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INTEGRATION OF DIGITAL TECHNOLOGIES INTO AGRICULTURAL PRODUCTION PROCESSES

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Abstract. *Purpose*. The study aims to provide theoretical justifications and practical recommendations for integrating digital technologies into agricultural production processes. This will improve the resource efficiency, productivity, competitiveness and sustainable development of agricultural enterprises in an era of economic and technological transformation. *Methodology*. The study is based on a comprehensive methodological approach that combines theoretical, analytical, empirical and economic-mathematical methods. Theoretical analysis was used to examine the conceptual foundations of the digitalisation of agriculture and international experience. The systematic approach involved treating agricultural enterprises as integrated organisational and economic systems. SWOT analysis, economic-statistical and financial-economic methods were applied to assess the effectiveness of digital technologies, whilst empirical methods and expert surveys were used to evaluate the level of digital maturity of enterprises. Economic and mathematical modelling and forecasting were used to analyse the relationship between digitalisation and enterprise performance, and to identify potential future developments. *Results*. The findings confirm that digital technologies significantly improve production efficiency, reduce costs, increase labour productivity and enhance managerial decision-making. These technologies include precision farming, ERP systems, GPS monitoring, cloud computing and big data analytics. The greatest economic benefits are achieved by integrating digital technologies across the entire production cycle, from planning and resource management to logistics and quality control. However, digital transformation is still being held back by limited investment resources, insufficient digital expertise, high implementation costs, inadequate digital infrastructure, and a lack of comprehensive digital strategies. Further progress hinges on infrastructure development, increased state support, public-private partnerships, and enhanced digital education. *Practical implications*. The proposed recommendations could help policymakers and managers develop digital transformation strategies, improve resource utilisation, strengthen planning and control systems, implement precision farming technologies and digital management platforms, and enhance the competitiveness and financial sustainability of agricultural enterprises. *Value/Originality*. This study presents a thorough conceptual framework for analysing the integration of digital technology in agriculture, combining principles from the digital economy, innovation management, and agricultural systems development. The framework clarifies the relationship between digitalisation levels and enterprise performance, proposes a systemic approach to assessing digital maturity and provides practical guidance on optimising digital transformation. This approach has the potential to increase the efficiency, innovation capacity, resilience and sustainable development of Ukraine's agricultural sector.

Keywords: digitalisation, agricultural production, precision farming, automation, ESG principles, sustainable development, strategy.

JEL Classification: O14, Q16, O33, Q55, M15, L86

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1. Introduction

In the context of globalisation, mounting competitive pressure in agricultural markets, climate change, and the growing demand for food security, integrating digital technologies into agricultural production processes has become strategically important. The digital transformation of the agricultural sector is considered essential for enhancing resource efficiency, promoting sustainable development and adapting production systems to external uncertainties.

Technologies such as digital farm management platforms, precision agriculture systems, big data analytics, artificial intelligence, the Internet of Things (IoT), remote sensing and Geographic Information Systems (GIS) are creating new opportunities to optimise production processes, reduce costs, minimise environmental impact and enhance agricultural productivity. The adoption of digital solutions allows agricultural enterprises to transition from traditional, extensive management models to innovative, knowledge-intensive, resource-efficient ones.

The issue of agricultural digitalisation is of particular pertinence for transition economies, including Ukraine, where the agricultural sector plays a pivotal role in the formation of gross domestic product, export potential and socio-economic development of rural areas. Concurrently, the implementation of digital technologies in the domestic agricultural sector is accompanied by a range of challenges, including insufficient digital infrastructure, limited access to investment resources, a shortage of digital competencies and institutional barriers.

In this context, research into the processes of integrating digital technologies into agricultural production is necessary to substantiate effective mechanisms of digital transformation, identify its economic, environmental and social impacts, and formulate practical recommendations aimed at enhancing the competitiveness of agricultural enterprises. This determines the relevance of the chosen topic and its significance for both theoretical research and practical application within the domain of agricultural management and state agricultural policy.

The study aims to provide theoretical substantiation and develop practical recommendations for integrating digital technologies into agricultural production processes. This will enhance the efficiency, productivity and competitiveness of agricultural enterprises and ensure their sustainable development in the context of contemporary economic and technological transformations.

To achieve the research aim, the following objectives were pursued: to analyse the theoretical foundations of digital transformation in agricultural production and its impact on enterprise competitiveness; to assess the current level of digitalisation in Ukraine's agricultural sector and identify the main barriers to digital technology adoption; to examine international experience in the application of digital technologies in agriculture and evaluate their potential for adaptation to Ukrainian conditions; to identify priority areas for integrating digital technologies into agricultural production processes; to develop methodological approaches for assessing the digital maturity of agricultural enterprises and evaluating the economic effects of digital transformation; and to formulate practical recommendations for promoting digitalisation and strengthening the sustainable development and competitiveness of the agricultural sector.

The research uses a combination of theoretical, analytical and empirical methods to provide a thorough evaluation of digital solutions and their effect on economic performance, organisational modernisation and competitiveness. The methodological framework comprises: theoretical analysis (to summarise academic approaches to digital transformation and to examine national and international experience); a systems approach (to consider agricultural production as an integrated organisational and economic system); analytical methods, in particular SWOT analysis, economic-statistical and financial tools (to assess the results of digitalisation); economic and mathematical modelling (to determine the relationship between levels of digitalisation and performance indicators, as well as to optimise resource flows); empirical methods (analysis of statistical data and expert assessments of digital maturity levels); forecasting methods (to develop development scenarios and assess expected economic effects).

The application of this methodological framework ensures a scientifically grounded evaluation of digital integration processes and enables the formulation of practical recommendations for improving enterprise performance under conditions of economic digital transformation.

The present study addresses the integration of digital technologies into agricultural production processes, with a particular focus on the analysis of contemporary digital tools such as precision agriculture systems, automated monitoring, big data management, digital platforms and information-analytical solutions. The aim of this analysis is to improve the efficiency, productivity and competitiveness of agricultural enterprises in the context of economic transformation and increasing global challenges.

Within the research framework, the organisational and economic foundations of digital transformation in the agricultural sector are established. Key factors and barriers to the implementation of digital technology are identified and their impact on the optimisation of production, the rational use of resources and improved managerial decision-making is assessed.

The findings enable the identification of effective mechanisms and tools for implementing digital solutions within agricultural production cycles, forecasting their economic impact and influence on financial sustainability, and developing practical recommendations for public authorities, agribusiness and investors regarding strategies for digital development and modernisation based on innovation and long-term competitiveness.

2. Conceptual Features of the Digital Modernisation of the Agricultural Sector

Digitalisation of agricultural production is one of the key drivers of transformation in the contemporary agricultural sector under conditions of global competition, technological change and increasing demands for resource efficiency. The integration of digital technologies into production processes has been demonstrated to enhance productivity, optimise costs, improve the quality of managerial decision-making and engender greater transparency in agribusiness operations (Sakhno, Polishchuk, Salkova, Kucher, 2019).

