

TRANSFORMATION, SOCIO-ECONOMIC PRINCIPLES OF POST-WAR RECONSTRUCTION:

MANAGEMENT, BUSINESS AND DIGITALIZATION
IN THE CONDITIONS OF SUSTAINABLE DEVELOPMENT

MONOGRAPH

According to the Scientific Edition

Doctor of Economics Sciences,
Professor

Nataliya Stoyanets



SUSTAINABLE
DEVELOPMENT



RESILIENT
SOCIETY



INNOVATION
AND DIGITALIZATION



RS Global

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Reviewers:

Rekunenko Igor

Doctor of Economics, Professor, Head of the Department of Management named after Oleg Balatsky, Sumy State University, Ukraine

Danko Yuriy

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Zheldubovsky Mykolai

The chairman of PPE Garant, Ukraine

Authors:

Nataliya Stoyanets, Inna Sokhan, Oriekhova Alvina, Khromushyna Lyudmyla, Tetyana Kharchenko, Viktoriia Tkachenko, Mohylina Liudmyla, Turchina Svitlana, Oleksandr Nazarenko, Tereshchenko Svitlana, Nazarenko Inna, Dehtiar Nataliia, Kovbasa Oleksandr, Shelekhov Igor, Ahadzhanova Svitlana and others.

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This monograph offers a comprehensive study of the mechanisms of adaptation of economic systems to the challenges of modernity. The main attention is paid to how international integration processes reformat the theory and practice of management in conditions of global instability. The publication contains specific recommendations for managers, entrepreneurs and civil servants. The authors consider strategies that allow not only to return to pre-war indicators, but to make a qualitative leap, using the tools of international integration as a catalyst for modernization.

For scientists, lecturers, graduate students and students, managers of enterprises and management bodies of various levels, entrepreneurs and everyone who is interested in issues of management, sustainable development and the impact of international integration processes.

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INTRODUCTION

Contemporary business faces an urgent imperative to reassess managerial practices within the context of global integration. In an environment characterized by expanding international connections, effective management emerges as a pivotal factor in achieving success within the global marketplace. The forces of globalization and market integration generate unprecedented challenges for management, necessitating that organizations adapt to evolving realities and formulate commensurate strategic responses. International integration processes impose distinct requirements upon managers, who must possess a profound understanding of the cultural, economic, and legal disparities among nations, alongside the capacity to operate proficiently within diverse multicultural settings. Intercultural communication skills, risk management acumen, and the ability to make strategic decisions based on the analysis of global trends and market conjunctures assume critical importance. The advancement of management within the framework of international integration mandates the exploration of innovative managerial approaches, the implementation of cutting-edge technologies, and the development of flexible strategies aimed at securing competitive advantages within the international market. Only through continuous improvement and the cultivation of adaptive capabilities can companies ensure sustained success in the face of globalization.

This monograph explores the intricate relationship between sustainable development and digital transformation, analyzing the challenges and opportunities they present for management. The work examines key aspects such as the impact of digital transformation on sustainable development, analyzing how digital technologies can facilitate or hinder the achievement of sustainable development goals; it highlights the issues associated with adapting management practices to rapid technological changes; it explores the potential of digital tools for optimizing resource utilization, reducing environmental impact, and enhancing social responsibility. Practical recommendations are offered for integrating sustainable development principles into management processes.

The work contains the provisions of the author's team, the totality of which allows solving an important scientific and practical problem regarding the aspects of restoring human capital in the information society and post-war realities, strategic management in the IT sector and agriculture, analysis of the impact of digital transformation on the sustainable development of agriculture, sustainable development and environmental management, the importance of the agricultural sector in the national development system and its role in achieving sustainable development goals, ensuring effective motivation of personnel in the operational management system, adaptive management of educational institutions in conditions of uncertainty.

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WORLD STRATEGIES FOR DEVELOPING AND RETAINING HUMAN CAPITAL IN THE RENEWABLE ENERGY SECTORS: EXPERIENCE FOR NATIONAL ADAPTATION¹

Nataliya Stoyanets

*Head of the Human Capital Research Laboratory, Principal Investigator, Doctor of Economic Sciences, Professor, Professor of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agrarian University
ORCID: 0000-0002-7526-6570*

Inna Sokhan

*Leading Researcher at the Human Capital Research Laboratory, Doctor of Economic Sciences, Professor, Professor of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agrarian University
ORCID: 0000-0002-8038-8484*

Tetyana Kharchenko

*Senior Researcher at the Human Capital Research Laboratory, PhD in Economics, Associate Professor, Associate Professor of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agrarian University
ORCID: 0000-0001-8967-4711*

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The scientific and practical problem of substantiating the type and content of the strategy for the post-war recovery of the Ukrainian economy, as well as the mechanisms and tools for implementing the strategy, especially from the point of view of European integration, lies in the lack of a systematic approach to integrating the principles of the modern green economy of the EU into the economic policy of Ukraine. It is obvious that the strategy for the economic recovery of Ukraine requires a fundamentally new paradigm that goes beyond traditional approaches to the reconstruction of infrastructure and industry. The European Union, within the framework of the European Green Deal, has formed an innovative development model that combines economic growth, decarbonization, circular economy and social justice. At the same time, in Ukraine, the issue of implementing the principles of the green economy into the post-war recovery strategy remains conceptually and institutionally inconsistent [1]. In 2026, the global energy architecture will undergo fundamental transformations. The transition to renewable energy sources has ceased to be exclusively a technological challenge; Today, this is primarily a challenge for human capital management systems. According to IRENA, the renewable energy sector already provides more than 15 million jobs worldwide, and this figure is expected to triple by 2050. However, the main obstacle remains the "skills gap".

We consider human capital in this area as a set of knowledge, skills, health and motivation of specialists who provide design, implementation and service of green technologies. For scientific analysis, it is important to distinguish four dominant global models, each of which offers its own mechanism for reproducing this specific asset.

The European model is the most regulated and socially oriented. It is based on strategic planning within the framework of the European Green Deal and the REPowerEU initiative.

Thus, the key characteristics of such planning are the successful combination of the concept of "just transition", according to which Europe is betting on the fact that the energy transformation does not cause social collapse in traditional energy regions. In many EU-27 countries, special funds (Just Transition Fund) have been created to finance reskilling programs for workers in the coal and oil and gas industries to meet social needs when changing the country's energy policy. The European model closely links the academic environment with production. Centers of excellence - specialized hubs where students work directly with manufacturers' equipment (for example, Vestas or Siemens Gamesa) provide advanced training for specialists, regardless of the country, which ensures the free migration of capital and knowledge. Unlike the USA, where competition reigns, the European model is based on a tripartite partnership: State - Business - Trade Unions. As part of the strategy, large players (for example, "Iberdrola", "Enel") cooperate with vocational education institutions to quickly develop new training standards. The EU is implementing a unified qualification framework that allows a heat pump installer or wind turbine service technician to work freely in any EU country, which increases the liquidity of human capital. The effectiveness of such a model is manifested in the

high quality of training and the low level of resistance from trade unions, since the state guarantees the stability of jobs in the green sector. The EU considers capital formation through the prism of transversal competencies. This means that a specialist in the renewable energy sector must have not only technical knowledge (panel installation), but also digital skills and an understanding of the principles of the circular economy. The EU is actively encouraging the involvement of women in STEM professions in the renewable energy sector, which is seen as a tool for eliminating the personnel shortage and maintaining social guarantees during the transition to decentralized energy systems [2].

But each country has its own vision of the transition. For example, in the USA, the transformational course has acquired the properties of innovative-market liberalism - it is a reference system where the main driver of progress is not a state directive, but the "invisible hand of the market", reinforced by venture capital and the cult of entrepreneurship. The US model is based on the belief that the state should create a field for action (legislative infrastructure), and not be an active player. Although the model is liberal, the role of the state in the USA is specific and highly effective: the state invests money in basic research (NASA, DARPA, ARPA-E in energy), the results of which are then commercialized for free or cheaply by the private sector. As an example, the Internet and GPS were by-products of a state defense order. Instead of direct subsidies to enterprises, the USA often uses tax breaks for consumers (for example, the Inflation Reduction Act - IRA), which forces companies to compete for a real client, and not for the loyalty of an official.

In 2024–2026, the American model of transforming the strategy of forming and preserving human capital in the renewable energy sectors industry is based on the concept that the US stimulates private generation through tax credits, creating a huge market for MarTech solutions (Smart Home, virtual power plants). In turn, companies fight for ESG ratings, as this opens up access to the cheapest capital in the world on Wall Street. The US has an extremely developed system of short-term intensive courses (bootcamps) and professional certifications from technology leaders. A diploma from a classical university is often inferior in importance to a current certificate from an equipment manufacturer. Human capital in the US is formed in the startup ecosystem. The close integration of universities (MIT, Stanford) with venture capital ensures an influx of highly qualified engineers-innovators focused on breakthrough technologies (for example, carbon capture or solid-state batteries). But the weak link in this model is high social inequality and the lack of systemic guarantees for low-skilled workers.

The US model is fundamentally different from the European one. Here, the main customer and architect of human capital is the private sector, and the role of the state is reduced to creating powerful economic incentives. The European model of the strategy for the formation and preservation of human capital in the renewable energy sector (RES) is fundamentally different from the liberal American model. If the USA focuses on market mobility and individual initiative, then Europe chooses the path of a socially oriented just transition.

So, if the American model maximizes the efficiency of capital at the moment, then the European model ensures its sustainability. In the context of globalization, it is the European path that allows you to create a sustainable ecosystem, where innovations in energy are synchronized with the development of society.

So, if Europe focuses on a just transition, then Asia (in particular China, South Korea, Japan and Vietnam) focuses on scalability, speed and state discipline. The Asian strategy for the formation and preservation of human capital in the renewable energy sector is a technocratic model of vertical leap, which is fundamentally different from the liberal American and social European models due to the tight integration of education, science and state industrial policy.

