	√	√				√
Abbasi et al. [12]	√	√		√	√	√	√		√		√
Leng et al. [23]	√	√				√					√
Priyadarshan et al. [24]		√				√					√
Belaud et al. [25]	√	√		√							
This study	√	√	√	√	√	√	√	√	√	√	√

A survey of relevant work was conducted to compare this study to current framework (SoA) articles and lead readers to other publications. We executed automatic searches on Scopus, IEEE Explore, and Web of Science, as all their articles contain abstracts that aid in the analysis of publications. Additionally, Google Scholar was used to search for gray literature in the field, such as white papers and technical reports. Search strings were formulated to include diverse relevant literature to produce a broad selection of results. The search strings were structured in terms of the main keyword that structured our paper. First, the selection procedure for the main studies was based on various queries. Later, our search string was created by combining the queries using 'AND' and 'OR' clauses. The

generated search string is provided below; it has been validated by searching several digital libraries. Generic search string: (("Industry") AND ("4.0" OR "5.0") AND ("Agriculture")).
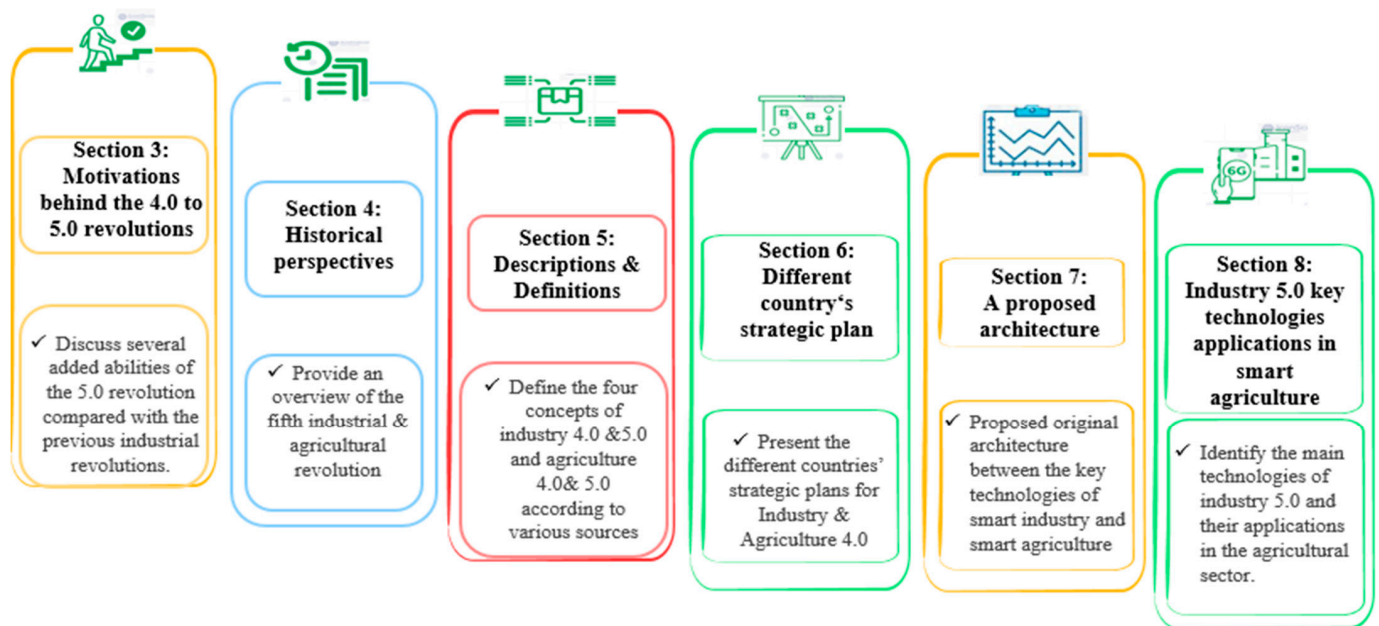

Figure 1. The paper structure.

3. Motivations behind the 4.0 to 5.0 Revolutions

3.1. Industrial Revolution

Industry 4.0's leading principle is to provide the industrial sector "smart" by interconnecting devices and machines that can control one another during the entirety of their life cycle [26,27]. The fundamental purpose of Industry 4.0 is to automate operations, which reduces human intervention in the production process [28,29]. Industry 4.0 concentrates on enhancing mass performance and productivity exploring machine learning (ML)-based intelligence between applications and devices [30,31]. Industry 5.0 is currently envisioned as a collaboration between the original innovation of human professionals and powerful, intelligent, and precise machinery. Experts in the field predict that the next version of Industry 5.0 is going to reintroduce the human element into manufacturing [32]. Industry 5.0 is expected to integrate fast and accurate technology with the essential cognitive talents of humans. Mass personalization is an additional significant contribution of Industry 5.0, allowing customers to prefer customized and personalized products based on their preferences and requirements. Industry 5.0 will significantly improve manufacturing efficiency and create adaptability between machines and humans, allowing for interaction and performance-measurement activities. The goal of the cooperation among machines and humans is to accelerate production. Industry 5.0 emphasizes the potential for increased skill development and enhanced production quality through the allocation of monotonous and repetitive tasks to robots/machines, while tasks that require critical thinking are assigned to humans. In Industry 4.0, the use of robots by intellectual experts aids in completing these types of tasks. Industry 5.0 emphasizes hyper customization, with people leading smart machines. In Industry 4.0, robots are directly involved in mass manufacturing, but Industry 5.0 is aimed at improving customer satisfaction. Industry 4.0 tends to focus on the connectivity of cyber-physical systems, whereas Industry 5.0 establishes a connection between collaborative robots and Industry 4.0 applications (robots). Industry 5.0's necessity of more sustainable alternatives than the current technological advances, which do not prioritize environmental preservation, is an exceedingly intriguing advantage [33]. Industry 5.0 uses forecasting modeling and intelligence to generate decision-making models that

are more precise and less volatile. Industry 5.0 will automate most of the manufacturing process using machine-collected real-time data in conjunction with highly skilled experts.

Concurrently, a current tendency of the fifth industrial revolution is evolving the creation of for-profit services and goods. Sector 5.0 introduces a new aesthetic to the industry and necessitates mental and behavioral shifts [34]. Industry 5.0 relies on the reintroduction of individuals into the production chain. In this revolution, man and machine collaborate to enhance the quality and productivity of output. In Industry 5.0, the relationship between humans and artificial intelligence is important. The environmental benefits of the fifth industrial revolution increase when corporations build systems that employ sustainable power and reduce waste [6–10,26–36]. Based on the EC, the power of Industry 5.0 is the social objective, beyond job creation and economic growth, of developing into a socially equitable and ecologically sustainable future that is a robust provider of well-being by making the manufacturing sector respect the planet's boundaries and putting industrial worker well-being at the center of the production process [35]. The participants of a summit of research and technology organizations held by the European Commission (EC) from 2–9 July 2020 [37] discussed the notion of Industry 5.0. Figure 2 compares the goals of Industry 5.0 to those of Industry 4.0 [38]. This is how Frost and Sullivan envision the future of these industries, where humans regain control and take charge on the shop floor. Industry 5.0 represents a paradigm shift towards future progress. It explores the resurgence of individuals in factories, the decentralization of production, the implementation of intelligent supply chains, and the rise of hyper-customization. These advancements aim to provide customers with a unique and personalized experience at every event [35].
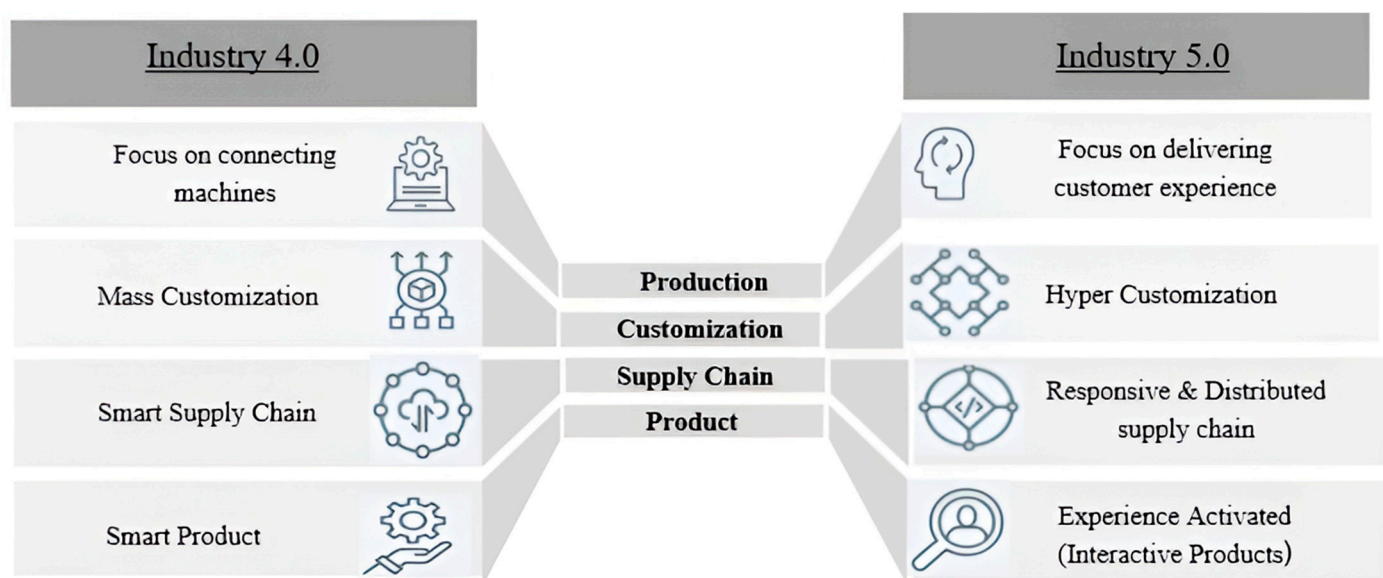

