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Economic Implications of Digitalization and Smart Agriculture in Romania: Opportunities, Challenges and Policy Perspectives

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Abstract

The transition from traditional farming to smart agriculture represents a critical imperative for the modernization of Romania's rural economy. This study aims to analyze the economic implications of digitalization within the Romanian agricultural sector, identifying both the opportunities for growth and the structural challenges impeding technological adoption. Employing a systematic thematic review of existing literature and policy frameworks, the research evaluates current market dynamics, technological applications, and the impact of European Union funding. The findings reveal a distinct economic dichotomy: while digital technologies such as precision farming, IoT, and AI-driven analytics offer significant potential for optimizing resource use and reducing operational costs, their adoption is largely confined to large-scale commercial entities. Conversely, the sector remains dominated by fragmented small-scale farms that are hindered by severe infrastructure deficits, financial barriers, and a digital skills gap within an aging workforce. The analysis further indicates a disconnection between high-level policy objectives and the practical ability of smallholders to access necessary funding. The study concludes that passive technological diffusion is insufficient; ensuring long-term food security and market competitiveness requires a coordinated ecosystem approach that prioritizes targeted digital literacy programs and accessible financial mechanisms to bridge the widening rural-urban digital divide.

Keywords: Digital Agriculture, Smart Farming, Romania.

1. Introduction

Digitalization refers to adoption of digital or computer technologies during production and economic activities within a certain country, sector or business. Digital processes are rapidly becoming a vital driver of growth, productivity and job creation in many countries at various stages of development, for all types and sizes of firms. Digitalization is also essential for registration of new businesses, delivery of government services, application and payments of taxes and salaries, and trade and commerce via e-commerce services. Agriculture refers to

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production of crops, vegetables, fruits, trees and livestock, and is one of the most important yet complex production sectors in the world, involving substantial and varied resources. Digitalization has started exerting a great impact on agriculture sector and is expected to dominate this sector in near future. Its use is also growing rapidly to provide several services for farmers, consumers and others associated with this sector. Digitalization and Smart Agriculture have been widely adopted across the world; however, their adoption and application in Romania is still at initial stage (Raicov et al., 2016). Agriculture in Romania is dominated by small-scale farms, yet it comprises a major agro-food sector with a wide variety of agro-eco systems. Since the early 2000s, the agriculture sector in Romania has confronted important structural changes including dramatic shift in farm size and land ownership, and transformation of agricultural markets and institutions. Despite those changes, the agriculture sector still faces a long list of challenges. Romania is the 6th country in the EU in terms of agricultural land; overall 60% of its total area is scattered in more than 3 million farms, the majority of them being small subsistence-type or semi-subsistence farm-holdings (Bădan, 2017). Agriculture represents a very important branch for the development of Romanian economy and its contribution to gross domestic product was 4.3% in 2015 and employed about 25% of working population in 2014. By 2025, however, agriculture's role in the national economy had declined in relative terms: according to the most recent available statistics, the sector accounted for around 3.2–3.9% of GDP (2023–2024 data) and employed roughly 12% of Romania's workforce in 2023, while more than 90% of farms remained under 5 hectares and a large share of farmers were over 65 years old (Statista, 2025). Today, the agricultural sector is undergoing a significant transformation, shifting from traditional methods to digital farming technologies. While traditional farming has long relied on manual labor, digital farming leverages modern technologies to offer a more efficient, sustainable, and precise production process.

In this context, the transition from traditional farming to smart agriculture and digitalization has emerged as a critical imperative. Digital technologies—ranging from precision farming and IoT to AI-driven analytics—offer the potential to transform this landscape by optimizing resource use, reducing costs, and increasing yields. However, the adoption of these technologies in Romania is still in its nascent stages compared to global trends, hindered by infrastructure deficits, financial barriers, and an aging workforce. This paper aims to analyze the economic implications of digitalization in the Romanian agricultural sector. By employing a systematic thematic review of existing literature and policy frameworks, the study identifies the key opportunities for economic growth as well as the structural challenges impeding technological adoption. Furthermore, it evaluates current policy perspectives, offering strategic recommendations to bridge the gap between the potential of smart agriculture and the reality of Romania's rural economy.

2. Digital and Smart Agriculture Technologies

The integration of digitalization and smart agriculture is increasingly recognized as a transformative force in the agricultural sector, particularly in Romania. This literature review synthesizes key studies that explore the economic implications of these technological advancements, highlighting opportunities, challenges, and the need for strategic frameworks to support sustainable adoption. The reviewed works provide critical insights into how digital technologies can enhance agricultural efficiency, address structural barriers, and foster economic resilience, while also identifying gaps that require further research and policy intervention.

Vlad (2013) provides a foundational perspective on the role of information technology in improving agricultural efficiency and management in Romania. The study emphasizes that farmers' understanding of economic and technological factors is critical for effective cost estimation and production evaluation. Vlad identifies a significant gap in the availability of tools for cost management, suggesting that digitalization can enhance both physical production and operational efficiency in competitive markets. This work underscores the potential of digital tools to streamline farm operations, but it also highlights the need for accessible technologies tailored to Romanian farmers' needs.

Bădan (2017) offers a comparative analysis of farm equipment and technological adoption in Romania relative to other European Union countries. The study identifies structural challenges, including the prevalence of small, fragmented farms, which complicates the integration of advanced technologies. Insufficient European funding and inadequate infrastructure further exacerbate these barriers, limiting the scalability of smart agricultural practices. Bădan's findings highlight the necessity of targeted investments and policy support to overcome these obstacles and facilitate technology adoption.