Digitalisation of agricultural production can be defined as the process of implementing and integrating digital technologies into all stages of agricultural activity (production, management, logistics and marketing) with the aim of enhancing resource efficiency, productivity, the quality of managerial decision-making and the competitiveness of agricultural enterprises.

In practical terms, digitalisation involves the use of (Tomashuk, 2025):

– Precision farming technologies;
– GPS-based machinery monitoring;
– sensors and IoT devices;
– unmanned aerial vehicles (UAVs);
– data analytics systems and artificial intelligence;
– digital farm management platforms, and others.

Despite the considerable potential of digital technologies to enhance the efficiency of agricultural production, their integration is hindered by a variety of systemic constraints. These include infrastructural, financial, economic, human resource, technological, institutional, informational, social, and security-related factors, which exert varying degrees of influence on the implementation of innovations in agriculture. Table 1 summarises the main challenges and barriers to the integration of digital technologies.

The digital transformation of agricultural production is characterised by a number of specific features, determined by natural and climatic conditions, the spatial structure of agricultural activity, the capital-intensive nature of technological solutions, and the need to develop the relevant digital skills (Fedoryshyna, 2024). These characteristics determine the directions for adapting innovative tools to the specific conditions of the agricultural sector and influence the effectiveness of their practical application. The following section presents a summary of the key features of digital transformation processes in agricultural production (see Table 2).

The agricultural sector is of critical importance in ensuring national food security, maintaining domestic stability, developing export potential and promoting the socio-economic development of rural areas.

Its functionality exerts a direct influence on the level of food provision for the population, the resilience of the national economy, and the country's competitiveness in global agricultural markets (Belkin,

Table 1
Challenges and Barriers to the Integration of Digital Technologies in Agriculture

Barrier group	Problem Content	Manifestation in agricultural production	Development implications
Infrastructural	Insufficient level of digital and telecommunications infrastructure	Limited access to high-speed internet in rural areas	Slowing down the adoption of digital solutions
Financial and economic	High cost of digital technologies and limited access to investment	Low level of digitalisation among small and medium-sized farms	Widening technological inequality
Human resources	Deficit of digital competencies and specialists	Low readiness of personnel to work with digital systems	Reducing the efficiency of implementation
Technological	Low level of interoperability and standardisation of digital solutions	Fragmentation of information systems	Limiting the scaling of technologies
Institutional	Imperfect regulatory framework	Lack of incentives for digital transformation	Slowing down innovation processes
Informational	Insufficient awareness of the benefits of digitalisation	Limited use of modern agricultural technologies	Preservation of traditional production models
Social	Resistance to change and low level of trust in digital tools	Slow introduction of new technologies	Delaying structural transformations
Security	Cyber risks and threats of data leakage	Vulnerability of digital platforms	Increasing operational risks

Source: (Zaremba, Sakhno, Chesnik, Nitsenko, Chikov, Zakharova, Boltovska, 2025; Tomashuk, 2025)

Table 2

Specific Features of the Digital Transformation Processes in Agricultural Production

Feature	Characteristics	Practical significance for the agricultural sector
Dependence on natural and climatic conditions	Implementation of digital technologies taking into account seasonality, weather risks, soil conditions	Increasing planning accuracy and reducing climate risks
Spatial dispersion of production	Large areas of land require the use of GPS, GIS and remote monitoring	Optimising control over equipment, crops and resources
Use of precision farming technologies	Application of sensors, drones, automated equipment	The rational application of fertilisers and plant protection products saves resources
Focus on data analytics	Processing of large data sets, forecasting of yields	Increasing the validity of management decisions
Capital intensity of digital solutions	The need for significant investment in equipment and software	The need for financial support and investment programs
Need for digital competencies	The need to train specialists and improve digital literacy	Forming modern human resources
Integrative nature of changes	Combining production, management and logistics processes into a single digital system	Increasing the efficiency and transparency of agribusiness
Focus on sustainable development	Reducing the environmental load and optimising the use of resources	Ensuring environmental and economic sustainability of production

Source: (Pronko, Furman, Kucher, Gontaruk, 2020; Burdyak, Tomashuk, 2026)

Trapaidze, Bondarenko, Omelianenko, Cherniavskyi, 2025). Concurrently, the full-scale military aggression has significantly complicated the operations of agricultural enterprises, resulting in the destruction of production infrastructure, loss of material and technical resources, disruption of supply chains, contamination of agricultural land with mines, increased production and financial risks, and restrictions on investment activity. Collectively, these factors have had a detrimental effect on production volumes, export potential and the overall economic resilience of the agricultural sector. This emphasises the urgent need for modernisation and digital transformation as a means of enhancing adaptability and recovery.

According to the Institute of Agricultural Economics, the direct losses incurred by Ukraine's agricultural sector due to the Russian Federation's full-scale military invasion amounted to 11.2 billion USD by the beginning of 2025 (see Figures 1-2).

In order to facilitate the recovery of the agricultural sector and enhance its efficiency in the face of contemporary challenges, it is imperative to implement innovative technologies and managerial solutions that contribute to increased productivity, competitiveness and the sustainable development of the industry (Logosha, Pidvalna, Dyachenko, 2025). The data presented in Table 3 indicate a positive trend in the innovative development of Ukraine's agro-industrial complex during 2019-2024, as evidenced by increased public funding, a significant rise in the share of enterprises implementing innovations, improved labour productivity, and an expanding share of organic production. This finding serves to corroborate the gradual intensification of modernisation processes and

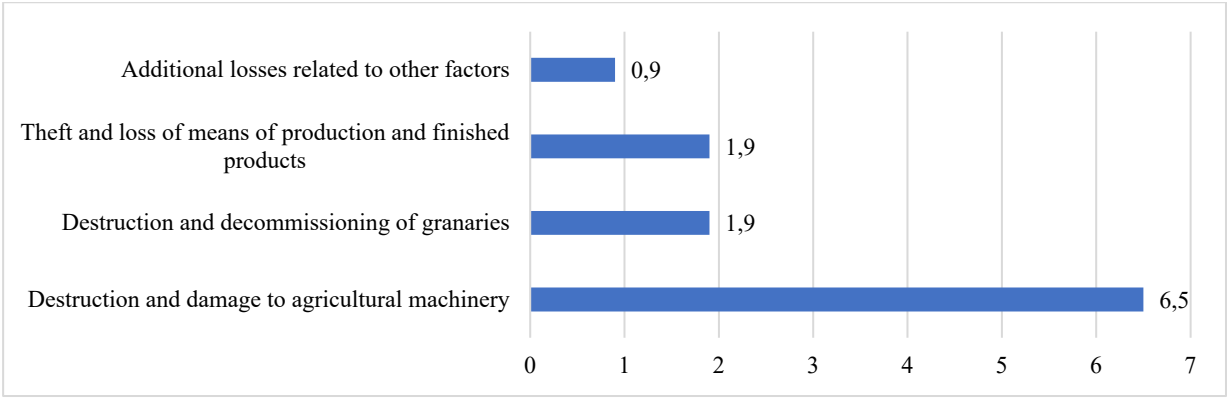

Figure 1. Losses Incurred by Ukraine's Agricultural Sector as a Result of the War, Early 2025, billion USD