Figure 2. Industry 4.0 and Industry 5.0 compared in the view of Frost and Sullivan.

3.2. Agricultural Revolution

From the perspective of industrialization, scientists frequently investigate the digitalization of agriculture. This advancement of technology, coupled with improved communication, will help create more efficient ways of making decisions in agriculture and allow us to make better use of the resources available to us. Liu studied the emergence of agriculture considering the effects of the rise of industrialization [11]. The correlation between Farming 4.0 and the 4.0 industrial revolution, regarding the improvement of the mechanization of fieldwork, is observed in [39]. Experts in the field of Farming 5.0 and food security have found that the use of artificial intelligence, robotics, machine learning (ML), and deep learning (DL) can predict crop yields with a 75% probability, detect agricultural diseases that affect crop quality, and increase the profitability of farms [40]. In crop production,

the transition from smart farming to the agricultural revolution 5.0 should be associated with more significant gain in yield, sustainability, and environmental conservation [41]. Agriculture 5.0 should be considered alongside Industry 4.0 and Society 5.0, together with the development of ecologically sound technology, the creation of smart and sustainable cities, and the promotion of industrial progress as a measure of human welfare [42]. Given the context, the notion of Edible Urbanism 5.0 utilizing an edible green infrastructure (EGI) strategy is contrasted with existing urbanity conceptions that include shared systems for food production in cities [43]. Research on the fourth and fifth agricultural revolutions has reached a pinnacle in agricultural science. All developed nations employ the methods and equipment of Agriculture 4.0, an advanced stage in agricultural development, in their agricultural output. Agricultural technologies are currently progressing toward a new phase, Farming 5.0. However, several issues in Agriculture 5.0 are debatable, and their solutions are just predictive. The advancement of bioeconomics in the context of Industry 5.0 highlights the intriguing aspects of sustainable agriculture, such as optimizing resource utilization, customizing the product, creating unique and innovative products, and implementing distinct decision-making systems through robotic systems.

The Agriculture 4.0 Evolution is a multifaceted phenomenon, owing to the intricacy of the evolving agricultural ecosystem [44,45] and external influences such as climate and environmental influence [46]. Consequently, Agriculture 4.0 provides numerous interrelated constraints that affect the acceptance of any new emerging technology concepts [47]. Few selections of research studies approach and examine the obstacles to the implementation of Agriculture 4.0 technologies [11,48], the difficulties associated with its inclusion and exclusion [44], and the problems that the new agricultural system may cause [17,49]. In addition, the scientific discussion over the obstacles that make Agriculture 4.0 difficult to develop is ongoing [17,47–50]. Despite the numerous benefits that the realization of Agriculture 4.0 could offer, there are still several unanswered questions and obstacles that must be resolved to permit a smooth transition to this paradigm. These obstacles have been stratified into five levels [51], as illustrated in Figure 3.

Figure 3. Obstacles to the advancement of Agriculture 4.0.

4. Historical Perspectives

4.1. Industrial Revolution

The steam engine and mechanical feedback speed controllers were revelations that ushered in the initial industrial revolution in 1760. The steam engine facilitated the modern manufacturing process, in contrast to feudal society and agriculture [52]. During this era, coal and railroads were the dominant forms of transportation and energy sources,

respectively. The production process had been mechanized. The textile and steel sectors held the utmost significance regarding capital investment, employment, and valuation [52]. The second industrial revolution commenced with the advent of the internal combustion engine in 1870. The refer-to term for this is technological transformation. The emergence of electricity, gas, and oil as new energy sources because of recent technological developments facilitated mass production expansion [53]. The era following World War II in 1969, commonly referred to as the third industrial revolution, was characterized by the implementation of information technology and electronics to automate manufacturing processes. Electro-mechanical control systems underwent a conversion to computer-based systems. The primary development and implementation of industrial automation systems for PLCs (programmable logic controllers) and SCADA (supervisory control and data acquisition systems) [54] involves the application of electronics with the intention of automating production. During the "Hannover Messe 2011", the German government unveiled Industry 4.0 with the dual goal of establishing Germany as the global leader in industrial manufacturing and preserving its hegemony in the equipment manufacturing sector. The fourth industrial revolution emphasizes machine learning and interconnectivity via the Internet of Things; it also places a greater emphasis on big data analytics to reach more intelligent and effective decisions. When compared to previous industrial revolutions, the fourth is characterized by exponential growth as opposed to linear development. Furthermore, the fourth industrial revolution impacts every industry in every nation. The magnitude and scope of these advancements hold the potential to revolutionize entire systems of governance, management, and production [55]. Participants from research and technology organizations (RTOs) and funding agencies throughout Europe engaged in two virtual seminars on 2 and 9 July 2020 [56], to analyze the concept of Industry 5.0. The goal was to gather feedback on the overarching concept and to analyze the facilitating technologies and potential barriers [57]. The fundamental tenet of Industry 5.0 is to prioritize the selection of processes that uphold human requirements and values through ethical deliberation, as opposed to relying exclusively on their technological or economic viability.

4.2. Agricultural Revolution

Agriculture follows the industrial sector in terms of technological advancement. Agriculture 1.0 marked the beginning of the agricultural revolution at the turn of the 20th century, through a system of intensive animal-powered labor. Despite low productivity, this system fed the population with a considerable number of small farms, and one-third of the population engaged in agricultural productivity [39]. Agriculture 2.0 started in the late 1950s, when new management techniques and technologies, such as herbicides, fertilizers, more efficient combustion-powered machines, and other inventions, were put into use. Thus, these advancements allowed for a substantial increase in the yield of the plantations. In the 20th century, the rapid development of computing, precision agriculture, and electronics led to the emergence of Agriculture 3.0. Precision agriculture is the third agricultural revolution. It started when the military made GPS (Global Positioning System) signals available to everyone [49]. In addition, it was during this time that telematics, inspired by the transportation industry, began to be used to supervise and optimize the supply chain processes on farms. During Agriculture 3.0, software for agricultural data management became accessible. Thus, it began to place a greater emphasis on cost reduction and farm profitability [49]. This evolution continued with the conception of Agriculture 4.0, also known as smart or digital agriculture. Agriculture 4.0 is evolving concurrently with equivalent changes in the industrial sector (Industry 4.0) as a vision for the future of manufacturing. Agriculture 4.0, like Industry 4.0, refers to the internal and external integration of farming operations, providing digital data in all agricultural sectors and activities [49]. The fourth agricultural revolution is known as "digital agriculture" in Australia and New Zealand, "agriculture numerique" in France [50], and "smart farming" in various European Union countries [35]. Currently, agricultural technology is advancing toward a new phase, Agriculture 5.0. However, many issues in Agriculture 5.0 are arguable,

