Agriculture 4.0 - Opportunities, Challenges, and Current Status in Serbia

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Abstract: - Industry 4.0, or the Fourth Industrial Revolution, is crucial in transforming agriculture, marking a significant turning point for the sector. Information technology enables more efficient agricultural production, alignment between production and technological innovations, and better management of farm markets and pricing policies. The primary objective of this work is to present the concept of Agriculture 4.0, discuss its application areas, and explore potential opportunities. Additionally, this work addresses the current situation and prospects in Serbia's field of study. Key factors for successfully implementing Agriculture 4.0 in Serbia include adapting farm sizes, enhancing farmers' education, improving broadband access, ensuring adequate agricultural funding, gaining support from policymakers, and raising technology awareness through media and institutions, based on secondary data from the Republic Statistical Office and Government of Serbia publications. With digital agricultural tools, which can be used in all farming and livestock systems, it becomes possible to achieve optimization, high precision, real-time information usage, and tailored resource application, thereby creating leverage in agricultural implementations. However, the transformation of the agricultural sector globally and in Serbia is a complex process that requires coordinated efforts from all stakeholders to ensure sustainable development and competitiveness in the global market. Regarding future research, it would be valuable to evaluate the feasibility of implementing this concept at the family farms level and assess farmers' willingness to adopt it.

Key-Words: - Agriculture 4.0, Development, Digital Technologies, Serbia, Precision Farming, Sustainable Development.

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1 Introduction

Industry 4.0, or the Fourth Industrial Revolution, is crucial in transforming agriculture, marking a significant turning point in this sector. Agriculture faces numerous global challenges, such as pollution, climate change, rising food demand driven by population growth, urbanization, the shrinking agricultural workforce, and limited resources like fertile land and water, [1]. In addition to ensuring food security and meeting diverse dietary needs, agriculture must also meet the demand for high-quality food products. Specific goals have also been established, such as increasing productivity, enhancing competitiveness, protecting the environment, and promoting sustainable development. Consequently, there is a growing need to utilize information and communication technologies in the agri-food sector to address these challenges effectively. Information technology allows for more efficient agricultural production, better alignment between production and technological innovations, and improved management of farm markets and price-related policies. The close link between agricultural development and technological innovation, combined with the ability to respond rapidly and concisely to changes, is crucial for advancing the sector.

To fully grasp Industry 4.0, it is essential first to clarify the concepts of the digital economy and digital technologies. The term "digital economy" refers to new business models, products, services, markets, and rapidly expanding sectors of the economy, particularly those that rely on digital technologies as the core infrastructure of business operations. The digital economy thrives on the intensive use of digital technologies in innovation, creativity, and creating new value, [2]. Modern digital technologies can be divided into two major groups: primary and secondary digital technologies. Primary technologies include mobile technologies (Mobile), social networks (Social), cloud computing

(Cloud), big data analytics (Big Data), and sensors and the Internet of Things (IoT), [3]. Secondary digital technologies encompass robotics, 3D printing, drones, wearable technologies, virtual and augmented reality, and embedded intelligence. Mobile technologies and social networks are widely known and used by almost everyone today.

Among the primary technologies, cloud computing has long been seen as the fulfillment of the dream of computing as a utility, enabling users to remotely store their data in the cloud and benefit from on-demand services and high-quality applications from a shared pool of configurable computing resources. This capability is particularly relevant in sustainability, as cloud computing supports the infrastructure needed for advanced technologies like big data analytics (BDA) and the Internet of Things (IoT), which are critical for optimizing resource use and reducing environmental impact, [4]. Big data analytics enables the processing of vast amounts of information. A prime example is Stockholmståg, Sweden's rail system, which uses big data analytics to predict train delays hours in advance. One of the best examples of the synergy between cloud computing, the Internet, mobile technologies, and big data is Netflix, [2]. Advances in information technology have also enabled the creation of a global network that connects users and uniquely identified objects, known as the Internet of Things. The IoT is a network of physical objects embedded with electronics, software, sensors, and connectivity, exchanging data between manufacturers, operators, and other connected devices. Communication between people, devices, and between people and devices in cyberspace requires a standardized communication language, internet connectivity, and an internet protocol with enough capacity to support many participants, [5]. IoT is increasingly present in various applications, from industrial uses to emergency services, city lighting, and other smart city initiatives. In urban areas, IoT technologies support the creation of smart cities, improving budget efficiency, quality of life, and the city's appeal to investors, [6]. The IoT represents a promising set of technologies with significant potential to modernize agriculture as well. This is supported by the fact that IoT's most extensively researched applications are in the agricultural sector, followed by its uses in the food industry and other fields such as energy, healthcare, and industrial sectors, [7].