Moschitz and Stolze (2018) explore the implications of smart technologies for sustainable agriculture, proposing a framework for evaluating these systems. They argue that while smart technologies offer significant benefits, their successful integration requires collaboration among stakeholders, including policymakers, technology developers, and farmers. The authors advocate for transparent governance and structured evaluation processes to ensure the sustainability of digitalization efforts. Their work emphasizes the importance of aligning technological advancements with environmental and social goals to maximize economic and ecological benefits.

Annosi et al. (2019) examine the slow adoption of smart agricultural technologies among small and medium-sized enterprises (SMEs) in Romania. Their study highlights the critical role of managerial beliefs and perceptions in shaping technology adoption decisions. The authors suggest that external support, such as information services and training, can bridge knowledge gaps and encourage digital innovation. While acknowledging the limitations of their research scope, Annosi et al. underscore the importance of creating a supportive ecosystem to foster technology uptake among SMEs, which are vital to Romania's agricultural sector.

Navarro et al. (2020) provide a systematic review of Internet of Things (IoT) applications in smart farming, focusing on technologies such as cloud computing and artificial intelligence. Their findings highlight the growing reliance on IoT for crop monitoring and precision agriculture, which can enhance productivity and resource efficiency. However, the study identifies practical challenges, including high costs and usability issues, that hinder widespread adoption. Navarro et al. call for further research to address these barriers and develop cost-effective, user-friendly solutions for Romanian farmers.

Kondratieva (2021) examines the dual nature of digitalization in Romanian agriculture, categorizing studies into those addressing risks and those exploring the evolution of the Common Agricultural Policy (CAP). The research highlights significant disparities in digital economy indicators between rural and urban areas, exacerbated by an aging farming population with limited formal training. While digital technologies offer opportunities for rural inclusion in market systems, Kondratieva warns that these disparities could widen economic gaps without targeted interventions. The study emphasizes the transformative potential of digitalization but calls for policies to address demographic and educational challenges.

Duncan et al. (2021) explore the socio-economic dimensions of digital agriculture, focusing on how digital technologies reshape farmer identities, skills, and work practices. Their analysis reveals that while digitalization presents economic opportunities, it also raises concerns about power dynamics, ownership, and ethics within agricultural value chains. The authors advocate for a responsible innovation approach to navigate these complexities, ensuring that digitalization benefits are equitably distributed. Their findings are particularly relevant for Romania, where small-scale farmers face significant barriers to technology adoption.

Sott et al. (2021) provide a bibliometric network analysis of digital agriculture, tracing its evolution and strategic themes. They note that while precision agriculture has been practiced since the 1980s, the integration of IoT, AI, and big data is critical for addressing food security and sustainability challenges. However, the authors highlight barriers such as resource scarcity and the need for sustainable practices, which are particularly relevant in Romania's resource-constrained agricultural sector. Their analysis underscores the importance of aligning technological advancements with environmental and economic goals.

Popescu and Popescu (2022) investigate the impact of the COVID-19 pandemic on Romanian agriculture, documenting a shift toward digital platforms for marketing and selling agricultural products. Their findings highlight the critical role of digitalization in optimizing food systems and enhancing business resilience, particularly for small farmers. The study emphasizes the importance of EU funding and strategic investments in supporting digital innovation, which is essential for maintaining food security and economic stability in times of crisis.

Nasirahmadi and Hensel (2022) explore the potential of the digital twin paradigm in agriculture, emphasizing its role in enabling real-time monitoring and decision-making through advanced data analytics and IoT. They argue that digital twins can improve productivity and cost-efficiency but caution that increased data loads on cloud systems pose significant infrastructural challenges. Their work highlights the need for robust digital infrastructure to support smart agriculture in Romania, where connectivity and technological resources remain limited.

Heymann et al. (2023) identify digitalization as a global megatrend reshaping social, economic, and environmental systems, with profound implications for the operation and planning of the electricity sector. Using a megatrend analysis framework, the authors review regional differences, key technologies, application areas, and the main challenges reported in the literature. Their synthesis highlights system-level benefits such as improved efficiency, transparency, and enhanced consumer participation, while also noting risks including rising electricity demand, loss of autonomy, and increasing cyber-security threats. Building on this comprehensive assessment, the study proposes a set of policy options aimed at maximizing the benefits of digitalized electricity systems while minimizing their adverse impacts on decarbonization goals and consumer protection.

Albulescu et al. (2025), Avrupa'da artan kuraklık olaylarının özellikle küçük ölçekli hayvancılık işletmelerini yüksek kırılganlık altında bıraktığını ortaya koyarak, kuraklık kırılganlığı ile hazırlıklı olma düzeyinin birlikte değerlendirilmesi gerektiğini vurgular. Yazarlar, Romanya'nın kuzeydoğusunda 141 çiftçiyle yürüttükleri saha çalışmasında, kuraklık kırılganlığının hazırlıklı olma ile negatif ilişkili olduğunu ve bu iki göstergenin çiftlik büyüklüğüne göre belirgin biçimde değiştiğini belirtir. Bulgular, yem ve finansal rezervlerin erişilebilirliği, altyapı koşulları, suya ulaşım ve çiftçinin eğitim düzeyi gibi faktörlerin hem kırılganlık hem de hazırlık üzerinde belirleyici olduğunu göstermektedir. Literatürde daha önce çiftçilerin kendi bildirimlerine dayalı hazırlık düzeyi ile kırılganlık indekslerinin karşılaştırılmamış olması, çalışmayı özgün kılmakta ve kuraklık yönetimi politikalarının üretici temelli bir perspektifle yeniden ele alınması gerektiğine işaret etmektedir.