and their answers are just predictive. Optimal resource utilization, mass personification and individualization of the final product, the development of creative product differentiation, and the introduction of autonomous automated decision-making systems based on robotic complexes are among the most promising areas of agricultural development, according to the development of bio economics in the concept of Society 5.0. The roadmaps of the agricultural revolution and industrial revolution are illustrated in Figure 4.
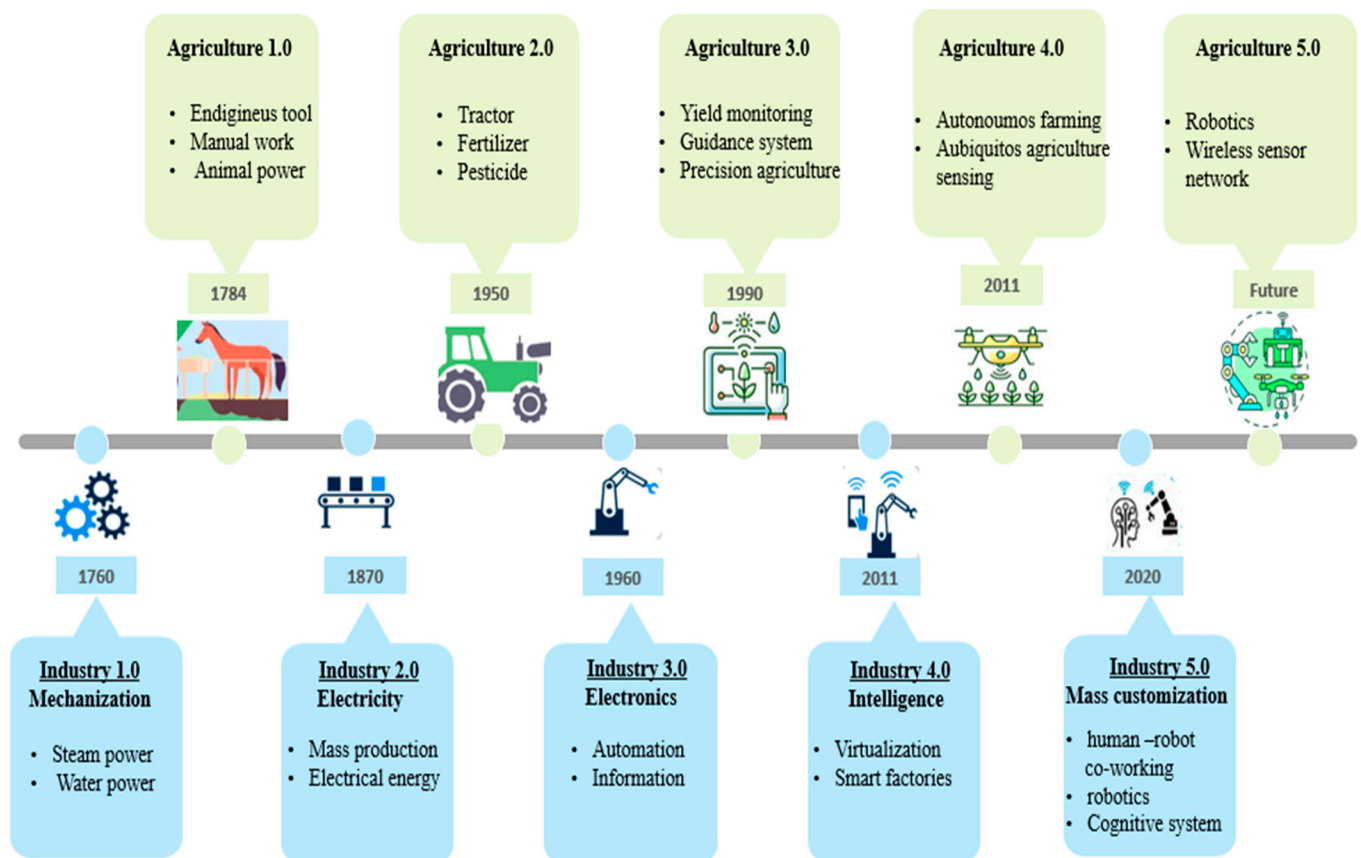

Figure 4. Historical perspectives on Industry and Agriculture 4.0–5.0.

5. Description

The objective of this section is to provide a clear and holistic definition of the four concepts, Industry 4.0 and 5.0 and Agriculture 4.0 and 5.0. Indeed, over the years, different authors have attempted to define the Industry 4.0 concept. The fourth industrial revolution, or "Industry 4.0", is a technologically driven transition in the manufacturing sector that conceptualizes the fast transformation of technology, industry, and societal processes and behaviors during the previous several decades [35,58]. Industry 4.0 refers to the present trend of data interchange and automation in manufacturing technologies. Cyber-physical devices, the Internet of Things, machine learning, and cloud computing are included. Industry 4.0 produces what is known as a Smart Factory. The cyber-physical components monitor and analyze physical processes, produce a virtual duplicate of the physical environment, and make intelligent decisions within smart factories with a modular framework. However, Industry 4.0 has some limitations since it prioritizes enhancing the efficiency and adaptability of the industry over industrial efficiency and worker well-being [35]. As a human-centered design strategy in which people and robots collaborate in a unified work environment, Industry 5.0 has gained traction in recent years as a response to the issues posed by Industry 4.0 [35,59]. Utilizing flexible and adaptable technology, the Industry 5.0 paradigm enhances the adaptability and resilience of systems. Moreover, it strives to be a leader in sustainable action, respects planetary boundaries, and supports

talent, creativity, and independence. We present different descriptions proposed by several authors for Industry 4.0 and 5.0 in Table 2. Agriculture 4.0, which is intricately linked to Industry 4.0 in terms of concepts, focuses on the seamless integration of farming processes both internally and externally. It is evident that digital information is present in all areas of agriculture, including communication with external partners and the automation of data transfer, processing, and analysis. At this critical juncture, it is imperative for us to strike a delicate balance between meeting the growing demand for nutritious and affordable food, while also safeguarding the very ecosystems that sustain us [60]. We need to shift our focus from the digital agricultural revolution to what we refer to as "Agriculture 5.0". Table 3 provides a summary of definitions related to the advancements in agriculture.

Table 2. Industry 4.0 and 5.0 definitions.

Concept	Authors	Description
Industry 4.0	J. Wan et al.	Industry 4.0 uses recent technologies to gather and analyze the data in real-time that provide the manufacturing system with useful information [61].
	H. Kagermann	A strategic plan for the creation of a new production system to improve production efficiency in the national industry [62].
	J. Lee	Industry 4.0 represents an interconnected business environment where employees, machinery, devices, and enterprise systems connect through CPSs and the Internet [63].
	NIST	Industry 4.0 is a completely integrated manufacturing system that responds in real-time to changing factories, customer demands, and supply networks [64].
	P. Zeng	Industry 4.0 is expected to improve current main development processes and have a significant effect on work and daily life, along with growing global income [65].
	U. Dombrowski	Real-time, smart, and digital people, equipment, and objects connect to manage business processes and build value networks [66].
	G. Aceto	Industry 4.0 embraces a collection of innovations and technologies that can be regarded as categorical government commitments to harness their full potential [16].
	Fact Sheet	Industry 4.0 enables the integration of devices and sophisticated machinery with software and networked sensors for improved business and social outcome prediction, control, and planning [67].
	Hermann et al.	A collective term for the technologies and concepts of value chain organization [68].
	Henning	A new degree of value chain structure and management throughout the product lifecycle [69].
Industry 5.0	Breque et al.	Industry 5.0 brings research and innovative ideas to Industry 4.0 to make the European industry sustainable, centered on people, and strong [6]. The European industry readjusts its role in society and encourages Industry 5.0 to describe the future prosperity of European industry [6].
	Sihan et al.	The Industry 5.0 paradigm promotes the adaptability and resilience of systems using flexible and adaptable technologies [70].
	Leong et al.	Industry 5.0, symmetrical innovation, and next-generation global governance are an improvement over Industry 4.0 [71].
	Mao et al.	Industry 5.0 recognizes the importance of the industry to accomplish societal goals beyond job creation and growth, to become an ever-resilient provider of prosperity [72].
	Mourtzis et al.	Industry 5.0 highlights the role of technology and research in supporting the industry to provide long-term services to people within planetary constraints [73].
	Singh et al.	Industry 5.0 is primarily marked by augmented reality, robots, the Internet of Things, brain–machine interface, and a focus on the customer experience [74].
	Nahavandi	Industry 5.0 underpins human–machine collaboration. It prioritizes human ingenuity, sustainable progress, and ambidexterity [32].
	Avila et al.	In Industry 5.0, human intelligence supervises the human–machine interfaces and makes high-level judgments [75].

Table 3. Agriculture 4.0 and 5.0 definitions.