Regarding secondary digital technologies, more and more people are incorporating these technologies into their daily lives and various fields of work. The Fifth Industrial Revolution is on the horizon. Robotics and drones are key examples of these technologies and have applications in many aspects of human life. These devices have become indispensable in industries, enhancing the efficiency and precision of production processes. In medicine, robotics enables sophisticated surgeries and improves diagnostics, while drones rapidly deliver medical supplies and emergency assistance, [8]. These technologies are revolutionizing agricultural practices through precise crop spraying, crop monitoring, and more efficient resource management, leading to significantly increased productivity and sustainability. These examples illustrate how secondary digital technologies are becoming a driving force behind progress in modern society.

2 Development of Industry and Agriculture

To grasp the concept of Agriculture 4.0, it is essential to first review the preceding phases of development. These phases frequently overlap, meaning that older and newer technologies can coexist simultaneously. Furthermore, agricultural development progresses at different intensities across various world regions. Four key phases can be identified in the evolution of the industrial and agricultural sectors. Tracing the history of agriculture and its pivotal milestones, the first phase, Agriculture 0.0, began around 5500 BCE. In this phase, people relied on animals to work the land. Agriculture was labor-intensive and had low productivity due to primitive tools. A significant turning point came with the start of the First Industrial Revolution, which coincided with Agriculture 1.0 and took place primarily in the 19th century. Industrialization brought new tools and machinery to agriculture, such as steam-powered tractors and combines, [9].

The Second Industrial Revolution, occurring in the late 19th and early 20th centuries, saw the rise of mass production and electricity use. A growing population and increasing consumer demand required a significant boost in production capacity. Large production complexes were established in response, capable of efficiently producing a wide range of consumer goods at scale. Achieving this required the construction of extensive industrial facilities, a revolution in work organization, and increasing mechanization in production processes, [10]. Agriculture 2.0 was characterized by a transition from animal power to machines during this period, enabling more complex processes. The Second Industrial Revolution facilitated the mass production of agricultural tools. Mechanization reduced the need for human labor in agriculture while using fertilizers, pesticides, and advanced machinery increased yields and productivity.

The Third Industrial Revolution is considered to have begun around 1974, characterized by rapidly declining prices for production machinery and computers, with computer prices falling by as much as 19% per year. This period was defined by technological advancements primarily driven by the rise of information technology. While companies in 1955 allocated only 7% of their investments to information technologies, that percentage grew to 30-40% during the 1980s, [11]. During the Agriculture 3.0 phase, GPS technology enabled the automation of management, digital data processing, and precision farming. This allowed farmers to optimize their production processes and use resources more efficiently, [10].

The Fourth Industrial Revolution introduced technologies to minimize resource consumption and maximize efficiency for increased production. Agriculture 4.0, in line with these advancements, incorporates drones, sensor technologies, robotics, automation, and data analysis for predictive decision-making. These innovations are driving the development of a new model of agricultural production known as sustainable agriculture, which leverages technology and data to enhance efficiency, productivity, and cost-effectiveness. The primary goal is to increase food yields while minimizing environmental impact, [12].