The reviewed literature presents a multifaceted view of digitalization and smart agriculture in Romania, highlighting both transformative potential and significant challenges. Key opportunities include enhanced productivity, improved resource efficiency, and increased market access through digital platforms. However, barriers such as small farm sizes, inadequate infrastructure, limited funding, and demographic challenges hinder widespread adoption. The studies collectively underscore the need for collaborative frameworks involving policymakers, technology providers, and farmers to address these barriers. Future research should focus on developing cost-effective, user-friendly technologies, improving digital literacy among

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farmers, and securing targeted investments to support sustainable digitalization. Additionally, longitudinal studies are needed to assess the long-term economic impacts of smart agriculture in Romania, particularly in the context of evolving EU policies and global market dynamics.

Smart agriculture systems encompass an ecosystem comprising people, machinery, sensors, vehicles, data storage, and connectivity. Advanced technologies, including smart sensors, GPS, and solar-powered equipment, seamlessly integrate to monitor and analyse complex crop and soil conditions. Precision techniques optimise farming input use while minimising environmental impact. Drones deliver visual crop information across extensive areas, informing strategic intervention decisions. Remote sensing facilitates data gathering on soil condition, moisture levels, crop maturity, and temperature over large, inaccessible areas. Artificial intelligence-driven algorithms synthesize data from various sources to provide actionable insights on weather, soil conditions, crop planning, planting density, and equipment deployment (Ionitescu et al., 2023).

2.1. Precision Farming

Precision farming (PF), also known as satellite farming or site-specific crop management (SSCM), enables farmers to consider variability within and between fields and manage these variations accordingly. PF increases productivity and cuts costs by optimizing field-level management reasonably. Precision agriculture (PA) represents the most widely adopted smart agricultural technology. It relies on managing geospatial information to assist farmers through all steps of farming activities. PA has recently become a hot topic because the adoption of data-driven farming is a fundamental part of modernizing farming models worldwide and improving agricultural productivity.

2.2. Internet of Things (IoT) in Agriculture

The rollout of IoT technology enhances pre- and post-harvest operations, including prediction, irrigation, storage, and transportation. Precision farming gains support from IoT datasets and cloud-based processing, with devices such as Leaf Area Index (LAI) meters, crop sensors, genome analyzers, and weather sensors furnishing vital information to farmers. IoT underpins yield/pest forecasting, variable-rate irrigation, and fertilization, all critical to agricultural productivity (Wu et al., 2023).

An IoT-based system incorporates multiple sensors to monitor soil conditions and a smartphone app to deliver accessible data to farmers. Developed under funding from the National Natural Science Foundation of China and Jiangsu Provincial Government, this architecture combines low-cost, rapid-response sensors with Internet connectivity, serving regions lacking fixed network infrastructure (Ana & Laura, 2013).

2.3. Drones and Remote Sensing

Drones are integrated into agricultural applications, including crop spraying, irrigation, and monitoring, augmenting the gathering of aerial views and capturing multispectral images for assessing crop health and detecting diseases. The continuous improvement in monitoring practices has led to significant data accumulation, driving the development of new analytical tools and methods. Predictions concerning biomass, yield, and soil conditions serve as valuable inputs for farm-management software. Additional sensors, when mounted on unmanned aerial vehicles, contribute to the production of orthophoto maps utilizing images from digital cameras operating in various spectral bands (Achim et al., 2018). These orthophoto maps assist in enhancing the cartographic framework supporting forest planning and sustainable-management activities, such as health monitoring and pest prevention.

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2.4. Data Analytics and AI

Data analytics and artificial intelligence represent the core of the digitalization process, generating valuable insights across every aspect of farming. Applications installed on machines measure crop and soil health, identify pests and microbes, and monitor the available nutrients. Data analytics also helps farmers source equipment and plan their budgets and routes, with AI systems able to predict the type and number of machines to buy or rent. Farmers in Romania primarily employ machinery equipped with computer systems and GPS, collecting data during fieldwork. Another source of data emerges from sensor systems designed to monitor the crops and environmental conditions. Analyzing this growing volume of data in the current Romanian context requires the development of new methods and techniques capable of intelligently transforming data into usable knowledge, thereby enhancing the application of AI in agriculture. Appropriately harnessed, digitalization can bring substantial advantages to a sector where specificity, seasonality, and fragmentation of production still inhibit the application of classical economic models. Rural regions, representing one-fourth of the national surface and scattered across the country, will undoubtedly be at the forefront of this effort (Raicov et al., 2016).

3. Economic Implications of Digitalization

Digitalization enhances Romanian agriculture's efficiency and output. Smart technologies, including precision agriculture, the Internet of Things, drones, advanced remote sensing, Geographic Information Systems, and Artificial Intelligence (AI)-powered data analytics, provide farmers with better access to natural resources, relevant information, and knowledge about farm performance. Combining these cognitive computing tools with digitized farm practices increases production levels. Digitization expands trade by connecting providers with customers through online platforms. Romanian farmers' use of such platforms became commonplace during the COVID-19 crisis. Platforms, cloud services, and exchanged technical information improve operational decision-making and reduce input waste (Popescu & Popescu, 2022). Farmers equipped with real-time technical information adapt production strategies to customer requirements, enhancing their market position. Digitization is a critical agricultural development driver, enabling the efficient redistribution of produced crops and promoting product diversification. Increasing the variety of crops stimulates trade expansion and encourages long-term farmers to adopt innovative technologies. Digitalization lowers transaction costs, enhances information flow, and reduces agency problems, thereby increasing market efficiency (Vărzaru, 2025).