Source: (Melnyk, 2025)

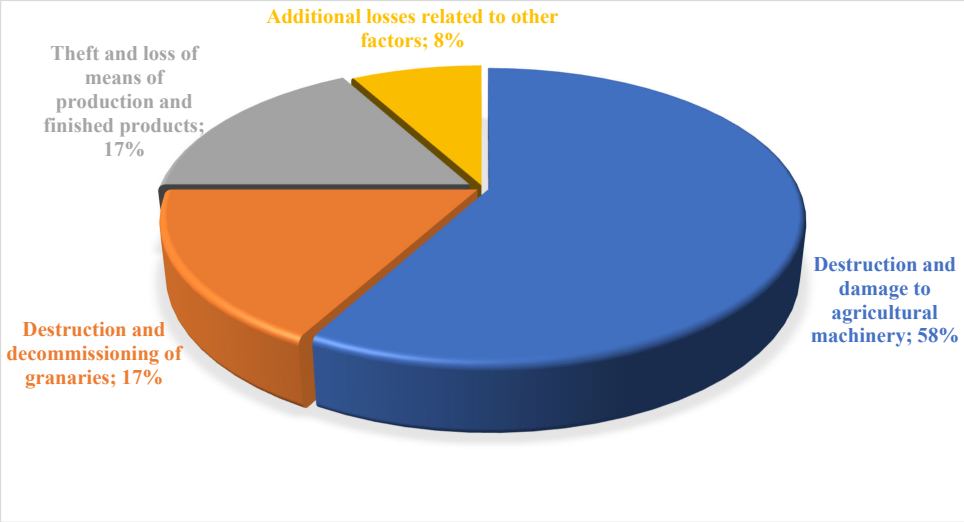

Figure 2. Structure of Losses in Ukraine's Agricultural Sector as a Result of the War, Early 2025, %

Source: (Melnyk, 2025)

the strengthening of the innovation orientation of the agricultural sector.

Moreover, the data presented in Table 4 demonstrate a sustained positive trend in the innovation and digital activity of Ukrainian agricultural enterprises during 2019–2024, reflected in the increasing share of enterprises implementing innovations and adopting digital technologies, the growth in funding allocated to innovation activities, and higher crop yields resulting from innovation.

The accelerated evolution and extensive practical implementation of innovations within the global agricultural sector are pivotal factors in the process of modernisation, thereby enhancing productivity, resource efficiency, and competitiveness in the context of global technological transformation (Pronko, Furman, Kucher, Gontaruk, 2020).

Table 5 provides a comparative analysis of the level of agricultural digitisation expected in 2025, highlighting notable cross-country variations in the digital development index and the adoption of Internet of Things (IoT) technologies, artificial intelligence, drones, and satellite technologies.

The highest indicators are observed in countries with well-developed state support mechanisms and advanced digital infrastructure, such as Poland, Estonia and the Czech Republic. Ukraine, meanwhile, occupies an intermediate position with considerable potential for further growth. Overall, the findings confirm favourable prospects for the digital transformation of the agricultural sector in most countries, provided infrastructural, financial, and human resource barriers are effectively addressed. International experience indeed demonstrates that integrating digital technologies into agricultural production processes is key to improving resource efficiency, labour productivity and the competitiveness of agricultural enterprises. The most successful practices have emerged in the European Union, where comprehensive public policies, advanced digital infrastructure, widespread adoption of innovative technologies and financial mechanisms that encourage investment in digital innovation support the digital transformation of agriculture.

Precision agriculture is one of the international practices that can be effectively adapted to the

Table 3

Dynamics of Key Indicators of Innovation Implementation in Ukraine's Agro-Industrial Complex, 2019-2024

Indicators	2019	2020	2021	2022	2023	2024	Deviation (+/-) 2024 to 2019
State funding, million UAH	1,20	1,35	1,60	1,78	1,98	1,99	0,79
Number of agricultural enterprises that have implemented innovations, %	5,2	6,3	8,1	10,4	12,7	15,5	10,3
Share of organic production in the agricultural sector, %	1,1	1,4	1,8	2,3	3,0	3,3	2,2
Labor productivity, t/ha (grain)	3,5	3,7	3,9	4,2	4,5	4,6	1,1

Source: (Official website of the State Statistics Service of Ukraine)

Table 4

Dynamics of Innovation Adoption and the Use of Digital Technologies in Ukrainian Agricultural Enterprises

Indicators	2019	2020	2021	2022	2023	2024	Deviation (+/-) 2024 to 2019
Number of agricultural enterprises that have implemented innovations, %	5,2	6,3	8,1	10,4	12,7	15,5	10,3
Percentage of agricultural enterprises that use digital technologies, %	6,5	7,8	9,4	11,5	13,6	14,2	7,7
Volume of financing for innovation activities, million UAH	520	610	735	820	940	980	460
Level of yield increase due to innovations, %	3,8	5,1	7,3	9,0	11,2	11,9	8,1

Source: (Official website of the State Statistics Service of Ukraine)

Table 5

International Analysis of the State of Agricultural Digitalisation in 2025

Country	Digital Agriculture Index (2025 est.)	IoT	AI	Drones	Satellite	Policy Support Level	Main Challenges	2025 Innovation Outlook
Poland	8.2 / 10	+	+	+	+	High	Workforce skills, small farm digital gap	Positive
Estonia	8.1 / 10	+	+	+	+	High	Smallholder outreach	Positive
Lithuania	7.8 / 10	+	+	+	+	High	Rural broadband, cost of adoption	Positive
Ukraine	7.2 / 10	+	+	+	+	Medium	Infrastructure, security risks	Neutral
Hungary	7.6 / 10	+	+	+	+	High	Economic disparities, digital literacy	Positive
Romania	7.1 / 10	+	+	+	+	Medium	Rural digital divide, investment	Positive
Kazakhstan	6.3 / 10	+		+	+	Medium	Rural connectivity, cost of tech	Positive
Uzbekistan	5.9 / 10	+		+	+	Medium	Infrastructure, education	Positive
Georgia	6.4 / 10	+	+		+	Medium	Capital, scale of farms	Positive
Bulgaria	7.0 / 10	+	+	+		Medium	Fragmented land, rural digital gap	Neutral
Serbia	6.7 / 10	+		+		Medium	Outreach, investment	Positive
Moldova	5.8 / 10	+		+		Low	Funding, access to tech	Neutral
Kyrgyzstan	5.6 / 10			+	+	Low	Internet, skilled staff	Positive
Slovakia	7.3 / 10	+	+	+		High	Farm structure, adoption costs	Positive
Czech Republic	7.7 / 10	+	+	+	+	High	Policy harmonisation	Positive
Turkey	6.7 / 10	+		+	+	Medium	Farm size, regional disparity	Positive
Latvia	7.0 / 10	+	+	+		High	Cost, aging farmers	Neutral
Croatia	6.9 / 10	+	+		+	Medium	Fragmented farms	Positive