In the Asian model, the state is not just a facilitator, but the main architect of the personnel order. Through centralized planning, governments define clear KPIs for the number of specialists in hydrogen energy or lithium battery production for 10–15 years ahead. In addition, the state creates technopolises and clusters (a combination of university cities integrated with industrial ones), which ensures zero lag between scientific discovery and its implementation in the curriculum.

The state here acts not just as a regulator, but as the main investor in the development of human potential. For example, China dominates the production of photovoltaic cells and wind turbines precisely thanks to the mass training of technical personnel. The state subsidizes thousands of specialized colleges that work in conjunction with gigafactories. This is a model of "vertical integration", where human capital is part of the industrial conveyor [3].

Instead, South Korea is betting on a digital green transition. Here, human capital is formed at the junction of IT and energy. Great attention is paid to training specialists in energy management, Smart Grids and Big Data management in energy systems.

Asia has bet on mass. While Europe trains high-class research engineers, China trains millions of certified technicians. The Asian model provides the lowest cost per unit of human capital with its colossal volumes, which makes these countries the production hubs of the planet. But Asian countries are actively using their diaspora in the USA and the EU to import competencies. Chinese government grants for scientists to create superpower laboratories within the country aim to bring back leading specialists from Silicon Valley. This is a key element of preserving and building intellectual capital.

So, the Asian strategy for the formation of human capital in renewable energy is, first of all, the marketing of national strength. If the European model teaches us cooperation, then the Asian one teaches us speed and scale [4].

In countries that are intensively developing, such as India or Brazil, the model of the strategy for the formation and preservation of human capital in the renewable energy sectors is based on inclusiveness and "Bottom-up" development. For these countries, renewable energy is not only an environmental issue, but also a tool for social uplift. Programs like the "National Solar Mission" in India are aimed at training residents of rural areas. Special attention is paid to women (the "Solar Mamas" projects), which allows ensuring energy autonomy in remote villages and at the same time creating jobs.

In Brazil, human capital has traditionally been developed around the biofuel sector. Skills are developed within agro-industrial clusters, where agricultural knowledge is complemented by competences in biochemistry.

Since the distributed networks in these countries are often imperfect, human capital is focused on off-grid systems, which requires specific local service skills. Comparing global strategies for the formation and preservation of human capital in renewable energy sectors, we can identify key characteristics (table 1).

Table 1. Comparative matrix of the effectiveness of strategies for the formation and preservation of human capital in renewable energy sectors

Parameter	Asian Model (State-Driven)	European Model (Social-Value)	American Model (Market-Agile)	Bottom-up model
Driver	National Competitiveness	Environmental Ethics and Human Rights	Individual Profit	Poverty alleviation
Formation Method	Directive Public Procurement	Social Dialogue	Market Demand	Population coverage
Speed	Ultra-High	Moderate	High	Low
Key Emphasis	Scalability and Exports	Sustainable Development and Inclusion	Disruptive Innovations	Social lift
Employee Role	Element of the Global Value Chain	Active Prosumer and Citizen	Entrepreneur-Innovator	High in inclusion
Strength	Social Protection	Disruptive Technologies	Scale and Price	Population coverage
Weakness	Bureaucracy	Social Inequality	System Rigidity	Lack of funding

Analysis of world models shows that in the 21st century, those economies that are capable of hybridization will win. For example, the US is beginning to borrow European elements of social support (IRA includes wage requirements), and the EU is trying to deregulate the education sector to increase American flexibility. A common feature of all successful models is the digitalization of skills, because human capital without software knowledge (SCADA, AI analytics) loses 80% of its value. The global trend in education is micro-qualifications and continuous learning. On the other hand, traditional 5-year energy training programs are becoming too inert.

Countries that combine European social guarantees with American innovation and Asian speed of scaling (such as Denmark or Germany) demonstrate the best results in the formation of high-quality human capital [5].

For countries in the process of transformation (in particular, for Ukraine), the most rational is to combine European certification standards with American flexibility of private educational initiatives and Asian speed of scaling through dual education. The future belongs not just to “green” energy workers, but to specialists whose human capital is simultaneously technological, digital and adaptive. A hybrid model for Ukraine is not just a compromise, but a strategic necessity. In a war period, when the country is actively rebuilding its energy system after destruction, copying only one approach would be ineffective. Ukraine has a unique context: a combination of European aspirations, American decentralization and the need for rapid Asian scaling.

The hybrid model “Ukrainian Energy Transition” can borrow the experience of creating energy free economic zones in China, where training is exempt from taxes on the condition of work on reconstruction. The Asian model proves that the best way for Ukraine is a strict standardization of skills and the introduction of digital management systems that reduce the requirements for the uniqueness of personnel. Ukraine can become a training ground for the whole world in the field of reconstruction after conflicts, converting its military experience into highly liquid human capital (table 2).

Table 2. Comparative architecture of the hybrid model for Ukraine

Component	What exactly are we borrowing	Expected result
Regulatory	EU Directives (Green Deal)	Compatibility with the EU network and investments
Technological	American Venture Capital Approach	Innovations in energy management (Smart Grid)
Educational	Asian Dual Education	Rapidly filling the staff shortage
Social	Inclusive Development (India)	Employment of vulnerable groups and veterans

So, we are borrowing the structure and regulations of EU standards for specialists. This allows Ukrainian engineers to be part of the single energy market. Ukraine has a powerful IT sector, which becomes the basis for "Smart Grids". Using the US experience in protecting energy facilities to create autonomous "microgrids", where human capital is focused on cybersecurity and autonomous management, will ensure the creation of conditions where private companies (and not just the state) invest in training installers and service engineers. But in order not to be just an importer of technologies, Ukraine needs elements of the Chinese model: the creation of powerful vocational schools directly at factories producing solar panels or components for wind turbines; rapid retraining courses for thousands of people, which will ensure low cost of implementing solutions [6].

Social inclusion (reintegration of veterans) is the most important component of the model of developing countries, adapted to our realities. Renewable energy is an ideal area for socialization of former military personnel. Working with drones (for inspecting wind turbines), engineering and logistics are skills that can easily be transformed into green professions. Such hybridity will allow Ukraine to be adaptive. In the event of a change in market conditions, either the market (American) or state (Asian) segment of personnel training can be strengthened. But gaps in education today are the main deterrent to the green transition. Even with the availability of investments and equipment, without qualified brains and hands, the system remains dead. The most effective tool is dual education. This is a format where a student spends 30% of his time at the university (theory), and 70% at a real VE facility. Also critically important is the creation of Micro-credentialing centers - short intensive courses that allow an engineer to obtain a specialization in 3 months, for example, in "maintenance of offshore wind farms."

Global models for building human capital in the renewable energy sector demonstrate effective approaches to training specialists, developing skills and integrating innovation into the industry. At the same time, their practical implementation highlights the need not only to create but also to retain this potential [7]. That is why the next logical step is to develop a strategy for retaining human capital in the renewable energy sector, which will ensure the retention of skilled personnel, their motivation and long-term development.

The transition to a low-carbon economy has led to unprecedented demand for specialists with ‘green’ skills. In the renewable energy sector, talent competition extends beyond the energy industry, encompassing IT and high-tech manufacturing. This requires developing specific incentive models that account for both the technical complexity of projects and employees' values.

Renewable energy is an industry where human capital is a strategic resource. Unlike traditional energy sectors, where tangible assets predominate, the success of renewable energy companies is determined by the

internal motivation of their staff: an awareness of their environmental mission, the social value of their work, and the technological innovation involved.

Intrinsic motivation is enhanced under three conditions: autonomy, competence and meaningfulness. For the renewable energy sector, it is the meaningfulness of work that acts as the most powerful driver of retention, innovative activity and organisational commitment. Two factors are at play in this context:

Factor 1: mission orientation. Employees increasingly perceive their professional activities not merely as the fulfilment of functional duties, but as a personal contribution to achieving broader socially significant goals, particularly climate stability and social justice. This shift in the perception of work fosters deeper intrinsic motivation and enhances loyalty to the organisation. Empirical data presented in the Deloitte Energy Workforce Report (2023) confirms this trend: companies that integrate an environmental mission into their corporate culture demonstrate a 27% lower staff turnover rate compared to the energy sector average.

Factor 2: Identification through strategy. An important factor in boosting staff engagement is their involvement in the strategic planning processes relating to the company's environmental impact. Such involvement helps to foster what is known as a 'green identity', which combines professional fulfilment with environmental responsibility. In this context, employees begin to align their own values with the organisation's goals, which minimises the risk of cognitive dissonance and has a positive impact on the level of organisational engagement [8].

The mechanism for developing a 'green identity' involves systematically engaging staff in the strategic planning of the company's environmental impact. This approach not only raises staff awareness but also fosters a sense of personal responsibility for the outcomes of the organisation's environmental activities. The mechanism is implemented across three interlinked stages.

The first stage involves integrating knowledge regarding the impact of business activities on the environment. Creating open platforms for assessing the 'carbon footprint' and the environmental consequences of project implementation helps foster environmental awareness at the level of each employee, making these issues personally meaningful.

The second stage involves the joint formulation of 'green goals'. Involving cross-functional teams in the development of ESG strategies ensures that employees feel a sense of ownership over tangible changes within the company's climate policy and strengthens their involvement in strategic processes.

The third stage involves symbolic recognition of the employee's role in achieving environmental goals. Recognising individual environmental initiatives, particularly those aimed at reducing energy consumption or implementing renewable solutions, helps foster a sense of 'internal ownership' of the organisation's mission.

Ultimately, this fosters the employee's personal 'green identity' – a firm belief that their professional activities have a positive impact on the environment. It is this identity that forms the core of intrinsic motivation for environmentally responsible behaviour.