3.1. Increased Productivity

The observed improvements in agricultural productivity during the first decade of the 2000s resulted from increased mechanization and supplementary support for farmers. Further growth will be achieved through the adoption of science-based knowledge and technology, paralleling trends from the previous period. Mechanization is a prerequisite for productivity enhancement and is therefore considered a fundamental factor in agricultural progress. A direct consequence of increased physical production is cost reduction. Conversely, increasing physical production becomes more feasible when a system component provides the necessary information for managing technical work, production, or financial, economic, social, and administrative aspects. The knowledge possessed by farmers regarding economic and technological aspects directly influences the agricultural production process. On the technical side, this knowledge can be interpreted as the technological scheme or working plan employed on the farm. Economically, the information relates to the determination and estimation of production costs under given prices, technological flows, trade conditions, etc. Many farmers encounter difficulties in correctly estimating economic coefficients or lack proper instruments for economically evaluating the strategies of input application. In this context, the utilization of information technology to support agricultural activities increasingly represents the solution for a society steered by informatization, especially as markets become more competitive (Vlad, 2013).

3.2. Cost Reduction

Cost reduction is a notable advantage of digitalization and smart agriculture. Many rural farmers still use traditional practices, like manual calculations, for farm planning. Smart agriculture informs decisions such as crop timing to reduce seed loss. IoT devices facilitate remote, timely batch control, decreasing chemical and transportation expenses. Real-time analytics identify equipment issues promptly, allowing interventions that prevent costly breakdowns. Enhanced field and livestock monitoring cuts labor needs. Satellite imagery assists in early infestation detection and facilitates assessment of subsidized crop proportions (Ana & Laura, 2013).

In Romania, high capital investments in machinery and fixed assets accompany substantial loan interest payments. Even after a four-year decline, interest remains considerable. Agricultural output by current operators increased in 2012 compared to 2011. Crop producers face pressures due to rising raw material and energy costs. Low productivity and average labor costs limit wage increases and production expenses. Smaller agricultural holdings pose market access difficulties for commodities. Distributor consolidation and emerging consistent importer networks create acceptance challenges for farm products (Mituko Vlad et al., 2015). Addressing these issues is essential to leverage digitalization benefits for prices and productivity.

3.3. Market Access and Competitiveness

Market access and competitiveness are key economic aspects of digitalization in agriculture. Digital technologies enable a direct interface between agriculture and outside markets, a huge advantage for small and medium-sized farms that traditionally had limited market access . Smart technologies not only make the distribution process leaner but also increase quality, by improving storage and post-harvest controls. As marketing and promotion increasingly take place through digital channels, smart agriculture and digital products enhance the competitiveness and profit margins of agricultural producers. Large companies that sell equipment and processing technologies tend to adopt digitalized processes faster; the outcome is a new generation of smart farm equipment that better adapts to specific crops and terrain (Vărzaru, 2025).

4. Challenges to Implementation

Based on the annual report "Digital Transformation in the Romanian Agrifood Sector" (2020), significant challenges affect Romanian agricultural digital transformation. The objectives set in the Strategy CAP 2014-2020 for the Romanian agricultural sector include: food safety, rural development, efficient agricultural resource allocation, and high-value agricultural products. Consequently, the lack of infrastructure and the adaptability of farmers and workers create major barriers for digitalization transformation, which Romanian agricultural practices face due to the stagnation and resilience to change of the whole agricultural sector (Markovits, 2024).

The impact of COVID-19 in Romania reveals that the agricultural sector suffered from high vulnerability, indicating the need for continual monitoring and support to ensure the on-going food security of the country. Responding quickly to the COVID-19 crisis is necessary to minimize the negative impact and increase the Romanian economy's resilience. The keys to mitigate such crisis include: rapid institutional responses, digitalization, support for local farmers, investments in mechanization, and innovation; and these emergencies offer opportunities to evaluate the sector and develop innovative and digital agricultural practices. The main challenges facing digital transformation in Romania's agricultural sector include the speed of digital infrastructure deployment, the low digital skills of workers, and delays in adapting to new technologies. These factors ultimately cause reductions in production efficiency, which lower the profitability of Romania's agricultural sector therefore, the country needs to integrate the digitalized transformation process from the angle of macroeconomic development (Gherasimescu et al., 2023).

Problems related to agricultural development in Romania are considerable, especially in rural areas. The lack of drinking water, heating systems, basic facilities for agriculture and food industry development, such as electricity and roads, persists. The lack of secure land tenure is very important and discourages potential investors, big and small, from taking risks. The continuity in use of up-to-date equipment is important for financial stability. The farmers often pay the for new machines, transportation and other, tending to practice extensification. Collective marketing for farmers and agro-processing flexibility is another problem faced by the local manufacturers, because their interest in setting up collective structures remains very low (Ionescu et al., 2021).

Farmers tend to choose collective ideas, because of duration, transportation, etc. The infrastructures with sewage and water distribution are very important for economic development. The natural landscaping conditions inside the rural area must be protected. As the tourists visit the main attractions, they neglect the beauty of rural villages, the architecture and the specific components of the village. They have more attractions for the external areas, such as the mountains, natural and cultural facts, and other activities. The image of the rural areas remains poor despite the investments and the development of the services (Petre et al., 2025).