Source: (Status of Digital Agriculture in 18 Countries: 2025 Insights)

Ukrainian agricultural sector. Having been successfully implemented in countries such as the Netherlands, Germany and France, this approach integrates Global Positioning System (GPS) technologies, Geographic Information Systems (GIS), remote sensing, unmanned aerial vehicles (UAVs), soil sensors and variable-rate application technologies. These solutions have been demonstrated to facilitate more efficient use of land, material and energy resources, enhance crop productivity, reduce production costs, and minimise environmental impacts (Avila, Barbosa, 2025). The adoption of these technologies is of particular pertinence to Ukraine, given the country's extensive agricultural land resources and the necessity to enhance resource efficiency while ensuring environmentally sustainable production. Another promising area is the implementation of integrated digital farm management platforms, including Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), and Farm Management Information Systems (FMIS). These are widely used in Denmark, Sweden, and Finland. These systems facilitate automated production accounting, resource planning, financial management, cost control, and real-time decision support. The implementation of these systems within Ukrainian agricultural enterprises has the potential to enhance business transparency, optimise resource allocation, and fortify strategic management practices.

Considerable attention should also be given to adopting the Internet of Things (IoT), artificial intelligence (AI), cloud computing and big data analytics, all of which have become integral components

of digital agriculture in Spain, Italy and Poland. Integrating these technologies enables the continuous monitoring of soil conditions, crop development, livestock production, weather patterns and operational performance. This improves the quality and timeliness of managerial decision-making while reducing production risks (Avila, Barbosa, 2025). In Ukraine, large agricultural holdings could initially implement these technologies, while small and medium-sized farms would benefit from co-operative digital platforms, shared service centres and digital advisory systems. A comparative assessment indicates that countries in the European Union achieve higher economic returns from the digitalisation of agriculture thanks to supportive public policies, well-developed innovation ecosystems and high levels of digital competence among farmers and managers. Adopting digital technologies can lower expenditure on fuel, seeds, fertilisers and crop protection products while increasing labour productivity, improving product quality, optimising logistics and enhancing enterprise profitability. Furthermore, digitalisation improves production transparency and product traceability, ensures compliance with European environmental standards, and facilitates access to international markets.

By contrast, Ukraine's agricultural sector is undergoing an uneven digital transformation due to limited investment capacity, inadequate digital infrastructure in rural areas, a shortage of qualified personnel and the significant financial costs of technological modernisation. Nevertheless, Ukrainian agriculture's considerable production potential, coupled with the growing adoption of digital technologies by large agribusinesses, creates favourable conditions for the implementation of advanced European practices. The most promising priorities for Ukraine therefore include wider implementation of precision agriculture, integrated farm management systems, the Internet of Things (IoT), artificial intelligence (AI), cloud-based technologies and big data analytics, accompanied by strengthened government support for digital transformation. Adopting these international practices would boost the economic efficiency of agricultural production, boost enterprise competitiveness, optimise resource utilisation and encourage the long-term sustainable development of Ukraine's agricultural sector, in line with European digital transformation approaches.

The rapid development of digital technologies is shaping a new paradigm for the agricultural sector, transforming traditional production organisation, resource management and managerial decision-making approaches. Utilising precision farming systems, geographic information technologies, unmanned aerial vehicles, sensor-based monitoring, automated machinery and big data analytics enhances productivity, improves resource efficiency and promotes environmental sustainability in agricultural production (see Table 6).

In consideration of the comprehensive nature of digital transformation, the integration of digital technologies into the agricultural sector encompasses interconnected production, managerial, analytical and institutional processes. Collectively, these processes form an integrated system that underlies the functioning of modern agribusiness. A synopsis of the particular characteristics of such integration is presented in Figure 3.

Table 6
Next-Generation Digital Technologies in the Agricultural Sector of the Economy

Digital Technology	Essence and tools	Scope	Expected effect
Precision Farming	GPS navigation, autopilots, yield maps	Plant production	Optimisation of seeding rates, fertilisers and plant protection products, cost reduction
Geographic Information Systems (GIS)	Spatial data analysis, field mapping	Plant planning and monitoring	Increased accuracy of land resource management
Remote Earth Sensing	Satellite images, NDVI analysis	Crop condition control	Early detection of plant stresses and diseases
Unmanned Aerial Vehicles (Drones)	Aerial photography, spraying	Plant monitoring and protection	Efficiency and reduction of resource costs
IoT (Internet of Things)	Sensors of soil moisture, temperature, microclimate	Plant production and animal husbandry	Automation and precise control of production processes
Big Data and Analytics	Processing of large agrodata arrays	Farm management	Yield and risk forecasting
Automated and Robotic Technology	Milking robots, autonomous tractors	Animal husbandry, crop production	Increased labor productivity
Blockchain Technologies	Digital accounting and traceability of products	Logistics and export	Transparency of supply chains
Agricultural Platforms and Digital ERP Systems	Management software	Planning and accounting	Optimisation of resource management

Source: (Burdyak, Tomashuk, 2026; Tomashuk, 2025)

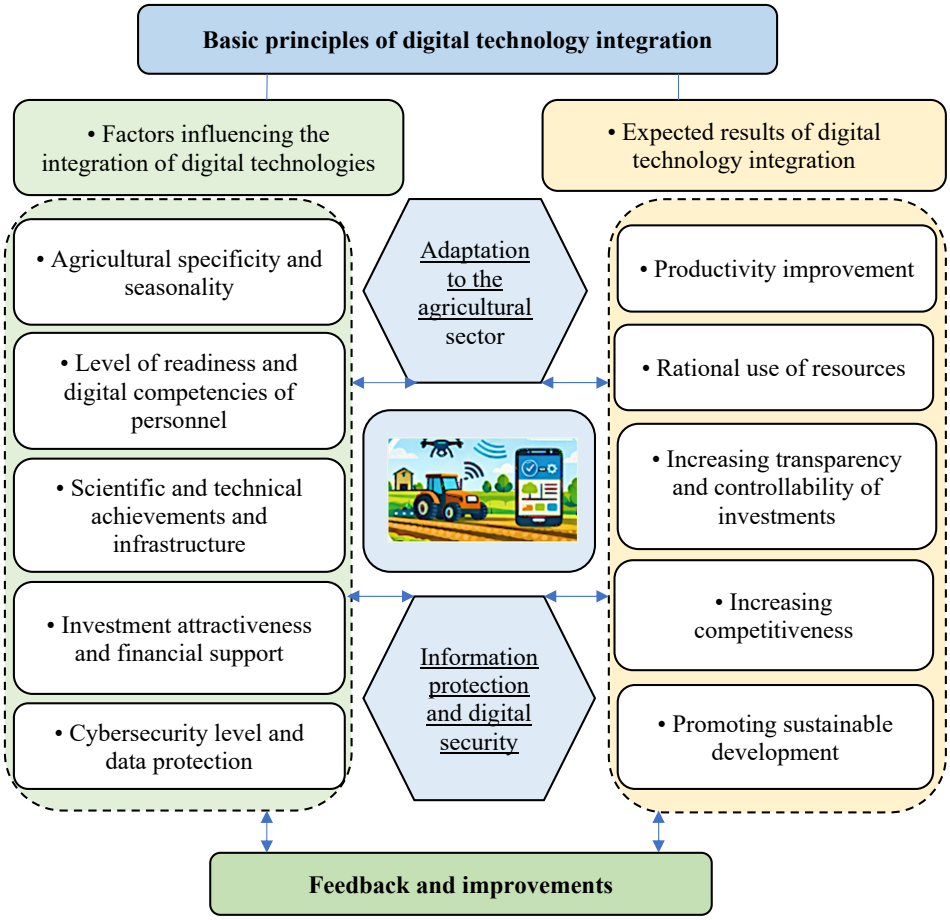

Figure 3. Specific Features of the Integration of Digital Technologies into the Functioning of the Agricultural Sector