Empirical indicators show that in companies with a high 'Meaningful Work' index (according to Gallup, 2022), the average tenure of renewable energy employees is 6.8 years, compared with 4.3 years in the traditional energy sector. Engagement Index. Increases by 35–40% where programmes for collective planning of environmental strategies are in place (IEA Workforce Survey, 2023). Correlation between ESG activity and innovation [9]. Teams with a strong 'green identity' submit 22% more innovative proposals directly related to energy efficiency and decarbonisation.

Policies on staff well-being and the provision of safe working conditions in the renewable energy sector are becoming a strategic tool for the preservation and development of human capital. In the current context of the energy transition, characterised by technological turbulence, a high pace of innovation and increasing demands on staff qualifications, employee well-being is viewed not merely as a social function of the enterprise, but as a key factor in long-term competitiveness and institutional resilience.

The renewable energy sector is characterised by heightened risks in the working environment, particularly in the wind power, solar power and hydrogen energy segments, where workers are often deployed in field conditions, working at height, with high-voltage equipment or in environments of increased technical complexity. In this context, the development of a comprehensive occupational health and safety system that integrates international safety standards (in particular ISO 45001) is a prerequisite for minimising occupational risks and reducing workplace injuries. At the same time, an effective safety policy entails not only compliance with regulatory requirements but also the fostering of a culture of safe behaviour, where every employee acts as an active participant in risk management.

Well-being policy in the renewable energy sector is multi-dimensional in nature and encompasses the physical, psychological and social aspects of well-being. The physical component involves creating a safe and

ergonomic working environment, implementing programmes to prevent occupational illnesses, regular medical monitoring and promoting a healthy lifestyle [10]. The psychological dimension involves ensuring the psychological and emotional resilience of staff in conditions of high responsibility and uncertainty, in particular through the development of psychological support programmes, the prevention of occupational burnout, and the fostering of an atmosphere of trust and open communication. The social aspect relates to ensuring a balance between professional and personal life, developing an inclusive environment, and supporting teamwork.

The integration of well-being policies into the strategic human resources management system is of particular importance. The practice of leading energy companies shows that investment in well-being contributes to increased labour productivity, reduced staff turnover and greater organisational loyalty. Thus, employee well-being becomes an important intangible asset that ensures the accumulation of knowledge, the retention of critical competencies and the maintenance of the enterprise's innovative potential.

Furthermore, a policy on safe and healthy working conditions aligns with the principles of sustainable development and ESG-focused management [11]. The social component of ESG entails a company's responsibility to create decent working conditions, which, in turn, builds a positive reputation as an employer and enhances its appeal in the global talent market. In the renewable energy sector, where competition for highly skilled personnel is particularly fierce, such factors play a decisive role in ensuring long-term workforce stability.

Consequently, policies on staff welfare and safe working conditions in the renewable energy sector should be viewed as an integrated strategy for retaining human capital, combining tools for occupational health and safety, psychological support and social responsibility. Its effective implementation creates the conditions for the sustainable development of enterprises, enhances their innovative capacity and fosters the formation of resilient organisations capable of adapting to the challenges of the global energy transition.

Talent management in high-tech sectors is a critical tool for ensuring sustainable development, particularly in the renewable energy sector, where the pace of technological innovation is two to three times faster than the industry average. According to estimates by the International Renewable Energy Agency (IRENA), over 38 million jobs will be created in the 'green' energy sector by 2030, generating unprecedented demand for highly skilled professionals [12]. In this context, talent management takes on strategic importance for the formation, development and retention of human capital capable of ensuring the sector's innovative growth (table 3).

Consequently, the strategy for retaining human capital in the renewable energy sector must be based on systematic talent management focused on the continuous development of skills, the fostering of innovative motivation, and the cultivation of environmentally responsible thinking. Implementing such approaches will enable human capital to become a key asset of the 'green' transition, ensuring the sector's technological self-sufficiency and competitiveness in the global market.

An organisational culture based on the principles of sustainable development, innovation and social responsibility creates an environment in which professionals feel engaged, trusted and motivated to pursue a long-term career in the 'green' economy. The culture that fosters openness to change, the search for new technological solutions and a readiness for interdisciplinary collaboration as key components of effective knowledge management in the dynamic energy sector.

Table 3. Hypotheses regarding the impact of talent management on innovation and staff retention

Hypothesis 1: Effective talent management is directly correlated with the level of innovation activity among companies in the renewable energy sector.	Companies that implement talent development systems (individual learning pathways, technical accelerators, leadership programmes) demonstrate, on average, 25–30% higher performance in innovation projects.
Hypothesis 2: Retaining human capital in the renewable energy sector depends to a large extent on the synergy between education, science and business.	The creation of flexible educational and scientific platforms bringing together universities, research institutes and companies in the energy sector helps to reduce staff turnover by 15–20% in the medium term.
Hypothesis 3: A key factor in motivating specialists is not only salary levels but also the availability of opportunities for professional self-expression.	High-tech organisations that implement the principles of a 'green corporate culture' and social responsibility retain up to 40% more talent than companies with a traditional HR management model.

ESG approaches serve as an institutional framework that complements companies' strategic objectives with a humanistic and environmental dimension. The implementation of practices relating to environmental responsibility (E), social justice (S) and high standards of corporate governance (G) creates the conditions for building trust among employees, investors and partners. Research shows that companies with integrated ESG strategies demonstrate 20–25% lower staff turnover and higher productivity in the field of innovation.

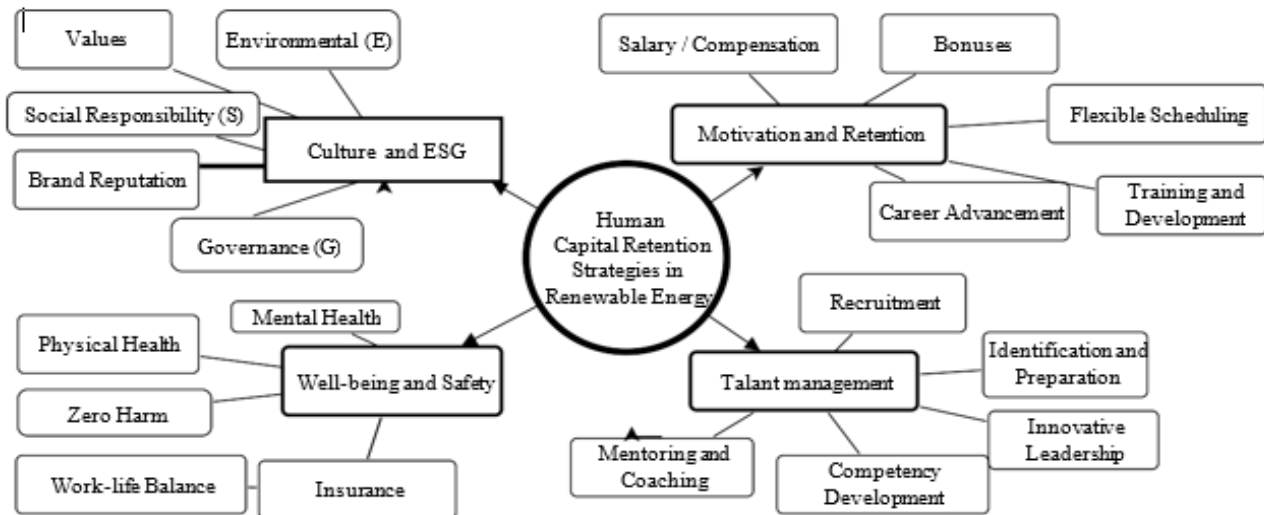


Figure 1. A networked framework for strategies to retain human capital in the renewable energy sector

Thus, in the context of renewable energy and human capital retention strategies, ESG approaches serve a dual purpose: on the one hand, they strengthen corporate identity and employees' ethical responsibility; on the other, they foster an attractive employer brand in the global labour market. A culture of sustainability, built on ESG principles, creates a value framework for the development of a competent, motivated and environmentally conscious workforce – a key resource for long-term success in the green energy sector.

Retaining specialists in the renewable energy sector relies not only on financial incentives, but above all on a sense of purpose in their work. When people see the contribution they are making to protecting the environment and shaping the future of energy, a deep sense of personal motivation and a natural desire to remain part of this endeavor take root.

Caring for an employee's physical and psychological well-being is an expression of respect for the individual as a key value. Safe working conditions, support for a work-life balance, and attention to emotional well-being create an environment in which people can develop steadily and work without burnout. Investments in training, professional growth and employee self-fulfilment are investments in the industry's future. People stay where they feel they can develop, realise their potential and influence innovation. An organisational culture built on trust, responsibility and environmental values fosters a community of like-minded individuals. ESG approaches not only strengthen a company's reputation but also help employees feel proud of their work and their part in an important mission.

The formation of human capital in the leading countries of the world today is based on the concept of Long-life learning and adaptability to the challenges of the digital economy. The relevance of the formation of human capital in modern conditions is due to the transition to a global knowledge economy, where intellectual potential becomes more important than natural resources or physical capital. Today, this process goes beyond classical education and is transformed into a strategic system of survival and development of states.

The relevance of the concept of human capital development in the era of global transformations is due to the need to find effective answers to the challenges of the modern BANI-world. In an environment where processes are fragile, disturbing, nonlinear and often incomprehensible, the ability to quickly retrain becomes a fundamental condition for maintaining the economic stability of both an individual and entire states. This need is reinforced by the processes of the "double transition" - simultaneous digital and "green" transformation. The introduction of artificial intelligence and the decarbonization of the economy require the formation of completely new "green" competencies that require constant updating throughout professional activity. An additional factor is demographic changes: the aging of the population in developed countries is

forcing governments to invest in “active longevity” programs and training for the 40+ category in order to maintain labor productivity in the long term.