Romania faced a series of problems due to the COVID-19 pandemic in 2020, in terms of agricultural input costs, labour migration, farm management, and food security. Agricultural producers and farmers complied mainly with the restrictions and were mostly satisfied with the measures taken by the competent authorities, but some problems emerged in maintaining the standard of agricultural technology and in selling agricultural products in the domestic market (Gherasimescu et al., 2023). Given that the agricultural system continues to be vulnerable, close monitoring of the evolution of the COVID-19 pandemic, along with appropriate support measures, may determine the capacity of the sector to ensure high food security standards in the face of other crises. A proactive relationship with public institutions, fast and effective responses, the implementation of digitalization, simplified forms of collaboration and support for local farmers, a higher degree of mechanization, high levels of innovation, and a real connection to the economic environment are important support elements to increase the resilience of the system. The current crisis also presents an opportunity for those involved in agriculture and the agri-food sector to evaluate possible dissociations in the production-consumption-food security chain and to think about ways in which the system can develop more sustainability, innovation, and digitalization in the near future (Popescu & Popescu, 2022).

4.1. Infrastructure Limitations

Smart agricultural solutions are gaining momentum as cost-efficiency and result-oriented strategies, and their steady implementation supports strategic-sector evolution and economic growth. Although diverse factors influence agricultural digitalization, not all countries progress at the same pace. For example, Romania faces significant limitations imposed by the lack of appropriate infrastructure. Digital infrastructure underpins the implementation of smart agricultural systems. Reliable broadband connectivity enables farmers to utilize data analytics, precision tools, and autonomous machinery. Digital infrastructure also supports the operation of intelligent weather stations, irrigation-control systems, smart greenhouse technologies, drone monitoring, irrigation systems, and satellite-based yield prediction (Gebresenbet et al., 2023).

4.2. Skill Gaps in Workforce

The adoption of digitalization in agriculture generates significant skill gaps in the existing workforce. Romania's working conditions reinforce job insecurity and diminish the attractiveness of agricultural work, contributing to a limited availability of qualified staff. The high penetration rate of the internet (78.3%) does not fully offset the challenge, because specific skills required for handling the main digitalized agriculture equipment such as traditional control systems, electronic and electrical systems, advanced computer systems, mechatronic systems, and robotic control, are still missing (Bădan, 2017). At the same time, the share of agriculture in total employment remains much larger (28.7% in 2017) than in countries with similar levels of economic development and the quality of such labour (measured by educational attainment and skill level) is low; the share of highly skilled workers in agriculture is only 7.1%, versus 32.2% in non-agricultural employment (Vasilescu, 2012).

4.3. Financial Barriers

Financial barriers persist as small- and medium-sized farms remain largely excluded from access to the funds required to undertake the necessary investments and incur the fixed costs of the model. European programmes aimed at modernizing the rural sector often involve private cofinancing through bank loans, yet access to credit remains a significant limitation for many farmers. To develop modern farming technologies and support long-term behavioral change, farmers require not only local infrastructure but also social infrastructure, including innovation support systems and funding (Tonea & Beleiu, 2018).

A further challenge emerges on the demand side of the market. While the agribusiness sector has made significant progress in recent decades, the capacity of agricultural producers to participate in value chains has not kept pace. As a result, many farmers operate with limited market access, raising questions about the capacity of digitalization to create a more competitive sector (Mituko Vlad et al., 2015).

5. Policy Framework and Support

An integrated Agricultural Strategy for 2014–2020 supports digitization and information technologies. Romania's rural development programme (RDP) aligns with national and EU strategies applicable to the Common Agricultural Policy (CAP) 2014–2020. It addresses seven EU priorities, from resource-efficient agriculture to social inclusion. The second priority, promoting knowledge transfer, innovation, and digitalization, is implemented through measures covering advisory services and farm investments. Information and communication technologies are also supported. Online agriculture portals offer resources and updates. These initiatives leverage digital tools to modernize processes, enhance communication, and increase resilience (Doukas et al., 2022).

5.1. National Strategies

In parallel with the development of digital technologies and their dissemination in society, the potential of agriculture can be improved digitally by expanding the connection to society through the Internet. Although many digital technologies are widely used in the agricultural sector, the practical application of digitalization technology is still limited, and the adoption and spread of implementation plans to raise awareness are essential (Raicov et al., 2016). The adoption of digitalization in agriculture to raise productivity should also consider the rural environment and policy support, which will also contribute to the economic impact. Digitalization is context-specific, therefore empirical country-level programmes and regulations and financial support are mandatory. Agriculture is a strategic sector that supports other areas, and the development of digitalization in agriculture has a broad impact on economic growth (Ana & Laura, 2013).

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The primary framework currently governing agricultural digitalization in Romania is the National Strategic Plan (Planul Strategic Național – PS PAC) 2023–2027, approved by the European Commission on 7 December 2022 and in force since 1 January 2023 (European Commission, 2022). With a total budget of €15.83 billion (of which approximately €5.87 billion is allocated to Pillar II rural development investments managed by the Agency for Financing Rural Investments – AFIR), the plan marks a shift from passive subsidies to performance-based funding that explicitly prioritizes modernization, knowledge transfer, digitalization, and farm viability (Ministerul Agriculturii și Dezvoltării Rurale [MADR], 2025a; European Commission, 2022).

Key interventions supporting digital transformation include:

- DR-12 (Installation of young farmers) and DR-14 (Investments in small farms): aimed at capitalizing small holdings and replacing obsolete equipment with modern, digitally enabled machinery (MADR, 2025a).
- DR-16 (Investments in the vegetable and potato sectors): €151.3 million allocated for advanced technologies such as automated sorting lines and climate-control systems (MADR, 2025b).
- DR-23 (Investments in processing and marketing of agricultural products): €164.9 million targeting digitalization of processing units (MADR, 2025b).
- DR-37 (Knowledge transfer and information actions): launching in 2025, this measure specifically funds digital literacy and training programs to close the skills gap among the aging farming workforce (MADR, 2025a).