The question arises as to whether the next phase, the Fifth Industrial Revolution, has already begun—and if not, when it will arrive. The Fifth Industrial Revolution is distinct from the Fourth, emphasizing collaborative synergy over competition (and possible replacement). In the Fourth Industrial Revolution, the goal was to expand the scope and number of innovative technologies across manufacturing, services, and retail sectors, where humans and robots competed for jobs, and the use of technology was maximized. In contrast, the Fifth Industrial Revolution shifted focus toward understanding where each participant, human or machine, excels and how they can work together instead of one replacing the other. Its core premise is that humans should collaborate with technology to leverage each other's strengths and offset their respective weaknesses, [13]. This collaboration has been metaphorically described as a 'joint dance' between humans and machines. By working together and building on mutual strengths rather than competing, humans and machines can achieve synergistic and harmonious outcomes for all stakeholders, [14].

3 Tools and Technologies Used in Agriculture 4.0

Digital agriculture encompasses a broad application of digital technologies in farming. In contrast, precision agriculture refers to a specific methodology that leverages these technologies to achieve more accurate and efficient farming practices. Though similar, they are not identical concepts. Digital agriculture uses computing and communication technologies to enhance profitability and sustainability in the agricultural sector. It introduces new opportunities alongside the widespread adoption of advanced, interconnected technologies—often called the Fourth Industrial Revolution—into farming. With digital agricultural tools applicable across all farming and livestock systems, farmers can achieve optimization, high precision, real-time information utilization, and tailored resource management, thus driving efficiency in agricultural operations, [15].

Efficiency and productivity are projected to increase in the coming years as precision agriculture, a key component of digital farming, becomes more prevalent and farms become increasingly connected. By 2050, the average farm is expected to generate 4.1 million data points daily, compared to 190,000 in 2014. However, while the growing number of connected devices presents a significant opportunity for food producers, it also adds complexity. Cognitive technologies will be crucial in managing this complexity by helping with understanding, learning, reasoning, interacting, and enhancing operational efficiency. The United Nations predicts that by 2050, two-thirds of the global population will reside in urban areas, reducing the rural workforce. New technologies will thus be essential to support farmers, making operations more informed, automating processes, identifying risks, and solving problems. In the future, farming skills will increasingly revolve around knowledge and data-driven decision-making rather than traditional agricultural tasks. Farmers will make data-informed decisions by analyzing and correlating information on weather conditions, seed types, soil quality, disease probabilities, historical trends, market data, and pricing. AI-powered chatbots, already used in retail, travel, healthcare, and insurance sectors, could also provide valuable insights and recommendations to farmers facing specific challenges, [16].

A key concept in Agriculture 4.0 is the smart farm. This innovative approach reduces the need for a large workforce once required for production. Instead, smart farms rely on sensors and meteorological data, allowing a central computer to automatically instruct drones and other devices on when and where to perform specific tasks. These devices autonomously execute the tasks, while farmers monitor the reports generated by these systems and intervene only when necessary. The technologies within the smart farm ecosystem do not operate in isolation but rather communicate and collaborate within a complex, dynamic digital environment. Although integrated, each technology can function independently, providing significant value to farmers. The Internet of Things (IoT) and Big Data are foundational elements of Agriculture 4.0. IoT devices facilitate wireless access, data collection, and communication with actuators and sensors, helping farmers make informed decisions. IoT technology connects structured and unstructured data, offering valuable insights into food production. IoT platforms like IBM's Watson use machine learning on data from sensors or drones to transform farm management systems into accurate AI-powered operations. These sensors continuously provide real-time data on crop or livestock conditions, including air and soil moisture levels, nutrient availability, leaf moisture, and other critical factors. This information is compiled into databases, allowing farmers to plan interventions more efficiently and effectively. A key pillar of Agriculture 4.0 is the continuous collection, storage, and analysis of accurate data, enabling a more productive and efficient agricultural system, [17].

Drones also play a significant role in Agriculture 4.0. Although it is no longer considered a new technology, drones have made a considerable impact thanks to investments and regulatory support. According to reports, the value of drone-based solutions across various industries could exceed $127 billion, with agriculture being one of the most promising areas for their application. Drones provide a high-tech transformation in agriculture, offering precise soil and field analysis, planting planning, and data collection for irrigation and nutrient management. Startups have developed drone-based planting systems that reduce planting costs by 85%. Drones can scan the terrain and spray crops in real time for uniform coverage, working five times faster than traditional machines. Crop monitoring, a challenging task, can be made more efficient using drones. Time-lapse images can track crop growth, revealing inefficiencies in production and enabling better management. Sensor-equipped drones can detect dry areas in fields that need attention.