Key approaches to ensuring high-quality human capital are currently being implemented through several strategic directions. Firstly, this is the creation of a Lifelong Learning ecosystem, where lifelong learning is transformed from a theoretical slogan into a real economic mechanism. The experience of countries such as Singapore and Finland demonstrates the effectiveness of the introduction of individual educational accounts, which allows citizens to adapt to automation without fear of losing social status. Secondly, the emphasis is shifting to adaptability to the digital economy, which involves the development of digital intelligence (DQ), in particular skills for working with Big Data, critical analysis of information and ethical interaction with artificial intelligence.

An important component is the integration along the Education - Science - Business vector, where human capital is formed at points of maximum synergy. Vivid examples are the German model of dual education, which combines a theoretical base with practice in the workplace, and American university incubators, which ensure the rapid commercialization of scientific ideas. After all, innovative sustainability increasingly depends on the development of “soft skills”. As highly technical competencies quickly become obsolete, emotional intelligence, cognitive flexibility, and cross-cultural communication skills become a priority, allowing professionals to remain effective in complex international projects and dynamic business environments. Figure 2 provides an overview of key approaches that ensure a high-quality workforce and innovative resilience for modern enterprises.

The German experience in human capital formation is a model example of how the state and business can jointly create a sustainable and adaptive economy [13]. This process is based on the deep integration of learning into the working environment and a strategic focus on energy transformation. The German approach is based on the division of responsibilities between state institutions and the private sector. This is not just formal education, but a living ecosystem of personnel training. The theoretical basis obtained in specialized schools takes up only a smaller share of the educational process. The main emphasis is on practice directly on production lines, in laboratories or offices of companies. Companies do not wait for a ready-made specialist, but “grow” him for their technical needs. The payment of scholarships to students is considered not as an expense, but as a long-term investment in the quality of their own personnel reserve. Such a model minimizes the gap between graduation from an educational institution and employment. Having received real professional skills, young specialists become competitive even before receiving a diploma. Development of intellectual potential in energy clusters. In parallel with basic education [14], Germany is actively forming human capital through specialized innovative associations focused on energy security and greening. Clusters combine the scientific potential of universities with the capabilities of large energy players. This creates an environment where scientific developments instantly become part of production processes. Much attention is paid to the formation of so-called Green Skills. This involves not only training new personnel, but also large-scale retraining of engineers and technicians from traditional industries to work with hydrogen technologies, solar generation and energy saving systems. Within these clusters, managers are trained who are able to make decisions in conditions of rapid technological change. This ensures the economy's resilience to global crises and market volatility [15].

Denmark is a world leader in wind energy, and its success is based not only on technology, but also on a unique system of training and human capital management. The Danish approach combines social stability, a flexible labor market and advanced training of specialists for the “green” sector. The foundation of human capital formation in Denmark is the Flexicurity model, which allows the country to quickly adapt the workforce to the energy transition. Employers can easily hire and fire employees, which allows businesses to quickly respond to technological changes. The state provides a high level of social guarantees and unemployment benefits, which removes the fear of changing professions. The main condition of the system is constant retraining. If an industry (for example, oil production) declines, the state and trade unions finance the training of workers for new sectors (wind energy).

Denmark was the first in the world to start mass introduction of wind power generation, which forced it to create a holistic system of development of specific skills. The city of Esbjerg is a classic example of reorientation of human capital. Previously, it was the center of the oil and gas industry, but thanks to the Offshore Academy program, the competencies of workers on offshore platforms were adapted to servicing offshore wind farms. Engineering knowledge of marine construction and safety on the water became the basis for the wind industry.

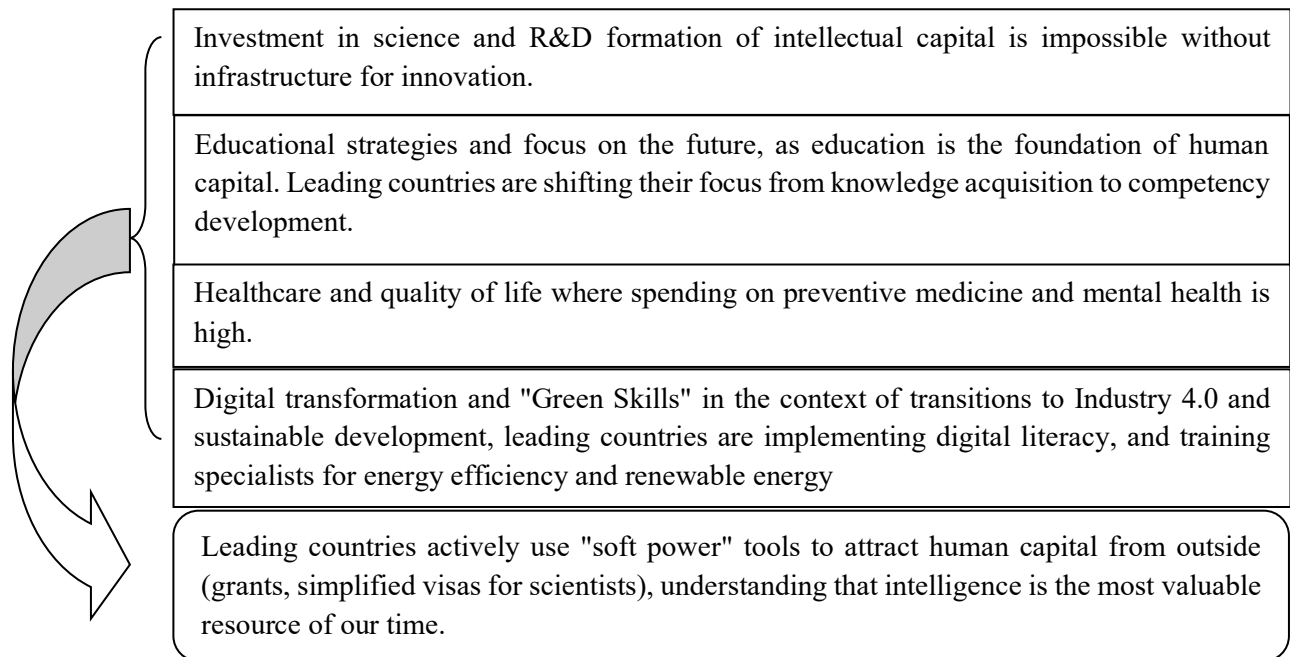


Figure 2. Overview of key approaches that ensure high-quality workforce and innovative sustainability.
Source: generated by the author [14, 16-18].

Training is carried out with the participation of market leaders, vocational colleges and universities have joint programs with business. Students work on real facilities already during their studies. Denmark has created a network of test centers (for example, Osterild), where specialists learn to work with giant turbines even before they become serial. Lifelong learning, in wind energy technologies change every 3–5 years. The Danish system supports “competence mobility”. A mechanic who has worked with car engines can take a state course and receive a certificate as a specialist in servicing wind turbine gearboxes. Environmental thinking and digital literacy are integrated into all levels of education, from schools to vocational courses.

China's human capital formation strategy is aimed at fundamentally transforming the country into a global innovation hub. The state considers the development of human resources as a national security priority, which is confirmed by stable investments at the level of 4% of GDP. Through the "Dual First-Class Status" program, China is creating a world-class university network, which should become a leading educational hub by mid-century. The main vector of education has shifted towards STEM disciplines, which has allowed the country to take first place in the world in the number of trained engineers and scientists. Special attention is paid to the introduction of courses in artificial intelligence, robotics and big data into curricula at all levels. In parallel, an aggressive repatriation policy is in effect, in particular the "Thousand Talents" program, which stimulates the return of leading scientists from abroad through the provision of large-scale grants and laboratories. In the field of vocational education, China is implementing the "Smart Manufacturing" reform, creating colleges in close cooperation with such technological giants as Huawei and BYD. This ensures the training of practitioners capable of working with digital ecosystems even in traditional industries, including the agricultural sector, where digital literacy and skills in managing UAVs or IoT systems are becoming a mandatory standard for modern managers [13].

The US experience in the formation of human capital is based on the creation of a unique ecosystem where academic knowledge is instantly converted into commercial innovations. The main emphasis is not only on state support, but also on the close integration of private capital, university science and entrepreneurial culture. American higher education is focused on flexibility and advanced training of specialists for emerging industries. Flexibility of curricula where students can combine fundamental disciplines with applied ones (for example, "Economics" and "Data Science"), which forms multidisciplinary human capital. Research universities such as MIT, Stanford and Harvard function as powerful R&D centers. Education here is integrated into real scientific research, funded by both the government (through NSF, NIH grants) and private corporations. US professional certification programs are actively developing short-term intensive courses (bootcamps) and micro-qualifications, which allows people to quickly change their profession according to the

needs of the labor market. In the US, a university is not just a place of study, but an incubator for business. Every large university has a unit that helps students and professors patent inventions and create startups based on them. Courses on the basics of business, critical thinking and risk management are often integrated into educational programs, even in the humanities. The presence of a developed network of "business angels" and venture funds allows talented graduates to receive financing at early stages, which keeps intellectual capital within the country.

The United States has been using a strategy of importing human capital for decades. Special visa programs (for example, O-1 for individuals with outstanding abilities or H-1B for highly qualified specialists) allow attracting the best minds from around the world. A large number of scholarships and grants for foreign students and researchers ensures a constant influx of new ideas and an intellectual advantage in global competition. The American model demonstrates that for the effective formation of human capital, high-quality education alone is not enough - it is necessary to create an environment where knowledge has a high market value, and the path from idea to commercial product is as short as possible.