Concept	Authors/Year	Description
Agriculture 4.0	Huh and Kim	Agriculture 4.0 is motivated by environmental and future technology concerns to identify eco-friendly yet more effective farming techniques that fulfill the needs of the supply chain, society, and consumers in particular [76].
	Rose and Chilvers	Agriculture 4.0 is the application of emerging technologies, including IoT, cloud-based artificial intelligence, and robotics [47].
	Klerkx et al.	Agriculture 4.0 requires that on-farm and off-farm management tasks mostly utilize sensors, machines, drones, and satellites to monitor animals, soil, water, plants, and humans [50].
	Kong et al.	Agriculture 4.0 has the potential to improve precision agriculture by incorporating digital and data innovations. It can improve the responsiveness of the agricultural sector [77].
	Zambon et al.	Agriculture 4.0, like Industry 4.0, provides digital transformation to all agricultural businesses through internal and external interactions. Agriculture 4.0 lets enterprises combine market response and productivity [49].
	Zhai et al.	Agriculture 4.0 creates a significant increase in agricultural productivity using smart technologies like big data, artificial intelligence (AI), and cloud computing. [17].
	Trendov et al.	The Food and Agriculture Organization (FAO) of the United Nations denominates this role as the "Digital Agricultural Revolution" [78].
	European Machinery	Agriculture 4.0 paves the way for the next agricultural evolution, which will include unmanned operational processes and autonomous decision systems [79].
	Harold et al.	Digital agriculture benefits from Industry 4.0's pervasive data-intensive and networked technology instruments [80].
Agriculture 5.0	Fraser	Agriculture 5.0 forecasts agricultural developments. It uses sensors, machine learning, the Internet of Things, cloud computing, and big data analytics to improve agricultural operations [60].
	Ragazou et al.	Agriculture 5.0 represents the future for investors focused on environmental, social, and governance (ESG) factors [81].
	Van et al.	Agriculture 5.0 is marked by the need for remote sensing and the utilization of sustainable energy sources like aerobic digestion and biogas [82].
	Fraser	It is time to move from the digital agricultural revolution to Agriculture 5.0. Food systems must balance healthy, cheap food production with ecosystem protection [60].
	Zambon	Agriculture 5.0 forecasts the presence of autonomous systems in rural areas [49].
	Siddharth et al.	In the coming years, manufacturers of off-road equipment can make a substantial impact on the shift towards Agriculture 5.0 [83].

6. Different Country's Strategic Plans

6.1. Industry 4.0

Several developing and developed countries are boosting their strategic plan for optimal and smart manufacturing. The German government proposed Industry 4.0. Industry 4.0 is a government initiative helmed by the Ministry of Education and Research (BMBF) and the Ministry of Economic Affairs and Energy (BMWI). It intends to advance digital industrial production by raising the digitization of business practices, value chains, and products, as well as their interconnection. It also aims to encourage research, industry partner networking, and standardization [84]. The fourth industrial revolution integrates communication and information into manufacturing technologies. Industry 4.0 is a new concept of intelligent manufacturing. It enables a higher degree of operational productivity and efficiency, as well as a higher level of automation. China outlined the strategy "Made in China 2025", a new vision and strategy to address the current situation. The strategy was designed for all high-tech industries, all of which contribute to economic growth in the world's leading economies. The "Made in China 2025" strategy proposes

a "three-step" plan to transform China into the leading industrial power in the world by 2049. The initial step is to transition from a manufacturing giant to a manufacturing powerhouse by 2025. The second step is to attain the middle tier of global manufacturing powers. The third step is to further integrate China's position as a manufacturing capability and to place China's comprehensive manufacturing strength on the list of the world's leading manufacturing powers by 2049 [85]. In the United States, Industry 4.0 is frequently related to the Internet of Things, smart manufacturing, or the Industrial Internet. Thus, they proposed the industrial internet consortium [86] (ICS) strategy, which aims to develop ecosystems that connect physical items to humans, processes, and data through common architectures, accessibility, and software platforms. Industrial Internet of Things (IIoT) systems have end-to-end characteristics that result from the properties of their elements and the nature of their connections. Security, safety, reliability, resilience, and privacy are the five characteristics that influence trust decisions in an IIoT deployment the most [87]. In 2015, the Japanese Virtual Engineering Community (VEC), and Communications firms introduced the Industry 4.1 J strategy. The Japan strategy connects manufacturing plants worldwide via a cloud platform. The platform's cloud monitoring system will collect and simulate real-time data from the production line [88]. We summarize in Table 4 Industry 4.0 initiatives in developed countries.

Table 4. Summary of Industry 4.0 initiatives in advanced countries.

Country	Strategy	Introduced	Promoted by	Field Goal	Core Technology
Germany	Industry 4.0	October 2012	Government	General recommendations coordinated by the government	Internet of Things, Smart Manufacturing
China	Made in China 2025	May 2015	Government	Manufacturing	Networking, Smart Manufacturing
Japan	Industry 4.1J	March 2015	Business	Secure cloud-based data processing	Internet of Things, Cloud Computing
US	Industrial Internet Consortium	March 2014	Business	Overacting themes input on standardization of new business models	Internet, Industry
South Korea	Korean Smart Factory Foundation	June 2015	Business and Government	Factory automation	Cyber-physical systems, Internet of Things, Big Data
Taiwan	Production 4.0	October 2015	Government	Address labor shortages and productivity issues	Internet of Things, Smart Robotics, Big Data
India	Make in India campaign	September 2014	Government	Facilitate investment and improve skill development	Biotechnology, Electronic Systems, Big Data

6.2. Agriculture 4.0

Multiple governments, including the EU, China, US, South Korea, and Japan, have implemented national strategies to revolutionize the agriculture industry through digital advancements. These strategies involve coordinating financial investments and establishing institutional frameworks to ensure long-term sustainability and resilience. In June 2018, the European Commission put forward legislative proposals for a new common agricultural policy (CAP). The aim was to create a more efficient policy that supports the adoption of smart and precision agriculture, boosts economic competitiveness, and safeguards the environment [89]. Investing significantly in ambitious EU initiatives for research and development (R&D) programs can help implement the new CAP. These programs aim to enhance photosynthesis for energy and food production, provide small farmers with access to precision agricultural techniques, promote sustainable land use to improve the condition of soils, and explore sustainable aquaculture methods [90]. Furthermore, in the United States, most advancements in agricultural technology and information systems related to smart agriculture and precision agriculture originate from institutions of higher education, businesses, and state cooperative extension specialists. As a result, no national policy for intelligent agricultural solutions exists currently [91]. However, there is currently

a national agriculture and food policy [92], referred to as the "2018 Farm Bill", which was set to be in effect from 2018 until 2023. This initiative centered on infrastructure investment to expand broadband Internet connectivity to rural areas. It aimed to enhance precision agriculture technologies, which can lead to increased production and profitability for small farmers [93]. Furthermore, in June 2016, the Japanese government identified agriculture as a crucial sector for structural reform as part of the "Japan Revitalization Strategy". The aim was to turn the farming industry into a profitable sector by encouraging the adoption of smart agriculture and technological advances [94]. Along with this, the government has made significant investments in national projects and programs to implement the innovation strategy. These initiatives aim to bring together key stakeholders for comprehensive data collection, analysis, and the development of an agricultural robot solution. In addition, the practical application of advanced smart-farming technologies and solutions is evident in the support provided for various projects in Japan. These projects encompass fields, paddy rice production, greenhouse farming, livestock, tea, and fruits [95,96]. Furthermore, the Korean government also focused on the national agricultural and food policy through two five-year comprehensive plans [97]. Additionally, the Korean government focused on national agricultural and food policy by implementing two significant programs [98]. These initiatives aimed to enhance technology, agricultural production, forestry, and food science. The first plan covered the period 2015–2019, while the second plan spanned from 2020 to 2024 [99]. In 2018, the new president highlighted the importance of developing smart farming as a key industry and put forward several national strategies to promote its adoption. These initiatives, including the Smart Farm Diffusion Plan, aimed to establish smart farming as a comprehensive system that ensures the long-term viability of agriculture [100]. The government is committed to transforming the agricultural sector to align with current trends and demands, such as digitization and low-carbon practices. In February 2019, the Chinese government released a proposal to advance rural digital economy development and facilitate agriculture digitalization. They worked to accelerate the implementation of big data, cloud computing, the IoT, and robotics in farming operations and administration to establish a system of intelligent agriculture [101]. The advent of digital technology presents a significant chance for individuals in poverty to narrow the socioeconomic gap, capitalize on digital prospects, distribute digital benefits, attain long-term poverty reduction, and halt the transfer of poverty across generations [90]. In February 2019, the Chinese government put out a proposal to advance the development of the rural digital economy and facilitate the digitalization of agriculture. Further, it is recommended to accelerate the adoption of cloud computing, big data, the Internet of Things, and artificial intelligence in agricultural production and administration to establish a system of intelligent agriculture [101]. The advent of digital technology presents a significant potential for those with limited financial resources to narrow the socioeconomic disparity, capitalize on digital prospects, distribute digital benefits, attain long-term poverty reduction, and prevent the perpetuation of poverty across generations [90]. In the following Table 5, we provided a concise overview of the Agriculture 4.0 initiatives implemented in developed nations. Figure 5 showcases the various strategic plans put forth by developed nations to promote the seamless integration of Agriculture 4.0 and Industry 4.0.

