Integrating artificial intelligence into agriculture in the EU

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Abstract: Artificial intelligence (AI) helps agriculture by automating routine tasks, optimizing decision-making, and making farming more efficient. Robots can perform physical work, drones can monitor crops and drought damage, and AI-based systems can assist with data analysis and farming decisions. Integrating artificial intelligence increases efficiency and reduces costs, but the digital transition and technology adoption also present challenges. Artificial intelligence is already embedded in many everyday devices used by businesses and consumers, often unnoticed. In recent years, the use of generative AI (GenAI) has spread rapidly across all sectors. For Europe, integrating artificial intelligence into agriculture is essential for competitiveness, while also enabling innovative solutions to be brought to market. This study analyzes the opportunities, barriers, and regulatory implications of AI adoption in European Union (EU) agriculture based on a qualitative assessment of a multi-stakeholder expert workshop organized by the European Commission. Using thematic content analysis, the research identifies key AI application domains, economic and environmental impacts, governance challenges, and adoption constraints—particularly for small and medium-sized farms. The findings indicate that although AI technologies such as robotics, decision support systems, and autonomous machinery demonstrate measurable potential in reducing inputs and improving efficiency, structural barriers including fragmented data ecosystems, regulatory uncertainty under the AI Act, *limited digital skills, and trust deficits significantly slow adoption. The study concludes that coordinated data governance, sector-specific liability clarification, targeted capacity building, and scalable business models are essential to unlocking AI's full competitiveness-enhancing potential in EU agriculture.*

Keywords: artificial intelligence, smart agriculture, precision farming, EU AI Act, agricultural competitiveness, digital transformation, robotics, data governance

1 Introduction

1.1 The impact of artificial intelligence on competitiveness

Artificial intelligence (AI) is already an integral part of many applications in the everyday activities of businesses and consumers, although this is not always obvious at first glance.

Artificial intelligence is a complex algorithm that mimics human intelligent thinking, cognitive processes, and behavior, and is also capable of learning. It follows that AI can best develop where extensive and complex data sets are available [1]. Artificial intelligence is a tool that can enable smart agriculture to achieve goals that go beyond the limits of human capabilities. With its help, one of the challenges of the future will be to process huge amounts of data and transform it into actionable elements [2]. In agriculture, the use of artificial intelligence is not yet a mature practice for solving many of the tasks that arise. In production, in addition to controllable conditions, circumstances may arise over which farmers have no control (weather factors). At the same time, artificial intelligence helps to increase efficiency and reduce costs, leading to greater profitability [3].

There are many small businesses in agriculture, and after a while, these businesses are likely to become users of artificial intelligence applications. Although many farms already generate a lot of data, including from precision farming, the data from a single farm is unlikely to be sufficient for the effective and efficient development of AI models. Therefore, data sharing will be essential to exploit the potential of AI [4].

1.2 Digitization and precision farming as precursors to artificial intelligence

According to [5], precision farming refers to the practical application of digitized agriculture, the use of digital solutions in agriculture, where developments are aimed at more competitive farming and increased efficiency, while also placing great emphasis on environmental sustainability. The dissemination of digitalization technologies and their widespread application in agricultural production is listed as the tenth objective of the Common Agricultural Policy after 2020, under the heading "Knowledge transfer, innovation, and digitalization."

According to [6], the widespread dissemination and application of digitalisation in agriculture could provide a solution for the development of sales channels for agricultural products in Hungary, enabling the opening of new sales channels. All these opportunities have already been outlined in Hungary's Digital Agricultural Strategy. Csiba & Ferencz [7] believe that, in addition to opening up sales channels, the above-mentioned strategic plan also recommends the use of higher-level digital precision technologies that promote the processing of products at a higher level and their development into products with higher added value. In addition, it emphasizes the need to make communication and, thus, business relations more efficient, which is also made possible by the widespread dissemination and application of digitalization.