Source: (formed by the authors)

The development of innovation in the context of current conditions is directly correlated with the level of digitalisation across the regions of Ukraine. The existence of access to digital infrastructure, electronic services, analytical platforms and artificial intelligence technologies creates an enabling environment for the generation and implementation of new solutions. A higher level of regional digital maturity has been shown to promote entrepreneurial activity, production modernisation and increased investment attractiveness. Collectively, these factors determine the dynamics of territorial innovation development. As illustrated in Figure 4, the level of digital transformation across the regions of Ukraine as of the third quarter of 2025 enables a comparative assessment of regional digital maturity and the identification of territorial disparities in the development of digital infrastructure and innovation processes.

The annual growth of the Digital Transformation Index of the regions (oblasts) of Ukraine indicates strengthening digital capacity at the territorial level and substantial national innovation potential. This, in turn, creates prerequisites for business development, stimulating entrepreneurial activity and exerting a positive impact on the country's economic growth.

3. Economic Outcomes and the Effectiveness of Implementing Digital Solutions in the Agricultural Production System

The economic efficiency of implementing digital solutions in agricultural production depends on the ability of such technologies to increase productivity, reduce costs and boost the competitiveness of agricultural enterprises. Digital tools, including precision farming systems, automated production management platforms, big data analytics and intelligent decision support systems, optimise the utilisation of material, labour and financial resources (Balaniuk, Shelenko, Shpykuliak, Sas, Cherneviy, Diuk, 2023).

To comprehensively assess the feasibility and effectiveness of implementing digital solutions in agricultural production, it is essential to consider the internal capabilities and constraints of enterprises, as well as the influence of the external environment on the strategic prospects of digital transformation. These

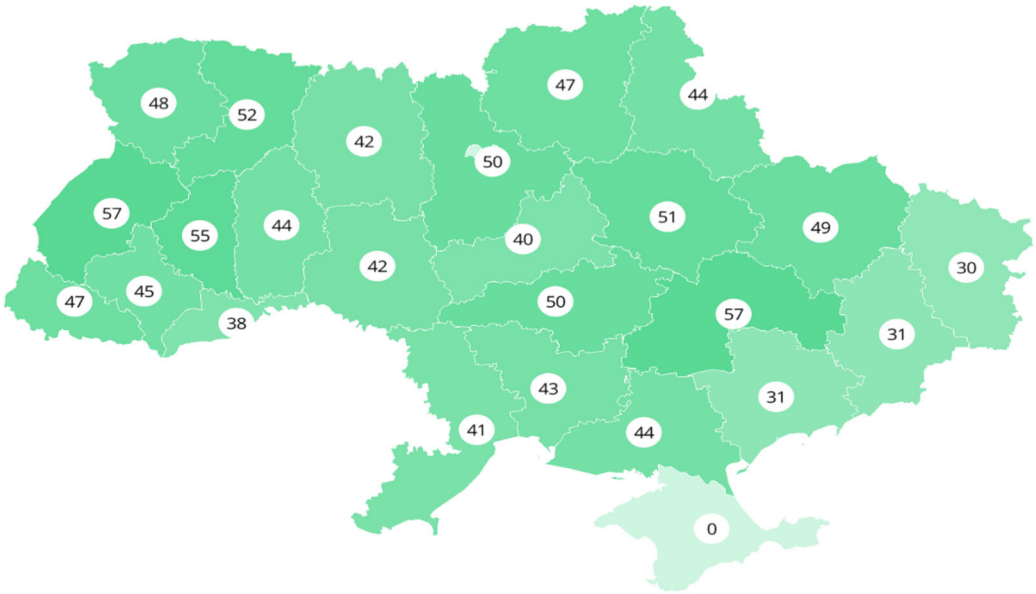

Figure 4. Digital Transformation Index of the Regions (Oblasts) of Ukraine, Third Quarter of 2025

Source: (Digital community)

aspects are synthesised in the form of a SWOT analysis in Table 7.

One of the key economic effects of digitalisation is reducing production input costs by applying fertilisers and plant protection products more efficiently, and using fuel and energy resources more rationally. This decreases production costs and increases the profitability of agricultural production. At the same time, digital solutions contribute to higher yields and greater stability in operational outcomes thanks to precise weather, soil and crop development forecasts.

An important aspect of economic efficiency is reducing production risks and losses caused by climatic instability and market fluctuations. Digital monitoring and forecasting systems facilitate timely responses to potential threats, positively influencing the financial sustainability of agricultural enterprises. Furthermore, automating managerial processes reduces transaction costs and improves the transparency of financial and economic activities.

At the same time, when assessing the economic efficiency of implementing digital solutions, it is important to consider initial investment costs, payback periods and the scale of operations. Digitalisation typically results in a faster return on investment for large agricultural enterprises, whereas for small and medium-sized farms, the economic effect largely depends on state support, access to finance, and the development of digital infrastructure (Pronko, Furman, Kucher, Gontaruk, 2020).

Table 7

SWOT Analysis of the Effectiveness of Implementing Digital Solutions in Agricultural Production

Internal environment	Strengths	Weaknesses
Organisational and production aspects	• Increasing productivity and yield. • Optimising the use of resources (seeds, fertilisers, water). • Automation of production processes. • Increasing the accuracy of management decisions.	• High cost of technology implementation. • Insufficient level of digital competences of personnel. • Difficulty of integration with existing systems. • Dependence on technical infrastructure.
External environment	Opportunities	Threats
Market and institutional aspects	• Access to international markets and digital platforms. • State programs to support digitalisation. • Development of an innovation ecosystem and agro-startups. • Growing demand for environmentally friendly and traceable products.	• Cyber threats and data leakage risks. • Technological dependence on external suppliers. • Instability of the regulatory environment. • Economic and geopolitical risks.

Source: (Balaniuk, Shelenko, Shpykuliak, Sas, Cherneviy, Diuk, 2023; Sakhno, Polishchuk, Salkova, Kucher, 2019)

Implementing digital solutions in agricultural production generates long-term economic advantages. These include improved operational efficiency, greater resilience to external challenges, and overall sustainable development of the agricultural sector.