The integration of education, science and business is a strategic foundation for countries striving for leadership in the global economy. Successful cases demonstrate that human capital is formed most effectively where knowledge has direct access to the market, and business takes an active part in creating educational standards. The experience of the United States of America in the formation of human capital is based on the creation of a unique ecosystem, where the academic environment acts not just as a relay of knowledge, but as a key driver of economic growth and innovation. The center of this model is the concept of the "university as an incubator", where the educational process is inextricably linked with practical business and high-tech developments [17].

The foundation of success was the functioning of specialized structures - Technology Transfer Offices. These units provide scientists, teachers and students with a full cycle of support: from legal support for patents to attracting initial venture capital. Thanks to this, scientific discoveries made in university laboratories do not remain theoretical works, but are transformed into viable commercial startups as quickly as possible. Such a system radically changes the very nature of human capital, forming a new generation of specialists - scientist-entrepreneurs. They operate equally effectively with complex scientific categories and have competencies in the field of management, marketing and risk management. Of particular importance is the integration of universities into regional innovation clusters, the most famous of which is Silicon Valley. A synergy effect is created here: proximity to top educational centers provides companies with a continuous influx of highly motivated talents, and students gain access to real cases and advanced technologies even at the stage of study. The state in this system acts as a strategic partner, providing flexible legislation and grant support for basic research, which later becomes the basis for breakthrough commercial products [14].

Such integration allows the United States to maintain global leadership in strategic industries such as artificial intelligence, biotechnology, and aerospace development. The model demonstrates that the most valuable asset of modern society is not just knowledge, but the ability of human capital to adapt this knowledge to market needs, creating new jobs and stimulating technological progress. The high concentration of intellectual and financial resources around academic centers makes this process self-replicating and resistant to global economic transformations.

The German model of human capital formation is a unique example of how institutional support for applied research and deep involvement of the private sector create one of the most resilient economies in the world. The central element of this system is a strategic partnership, where education and science do not exist autonomously, but function as a service for technological and industrial development.

The basis of professional development of specialists in Germany is the dual system of education, which is radically different from traditional academic models. In this system, business becomes a full-fledged subject of the educational process, taking on part of the costs of training personnel from the moment they enroll in an educational institution. The student actually becomes an employee of the enterprise, where he spends most of his time, mastering the most modern equipment and real production cycles. This creates a win-win situation: the young specialist acquires relevant market skills and guaranteed employment, and the company receives a loyal employee whose qualifications fully meet its technical standards. An important link connecting academic science with industry is the activities of the Fraunhofer Society. This is an extensive network of research centers specializing exclusively in applied developments. The society acts as an intellectual "bridge": private companies order the centers to solve specific technological problems, and scientists, involving talented students and postgraduates, develop innovative products and processes. Such interaction ensures a continuous

flow of “practical science” directly into industry, allowing Germany to quickly implement innovations in the fields of mechanical engineering, renewable energy and digital technologies [15].

The effectiveness of the German experience lies in creating an ecosystem where human capital is seen as a shared responsibility of the state and business. Thanks to a high proportion of practical training and an orientation to specific production needs, the country achieves one of the lowest youth unemployment rates in Europe. Such an integrated model ensures that investments in education and science are converted into real labor productivity and high competitiveness of national goods in the global market.

Israel's experience in the formation of human capital is an example of a unique national strategy where the security sector, academic science and state stimulation of venture capital form a holistic ecosystem. This model has allowed a country with practically no natural resources to become one of the world's leading centers of high technology, known as the “startup nation”. A key element of the Israeli approach is the specific role of the military as the primary incubator of talent. Elite units, in particular in the field of cybersecurity and intelligence, play the role of leading technical universities. During their service, young people work with the most complex technological challenges in real-time and with high responsibility. This forms a special type of human capital - specialists who have not only deep knowledge in coding or engineering, but also possess critical thinking skills, teamwork and the ability to adapt quickly. After completing their service, these personnel become founders of innovative companies, bringing unique developments and managerial resilience to the civilian sector.

An important component of success was the state program to stimulate venture capital investments, known as Yozma. In the early 1990s, the state assumed significant financial risks, offering foreign investors attractive co-financing conditions. This allowed attracting global capital to local scientific developers. The created system ensured that talented scientists and engineers had access to resources to transform their ideas into global products. State support, combined with private investment, created an environment where innovation becomes the basis of exports and economic growth.

Today, the integration of education, the army and business in Israel provides the world's highest concentration of scientists and engineers per capita. The state continues to invest in research centers at universities that work closely with transnational corporations. This model demonstrates that the effective formation of human capital in the modern world requires not only high-quality education, but also the creation of “elevators” that allow talents to quickly go from specialized training to creating their own high-tech business that competes on a global scale.

Finland's experience in human capital development is an example of extraordinary adaptability and the ability to rapidly transform the national economy through intellectual resources. The Finnish approach is based on the creation of open innovation ecosystems and the introduction of the concept of lifelong learning as the foundation of public welfare. One of the most striking examples of such integration is the experience of the city of Oulu, which has become a global technology hub. The success of this location was made possible by close interaction between the university, research centers and business. The uniqueness of the Oulu model lies in the physical and mental unification of the participants in the process: students, researchers and developers from private companies work in common spaces. Such an ecosystem promotes the instant exchange of ideas, where academic research is immediately tested for market viability. Even after serious structural changes in large corporations such as Nokia, this region was able not only to preserve human capital, but also to diversify it, creating hundreds of new startups based on the accumulated competencies.

A key factor in Finland's sustainability is the state policy of “lifelong learning”. The Finnish education system is designed so that a person at any age can easily change professions or improve their qualifications without losing their social status. When certain industries lose their relevance, the state, together with new technological clusters, launches large-scale retraining programs. This allows workers to quickly move from traditional sectors to the digital economy, energy or creative industries. Educational programs are developed in partnership with business, which ensures that knowledge meets real market needs.

Thanks to radical openness and an emphasis on adaptability, Finland is forming human capital ready for the challenges of an unstable and unpredictable world. The state invests not just in diplomas, but in the ability of citizens to constantly update their own competencies. This strategy allows the country to maintain leadership in human development and innovation activity indices, demonstrating that the main advantage in a modern economy is the ability to learn faster than competitors.

Analysis of the experience of the world's leading countries allows us to conclude that effective formation of human capital in modern conditions is possible only with deep integration of education, science and the real sector of the economy. Each of the countries under consideration is building a unique ecosystem where knowledge has

direct access to the market, and business acts as an active customer and co-author of training programs. Germany demonstrates success through a dual system of training and applied science clusters that provide industry with ready-made specialists. Denmark focuses on the concept of "Flexicurity" and "green" energy, creating conditions for a painless change of profession throughout life. China is implementing a large-scale state strategy of investments in STEM disciplines and digitalization, striving for global technological leadership. The United States focuses on the "university-incubator" model, where scientific discoveries are instantly converted into commercial startups and venture projects. Israel effectively uses military experience as an incubator for high-tech talents, which later form the basis of a "startup nation". Finland relies on the radical openness of innovation ecosystems and the ability of a person to continuously update their competencies. Common to all leaders is the understanding of human capital as the main asset of national security and economic resilience to crises. Thus, modern education is transformed from a process of relaying knowledge into a flexible mechanism for human adaptation to the requirements of a high-tech and changing world.

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CONCEPTUALIZING “GREEN” HUMAN CAPITAL IN THE PARADIGM OF THE GLOBAL ENERGY TRANSITION¹

Oriekhova Alvina

Leading Researcher at the Human Capital Research Laboratory, Doctor of Economic Sciences, Professor, Professor of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agrarian University
ORCID ID: 0000-0003-1016-3287

Khromushyna Lyudmyla

Senior Researcher at the Human Capital Research Laboratory, PhD in Economics, Associate Professor, Associate Professor of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agrarian University
ORCID ID: 0000-0001-9134-9010

Tkachenko Viktoriia

Senior Researcher at the Human Capital Research Laboratory, PhD in Economics, Associate Professor, Associate Professor of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agrarian University
ORCID ID: 0000-0002-2924-4012

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The global energy transition, driven by the need to decarbonise the economy and implement the goals of sustainable development, is radically changing the understanding of the driving forces of economic growth. The traditional theory of human capital, which for a long time was based on the anthropocentric principle of *homo economicus* and ignored the environmental context, has proven to be conceptually limited. The realisation that human capital cannot exist in a vacuum and that the degradation of the biosphere accelerates its depreciation has necessitated a revision of established paradigms. Modern science requires new approaches to the interpretation, structuring, and assessment of "green" human capital (GHC) as a key factor in ensuring competitiveness in the context of low-carbon transformation.

The purpose of this chapter is to conceptualise "green" human capital within the paradigm of the global energy transition, as well as to substantiate the mechanisms for the transformation of personnel competencies and the capitalization of "green" knowledge in the corporate governance system.

1. The evolution of human capital theories in the context of environmental challenges

The emergence of human capital theory in the 1960s, marked by the seminal works of Theodore Schultz and Gary Becker, was a true Copernican revolution in economic thought. The recognition of knowledge, skills, and health of the individual as a key factor in economic growth allowed us to overcome the limitations of the classical triangle of labor-land-capital. However, from the perspective of a retrospective analysis of the 21st century, it becomes obvious that the neoclassical foundation of this theory contains a deep conceptual lacuna - a complete disregard for the ecological context of the reproduction of human potential.

G. Becker's methodological approach was based on the principle of *homo economicus*, where investments in a person were considered exclusively through the prism of maximizing individual utility and future income. In this model, "human capital" appears as an isolated autonomous unit, whose productivity depends only on internal investments (education, medicine).

However, this model is extremely anthropocentric. It considers the natural environment only as a passive background or a free repository of resources. Neoclassicists have effectively taken environmental conditions out of the calculation, assuming that the biosphere is an unchanging constant that does not affect the depreciation of human capital.