In contrast, drones with visible and near-infrared scanning capabilities can monitor plant health and alert farmers to potential diseases. In the future, drones could operate as autonomous swarms, collecting data and performing tasks. However, the current challenge lies in developing sensors that can gather high-quality data and software capable of processing that data effectively to perform these tasks, [16].

Table 1 summarizes the areas of application, the latest technologies used, and the tools, equipment, and sensors employed in Agriculture 4.0.

Table 1. Areas of application, technologies, tools, equipment, and sensors in digital agriculture, [17]

Areas of Application	**Technologies, Tools, and Equipment**	**Sensors**
Irrigation system management	Drones	Leaf sensors
Identification of diseases and pests	Autonomous tractors	Tree sensors
Assessment of agricultural land condition	3D printing	Temperature sensors
Crop condition assessment and monitoring	Harvesting and collection robots	Humidity sensors
Efficient input utilization		Size measurement sensors

4 Status and Conditions for the Application of Agriculture Digitalization in Serbia

This study uses secondary data from official publications and reports published by the Government of the Republic of Serbia, the Ministry of Agriculture, Forestry, and Water Economy of the Republic of Serbia, and the Statistical Office of the Republic of Serbia. The information was obtained by means of a thorough review of publicly available documents, such as agricultural reports, policy analyses, and digital transformation plans published by these organizations. These resources provide reliable and up-to-date data on agricultural methods, technology adoption, and economic metrics critical to Serbia's progress toward Agriculture 4.0. Finding trends and patterns in the use of digital technologies in agriculture is made possible by data analysis, which spans several years and combines qualitative and quantitative methodologies. Relevance and dependability were guiding principles in the data selection process, guaranteeing that only information from reliable sources—such as the official documents of the aforementioned institutions—was examined. This guarantees the reliability of the research findings and the data's correctness and credibility.

Agriculture 4.0 refers to the integration of information and communication technologies into agricultural production, inspired by the Industry 4.0 concept. However, its implementation has been slower compared to other sectors. While Industry 5.0 is already emerging, Agriculture 4.0 is still not widely adopted, as it is currently utilized on a limited number of farms worldwide, [18]. Presently, it is only applied to a small fraction of farms. The digitalization of agriculture requires continuous enhancement of workers' knowledge and skills, with well-educated managers playing a key role in establishing an efficient system that integrates electronics and information technologies. The digital transformation of the agrifood sector offers considerable benefits. Still, to fully realize these advantages, we will need to implement significant changes across agricultural practices, rural economies, community structures, and natural resource management. This journey will be challenging and will require a comprehensive and coordinated approach, [19].

Serbia's food sector holds significant economic importance due to favorable agroecological conditions, the availability and structure of arable land, a long tradition of food production, and proximity to EU markets. Shifting consumer preferences drive global demand for high-quality, diverse food products, creating substantial opportunities for the sector's growth in Serbia. However, Serbian companies striving to remain competitive must address challenges such as increasing productivity, improving environmental performance, and strengthening resilience to weather conditions and market fluctuations. The most significant potential lies in innovative trends that optimize the use of natural resources, transforming Serbia's centuries-old agricultural tradition into a modern development resource. To enhance productivity in this sector, capital investments and investments in research, development, and education are essential.

The Government of the Republic of Serbia has prioritized digitalization across all sectors, including agriculture. Agriculture is identified as one of the priority areas within the Smart Specialization Strategy of the Republic of Serbia (2020-2027). Interviews with food production and processing stakeholders highlight significant potential and innovative trends in optimizing Serbia's natural resources for agricultural production. As outlined in the strategy, food, and beverage production should be positioned as a strategic focus for Serbia under the "Food for the Future" initiative, which includes three core sub-sectors: high-tech agricultural production, value-added food products, and sustainable food production chain, [20].