It is proposed to consider the set of indicators used to assess the economic efficiency of implementing digital solutions in agricultural production, in particular (Burdyak, Tomashuk, 2026):

1. Overall economic efficiency indicator reflecting the amount of economic effect obtained per unit of monetary expenditure.

$$E_e = \frac{E_r}{C_d}$$

where:

E_e – Economic Efficiency of Implementing Digital Solutions;

E_r – Economic outcome (additional profit or cost savings);

C_d – Total costs associated with the implementation and utilisation of digital technologies.

2. The additional economic effects of digitalisation reflect its dual impact of revenue growth and cost reduction.

$E_r = (P_1 - P_0) + (C_0 - C_1)$

where:

P_1, P_0 – Profit after and prior to the implementation of digital solutions;

C_1, C_0 – Production costs before and after digitalisation.

3. Return on investment (ROI) in digital technologies enables the effectiveness of digital projects to be compared with one another.

$$ROI = \frac{E_r - I}{I} \times 100\%$$

where:

ROI – Return on Investment;

E_r – Total economic effect;

I – Investments in digital solutions.

4. The payback period for investments in digital technologies – the shorter the payback period, the greater the investment appeal of the digital solution.

$$T_{pb} = \frac{I}{E_{avg}}$$

where:

T_{pb} – Payback period;

I – Initial investment;

E_{avg} – Average annual economic effect.

5. Net Present Value (NPV):

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - I$$

where:

CF_t – Cash flow over the period t;

R – Discount rate;

N – Project implementation period;

I – Initial investment.

If NPV > 0, the implementation of digital solutions is economically feasible.

A reduction in production costs is a reflection of the resource efficiency offered by digital technologies.

$$\Delta C = \frac{C_0 - C_1}{C_0} \times 100\%$$

where:

ΔC – Percentage reduction in production costs;

C_0, C_1 – Production costs before and after digitalisation.

7. The increase in productivity resulting from digital solutions is indicative of their impact on agricultural production performance.

$$\Delta Q = \frac{Q_1 - Q_0}{Q_0} \times 100\%$$

where:

Q_1, Q_0 – Production volume (or yield) before and after implementation.

8. An integrated indicator of the economic efficiency of digitalisation, which is suitable for comprehensively assessing the digital transformation of agricultural enterprises.

$$IE = \sum_{i=1}^{k} w_i \cdot E_i$$

where:

IE – Integrated efficiency index;

E_i – Normalised indicators (ROI, NPV, cost reduction, etc.);

w_i – Significance weighting coefficients.

Using a system of quantitative indicators allows an objective assessment of the economic feasibility of implementing digital solutions. It also determines their investment attractiveness and supports managerial decision-making in the context of sustainable agricultural development.

4. Social and Environmental Determinants of the Digitalisation of the Agricultural Sector in the Context of Sustainable Development

The digital transformation of the agricultural sector enhances production efficiency and exerts a significant impact on environmental and social dimensions. Using modern digital technologies helps to make land, water and energy resources more efficient, reduces adverse environmental impacts and strengthens production resilience to climate change. At the same time, digitalisation stimulates the development of human capital and supports employment growth. It also creates conditions for greater social responsibility within agribusiness. This improves the quality of life for rural populations and fosters the sustainable development

of the agricultural sector as a whole (Sydoruk, Sava, Korzhenivska, Zdyrko, Khaietska, 2021).

The digital transformation of the agricultural sector has given rise to a range of comprehensive environmental and social effects. These are manifested through the rational use of natural resources, the reduction of negative environmental impacts, and the promotion of social responsibility and human capital development. A summary of these outcomes can be found in Table 8.

In the context of ensuring balanced development in the agricultural sector, implementing the ESG approach is particularly important. It is an integrative model that combines environmental, social and governance components into a unified system of strategic orientations for sustainable development. Figure 5 provides a conceptual overview of this paradigm.

Adherence to the ESG paradigm is an important instrument for ensuring sustainable development, as the integration of environmental, social and governance principles into corporate activities contributes to enhancing their long-term resilience, investment attractiveness and accountability to society.

5. Prospects for the Digital Development of Agricultural Production in the Context of Sustainable Development

The prospects for the digital development of agricultural production are closely linked to the concept of sustainable development. Modern digital technologies are becoming a vital tool for improving productivity, efficiency, and environmental safety in agriculture. Integrating innovative solutions, such as precision farming, automated management systems, big data analytics and digital platforms, creates the prerequisites for the rational use of natural resources, reducing negative environmental impacts, developing human capital and strengthening social responsibility in agribusiness. In this context, digitalisation is a key factor in ensuring the agricultural sector's long-term competitiveness, production resilience, and integration into global economic and environmental processes (Sakhno, Polishchuk, Salkova, Kucher, 2019).

An effective development model for the agricultural sector requires the systematic integration of economic, environmental and social priorities within a comprehensive sustainable development framework. This framework defines the strategic guidelines for the sector's long-term functioning. Figure 6 presents the conceptual foundations of this approach.

The implementation of the concept of sustainable development in agricultural production requires the identification of strategic priorities for digital transformation, aimed at enhancing the sector's economic efficiency, environmental safety and social responsibility (Honcharuk, Yemchyk, Tokarchuk, Bondarenko, 2023). Table 9 provides a brief overview of the main areas of digital development.

The establishment of an effective system for the digital development of innovative activity necessitates the identification of strategic orientations, institutional mechanisms and implementation instruments that ensure the coherence of technological, economic and managerial processes within an innovation-driven development model. The *Strategy for the Digital Development of Innovations until 2030* is a key strategic document for Ukraine, as it defines the priorities of digital transformation, supports the development of an innovation-based economy, enhances national competitiveness and facilitates integration into the global digital space. A summary of the relevant strategic foundations is presented in Figure 7.

It is important to emphasise the significance of assessing the macroeconomic impact of digital transformation. This makes it possible to determine its strategic importance in terms of national economic growth, enhancing labour productivity, creating

Table 8
The Environmental and Social Impacts of the Digital Transformation of the Agricultural Sector

Effect category	Specific effects	Implementation mechanism through digital technologies
Environmental effects	Rational use of land resources	Precision farming, GPS monitoring, GIS yield maps
	Optimization of water consumption and irrigation	Soil moisture sensors, automated irrigation systems
	Reduction of chemical load on the environment	Control of fertiliser application and plant protection products based on sensor and drone data
	Reduction of greenhouse gas emissions	Energy-efficient technology, automation of logistics and production processes
	Monitoring the state of ecosystems	Remote sensing, big data analysis (big data)
Social effects	Increasing employment and qualifications	Human resource training, digital learning and management platforms
	Increasing transparency and management efficiency	ERP systems, digital accounting, communication platforms
	Improving the quality of life of the rural population	Access to information, development of services and infrastructure
	Promoting social responsibility of business	Implementation of ESG principles and transparent digital reports
	Expanding opportunities for co-operation and community development	Digital platforms for farmer co-operatives and local initiatives