Table 5. Summary of Agriculture 4.0 and initiatives in advanced countries.

Country	Strategy	Introduced	Promoted by	Field Goal
EU	Common agricultural policy	June 2018	European Commission	Defends farm revenues for families. Encourages the rural economy. Produces safe, high-quality food and protects rural areas and the environment.
US	2018 Farm Bill	December 2018	Government	Improving farm aid programs. Improving crop insurance. Supporting emergency programs. Supporting and encouraging volunteer conservation.

Table 5. *Cont.*

| Country	Strategy	Introduced	Promoted by	Field Goal
Japan	Japan Revitalization Strategy	June 2016	Government	Develop new "promising markets". Achieve "Revolution in productivity" to circumvent supply regulations. "Enhancing capabilities of individuals" to alter smart industry
South Korea	Smart Farm Expansion Plan	April 2018	Government	Developed to expand smart farming based on artificial intelligence (AI) and big data. Help farmers secure sales and expand exports. Create high-quality jobs suitable for young people, such as smart farm operation system development.
China	The rural digital economy	February 2019	Government	Encourage the economic transformation of rural areas. Promote the use of mobile payments in rural areas. Enhancing rural community inclusive and sustainable methodology, techniques, and solutions.
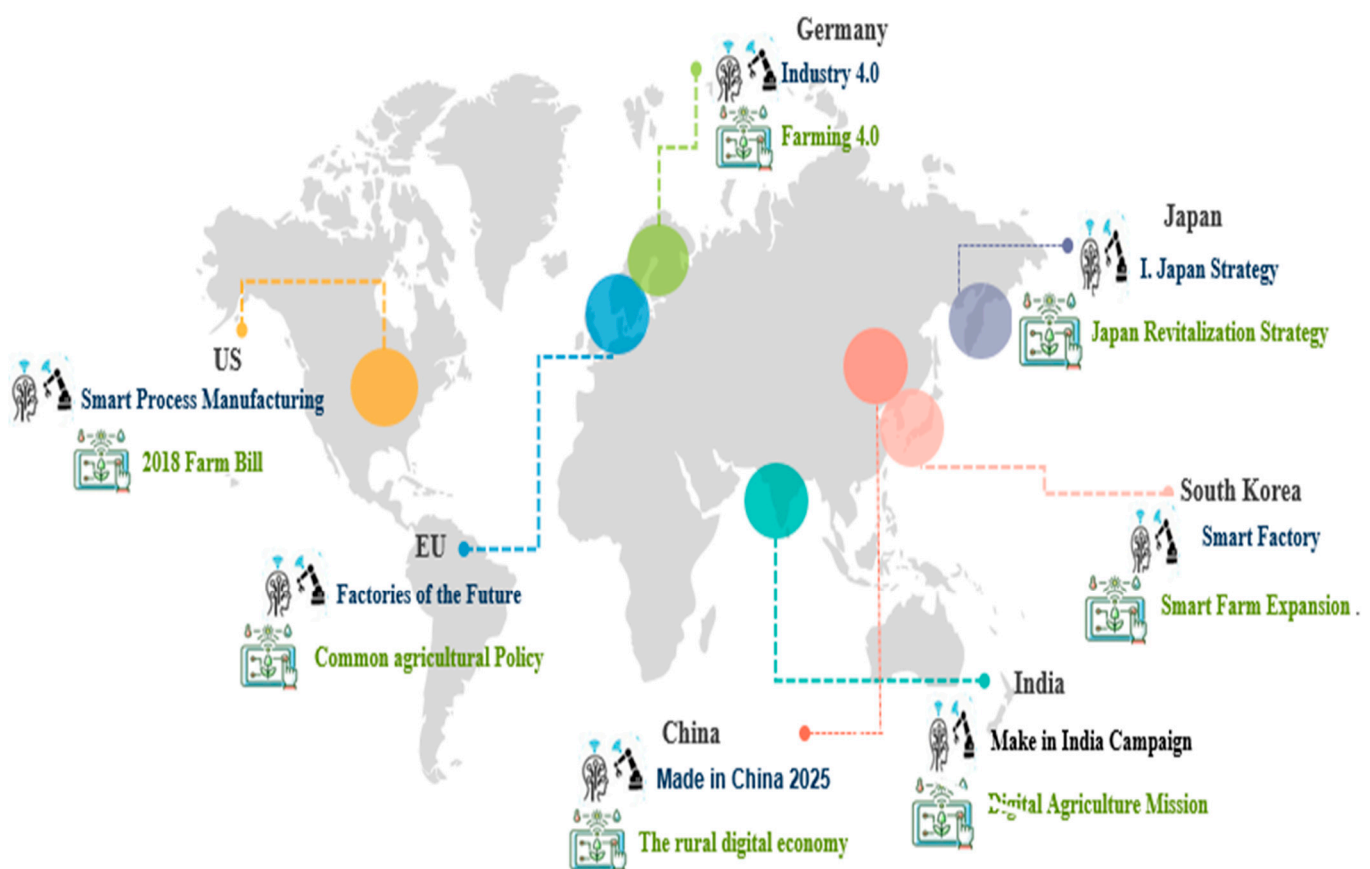
Figure 5. The fourth industrial and agricultural initiatives in advanced countries.

7. A Proposed Architecture on Industry 4.0 Key Technologies Applications in Smart Agriculture

This section proposes original architecture that connects the main technologies of smart industry and smart agriculture; then, we present various Industry 4.0 technology applications in the agriculture field. The utilization of upcoming Industry 4.0 technology offers a potential advantage in the agriculture production system. Due to advancements in these technologies, there is a significant increase in the generation and analysis of large volumes of data on a regular basis. The agriculture industry has emerged as a promising field for the implementation of technology that may significantly enhance the performance of agricultural operations. This is due to the constant need for monitoring and control in these operations.