Serbia's agriculture has low productivity and a lack of processing industries. Yields are lower due to inefficient use of modern agricultural machinery and agrotechnical practices, with lower labor, energy, and land costs often compensating for this. However, boosting productivity is crucial for driving competitiveness. The number of producers transitioning to high-tech agricultural production is rising, with investments from local farmers, other industries, and foreign investors. High-tech agriculture requires advanced solutions, fostering innovations in seed production, fertilizers, plantation infrastructure, measurement and control equipment, growth regulation, plant protection, waste valorization, packaging, and logistics systems. While some of these sectors are already developed in Serbia, others hold additional potential for growth. Beyond conventional agriculture, modern technologies such as molecular genetics, biotechnology, intelligent machines, sensors, the Internet of Things, geolocation, satellites, drones, robotics, and artificial intelligence are revolutionizing the industry. Digital agriculture fosters synergy between innovators, the private sector, farmers, universities, and research centers, linking producers to markets while shortening value chains and reducing transaction costs, [20].

Key indicators for developing digital or e-agriculture in Serbia are primarily related to the state of telecommunications infrastructure, as modern telecommunications networks are a prerequisite for successfully adopting the Agriculture 4.0 concept. Table 2 presents the key factors influencing the development of digital agriculture in the Republic of Serbia, [5].

The data presented on the factors influencing digital agriculture pertains to rural households and those located in urban areas. According to the Republic Statistical Office, in 2023, urban households have 11.10 percentage points more internet connections than their rural counterparts. Additionally, the percentage of rural households that own a computer is 15.40 percentage points lower compared to urban households in 2023. This underscores the need to expand access to information and communication technologies in rural regions.

Table 2. Usage of Information and Communication Technologies in Households from 2021 to 2023, [5]

Indicators	2021	2022	2023
Percentage of urban households with internet access	85.60%	87.60%	88.90%
Percentage of rural households with internet access	74.70%	75.85%	79.80%
Percentage of urban households with a computer	82.40%	82.90%	81.50%
Percentage of rural households with a computer	67.20%	67.20%	66.10%
Percentage of the population using mobile phones	94.60%	95.00%	94.40%

When examining growth trends over the past three years, a notable increase in internet connections among rural households is evident, while computer ownership has stagnated or slightly declined. The use of mobile phones demonstrates a relatively stable trend across the entire population.

Another aspect that highlights the potential for digitalization at the national level is the Network Readiness Index (NRI). This index measures a country's ability to leverage the opportunities presented by information-communication technologies. The NRI serves as a key indicator for assessing digital trends and understanding the evolution of trust in online environments. Its purpose is to identify and analyze major trends, determine the driving forces behind the development of media and information-communication technologies, and examine their social implications while providing concrete recommendations for policy and practice.

The index value is derived from four criteria: technology, people, governance, and impact. According to this index, the Republic of Serbia ranks 55th out of 134 analyzed countries, with a score of 51.68 points in 2023 (Figure 1). In a regional context, Serbia outperforms Montenegro, Bosnia and Herzegovina, Albania, and North Macedonia, but lags behind all European Union countries. Overall, it can be concluded that Serbia occupies a more favorable position compared to other upper-middle-income countries, [21].

Suppose the question arises regarding the government's steps toward achieving digital agriculture. In that case, one of the key answers is introducing an advanced information system in this sector.