Source: (Kaletnik, Sakhno, Pryshliak, Lutkovska, Kolomiiets, 2025)

ESG Principles in the Agricultural Sector		
E – Environmental	*S – Social*	*G – Governance*
Core content		
Focus on reducing negative environmental impact	Ensuring social responsibility and human capital development	Effective corporate governance and transparency of activities
Key areas of implementation		
- Rational use of land and water resources; - reduction of greenhouse gas emissions; - implementation of energy-efficient technologies; - waste management; - protection of biodiversity	- Decent working conditions; - occupational health and safety; - rural development; - community support; - staff training	- Transparency of financial reporting; - anti-corruption policy; digital management systems; - risk management; - strategic planning
Expected results		
- Increasing the environmental sustainability of production; - conservation of natural resources; - climate adaptability	- Increasing social stability; - improving the quality of life of the population; - building a positive reputation	- Increasing investor confidence; - investment attractiveness; - management efficiency
Socially responsible and sustainable development		

Figure 5. The ESG Paradigm as an Instrument for Ensuring Sustainable Development

Source: (Bondarenko, Pokynchereda, Pidvalna, Kolesnyk, Sokoliuk, 2023)

value and strengthening the state's fiscal capacity. Table 10 presents the aggregated projected effects of digitalisation on Ukraine's economy and state budget. These results indicate a substantial multiplier effect of digitalisation, characterised by increased investment, higher labour productivity, substantial GDP growth, rising budget revenues, and job creation.

The projected increase in the digital economy's share to 65% by 2030 highlights its pivotal role in the structural transformation of the national economy.

6. Conclusions

The integration of digital technology forms a new paradigm for developing the agricultural sector, transforming traditional production, management and logistics processes into a unified digital ecosystem that enhances efficiency, competitiveness and sustainability.

Digitalisation of agricultural production is defined as a systematic process of implementing precision farming technologies, GPS/GIS systems, IoT devices, unmanned aerial vehicles, big data analytics, artificial intelligence and digital management platforms. The purpose of this process is to ensure optimisation of resources and increased productivity.

The conceptual features of digital transformation in the agricultural sector are defined by the sector's natural and climatic dependencies, the spatial dispersion of land resources, the capital-intensive nature of innovations, and the requirement for a high level of digital expertise.

The barriers identified in terms of infrastructure, finance, the economy, human resources, technology, institutions, information, society and security indicate the need for comprehensive state support for the digital modernisation of the agricultural sector.

The dynamics of innovation adoption in Ukrainian agricultural enterprises between 2019 and 2024 demonstrate a positive trend: an increasing number of enterprises are implementing innovations and digital technologies, which is accompanied by improvements in labour productivity and a greater utilisation of digital solutions.

An international analysis of the level of digitalisation in the agricultural sector reveals that countries vary in their level of digital maturity, which is determined by infrastructure development, public policy support, and investment activity. Ukraine, for example, demonstrates a medium level of digital development, but has significant growth potential.

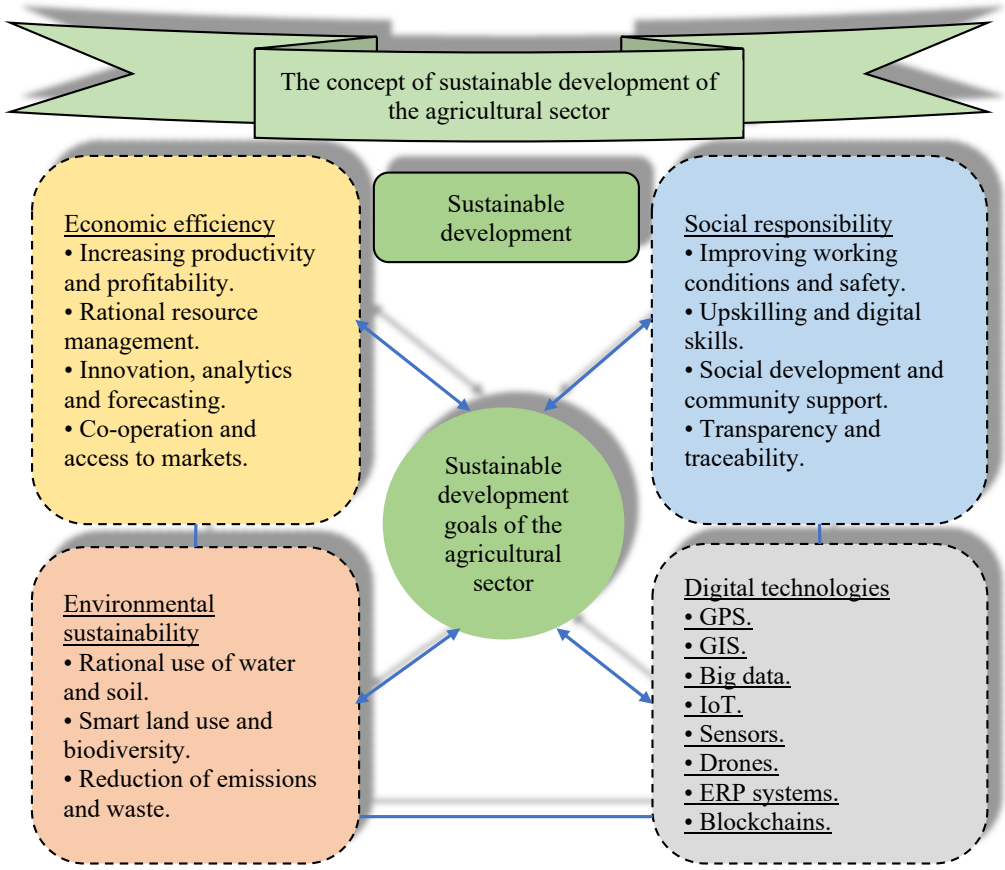

Figure 6. Conceptual Foundations of the Sustainable Development of the Agricultural Sector

Source: (Kaletnik, Lutkovska, 2020; Avila, Barbosa, 2025)

Table 9

Priority Areas for the Digital Development of Agricultural Production in the Context of Implementing the Sustainable Development Concept

Digital development direction	Key digital technologies	Expected economic effects	Environmental effects	Social effects
Digitalisation of production processes	Precision farming, IoT sensors, GPS navigation, AI-based systems	Reduction in production costs, increased yields and productivity	Optimising the use of fertiliser and plant protection products and reducing soil degradation	Upgrading staff qualifications
Resource management	Big data, analytical platforms, AI	Rationalisation of the use of land, water and energy resources	Reduction of water and energy consumption	Forming a culture of resource efficiency
Monitoring and forecasting	Remote sensing of the Earth, GIS technologies, AI algorithms	Reduction in the risks of crop losses, increased income stability	Early detection of environmental threats	Reducing production uncertainty
Digital management platforms	ERP systems, Farm Management Systems, AI analytics	Increase in management efficiency and transparency	Control of environmental performance indicators	Improving working conditions
Innovative business models	AgTech platforms, digital marketplaces, AI-recommended systems	Expansion of sales markets, increased farmers' incomes	Reduction of logistics losses	Supporting the development of rural areas
Institutional digital transformation	E-services, digital registries, smart contracts, AI-based intelligent decision-making systems	Reduction in transaction costs	Increasing transparency of environmental control	Strengthening trust in institutions