As a result of this development, various digital tools and software are now available to farmers in Hungary. Farms are open to precision solutions, but there are also challenges to their successful dissemination, such as a suitably trained workforce, capital, etc. Precision farming is the practical manifestation of digitized agriculture, involving the application of digital solutions in agriculture, where developments are aimed at how to farm competitively and increase productivity, while placing great emphasis on environmental sustainability [8].

1.3 The impact of artificial intelligence on labor shortages

Artificial intelligence can be a significant help in solving labor shortages in certain areas of agriculture. In many farms, labor shortages and quality are serious problems. Artificial intelligence can help by automating many tasks, especially those that require significant human intervention. Good examples of this are self-driving tractors based on artificial intelligence and robots used in agriculture and other areas [9]. AI technologies are primarily used in large-scale farming to help solve problems caused by labor shortages, for example through the use of robotics. The use of self-driving robotic machines reduces operating costs and further improves crop yields [10]. According to farmers using AI, automated production can transform agriculture from labor-intensive manual work into intelligent, efficient activities powered by robotics and artificial intelligence. These technologies increase productivity and profitability on farms of all sizes [11].

The use of artificial intelligence also results in excellent efficiency and accuracy. GPS-controlled equipment and robotic machines operate with human-impossible precision, minimizing errors, reducing waste, and enabling real-time adaptation to changing agricultural conditions throughout the growing season [12]. Continuous operation is ensured as robotic equipment operates day and night, regardless of weather, darkness, or fatigue, maximizing productivity during critical campaign periods when timing directly affects yield and quality [13].

1.4 The EU's view of artificial intelligence

Europe's competitiveness and economic resilience will depend crucially on its ability to integrate artificial intelligence in a tailored way into key sectors such as agriculture. The EU has potential solutions and knowledge in the field of artificial intelligence applications that can reliably ensure the effectiveness of AI-based models [4]. As agricultural production is influenced by a number of micro- and macro-level factors, including local environmental conditions, climate, and global markets, artificial intelligence has the potential to have a significant impact on the competitiveness of agriculture. Decision support tools, in particular farm management information systems, already assist many farmers in their work [4].

The European Commission is working with Member States, industry, and civil society to develop an AI strategy aimed at promoting the use of artificial intelligence in production and improving the delivery of public services. Although the EU is committed to ethical and human-centered AI, a number of challenges remain. These include fragmented (non-uniform) ecosystems, limited access to data and computing resources, and concerns about data protection, job losses, and fairness [14].

The first European AI strategy aimed to make the European Union a world-class center for artificial intelligence and to ensure that its use is human-centered and trustworthy. This objective was followed by a number of further initiatives aimed at boosting the development and deployment of artificial intelligence in Europe, strengthening competitiveness and technological sovereignty [4].

1.5 EU legislation on artificial intelligence

The AI Act, which entered into force on August 1, 2024, creates a single market and harmonized rules for trustworthy artificial intelligence in the EU. It aims to promote innovation and the uptake of artificial intelligence, while addressing potential risks to people's health, safety, and fundamental rights, and protecting democracy and the rule of law. The adoption of the AI Act is a major milestone for the EU, and ensuring its effective implementation is now a key priority for the Commission [15].

The AI Act introduces a clear, easy-to-understand approach and makes it clear to AI developers, implementers, and users how to manage the risks generated by specific uses of AI. The legislation strikes a balance between promoting research and innovation in artificial intelligence and ensuring that Europeans can enjoy its safe and reliable benefits [16].

The AI Act sets out risk-based rules for AI developers and deployers for specific uses of AI. The AI Act is part of a broader policy package supporting the development of trustworthy artificial intelligence (Regulation (EU) 2024/1689 on establishing harmonized rules on artificial intelligence). Together, these measures guarantee safety, fundamental rights, and human-centered artificial intelligence, and strengthen the uptake, investment, and innovation of artificial intelligence in the EU [17].