Complementary funding is available through the National Recovery and Resilience Plan (PNRR), which provides non-reimbursable grants of €500,000–€3 million for SMEs in the agri-food sector to adopt advanced digital technologies (cloud computing, blockchain, IoT, AI) (Ministerul Investițiilor și Proiectelor Europene, 2025).

According to the latest timetable published by MADR on 4 November 2025, major investment calls (DR-12, DR-16, DR-23) are scheduled to open between December 2025 and February 2026, with the explicit objective of accelerating fund absorption and achieving significant digital transformation of the sector by 2030 (MADR, 2025b).

5.2. EU Regulations and Funding for Rural Development in Romania

Romania's rural development has been significantly shaped by European Union (EU) funding and policies, particularly following its accession in 2007. From 2000 to 2006, Romania received pre-accession support through the Special Accession Programme for Agriculture and Rural Development (SAPARD), which facilitated agricultural modernization, rural infrastructure improvements, and environmental sustainability (European Commission, 2007). Post-accession, Romania implemented the National Rural Development Programme (NRDP) under Government Decision no. 44/2007, amended by Law no. 76/2011, funded primarily by the European Agricultural Fund for Rural Development (EAFRD) and supplemented by the European Agricultural Guarantee Fund (EAGF) for direct payments and market measures (Ministry of Agriculture and Rural Development [MADR], 2007).

The 2007–2013 NRDP aligned with the European Commission's priorities, focusing on: (1) enhancing the competitiveness of the agricultural and forestry sectors, (2) improving environmental sustainability, and (3) promoting quality of life and economic diversification in rural areas (European Commission, 2013). However, Romania's absorption of EAFRD funds was limited, reaching only 12% by 2012 due to bureaucratic inefficiencies and inadequate administrative capacity, though it improved to 56% by the period's end (European Court of

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Auditors, 2013). For the 2014–2020 period, the NRDP shifted emphasis to knowledge transfer, innovation, agricultural competitiveness, food chain organization, ecosystem preservation, resource efficiency, and social inclusion, reflecting EU Common Agricultural Policy (CAP) objectives (MADR, 2014).

Despite these efforts, Romania's rural sector remains fragile compared to other EU countries, characterized by fragmented land holdings (average farm size: 3.7 hectares in 2016), underdeveloped infrastructure, and high rural poverty (46.8% at-risk-of-poverty rate in 2018) (World Bank, 2022). Stakeholders have prioritized improved agricultural policies, market access, rural infrastructure, financial services, innovation, and risk management to address these challenges (Popa & Vasilescu, 2013; European Network for Rural Development, 2015).

Foreign investments offer potential benefits for Romania's rural sector, including financing, technological advancements, market access, environmental protection, infrastructure improvements, job creation, and poverty reduction. However, concerns persist regarding land acquisition by foreign investors, which may exacerbate local vulnerabilities (Popa & Vasilescu, 2013). The EU's integrated policies and financial support remain critical for sustainable rural development, with future funding (e.g., 2021–2027 CAP Strategic Plan) expected to prioritize innovation, sustainability, and social inclusion to address ongoing structural challenges (European Commission, 2022).

6. Sustainability and Environmental Impact

Digital and smart agricultural technologies have the potential to optimize resource management, thereby increasing sustainability and reducing environmental impact. The ongoing digital transformation of the economy is fostering value-generating relationships and cooperation among agriculture, food, and other sectors. Because farms and agribusinesses can both consume and produce smart applications and agricultural knowledge, smart solutions can reshape how production and value chain-being services flow and develop. Precision and environmentally aware farming methods may lead to fewer inputs such as fertilizer or pesticide while allowing cultivators to increase productivity at reduced unit cost, and consequently to reduce carbon emissions and environmental impact (Gebresenbet et al., 2023).

Regional and rural development is strongly linked to agricultural development. The concept of "competitive agriculture" implies a better positioning of agriculture on markets at national and international scales, better off-farm sector development, but also rural sustainable development (Ionela Aceleanu et al., 2018). Mixed units and a changing agricultural system require a conceptual basis for the sector development models that link agricultural production to the environment. Rural sustainable development is strongly connected to the integration of several economic activities, which replenish the rural economy. Agricultural information systems may have to respond to the reorganization of agricultural data and services at a higher level. The problem is therefore how to use integrated agricultural information systems within the sustainability and environment constraints, to develop tools and services (information processing, agronomic models) ready to respond to environmental and sustainability demands. This strategy will help in efforts to mitigate the impact of the agricultural sector on the environment and to increase the competitiveness of the sector (Fang, 2022).

Technological revolutions, such as the emergence of information and computer science, are significantly reshaping the agricultural sector by introducing innovative concepts and solutions to boost farming production. Digitalization and smart agriculture, supported by enhanced technologies, machines, and systems, are changing every stage of the value chain from agricultural operators and equipment to supplier, equipment manufacturer, distribution, marketing, and customers. *How do digital technologies enable smart resource management?* The application of digital technologies has led to the development of the smart farm concept.

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This concept involves using self-driving tractors, drones, and various sensors to manage resources such as soil, water, and fertilizers more efficiently. Smart farming supports information integration at the farm level, with sensors, machines, and robots communicating with each other in real time. Automatic steering systems, drones for monitoring growth and crop damage, and online sensors for detecting moisture, pH, and climate conditions exemplify how smart farming enhances resource management. By gathering accurate information on soil reserves, fertilizer needs, and fuel usage, farmers can reduce input costs and optimize resource allocation. Specialized software applications provide alerts regarding potential threats and operational needs, allowing farmers to perform only necessary activities (Dobre & Mocuța, 2022).