The main complaint about the approaches of Schultz and Becker is that they treat the environmental consequences of activities as “externalities” that are not included in the cost of human capital reproduction. Within the neoclassical paradigm:

– erosion of health as depreciation -Becker viewed health as a capital asset that depreciates with age. However, he did not take into account the accelerated depreciation of this capital due to environmental

degradation (air pollution, microplastics, climate change). Thus, the social costs of treating the effects of environmental pollution were not included in the investment model;

– education beyond eco-ethics -T. Schultz emphasized the role of education in increasing labor productivity. However, in his works, education was viewed as a tool for intensifying the exploitation of natural resources. Knowledge that leads to the destruction of ecosystems was considered by neoclassicists as a positive capital gain, since it generated short-term profits.

The neoclassical approach relied on the principle of “weak substitutability,” where human capital could supposedly compensate for the loss of natural capital. This illusion of “technological optimism” claimed that the more we invested in brains (human capital), the faster we would find substitutes for depleted natural resources.

Today we understand the fallacy of this thesis: human capital cannot exist in a vacuum. If the ecological system collapses, no amount of IQ or accumulated degrees will be able to ensure the functioning of the economic system.

A critical review of the legacy of Schultz and Becker forces us to move from a “linear” model of human capital to a “circular” or “planetary” one. Modern theory must recognize that:

- the ecological environment is a basic asset that determines the quality of human capital;
- Investments in humans that harm the biosphere are not capital gains, but hidden losses (decapitalization of the future);
- Environmental externalities must be internalized into the assessment of the value of human labor and its reproduction.

Thus, the rejection of narrow neoclassical anthropocentrism is not only a requirement of ethics, but also a condition for the survival of economic science in the Anthropocene era.

The publication of the Brundtland Commission report “Our Common Future” (1987) and the subsequent UN Conference in Rio de Janeiro (1992) marked the emergence of humanity beyond the limits of purely economic determinism. The concept of sustainable development did not simply add an “ecological block” to the agenda, it radically changed the architecture of human capital, transforming it from a highly specialized productive resource into the intellectual foundation of the triune system “economy – society – ecology”.

Within the concept of sustainable development, human capital ceases to be just a means of maximizing added value. Its new role is to ensure a dynamic balance between three vectors:

1. economic efficiency -knowledge as a tool for resource conservation and transition to a circular model;
2. social justice -intellectual development as a path to overcoming inequality and inclusion;
3. ecological integrity -understanding the limits of the biosphere and ethical responsibility for preserving natural capital for future generations.

In the sustainable development paradigm, there is a “qualitative leap” in determining what knowledge and skills constitute value. If in the era of industrialism, capital was considered knowledge that allowed for the most effective “conquest” of nature, today the emphasis is shifting to systems thinking (the ability to see the relationship between local production decisions and global climate change); eco-innovation literacy (knowledge aimed at decarbonizing the economy and developing renewable energy sources); ethical competence (the ability to make decisions based on the long-term principle of “do no harm”).

The concept of sustainable development has introduced a critically important distinction between “weak” and “strong” sustainability. While neoclassical assumed that human capital could replace natural capital (technogenic optimism), within sustainable development, human capital is recognized as a tool for preserving, not replacing, nature. Knowledge is now seen as a resource that should prevent the degradation of ecosystems, since the latter are recognized as irreplaceable (critical natural capital).

Sustainable development requires continuous adaptation of human capital to the conditions of ecological turbulence. Education ceases to be a stage of preparation for a profession; it becomes a process of constant rethinking by a person of his place in the ecosystem. This leads to the formation of the concept of “green skills”, which become a mandatory attribute of a competitive employee in any industry - from agribusiness to IT.

Thus, the emergence of the concept of sustainable development transformed the theory of human capital, integrating the ecological dimension into it. Knowledge within the triad “economy - society - ecology” began to be considered not as a means of extracting natural rent, but as the main safeguard against global disasters. Human capital in the 21st century is the ability of civilization to develop without destroying the biological platform of its own existence.

The modern management paradigm, based on the resource-based approach (Resource-Based View - RBV), traditionally considers human and intellectual capital as strategic assets that provide a sustainable competitive advantage due to their rarity and irreproducibility. However, in the context of the global environmental crisis, this approach requires a fundamental rethinking. The theoretical synthesis of the resource approach and environmental ethics allows transforming the classical structure of intellectual capital (human, structural and relational capital) into a new quality - "green" intellectual capital.

The integration of environmental ethics into the individual level of human capital entails the transformation of professional competence, which is now incomplete without "ecological intelligence" - a synthesis of the resource and ethical aspects of activity. In the resource dimension, this allows the organization to accumulate specialists capable of critically minimizing the material intensity of processes, while in the ethical dimension, the employee begins to be guided by an internal moral imperative, where the preservation of the ecosystem becomes a priority over short-term operational efficiency. Thus, the accumulated knowledge is transformed into professional "wisdom," which acts as a safeguard against making technologically advanced, but environmentally destructive decisions, ensuring the sustainability of development at the anthropological level.

Structural capital (databases, processes, patents) in the light of environmental ethics ceases to be just a repository of corporate knowledge. It becomes the architecture of "regenerative management". Organizational knowledge is encoded in the algorithms of the circular economy. Patents and technologies are evaluated not by the volume of future royalties, but by their ability to reduce anthropogenic pressure. Environmental ethics is institutionalized in internal regulations, transforming an "intangible asset" into "ecological brand capital".

In parallel, the transformation of relational capital within the framework of environmental ethics expands the classical understanding of market relations, including the "silent partner" - Nature - in the circle of stakeholders, which requires a revision of strategies for interaction with customers and counterparties. In the new structure, relational capital encompasses community trust in the company's environmental policy and ethical synergy with suppliers, where knowledge about building waste-free supply chains becomes the most valuable element of intellectual capital. This approach converts environmental responsibility into long-term loyalty of a conscious consumer, creating an intangible asset that ensures the strategic stability of the organization in the face of global eco-challenges.

As a result of theoretical synthesis, we obtain a model where environmental ethics is not an external constraint, but an "operating system" of intellectual capital:

- resource approach provides tools (how to do);
- environmental ethics provides goal setting (why do it).

This leads to the emergence of "green innovation capacity" - a higher form of intellectual capital that allows an organization to create economic value in parallel with the restoration of natural capital.

The integration of environmental ethics into the structure of intellectual capital marks the transition from "extractive management" (resource extraction) to "holistic management". In this new retrospective, the most valuable resource of an organization is not just a "smart person", but an "ethical person", whose intellectual efforts are integrated into the natural cycles of the biosphere. Such a theoretical synthesis lays the foundation for the creation of a new type of organization, where intellectual capital becomes the main guarantor of planetary sustainability.

2. Terminological field and structure of "green" human capital (GHC)

In the current conditions of the global energy transition, accompanied by the decarbonisation of the economy, the development of renewable energy sources and the implementation of the principles of the circular economy, a significant transformation of the content and functional purpose of human capital are taking place. These processes are not isolated, but form a new paradigm of socio-economic development, in which the human factor acts not only as a production resource, but also as an effective agent of environmental change.

Traditional approaches to the interpretation of human capital, which focused mainly on labour productivity, professional skills and individual returns on investment in education, are gradually being supplemented by an environmental component, reflecting new requirements for employee competencies. Within the framework of classical concepts, human capital was considered as a factor of economic growth, but its impact on environmental sustainability and long-term balanced development was ignored.

In this context, the concept of «green» human capital is being formed (Green Human Capital, GHC), which is increasingly used in scientific discourse to describe the ability of workers to ensure environmentally friendly development of economic systems. As modern research shows, human capital is becoming an

important factor in achieving sustainable development, since it is the knowledge, innovation and behavioural attitudes of people that determine the efficiency of resource use and the level of environmental load (Šlaus & Jacobs, 2011).

It is important to emphasize that in the context of energy transition, human capital ceases to be a passive element of the economic system. It takes on an active transformational role, influencing the speed and quality of the implementation of low-carbon technologies, the formation of new labour markets, and the adaptation of organizations to environmental challenges.

The analysis of the scientific literature allows us to distinguish several approaches to understanding «green» human capital. First, it is considered as an extension of classical human capital, encompassing environmentally oriented knowledge and skills (Kaushiva, 2025). This approach is evolutionary and reflects the gradual integration of the environmental component into existing theoretical frameworks.

Secondly, GHC is interpreted as a tool for economic transformation, ensuring the transition to a low-carbon development model through the formation of new competencies and professional standards (Nofriansyah and al., 2025). In this case, human capital becomes a catalyst for structural change.

Third, GHC is seen as a corporate sustainability factor that contributes to reducing carbon emissions, increasing energy efficiency, and implementing innovation (Li and al., 2026). This approach focuses on the micro level (organizational level).

Thus, it can be stated that the concept of «green» human capital is multidimensional and encompasses both the individual characteristics of employees and their role in the functioning of economic systems at different levels.

A feature of the current stage is that human capital ceases to be neutral in relation to the environment. It acquires a clearly expressed environmental orientation, which is manifested in the ability of employees to make decisions taking into account the principles of sustainable development, optimize the use of resources and implement environmental innovations. In this sense, «green» human capital becomes not only an economic, but also a socio-ecological category, combining material and non-material aspects of development.

Taking into account the analysis conducted, it is advisable to formulate the following definition: «Green human capital (GHC) is an integrated set of environmentally oriented knowledge, professional skills, innovative abilities, and value and motivational attitudes of individuals that ensure the effective functioning and development of economic systems within the framework of a low-carbon, resource-efficient paradigm and the principles of sustainable development».

The proposed definition emphasizes the multidimensionality of GHC and its role as a systemic driver of the energy transition, and also allows for the integration of economic, environmental, and social dimensions of development.