The AI Act ensures that Europeans can trust what artificial intelligence has to offer. While most AI systems are risk-free and can contribute to solving many societal challenges, certain artificial intelligence systems pose risks that we need to address to avoid undesirable consequences. Although existing legislation provides some protection, it is not sufficient to address the specific challenges that AI systems may pose [18].

The European agricultural sector faces structural pressures, including labor shortages, rising input costs, climate change, and global competition. Against this background, AI is positioned as a strategic technology capable of enhancing productivity while supporting sustainability objectives. However, AI adoption remains uneven across the European Union (EU), and its transformative potential is not yet fully realized.

This paper investigates the following research questions:

- What are the principal areas of AI application in EU agriculture?
- How does AI contribute to competitiveness and operational efficiency?
- What regulatory and structural barriers constrain adoption?
- What policy measures could enhance scalable and trustworthy AI integration?

2 Methods

This study applies a qualitative exploratory research design based on a structured analysis of a multi-stakeholder expert workshop organized by the European Commission's Directorate-General for Communications Networks, Content and Technology (DG CNECT) and Directorate-General for Agriculture and Rural Development (DG AGRI) entitled "Artificial intelligence in agriculture: harnessing opportunities, overcoming challenges, mitigating risks and exploiting data". On March 27, 2025, more than 200 experts from industry, research, policy, and agriculture gathered for an EU workshop focused on accelerating the development and deployment of AI in European agriculture. The main objectives of the event were:

1. To identify untapped opportunities and market gaps in AI for specific areas of agriculture.
2. To explore opportunities for improving the availability of data for AI. Here, the varying levels of availability of data across different areas had to be taken into account.
3. Discussing approaches to AI models that are driven by a diversified innovation ecosystem and serve the needs of the sector.

The research follows a policy-oriented multi-stakeholder analysis approach, aiming to identify opportunities, barriers, and regulatory implications of AI deployment in EU agriculture. The analysis was structured along three analytical dimensions (Table 1):

Dimension	**Focus**
Technological	AI applications, infrastructure, interoperability
Economic	Cost-effectiveness, competitiveness, market gaps
Regulatory	AI Act implications, liability, compliance burdens

Table 1

Thematic focus

3 Results

3.1 Areas of application for artificial intelligence in agriculture

The workshop presented summarizes the areas in which artificial intelligence supports agricultural production. The workshop highlighted the significant but largely untapped potential of artificial intelligence in the EU agricultural sector (Table 2).

- Robots: They perform routine tasks such as sowing, spraying, and harvesting, especially in areas with labor shortages.
- Drones: They can survey areas horizontally and vertically, check plant health, and identify drought damage or other problems.

- Decision support systems: AI-based software analyzes natural and farming data to help farmers make more informed decisions about crops, irrigation, and fertilization.
- Automated systems: AI helps machines operate precisely and automatically, improving efficiency and reducing errors.
- Increased efficiency: Optimizes processes and reduces waste.
- Cost reduction: Less resource consumption (water, fertilizer, pesticides, labor, etc.).
- Addressing labor shortages: Robots perform heavy, physical work, which is particularly useful in areas struggling with labor shortages.
- Data-driven decision-making: Decisions can be made based on more accurate information.
- Regulation: In some areas, legislation has not yet fully adapted to new technologies.
- Data protection and security: The management and protection of collected data is a fundamental consideration.
- Technological transition: The introduction of modern technologies can pose financial and technical challenges.
- Skilled workforce: There is a need for professionals who are capable of managing the systems.

Application Area	**Function**	**Strategic Impact**
Robotics	Sowing, spraying, harvesting	Labor substitution
Drones	Crop monitoring	Precision input use
Decision Support Systems	Farm analytics	Data-driven decisions
Autonomous Machinery	Precision field operations	Efficiency gains
Generative AI	Administrative support	Reduced bureaucracy

Table 2
AI applications in EU agriculture

3.2. Economic and Operational Impacts

The potential of artificial intelligence in agriculture is diverse and affects all stages of production. According to the EU position, precision farming and other forms of decision support are currently considered relevant areas of AI application.