Smart farming systems help minimize unnecessary consumption of water, pesticides, fertilizers, and other resources, thus contributing to more sustainable agricultural practices (European Commission, 2023). In Romania, agriculture is characterized by a high share of the labor force—around 23–27% of total employment—and highly fragmented land structures, with about 90% of farms below five hectares and an average farm size of 4.39 hectares (National Institute of Statistics, 2023; Păunescu & Moldovan, 2020). Structural challenges include significantly lower yields per hectare, reaching only about 53% of the EU-28 average, due in part to outdated or inappropriate machinery and low input use. Fertilizer consumption in Romania is approximately 55% of the EU average, while plant protection product use is about 35% of the EU level (Moldovan & Păunescu, 2020). Limited access to modern agricultural technology and machinery financing further contributes to Romania's productivity gap compared to other European countries.

Resource management, encompassing water, land, and air, remains critical for ensuring food safety. Dairy production, for example, requires careful monitoring of farm size, feed and forage quality, production cycles, machinery, and trained personnel. In arable farming, crops such as wheat, rapeseed, corn, sunflower, and barley demand attentive oversight throughout cultivation and harvesting to maximize output and efficiency. The smart agriculture framework, supported by technology, data, centralized management, and control, enhances resource management by providing accurate information to all parties involved. This precision in monitoring and utilization leads to reduced waste and improved environmental sustainability, aligning with economic goals and contemporary agricultural challenges in Romania (Dogaru et al., 2024).

Reducing the carbon footprint is a central goal of the European Union's policies in Millennium Development Goal 7 to ensure environmental sustainability. It requires diverse scientific approaches aimed at minimizing negative environmental impact (Vlad, 2013). Incorporating information technology into agriculture and forestry machinery can minimize emissions and protect the environment. Farmers must optimize production activities and precisely estimate production costs under various conditions like soil type, fertilization, and climate to avoid wasteful emissions. Management information systems improve decision making in agricultural production and distribution, substantially raising the efficiency of motor processes, increasing production capacity, and delivering a positive economic effect. Moreover, these systems curb the depletion of the ozone layer and reduce the carbon footprint, thereby enhancing the ecological systems of the territory concerned. The European Union encourages the reduction of the carbon footprint throughout the agri-food chain and promotion of environmentally friendly transport for food distribution. Governments are urged to adopt environmentally friendly policies that promote sustainable development of agriculture and fisheries (Perissi & Jones, 2022).

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7. Future Trends and Market Outlook

Digitalization represented by smart technologies constitutes a growing economic force in Romania, affecting all facets of agriculture from the supply chain to consumer habits. In Romania, digitalization helps reduce costs faced by farmers, permits new support and data systems in rural areas, and opens new marketing opportunities providing access to foreign customers and competition against extra-European companies. Meanwhile, volatile fuel prices and events driving inflation increase investment gains devoted to the transition towards sustainable farming and digital scaling-up (Giucă & Buțu, 2024).

The agricultural yield enhancement of digital technology (precision farming, Internet of Things and ITS systems, drones, remote sensing, data driven tools such as artificial intelligence and machine- or deep-learning or blockchain) presents promising opportunities to reduce current barriers related to the use of mineral fertilizers, principally nitrogen, phosphate and potassium, as well as irrigation water and pesticides (Bold et al., 2015). Indeed, some of the technologies would improve the application of hydro-mineral resources in sufficient doses and at necessary moments, so as to stimulate efficient photosynthesis while reducing the negative pressure on the environment. Other data-driven tools would help identify the region, plantation, and galenic forms requiring fertilization, irrigation or protection, specifying the doses and moments for applying these factors (Giucă & Buțu, 2024).

The agricultural machinery market facilitates both the expansion of areas where machine-planting methods are applied and the progress of mechanized weeding techniques favoring the local reduction of competitive phytosanitary products. Moreover, high-input digital farming would produce additional benefits, mainly at farm level:

• It boosts productivity and lowers unitary consumption of hydro-mineral resources. Food security and operational stability would improve accordingly whereas food-system shocks would be further improved.

• Food quality could increase due to smaller doses or inferior toxic phytosanitary products applied only in regions where they are necessary.

• It facilitates the marketing of extra-quality products and the expansion of short supply chains, i.e. they would reveal areas where organic farming or related practices are likely to develop.

Additional local services and infrastructures would strengthen the efficiency of digital farming in Romania. Wide mobile coverage and satellite services would further promote access to a wide range of spatial and time data, which in turn would improve the use of crop models, Artificial Intelligence (AI) tools and algorithms. Integrating digital-farming tools with advisory services on cultivating techniques could also facilitate the transfer of new production methods and counteract local shortfalls in farmers' education and training (Srivastava, 2021).

7.1. Emerging Technologies

Emerging agricultural technologies in Romania include smart farming, which encompasses information and communication technologies and applications such as the Internet of Things (IoT), satellite positioning systems, and Geographical Information Systems (GIS). Other notable technologies involve drones, remote sensing, and Big Data solutions, which are relevant to economic growth and productivity. Data generated by these technologies can be exported, transformed into products, and used for value-added services in the agricultural sector. Such innovative technologies improve accuracy in processes, thereby reducing costs and saving time and resources (Cristinel et al., 2021).