Today, industrial competitiveness in the Industry 4.0 context is based on the capacity of companies to improve their performance level of production systems and to enhance flexibility and agility. The fourth industrial revolution, or the evolution to Smart Manufacturing, made the farming sector smart and automated from the reception of the crops to the delivery of the final food product, based on various tools such as simulation, modeling, or virtualization. Embracing Industry 4.0 necessitates the seamless incorporation of innovative technologies throughout the entire food supply chain, encompassing production, manufacturing, distribution, and retail. Achieving integration makes decision-making (predictive, corrective, and adaptive) an easily achievable reality. The key technologies of intelligent manufacturing can be divided into two main types of technologies: base technology and front-end technologies, which are interrelated to achieve Industry 4.0. The first layer of technologies (Smart Product, Smart manufacturing, Smart Supply Chain, and Smart Working) is considered front-end technology. The four smart dimensions are concerned with organizational and business requirements on purpose to add value to manufacturing and the whole product lifecycle, also to provide efficiency to the complementary operational activities. The second layer of technologies is composed of artificial intelligence, big data analytics, cloud computing, the Internet of Things artificial and cyber-physical systems. The base technologies are base and presented in all the dimensions of different technologies. As stated in Figure 6, we propose a new architecture that present and structure the connection between the key technologies of Industry 4.0 and Agriculture 4.0.
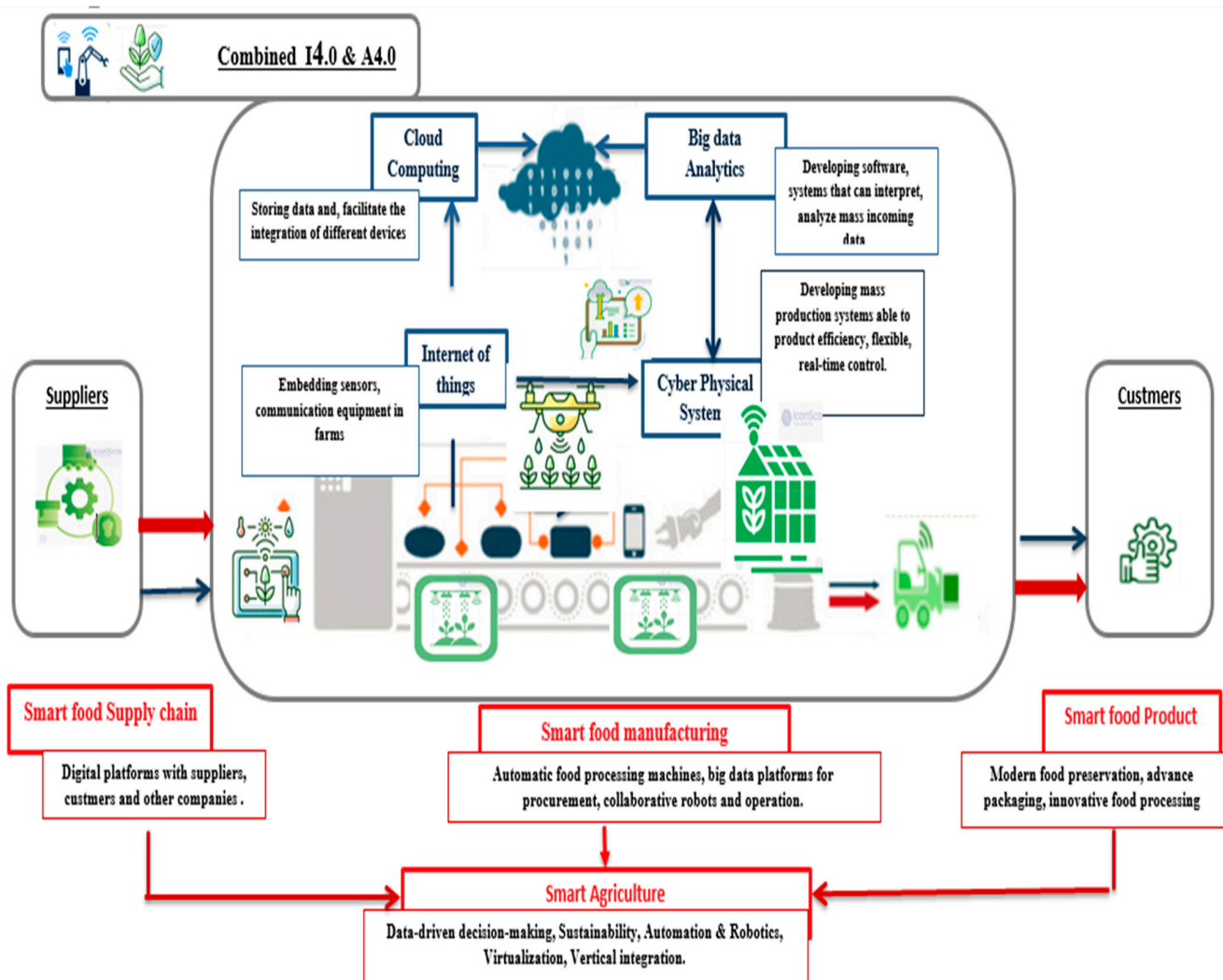

Figure 6. A proposed architecture between key technologies of I4.0 and A4.0.

7.1. Internet of Things

IoT is a concept that explores the link between physical and digital objects through standardized and interoperable communication systems [102]. It has been widely utilized in various fields, including smart cities, home automation, and medical services. Agriculture is not exempt from the implementation of Internet of Things (IoT) devices, as continuous monitoring and control of agricultural activities are essential. The combination of various Agriculture 4.0 technologies with IoT has demonstrated significant potential for increasing agricultural efficiency, with each providing a unique set of requirements [103]. The agricultural literature on IoT has employed various communication protocols and technologies to tackle these issues. With the rapid progress of communication technology, a wide range of wireless networks are now available to cater to the diverse requirements of agricultural applications. These networks, including WiFi, RFID, Bluetooth, NFC, ZigBee, and Sigfox, offer improved coverage, capacity, connection density, and end-to-end latency. This enables high-throughput phenotyping of crops and real-time remote machine control, among other benefits. An investigation article discusses a smart agriculture system based on Internet-of-Things technology [104]. By implementing an advanced agricultural system, they explored the difficulties associated with implementing IoT technology in the agricultural sector and, more specifically, the emerging trends in IoT technology development [105].

7.2. Artificial Intelligence (AI)

AI is a discipline within computer science. Artificial intelligence seeks to understand the essence of human intelligence through the execution of tasks in a manner like humans [106]. Currently, the primary AI research areas are intelligent robotics, natural language processing, and image processing. Similarly, AI's application domains are expanding rapidly. AI has several agricultural applications, including the detection of plant diseases [107], monitoring the health of agricultural machinery [108], and digital soil mapping [109]. Ref. [110] provided an update on the latest scientific progress regarding the use of artificial intelligence in agriculture, which enhances our understanding of AI-driven smart farming [111]. The existing literature mostly focuses on integrating artificial intelligence (AI) into networks of wireless sensors for smart sensing and monitoring in agricultural applications. An automated irrigation system was created in [112]. A network of wireless sensors was used to gather data about the conditions of the farmland (humidity, moisture, etc.). To determine the optimal time for irrigation, the data were fed into an artificial neural network for analysis. The proposed system can save 92% of the water used by conventional irrigation systems. Vincent developed a sensor network that can supervise soil parameters and analyze soil conditions using artificial intelligence [113]. The system can assist farmers in determining whether the land is appropriate for further cultivation, which contributes to the efficient use of farmland. Artificial intelligence was proposed for use in the agricultural industry by Dasgupta et al. [114]. Using machine learning, the system can intelligently recommend suitable crop precipitation to agricultural producers based on agricultural information such as annual rainfall, soil pH, and so forth. Somov developed an Internet of Things (IoT)-based monitoring system [115]. Using a wireless sensor network, the system is used to monitor greenhouse environmental parameters and make the necessary adjustments to maintain a crop-growing environment that is optimal. In addition, neural networks are also used to forecast whether the current greenhouse environment will result in crop diseases, allowing for early prevention.

7.3. Robotics

Robotics have become widely embraced in manufacturing industries to enhance productivity, ensure goods authenticity, and remove the necessity for humans to conduct repetitive tasks. Meanwhile, there is a significant shift happening in agricultural production due to the integration of robotics in the field. In addition, robotics is revolutionizing agricultural output, with notable applications such as monitoring, aerial spraying, and autonomous farming. In protected cultivation's cluttered environments, manipulation

is quite difficult. While conducting a task, the robot must avoid damaging the crop, as this would immediately diminish its value. However, the robot should be permitted to strike objects like leaves [116]. Through collaborative efforts, advanced tractors can generate efficient operating paths and autonomously navigate around barriers in the field, prioritizing the safety of farms and workers [117]. Using computer vision technology, robotic weeders can differentiate between weeds and crops. This allows them to accurately target and apply pesticides specifically to the weeds, effectively removing them without causing harm to the crops [118]. Socioeconomic barriers to the adoption of robots in agricultural production are an additional crucial aspect of their successful introduction. In addition to being able to correctly complete a task, the robot must do so in a cost-efficient manner [116].

7.4. Big Data Analytics

BDA allows for a comprehensive exploration and valuable analysis across various sectors including farming, medical care, the cyber-physical environment, smart towns, supply chains, and more. This offers valuable insights by utilizing innovative BDA tools like NoSQL, BigQuery, Map Reduce, Hadoop, Flume, Mahout, Spark, WibiData, and Skytree to improve the effectiveness and make decisions in agricultural production. The Internet of Things facilitates the gathering of data at every step of farming operations and the management of the supply chain for agricultural and food products. Therefore, the incorporation of big data analytics in marketing, processing, transportation, and food manufacturing will have a substantial impact [119]. The implementation of a data-driven agricultural economy would significantly transform the patterns of agricultural output and consumption. For instance, agricultural predictive analytics and mobile agricultural expert systems depend on the capabilities of big data to provide farmers with intelligent suggestions for precision farming. Accurate risk evaluation can help farmers better manage agricultural risks, including those related to production, economy, associations, as well as personal and financial aspects. A data-driven agriculture strategy was described in [25] to manage durability in the by-products supply chain. Ref. [120] provided a thorough evaluation of the impacts of BDA on the agri-food supply chain, considering several perspectives such as functional, economic, environmental, social, and technological. Studies [120–122] recently conducted comprehensive evaluations of the challenges related to the utilization of big data analytics in farming.