Artificial intelligence can be a tool for supporting farmers and meeting their specific needs. Farmers should use AI-based solutions to remain competitive. Even if they are sometimes unaware that the tools they use contain AI, for example to improve the performance of their machines. A number of AI-based solutions would be gradually introduced on farms to support specific processes. At the same time, opportunities may arise to explore areas of application that will completely transform the organization of agricultural work.

The expert workshop summarized the potential role of artificial intelligence as follows (Table 3):

- AI has great potential to improve agricultural performance, but this remains largely untapped in the EU.
- The impact of artificial intelligence can be quantified, for example in terms of reductions in pesticides, fertilizers, water, and costs. The most important applications of AI include precision farming, decision support tools (e.g., farm management information systems), and robotics.
- AI has great potential to support climate adaptation. New applications include autonomous machines and risk management tools.
- AI could play a role in filling market gaps, for example in training agricultural producers and collecting and integrating data.
- GenAI is particularly promising in reducing administrative tasks and supporting advisory services and training.

Impact Area	Mechanism	Measurable Indicator
Cost Reduction	Lower input usage	€ / hectare
Yield Increase	Optimized timing	Tons / hectare
Labor Substitution	Robotics	Labor hours saved
Climate Adaptation	Risk forecasting	Yield variance reduction
Administrative Efficiency	Automation	Time saved per report

Table 3
Economic and Operational Impacts

2. Distrust of artificial intelligence, concerns about loss of control over decision-making, and reluctance to share data. 3. Uncertainty about responsibility for results generated by artificial intelligence is a deterrent.

3.3 Strategic Autonomy and Market Relevance

The EU faces challenges in several areas concerning marketability and autonomy.

The immaturity and lack of market relevance of AI-based solutions driven by scientific efforts slows down the emergence of a dynamic market for AI-based services. Academic-led projects are often unable to develop economically viable products.

Competing with the United States and China while upholding European values may pose challenges for the European innovation ecosystem and agricultural producers, for example if AI services offered to agricultural producers in the EU are trained using data from farms in third countries.

Avoiding vulnerability and dependence on non-EU countries appears to be a challenge for participants, as most artificial intelligence models currently run in the cloud and cloud service providers are often based in third countries. The EU needs to ensure that sector-specific AI models are trained on European agricultural data.

Stakeholders have differing opinions on certain areas of the new legislation. For example, while the AI Act and product safety requirements are considered important, they may also lead to higher manufacturing and maintenance costs. This may pose a challenge to the market entry of machines with AI-based solutions. In addition, inconsistent national legislation results in multiple testing environments, which also increases production costs.

3.4 Difficulties in introducing AI-based solutions

The EU has identified a number of difficulties in the use of artificial intelligence, of which the following are worth highlighting.

A key barrier to the development and adoption of AI-based solutions is the limited availability of accessible data needed to provide cost-effective services. The lack of sufficient quantity and quality of data hinders scalability and increases production costs.

There is a high proportion of small farms in the EU for which AI-based tools would not be cost-effective. Cost-effectiveness primarily favors larger farms. Proposals to mitigate this include the use of contractors' services, the sharing of machines in the form of cooperatives, and the extension of CAP investment support measures.

Many technological developments related to AI are taking place in parallel in agriculture, such as sensors, cameras, and drones in the field of IoT, to which agricultural systems must adapt, while the lifespan of machines is relatively long. At the same time, these technologies need to work together for AI to be effectively applied in agricultural practice. Simple and intuitive tools are needed, which has led to the suggestion that farmers could be involved in the development process of AI-based solutions.

Some participants see the lack of digital skills as a potential barrier, while others believe that farmers would be willing to learn these skills quickly if they saw a real benefit. Currently, however, many AI-based tools have their own specific settings, which means that businesses have to familiarize themselves with many different applications. At the same time, poor network connectivity in rural areas continues to hinder the adoption of AI-based solutions in agriculture.