The formation of the GHC concept occurs at the intersection of several scientific areas: human capital theory, environmental economics, human resource management, and sustainable development theory, which results in a wide terminological field.

One of the important elements of this field is the concept of «green skills», which refers to the knowledge and competences necessary to function in a «green» economy. As Fuchs (2024) notes, such skills are heterogeneous in nature and encompass both technical competences related to the use of renewable energy sources and increasing energy efficiency, and universal competences, including systems thinking, the ability to interdisciplinary interaction and environmental responsibility.

Green skills become the basic tool for adapting the workforce to new conditions, as the energy transition is accompanied by the emergence of new professions, the transformation of existing activities and increased requirements for employee qualifications (Kaushiva, 2025). At the same time, the insufficient level of development of such skills forms the so-called «green skills gap», which slows down the pace of transition to a sustainable economy.

Another important concept is «green human resource management» (Green HRM), which involves the integration of environmental principles into all HR practices: recruitment, training, evaluation and motivation of personnel (Papademetriou and al., 2025). The application of GHRM contributes to the formation of an organizational culture focused on sustainable development and creates institutional conditions for the accumulation of «green» human capital.

The concept of «green workforce readiness» reflects the degree to which existing competencies are relevant to sustainable development. Research shows that the main problem is the gap between the demand for green skills and their supply, which necessitates the reform of the education and training system (Organisation for Economic Cooperation and Development, 2017).

In a broader context, GHC is a component of human capital for sustainable development, which encompasses not only environmental but also social aspects, including quality of life, educational attainment, and social responsibility (Šlaus & Jacobs, 2011).

Given the multidimensional nature of GHC, it is appropriate to consider it as a system of interconnected components.

1. Ecological cognitive resource:
 - knowledge about climate change;
 - understanding the principles of the circular economy;
 - awareness in the field of energy efficiency.

Research shows that knowledge is the basis for shaping environmentally responsible behaviour and decision-making (Darwisman and al., 2025). They ensure the ability of employees to integrate environmental criteria into professional activities.

2. Green Skills (functional and operational component, practical skills): - work with renewable energy sources; - environmental risk management;- implementation of eco-innovations.

Green Skills are critical for the implementation of the energy transition, as they ensure the practical implementation of technological changes (Kaushiva, 2025; Fuchs, 2024).

3. Innovative and adaptive potential – the ability to:
 - generation of new ideas;
 - adaptation to technological changes;
 - participation in the processes of digital-green transition.

Empirical research shows that human capital development combined with digital competencies significantly enhances the effectiveness of decarbonisation (Javed and al., 2025).

4. Value-motivational component (ecological identity):
 - environmental values;
 - environmental responsibility;
 - willingness to change behavioural patterns.

It is this component that determines the depth of integration of environmental principles into the activities of employees and organizations (Papademetriou and al., 2025).

GHC performs a number of basic functions:

1. Innovation function – ensures the development and implementation of green technologies (International Energy Agency, 2023).
2. Transformational function – contributes to changing the structure of the labour market.
3. Environmental function – reduces the carbon footprint of organizations (Li and al., 2025).
4. Institutional function – forms new management standards (ESG, GHRM).

We propose an author's model of the GHC structure (Fig. 1).

The proposed author's model allows us to systematize the structure of GHC and can be used as a methodological basis for further empirical research and practical developments in the field of HRM and energy management.

Thus, «green» human capital is a complex multi-level category that combines knowledge, skills, innovative abilities and values aimed at achieving sustainable development. Its formation is a basic prerequisite for a successful energy transition, since it is the human factor that determines the effectiveness of the implementation of environmental innovations and the transformation of economic systems.

In the current conditions of the intensification of the global energy transition, the problem of not only conceptualizing «green» human capital, but also developing methodological approaches to its assessment and development, is becoming particularly relevant, which is due to the need to form effective human resources management tools capable of ensuring the achievement of the goals of sustainable development and climate neutrality.

At the international level, the issue of developing «green» human capital is in the focus of the activities of leading organizations, in particular the International Labour Organization, Organization for Economic Cooperation and Development and European Commission (ILO, 2018; OECD, 2017; European Commission, 2019). Their analytical and policy documents from the methodological basis for assessing the competences needed for the transition to a green economy.

In particular, within the framework of the International approaches Labour Organization focuses on the concept of «green jobs» and the need to integrate environmental competencies into the vocational education system. The organization defines «green» jobs as those that contribute to the preservation or restoration of the

environment, which, in turn, requires the formation of appropriate human capital. In this context, the GHC assessment involves an analysis of the level of employment in «green» sectors, as well as the degree to which qualifications meet the requirements of sustainable development.

Analytical approaches Organisation for Economic Cooperation and Development are based on the concept of «skills for green transition», which involves identifying, measuring and forecasting needs for «green» skills. The OECD suggests using comprehensive indicators covering:

- the level of environmental education of the population;
- intensity of professional training in the field of sustainable development;
- adaptability of the workforce to technological changes.

Particular attention is paid to the assessment of the so-called «green skills gap», which characterizes the imbalance between demand and supply of environmental competencies.

Within the framework of the European policy Commission, in particular in the context of the European Green Deal (EGD), human capital development is seen as a key prerequisite for achieving climate neutrality. The European Commission is implementing a number of initiatives aimed at creating a «green» workforce, including retraining programs, developing STEM education, and supporting innovation ecosystems.

Methodologically, the assessment of «green» human capital can be carried out at three levels:

1. Individual level – is basic, since it is individual characteristics that form the overall potential of human capital. It involves assessing:

- level of environmental knowledge;
- availability of green skills;
- formation of environmental values.

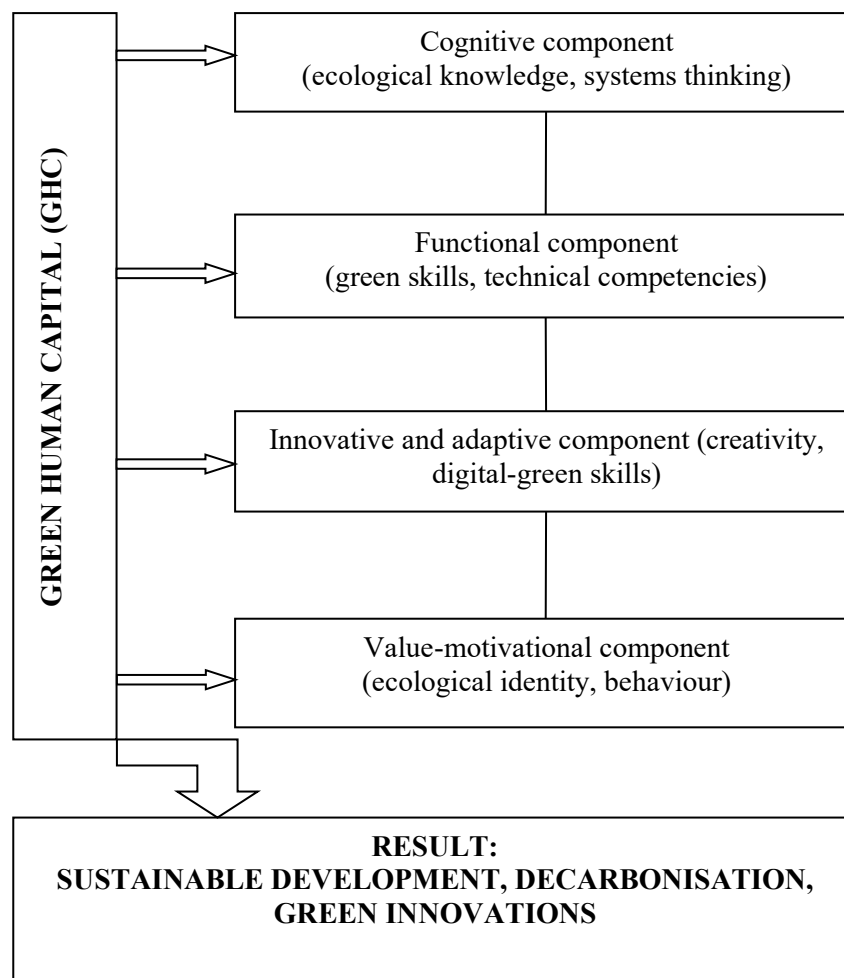


Figure 1. GHC structure model
Source: proposed by the authors.

2. Organizational level – includes: - integration of GHRM principles; - investments in «green» personnel training; - participation in ESG practices.

At this level, GHC is a factor in the competitiveness of enterprises and their ability to innovate.

3. Macroeconomic level – at this level, the strategic context for GHC development is formed:

- employment structure in «green» sectors;
- state policy in the field of education and the labour market;
- the level of development of the «green» economy.

Synthesizing international approaches, we can identify the following main indicators for assessing «green» human capital: - share of employees with «green» competencies; - level of participation in sustainable learning programs; - intensity of innovations in the field of «green» technologies; - indicators of environmental efficiency of organizations (Table 1).

Table 1. GHC Evaluation Indicator System

Assessment level	Indicator group	Indicators	Source (assessment method)
Individual	Cognitive	Level of environmental knowledge; awareness of climate change	Tests, certification
	Green skills	Proficiency in renewable energy technologies; energy efficiency skills	Professional standards
	Valuable	Environmental awareness; willingness to adopt sustainable practices	Surveys, ESG questionnaires
Organizational	HRM practices	Availability of Green HRM; environmental training for staff	HR reports
	Innovation	Number of «green» innovations; introduction of eco-technologies	R&D indicators
	ESG	ESG rating; CO ₂ emissions level	ESG reporting
Macro level	Labour market	Share of green jobs	Employment statistics
	Education	Share of sustainable development programs	Educational data
	Economy	Level of decarbonisation; development of renewable energy sources	National statistics

Source: compiled by the authors based on (ILO, 2018; OECD, 2017; European Commission, 2019; Kaushiva, 2025; Fuchs, 2024)

An important aspect is that the development of GHC should be continuous and integrated into the education system throughout life (lifelong learning), which meets modern challenges associated with rapid technological change and the need for constant updating of competencies.