7.5. Wireless Sensor Network (WSN)

WSNs have become increasingly used in various ways in agriculture to improve the effectiveness of conventional farming techniques [123,124]. Sensor networks perform three fundamental functions: identification, connection among the network's components, and calculation, utilizing hardware, software, and algorithms [12]. A wireless sensor and actuator network (WSAN) is a specialized version of a wireless sensor network (WSN) that incorporates an actuator component. An actuator is a tangible apparatus, such as lighting, fans, valves, pumps, irrigation sprinklers, and similar devices, that engages with and affects the surrounding environment. These networks consist of multiple sensors and actuator nodes that are interconnected over a wireless connection. These nodes frequently consist of multiple components, each with a distinct function, such as detection, control, computation, and communication. WSNs (wireless sensor networks) and WSANs (wireless sensor and actuator networks) are utilized in many ways within the framework of Agriculture 4.0 to enhance agricultural techniques [125]. These technologies have facilitated the real-time monitoring of several elements, including water parameters, soil characteristics, and weather conditions. This allows for prompt responses in the field [126].

8. Industry 5.0 Key Technology Applications in Smart Agriculture

The agricultural sector has undergone significant changes in the transition from Agriculture 2.0 to Agriculture 5.0, marking a historic evolution. Agriculture 5.0 signifies a

groundbreaking era, in which innovative technologies are incorporated to improve efficiency and sustainability tailored to the specific requirements of fields and livestock. The convergence of robotics, extended reality, and 6G technologies represents a major advancement, facilitating the real-time monitoring and automation of farming practices. Artificial intelligence and big data play a crucial role in Agriculture 5.0, providing valuable insights for decision-making and predictive analytics. The effective interaction and processing of data are facilitated using natural language processing. When moving towards Agriculture 5.0, it is important to consider the societal challenges that may arise. These challenges include technological advances, lock-ins, and the necessity for stakeholders to change their behaviors to adopt and customize solutions more quickly. Industry 5.0 has become increasingly important in various applications [127], thanks to the adoption of innovative technologies. These include big data analytics, 6G and beyond robotics, digital twins, and others. These incorporated technologies, combined with cognitive skills and innovation, have the potential to enhance agriculture production capabilities and expedite the delivery of personalized food products for digital farms. We offer a comprehensive and precise explanation of smart agriculture and its associated parameters. Figure 7 illustrates the four Industry 5.0 technologies and their agriculture applications discussed in this section.
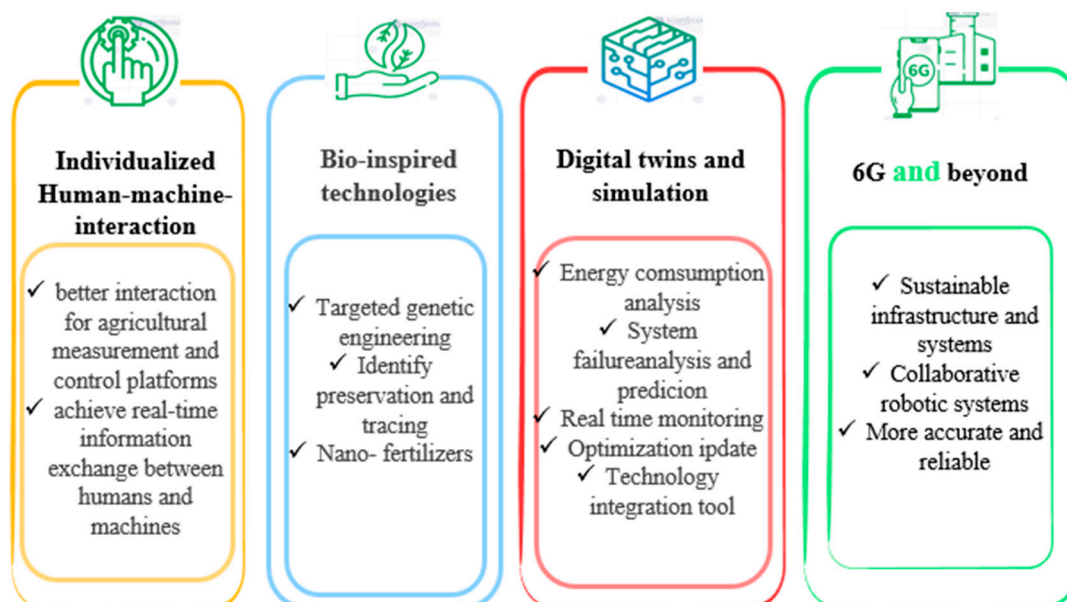

Figure 7. Industry 5.0 technologies and their agriculture applications.

8.1. Individualized Human–Machine Interaction

Combining intelligent machines and systems in agriculture can optimize the use of land and water resources, reduce the use of pesticides and fertilizers, and reduce costs, to name a few advantages. Another nontrivial aspect is the significant reduction in accident risk in extreme environments, such as mountainous terrain or steep slopes. Intelligent machines and systems are important parts of future infrastructures that will be based on how people and machines interact and share information [128–130]. Various experts and entrepreneurs are engaged in the advancement of automated agricultural machinery (i.e., robots). If developed properly, automated agricultural machines could reduce farm employees' workloads by allowing one worker to remotely supervise many units from a main place [131]. The final effectiveness of a similar human–machine (or human automation) system will depend on the farmer's ability to obtain information from each autonomous agricultural machine through an interface quickly and effectively. The design of the interface must give significant weight to optimize human interaction with the autonomous agricultural machine. The effectiveness of this human–autonomy team will depend on both team members having a shared understanding of system status [131].

Different studies explore the human–machine interaction in agriculture. First, Ref. [132] performed a laboratory experiment in which research members, acting as remote supervisors, were tasked with identifying machine malfunctions presented via graphical indicators or video footage. The experimental findings revealed that live video footage did not prove particularly effective in identifying machine difficulties or malfunctions. Nevertheless, the presence of live video instilled supervisors with a greater sense of confidence in fulfilling their supervisory responsibilities. Their findings suggest that an interface for remote monitoring should include real-time video footage of the agricultural machine's overall view, along with graphical indicators that provide comprehensive details about the machine's status. Second, Ref. [133] gathered auditory data from combined harvesters operating in three separate modes. By employing a neural network to categorize the auditory signals, it became feasible to precisely distinguish the three unique operating modes. The results obtained from Simundsson's proof-of-concept research suggest that the technology for remotely supervising an autonomous agricultural machine via an automated interface could be enhanced to include auditory data [133]. In this paper [128], the retrofitting of a tracked vehicle to make it capable of conducting independent operations is described. The objective was to develop a machine for agricultural applications that can assist harvesting operations in mountainous areas with steep terrain while protecting the operator.

8.2. Bio-Inspired Technologies

Bio-inspired technologies allow large agriculture to be more productive and efficient while having less of a negative effect on the environment [134,135]. This improved with robotics for picking fruits and vegetables and swarm robotics [136]. The sub-categories of bio-inspired technologies used in resource management include solar energy harvesting and water conservation. In addition, numerous bio-inspired innovations have acquired widespread recognition, such as the fog water collection, which was inspired by the darkling beetles of the Namib Desert, biomimetic materials that display distinctive relaxing, dynamic, and multifunctional properties, and hierarchical characteristics for applications requiring lightweight and durable construction [137]. With the development of micro-robots that can perform specialized tasks, robots designed with the utmost precision for agriculture would enhance. A group of scientists from the University of Exeter effectively developed bio-hybrid micro-robots inspired by nature that integrated synthetic and biological elements to execute nanoscale biochemical procedures with extreme accuracy [138]. Nevertheless, there is significant backing for bio-inspired technology in agriculture to enhance crop yields and boost productivity. Muller et al. successfully demonstrated the progression of a self-governing aircraft that mimics birds, with the aim of controlling bird populations [139]. A bio-inspired coordination protocol was proposed for the management of Unmanned Aerial Vehicles (UAVs) in the agriculture domain [140]. The bio-inspired approach appears to be the most effective at killing parasites and the most scalable in terms of network bytes transmitted. Consequently, bio-inspired algorithms with specific metrics for the agriculture precision domain could be an intriguing research topic for the coordination strategy. The concerns raised by [141] were in line with [142] research, which asserted that bio-inspired robotic systems cannot outperform humans shortly. Briefly, bio-inspired robots can supplement human labor. Nevertheless, the unique characteristics incur substantial costs. Unlike rigid-bodied robots, soft bio-inspired composites are costly because they incorporate artificial intelligence [143]. Advanced technologies like robot software (ROS) [144], deep learning systems, and RGB-D cameras with GPU processors [143] can be combined with soft robots. Recent breakthroughs have shown that it is possible to modify materials with the aim of achieving certain agricultural purposes.