There is a lack of trust in new AI-based solutions, which could be overcome through communication efforts. Farmers are reluctant to use these tools due to uncertainty about who is responsible for AI-based solution failures. They distrust artificial intelligence, have concerns about loss of control over decision-making, and they are also reluctant to share data. New EU legislation can also sometimes prevent AI-based solutions from being introduced to the market and increase production costs, for example due to uncertainty in the interpretation of legislation (Table 4).

Barrier	**Type**	**Affected Stakeholders**	**Impact**	**Severity**
Data Scarcity	Technological	SMEs	Reduces model performance	High
High Investment Costs	Economic	Small farms	Limits SME adoption	High
Regulatory Uncertainty	Legal	Farmers, Manufacturers	Reduces willingness	Medium–High
Lack of Skills	Human capital	Farmers	Slows uptake	Medium
Low Trust	Behavioral	Farmers	Reduces willingness	Medium
Poor Connectivity	Infrastructure	Rural areas	Limits deployment	High

Table 4

Key Barriers to AI Adoption

Conclusion and Recommendations

Artificial intelligence represents a transformative opportunity for European agriculture. Robotics, precision systems, and AI-driven decision tools can significantly improve productivity, sustainability, and resilience. However, structural barriers, including fragmented data ecosystems, regulatory complexity, limited digital skills, and trust deficits, impede widespread adoption.

The cost-effectiveness of AI-based services in various agricultural applications can be improved through systemic measures, for example in the areas of data sets, machines, tools, and applications. Digital Farm ID is one example of such a solution.

Coordinated efforts are needed to capitalize on data, develop sector-specific AI models, and exchange best practices in agriculture in terms of responsibility, obligations, and data sharing.

Building trust is critical for both the adoption of AI and the willingness to share data. Clear, unbiased communication about the benefits and risks of AI, as well as targeted capacity building for end users, will be key to promoting trust and engagement.

Precision farming technologies increase resource efficiency. They help farmers minimize water and fertilizer use, thereby contributing to reduced emissions and increased profitability.

Data (e.g., crop and environmental information) is critical to the effectiveness of precision farming and other decision support tools. Autonomous machines and robotics improve working conditions, for example, autonomous tractors make the driver's job easier, and robots can take over certain dangerous or physically demanding tasks. Both have the potential to reduce labor shortages.

While AI-based solutions are already actively transforming agricultural production, stakeholders in the agricultural value chain on some continents are ahead of others. Significant barriers remain to the development, expansion, and adoption of AI-based solutions.

Emerging AI-driven risk management systems also have significant potential to improve forecasting capabilities related to climate risks, food security, and market volatility. This may require the creation of a digital economy ID that facilitates secure and seamless data sharing. Sector-specific guidelines on liability for AI system failures are needed.

Targeted training focused on developing the digital skills of farmers, agricultural workers, and advisors is critical. Demonstrating the added value of AI applications and disseminating examples of best practices can be recommended as a strategic measure to increase farmers' confidence and accelerate the uptake of the technology. It is essential that farmers are directly involved in the development of AI solutions to ensure that the technologies meet practical requirements.

The European Union's AI Act is the first legal framework for artificial intelligence that addresses the risks of artificial intelligence, putting Europe at the forefront globally. The rules aim to promote trustworthy artificial intelligence in Europe and provide guidance to other countries around the world.

Limitations and Further Research

This study is subject to several limitations that should be acknowledged when interpreting its findings. First, the analysis is based primarily on qualitative insights derived from a single expert workshop organized by the European Commission, which may reflect institutional priorities and stakeholder perspectives present at the event rather than the full diversity of views across the European agricultural sector. The absence of farm-level quantitative data limits the ability to empirically measure the economic and productivity impacts of AI adoption. Future research should therefore incorporate longitudinal and quantitative studies assessing farm performance, and micro-level investigations into behavioral factors such as trust, risk perception, and willingness to share data.

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