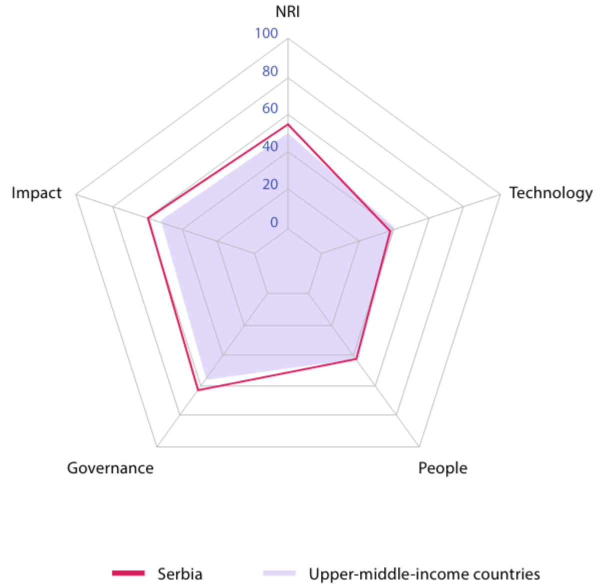

Fig. 1: Position of Serbia among upper-middle-income countries

Specifically, the new information system, eAgrar, which began operations in the spring of 2023, was implemented to modernize and expedite the processes of registration, data modification in the Register of Agricultural Holdings (RPG), and the approval and payment of agricultural incentives. eAgrar enables online registration of agricultural holdings and daily access to and management of data related to these holdings through a portal. Farmers can submit online requests for registration, changes, and data deletions in the RPG and for agricultural incentives.

With the introduction of eAgrar, significant time savings have been realized in processing requests through automatic verification of formal conditions and electronic processing. This facilitates faster approval of incentives and their payment while reducing errors during the submission and processing of requests. The system eliminates the need for printing and archiving paper documentation, thereby contributing to more efficient reporting and monitoring of incentive statistics. The legislative framework for the introduction of eAgrar was established by amendments to the Law on Agriculture and Rural Development at the end of 2021. Previous procedures, formulated in 2004, were outdated and cumbersome, causing delays in approving and paying incentives. For instance, registration in the RPG required visiting at least four counters and filling out eight different forms, which took approximately 4.5 hours and cost 1,320 dinars. Previously, processors had to manually verify each piece of data using three different applications, which was time-consuming. With the introduction of eAgrar, this process has been significantly simplified and expedited. Agricultural producers are promptly informed about all details and next steps through the official communication channels of the Ministry of Agriculture, Forestry, and Water Management, including its website and social media, [22].

5 Conclusion

In addition to contributing to economic development, generating gross domestic product, and creating jobs, agriculture plays a crucial role in ensuring food security. This role has become especially significant in light of recent events, such as the COVID-19 pandemic and international conflicts that have jeopardized the production of agricultural raw materials in both energy and food markets. Recognizing the importance of agriculture, the government provides various forms of support. One key measure stipulated by the Law on Agricultural Incentives and Rural Development mandates that the ministry responsible for agriculture cannot be less than 5% of the Republic of Serbia's total budget for the current year. This provision ensures a sure guarantee that funds will contribute, either directly or indirectly, to the agricultural sector.

Although the technological revolutions in agricultural production are already at stage 5.0, most farmers in Serbia and neighboring countries are still in the early stages of adopting Agriculture 4.0. For example, in Hungary, most farmers are familiar with the concepts of Agriculture 4.0 in theory, but many still primarily rely on technologies from earlier stages of agricultural development, [23]. Croatia also allocates significant funds for the digitalization of agriculture. In the Digital Croatia Strategy, the government highlights the insufficient use of artificial intelligence in business operations as a key weakness. This includes underutilized automation in urban traffic systems, limited application of IoT in agriculture, and the lack of a flexible legal framework that would enable faster and more cost-effective innovation, [24].

Capital investments are essential to achieving the agricultural sector's transformation and realizing the digital agriculture concept. However, farmers, particularly small producers, often lack sufficient personal resources for such investments. Therefore, bank and government support through specialized financing schemes is vital. Additionally, farmers need to adopt new mindsets and find solutions to enhance the processing of their products, as low-value-added goods currently dominate the market. The introduction of digital technologies is becoming imperative for transforming agricultural operations. Key factors for the successful implementation of the Agriculture 4.0 concept in Serbia include adjusting farm sizes, improving the education and experience of farmers, ensuring better access—primarily to broadband internet—developing mobile networks, maintaining an adequate agricultural budget, supporting agricultural and economic policymakers, and enhancing awareness of new technologies through media, chambers of commerce, and scientific institutions.

The transformation of Serbia's agricultural sector is a complex process that requires coordinated efforts from all stakeholders to ensure sustainable development and competitiveness in the global market.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the authors used Grammarly in order to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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