8.3. Digital Twins and Simulation Technologies

Digital twins have the potential to bring smart agriculture to new levels of productivity and sustainability. Using digital twins as the primary means of farm management facilitates the decoupling of physical flows from their planning and control. Due to their emergence,

there are numerous definitions of digital twins in the literature. Initially, from a Product Life Cycle (PLC) standpoint [145], a complex product's digital twin is a multi-physical, multi-scale, and probabilistic simulation model. It employs up-to-date sensors and physical models to replicate the physical world in the digital realm and vice versa. Second, from the perspective of the Internet of Things (IoT) [146], a "Digital Twin" is a computer program that takes, as inputs, real-world data about a physical object or system and generates, as outputs, predictions or simulations of how those inputs will affect the physical object or system. Digital twins have recently generated considerable interest, but a solid foundation for their development and implementation is still being established [147]. Digital twins' applications in smart farming are in their infancy [148]. There have been a few studies and cases examining the use of digital twins in farm management. Still, further investigation is needed to fully understand how digital twins may be effectively utilized for planning, monitoring, controlling, and optimizing agricultural processes.

Digital twins represent a revolutionary improvement in the field of smart farming. It utilizes and expands upon current technologies, such as precision farming, the Internet of Things, and simulation [149]. Consequently, there are numerous uses in the farming industry, even though they may not always be classified as digital twins. However, many of these applications are still quite basic digital twins, with a primary focus on digital representation in cloud dashboards, for example. The advancement of more intricate programs, with the ability to predict and prescribe actions all through the entire lifecycle of a product, is still in its preliminary stages.

The initial exploration of the possibilities of digital twins in agricultural management was conducted by [150]. This study explored the concept of digital twins within the context of the Internet of Things, where physical things are connected to their digital representations in real-time by a network of networked sensors. The paper demonstrated the implicit adoption of digital twins in smart farming, although most current applications only provide the most fundamental monitoring features. To better understand how digital twins could be implemented in pig farms, ref. [151] conducted a feasibility study. They proposed a smart livestock farming system that could be designed with the help of these so-called digital twin platforms, and they introduced three of them (Prefix, Ditto, and Watson). To put digital twins into practice in vertical farming, ref. [148] presented a technical model and prototype based on the Internet of Things. The paper's digital twin is meant to aid in all phases of a vertical farm's existence, from initial conception to ongoing maintenance and improvement. Finally, ref. [152] claimed that, compared to other fields, agriculture has seen comparatively fewer studies of digital twins. As an added benefit, they talked about the role that digital twins could play in hydroponics agriculture.

8.4. 6G and beyond

With 5G New Radio (NR), the fifth generation of wireless communication systems, users can take advantage of extremely high transfer rates as well as dependable, low-latency services [153,154]. Already, 5G is being incorporated into the development of industrial automation systems, which will be used, among other things, to outfit Industry 4.0 smart factories. Now, 5G (the fifth generation of mobile technology) is commercially viable on a large scale, as millions of base stations have been deployed. Nevertheless, 5G still has limitations [155]. The extremely prohibitive cost of 5G infrastructure is a problem. It is worth noting that the coverage area of 5G base stations is smaller compared to that of 4G base stations. Therefore, a greater number of center stations are necessary to reach the complete 5G network. An additional crucial factor to contemplate is the security of 5G technologies. As an example, the reliability of management services and controllers is not adequately verified in software-defined networks (SDNs) [156]. Furthermore, it should be noted that ground-based networks exclusively incorporate the foundational network structures of 5G, such as heterogeneous networks (HertNets). Several nations, including China and the EU, have initiated investigations into 6G technology, which is anticipated to revolutionize connectivity, intelligence, and perception. The amalgamation of the biological,

physical, and digital realms shall propel every industry's digital transformation [157]. Currently, academic and industrial research is shifting its attention to 6G. There have been numerous publications [158,159] detailing the vision and technologies of 6G. A recurring theme in many of these works is that the 6G network will be designed for combined communication and sensing, transforming it into a sensor to create a digital sixth sense that augments human intelligence. The 6G system and beyond will satisfy the needs of a networked world and provide ubiquitous wireless connectivity for everyone. The advent of digital technology presents a significant opportunity for individuals in poverty to narrow the socioeconomic gap, capitalize on digital prospects, distribute digital benefits, achieve long-term poverty reduction, and halt poverty transfer across generations [160]. In the context of precision agriculture, soil moisture indicators have been a vital component of irrigation decision-making for decades. However, real-time measurement and irrigation automation solutions continue to face obstacles due to insufficient wireless coverage. The advent of digital technology presents a significant opportunity for individuals in poverty to narrow the socioeconomic gap, capitalize on digital opportunities, distribute digital benefits, achieve long-term poverty reduction, and halt poverty transfer across generations. As a result of rural connectivity gaps, scalable and timely access to such data is a major obstacle. Consequently, we anticipate that 6G, with its emphasis on ubiquitous wireless access, will play a significant role in accelerating technology adoption in agricultural production [160].

9. Limitations and Future Practical Implications

The fourth industrial revolution enables companies to integrate productivity and velocity to effectively address market demands, hence enhancing their system's productivity and competitiveness. Nevertheless, individuals who choose not to pursue this route face the possibility of being marginalized by global competition [161]. Thanks to the advancements in agriculture, numerous technologies have emerged that enable the establishment of intelligent farms. However, whether individual farmers embrace them or not depends on several other factors, including usability and the discovery of optimal methods. It is important to consider both the farming and farmer-centered aspects. By adopting this approach, the concept of smart agriculture can ensure long-term sustainability. It is essential for farmers to adopt a new mindset to establish a productive and resilient farming system that can endure over time [11]. Instead, these ideas form the foundation of a thriving industry.

Global competition may marginalize individuals who choose not to pursue this route. Nevertheless, there is a lack of widespread implementation of innovative models on individual farms, even though the numerous benefits that smart farming could offer. The methods for achieving these benefits in terms of efficiency, profitability, and sustainability are still uncertain. The success of Agriculture 4.0 [50] and the potential Agriculture 5.0 relies heavily on establishing a suitable structural and governmental structure, embracing novel innovations, training, and skills [41].

Industry's current practices also impact the agricultural food producing process. The rapid industrialization of the farming industry has resulted in significant environmental issues, such as soil deterioration, erosion, compaction, and contamination. The comprehension of how industrial processes are impacting agriculture has led to soil erosion that requires improvement. The 4.0 revolution should encompass both technology innovation and environmental concerns.

There is a growing concern about the potential risks that agriculture faces due to its heavy reliance on technological advancements [162]. These risks include technical problems, system malfunctions, and external disruptions [25]. Farmers should consider developing backup plans and establishing support systems to mitigate the risks associated with relying heavily on technology. By establishing redundant measures and backup solutions, the durability of agricultural systems can be significantly enhanced [9].

There is a noticeable difference in the availability of technologies and resources needed for adopting digital farming among farmers. The digital divide, which includes disparities

in access to and proficiency with digital technologies, exacerbates current disparities even more [38]. We must make efforts to bridge the digital gap, enabling small-scale and resource-constrained farmers to reap the benefits of Agricultural 4.0. We can effectively mitigate this difficulty by implementing policies, establishing training programs, and adopting cost-effective technological solutions [126].

10. Conclusions

The fourth industrial revolution enables firms to integrate market responsiveness and productivity, enhancing the efficiency and competitiveness of their systems. However, individuals who fail to follow this path face the possibility of being left out of global competition. The implementation of essential technologies from the new industrial revolution in agriculture has made smart farms a feasible reality. Nevertheless, the individual farmers' adoption of these criteria is dependent on various other factors, such as their applicability and the identification of optimal methods. The agricultural sector and farmer-centric approach is necessary. The concept of smart farming will only be future proof if implemented in this specific manner. To establish a prosperous and enduring agricultural system, farmers must embrace a new mindset. Instead, these concepts form the basis of a competitive industry. Although Industry 4.0 has made significant advancements in both scientific study and practical implementation, Agriculture 4.0 is still limited to theoretical concepts and has not been widely implemented by companies. Furthermore, the industry is progressing towards a 5.0 industry, notwithstanding the main sector's current inadequacy. However, Agriculture 5.0 represents a significant advancement for ESG (environmental, social, and governance) investors, as it has the potential to tackle climate change and various other serious problems while also considering environmental, social, and governance factors. This paper discussed the connections between the fourth and fifth industrial and agricultural revolutions. Initially, we outlined the driving force behind the transition from 4.0 to 5.0 in the fields of industry and agriculture. Furthermore, we provided precise explanations of Industry 4.0 and 5.0, as well as Agriculture 4.0 and 5.0, and discussed the constraints associated with these concepts. Third, we delved into the historical perspectives surrounding the five steps of the industrial and agricultural revolutions. In addition, we provided an overview of the strategic plans for Industry and Agriculture 4.0 in various countries. We uncovered the primary technologies utilized in the realms of Industries 4.0 and 5.0, along with their specific implementations within the farming industry.

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