Source: (Bondarenko, Pokynchereda, Pidvalna, Kolesnyk, Sokoliuk, 2023; Kaletnik, Lutkovska, 2020; Burdyak, Tomashuk, 2026; You, Decardi-Nelson, 2024; Chen, Decardi-Nelson, You, 2025)

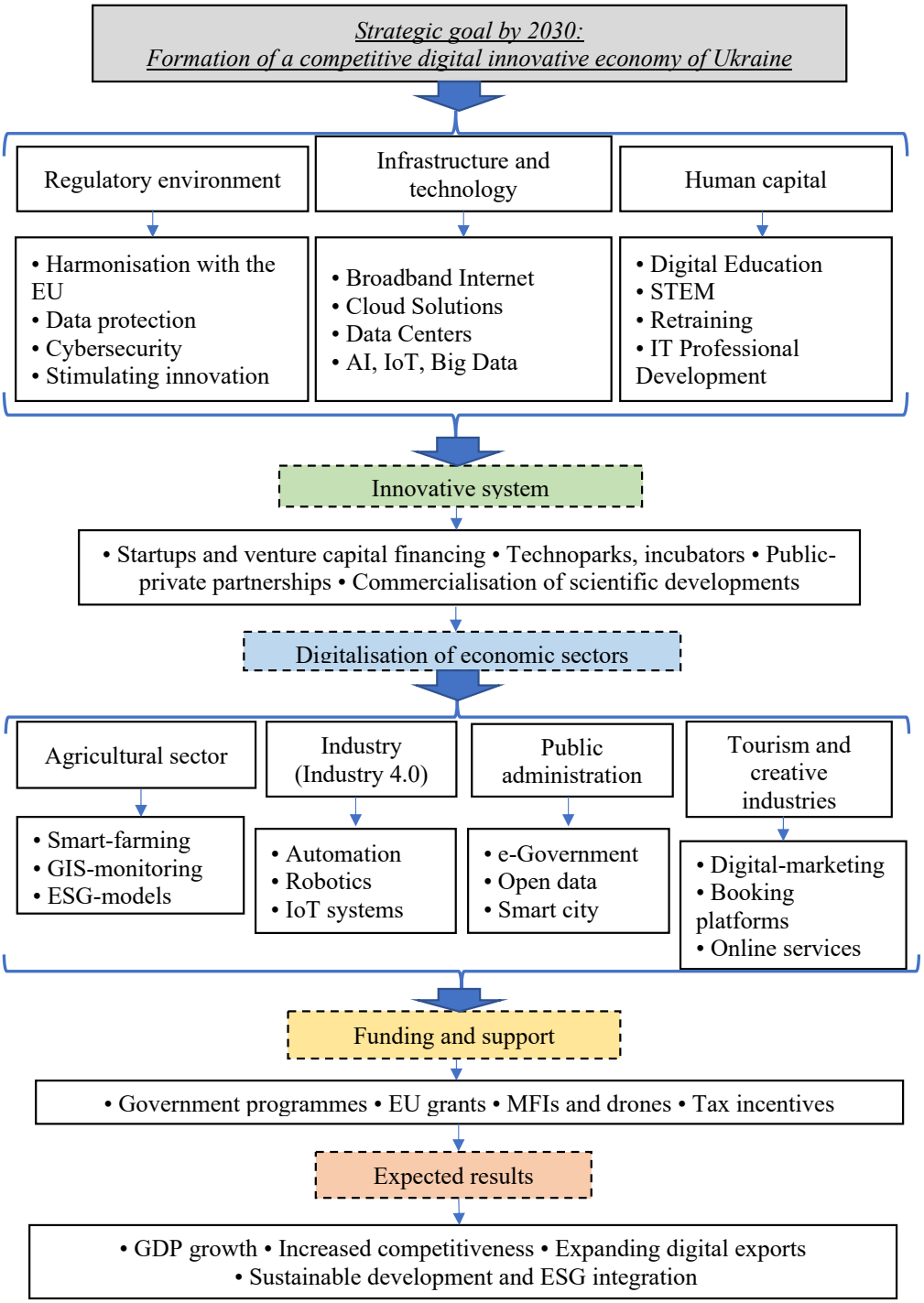

Figure 7. Strategic Foundations of the Digital Development of Innovative Activity

Source: (Ministry of Digital Transformation of Ukraine; Rogach, Vdovenko, Polishchuk, 2019; Hassoun, 2025)

The economic effectiveness of integrating digital technology is reflected in reduced production costs, optimised resource expenditure, increased yields and improved profitability, as well as the generation of additional economic value through higher revenues and cost savings.

The proposed system of performance indicators – including ROI, NPV, payback period, integrated efficiency index, cost reduction rate, and productivity growth – ensures a comprehensive approach to assessing the feasibility of digital investments in agricultural production.

Table 10
Effects of Digitalisation on Ukraine's Economy and the State Budget

Indicator	2021E	2025E	2030E	Total in 2021–2030EE
Investments in digital infrastructure, billion USD	0,7	3	6	16
Investments in digitalisation of production, business, industry, billion USD	1,5	5	14	70
Increase in labor productivity due to digitalisation, %	+1,1	+13	+13	-
Additional GDP created due to digitalisation (only the effect of investments and productivity increase), billion USD	17	93	280	1260
- additional GDP in %	+11	+44	+95	-
Additional revenues to the Budget, billion USD	3,2	17	50	240
Number of jobs created (excluding the IT export sector), people	150 000	300 000	700 000	-
Share of the digital economy in Ukraine (in total GDP), %	3	15	65	-

Source: (Ukraine 2030E – a country with a developed digital economy)

Digital transformation has a positive environmental impact by promoting the efficient use of land and water resources, reducing chemical inputs, lowering greenhouse gas emissions, and improving the climate resilience of agricultural production.

The social effects of digitalisation include developing human capital, improving digital literacy, enhancing working conditions, increasing management transparency and strengthening corporate social responsibility within agribusiness.

Integrating ESG principles into the digital transformation of the agricultural sector ensures a balance between economic, environmental, and social outcomes, forming the basis of long-term sustainable development.

The prospects for the digital development of agricultural production are linked to the growth of artificial intelligence applications, big data analytics, automated management systems, digital platforms, blockchain technologies, and the digitalisation of institutions.

The strategic importance of digitalisation for the national economy lies in its multiplier effect: growth in GDP, increased budget revenues, the creation of new jobs, and the strengthening of the country's competitive position amid global digital transformation.

The integration of digital technologies into agricultural production processes is instrumental in ensuring innovative development, improving economic efficiency, enhancing environmental security and strengthening social responsibility within the agricultural sector in the context of sustainable development.

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