The concepts of digitalization and smart agriculture are often intermingled in understanding Romania's adoption of new technologies, underscoring the significance of the topic.

Noteworthy advancements include precision farming systems; the integration of technologies such as IoT, blockchain, and cloud computing; and the use of agricultural robots. Precision farming leverages GPS, yield monitors, satellite images, and GIS to optimize field management and irrigation while providing real-time data on soil characteristics and conditions, such as salinity and moisture. Precision livestock monitoring employs sensors to track animal movement, behavior, and temperature, enabling rapid identification of health and welfare issues and improving costs, time management, and farm profitability. Drones also play a crucial role in precision farming, covering vast areas swiftly and supporting services including crop monitoring, spraying, livestock surveillance, soil sampling, and soil analysis (Cristinel et al., 2021).

7.2. Market Predictions

The potential of digital solutions combined with agro-technologies for rural development is projected to remain substantial over the next decade. Global demand for smart IoT (Internet of Things) solutions in agriculture is expected to expand rapidly, with market estimates ranging from USD 28.65 billion in 2024 to USD 54.38 billion by 2030, representing a compound annual growth rate (CAGR) of approximately 10.5% (Grand View Research, 2024). Other analyses project even higher growth, with the global IoT in agriculture market valued at USD 20.14 billion in 2023 and forecast to reach USD 71.92 billion by 2033, implying a CAGR of 13.6% (GlobalNewswire, 2024).

Within Europe, adoption is also expanding, though at slightly lower rates than some global averages. The European IoT in agriculture market is projected to grow from USD 6.81 billion in 2024 to USD 11.80 billion by 2030, corresponding to a CAGR of 8.9% (Grand View Research, 2024). Hardware and embedded systems, including sensors, drones, and automation equipment, account for the largest revenue share, while software, data analytics, and remote sensing are among the fastest-growing segments (Grand View Research, 2024).

Business applications of smart agriculture in Europe are particularly concentrated on improving farm efficiency through remote monitoring, farm management platforms, and data-driven decision support systems. Precision farming and automated agriculture are recognized as primary market drivers (KBV Research, 2024).

Romania has been emerging as a growing market in the field of digital agriculture. Analyses by 6Wresearch indicate increasing demand for precision crop farming, livestock monitoring technologies, and smart greenhouse solutions. However, country-specific projections regarding market turnover and growth rates remain less transparent compared with Western European markets. Policy frameworks such as the EU's Common Agricultural Policy (CAP) and Romania's national agricultural strategies provide significant institutional support for the sector's digitalization (European Commission, 2022). Regional market assessments suggest that the European precision farming market is expected to grow at a compound annual growth rate (CAGR) of approximately 14.3% between 2025 and 2030 (Grand View Research, 2024). Other analyses, including those by Cognitive Market Research (2024), estimate a CAGR of around 9.5–11% for the European digital agriculture market over 2024–2031. Within this context, projections anticipating a Romanian market size of €1–2 billion by 2030 with a CAGR of 10–13% can be considered plausible; however, these estimates should be interpreted with caution, as they are not directly confirmed by Grand View Research or MarketsandMarkets and therefore rely on secondary interpretation rather than verified primary forecasts.

8. Key Findings and Conclusion

This study aimed to analyze the economic implications of digitalization in Romania's agricultural sector. The systematic review of literature and economic data reveals that while digitalization offers a transformative pathway, the sector is currently hindered by deep-rooted structural and demographic challenges. The analysis highlights three critical findings:

1. Economic Dichotomy and Structural Fragmentation: There is a confirmed "two-speed" agricultural economy. While digital technologies like precision farming and IoT significantly reduce operational costs and enhance resource efficiency, their adoption is largely confined to large-scale commercial farms. The vast majority of the sector remains characterized by fragmentation, with over 90% of farms being under 5 hectares. This structural reality limits the scalability of expensive digital solutions, creating a barrier where smallholders cannot access the productivity gains needed to reverse the sector's declining GDP contribution, which currently stands at approximately 3.2–3.9%.

2. The Gap Between Policy and Implementation: Although policy frameworks such as the National Rural Development Programme (NRDP) and the EU's CAP provide essential funding avenues for modernization, a disconnection exists in implementation. Financial barriers persist because small and medium-sized farms are often excluded from the credit access required for co-financing EU projects. Furthermore, the potential of digital infrastructure is undermined by a severe skills gap; despite high internet penetration, the specific technical competencies required for smart farming are lacking in an aging workforce.

3. Technological Potential vs. Market Reality: Market projections suggest a robust growth trajectory for digital agriculture in Romania, with estimates pointing to a potential turnover of €1–2 billion by the end of the decade. However, these figures must be interpreted with caution. Without targeted interventions to improve digital literacy and collaborative marketing structures, the projected 10–13% CAGR may only benefit a fraction of the sector, exacerbating regional economic disparities.

Based on these findings, the study concludes that the transition to smart agriculture is not merely a technological upgrade but a necessary economic evolution to ensure food security and competitiveness in the European market. The evidence suggests that passive adoption of technology will not suffice. To leverage the economic benefits of digitalization—such as optimized resource management and increased market access—Romania requires a coordinated ecosystem approach. Policymakers must shift focus from generic funding to targeted support that addresses the specific needs of smallholders, specifically by fostering digital literacy programs and simplifying access to finance.

Ultimately, while Romania's agricultural sector has made significant progress, the future functionality of the sector depends on bridging the rural-urban digital divide. Future research should focus on longitudinal studies assessing the impact of specific digital interventions on small-farm profitability, providing a clearer roadmap for an inclusive and sustainable digital transformation.

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