Thus, methodological approaches to the assessment and development of «green» human capital are based on a combination of individual, organizational and institutional factors, and also take into account international experience and recommendations of leading organizations. Their application allows providing a systematic approach to the formation of human potential capable of functioning effectively in the conditions of global energy transition.

Summarizing the conducted research, it should be noted that «green» human capital is being formed as a qualitatively new category in the context of the global energy transition, integrating economic, environmental and social dimensions of development. Its essence is revealed through a set of environmental knowledge, specialized skills, innovative potential and value orientations that ensure the adaptation of economic systems to the requirements of decarbonisation. The proposed structural model of GHC allows us to systematize its main components and substantiate methodological approaches to assessment. At the same time, international experience confirms the decisive role of human capital as a driver of sustainable development and ecological transformation.

3. Impact of energy transition on transformation of personnel competencies

The connection of the energy transition with global trends in sustainable development, ESG and climate policy is crucial for understanding modern transformations in the field of human resources management. The energy transition, which involves the gradual abandonment of fossil energy sources in favor of renewable ones, is a key tool for achieving sustainable development goals, in particular in terms of ensuring environmental safety, rational use of resources and reducing greenhouse gas emissions. In this context, the transformation of personnel competencies becomes not only a consequence of technological changes, but also a necessary condition for their effective implementation.

The concept of sustainable development emphasizes the balance between economic, social and environmental aspects of development, which directly affects the formation of new requirements for human capital. Enterprises are forced to adapt to new standards of operation, implement environmentally friendly technologies and ensure responsible use of resources, which, in turn, requires employees to have the appropriate knowledge, skills and values. Thus, the demand for so-called "green" competencies is growing, which include an understanding of environmental processes, energy efficiency and the principles of the circular economy.

An important role in this process is played by the ESG concept, which integrates environmental, social and governance criteria into the activities of companies. The implementation of ESG approaches stimulates businesses to increase transparency, social responsibility and environmental awareness, which is directly reflected in human resource management policies. In particular, companies are increasingly investing in the development of employee competencies in the field of sustainable development, energy efficiency and digital technologies, as well as forming a corporate culture focused on long-term sustainability.

Climate policy, implemented at the global and national levels, is also a powerful driver of change. Strengthening regulatory requirements for reducing emissions, implementing carbon regulation and developing "green" energy create new conditions for the functioning of enterprises. In these conditions, the ability of personnel to quickly adapt to changes, master new technologies and work in conditions of uncertainty becomes of particular importance. This necessitates continuous training, retraining and development of flexible skills.

Therefore, the energy transition is an integral part of global transformations covering the economic, social and environmental spheres. Its implementation is impossible without a corresponding transformation of personnel competencies, which becomes a strategic priority for enterprises and the state. It is through the prism of these global trends that a new model of human capital development is being formed, focused on sustainability, innovation and responsibility.

The essence of the energy transition from fossil fuels to renewable energy sources is a profound transformation of the ways in which energy is produced, distributed and consumed in order to ensure environmental sustainability, economic efficiency and energy security. The traditional energy model, based on the use of coal, oil and natural gas, has long ensured industrial development, but at the same time has become a source of significant environmental problems, in particular climate change, air pollution and depletion of natural resources. In this regard, there is an objective need to transition to a new energy paradigm based on the use of renewable energy sources.

The energy transition involves the gradual abandonment of carbon-intensive technologies and their replacement with cleaner alternatives, such as solar, wind, hydropower, bioenergy and geothermal energy. These sources are characterized by inexhaustibility, environmental safety and significantly lower greenhouse gas emissions. At the same time, the transition is not limited to changing energy resources, but encompasses comprehensive structural changes in the energy system, including infrastructure modernization, the development of smart grids, the introduction of energy storage technologies and the digitalization of management processes.

An important component of the energy transition is the decentralization of energy systems, which involves increasing the role of local generation sources and actively involving consumers in the energy production process. This model contributes to increasing the flexibility and reliability of energy supply, reducing losses during energy transmission and developing energy democracy. In addition, the concept of "prosumers" is gaining significant popularity, when consumers simultaneously act as energy producers, for example, by installing solar panels.

The energy transition also has a significant economic dimension, as it stimulates the development of new industries, job creation and investment. At the same time, it is accompanied by certain challenges, in particular the need for significant capital investments, the transformation of traditional energy sectors and ensuring social justice in the process of change. Of particular importance is the issue of a "just transition", which involves supporting workers and regions dependent on fossil fuels.

Therefore, the energy transition is a multidimensional process that encompasses technological, economic, social and institutional aspects of development. Its implementation is aimed at creating a low-carbon economy capable of ensuring long-term sustainability and competitiveness. In this context, the transition to renewable energy sources is not only an environmental necessity, but also a strategic direction for global development.

The concept of personnel competencies in modern conditions of economic development encompasses a set of knowledge, skills, abilities, experience and personal characteristics that ensure the effective performance of professional tasks and the ability to adapt to a changing environment. In the context of transformations caused by digitalization, globalization and energy transition, a comprehensive approach to the formation of competencies, which includes hard skills, soft skills, green skills and digital skills, is of particular importance. It is their combination that forms a competitive employee who is able to act effectively in the new economic reality.

Hard skills, or professional (technical) competencies, are specialized knowledge and practical skills required to perform specific work tasks. They are usually acquired in the process of formal education or vocational training and can be clearly measured and assessed. Such competencies include, for example, knowledge of technological processes, possession of specialized software, engineering skills, financial analysis or agronomic knowledge. In traditional industries, hard skills have long been a determining factor in professional success, but in modern conditions they are no longer enough to ensure high employee efficiency.

Soft skills, or flexible (superprofessional) competencies, include social, communicative and personal qualities that determine a person's ability to interact with others, work in a team, resolve conflicts and make decisions under conditions of uncertainty. These include emotional intelligence, critical thinking, creativity, leadership, adaptability, learning ability and time management. In today's dynamic environment, soft skills are becoming key to ensuring the organization's flexibility and its ability to respond quickly to changes. They complement professional knowledge and allow them to be effectively applied in practical activities.

In connection with the intensification of environmental challenges and the development of the concept of sustainable development, a new group of competencies is being formed - green skills. They include knowledge, skills and values related to the rational use of natural resources, reducing negative environmental impact and implementing environmentally friendly technologies. Green skills include understanding the principles of energy efficiency, waste management, knowledge of renewable energy sources, environmental thinking and responsible behavior. These competencies are becoming increasingly important in the context of energy transition, as they ensure the ability of personnel to work in accordance with new environmental standards and requirements.

Digital skills, or digital competencies, are another key element of the modern system of personnel competencies. They include the ability to effectively use digital technologies, work with information systems, analyze data and apply modern automation tools. They include both basic computer skills and digital platforms, as well as more complex competencies related to programming, cybersecurity, big data processing or the use of artificial intelligence. In the context of the digital transformation of the economy, digital skills are becoming a necessary condition for professional activity in almost all areas.

The relationship between technological changes and personnel requirements is one of the key factors in the transformation of modern organizations and the labor market. The development of new technologies, in particular automation, digitalization, artificial intelligence and energy-efficient solutions, leads to significant changes in the content of work, employment structure and the nature of professional activity. In these conditions, personnel requirements are constantly evolving, which necessitates the adaptation of competencies to new technological realities.

Technological changes, on the one hand, contribute to increasing labor productivity and optimizing production processes, and on the other hand, lead to the displacement of traditional professions and the emergence of new types of activities. Automation of routine operations reduces the need to perform standard tasks, while the demand for employees who can work with complex systems, analyze data and make management decisions is growing. This means that a modern employee must possess not only professional knowledge, but also analytical skills, critical thinking and the ability to learn quickly.

A special role in shaping new requirements for personnel is played by digitalization, which changes the ways of organizing work, communication and management. The use of information systems, digital platforms and cloud technologies requires employees to develop digital competencies and readiness to work in a virtual environment. In addition, the integration of artificial intelligence technologies and big data analysis is changing the nature of decision-making, which increases the importance of information interpretation and interdisciplinary knowledge.

At the same time, technological changes increase the importance of flexible skills, as the speed of knowledge and technology renewal requires employees to be highly adaptable. The ability to work in a team, communicate effectively, solve problems and manage change becomes no less important than technical competencies. In this context, the concept of lifelong learning, which involves constant updating of knowledge and development of new skills throughout professional life, acquires particular importance.

In addition, technological transformations associated with the energy transition are creating a demand for environmentally-oriented competencies. The introduction of renewable energy sources, energy-efficient technologies and sustainable development principles requires staff to understand the environmental aspects of their activities and the ability to work in accordance with new standards. Thus, technological changes not only change the tools of work, but also form a new system of values and approaches to professional activity.

Therefore, the relationship between technological changes and personnel requirements is dynamic and interdependent. Technologies determine the direction of competence development, while the level of personnel training affects the effectiveness of their implementation. In these conditions, the success of organizations largely depends on the ability to timely adapt personnel policies to new challenges, invest in human capital development, and create an environment conducive to innovation and learning.

In today's dynamic economic and technological changes, the concepts of reskilling and upskilling, as well as rethinking the role of human capital in transformation processes, are of particular importance. These approaches form the basis for adapting personnel to new labor market requirements caused by digitalization, automation, globalization, and energy transition. They are aimed at ensuring the competitiveness of employees and the sustainable development of organizations in the long term.

The concept of upskilling involves increasing the level of existing competencies of an employee within the framework of his current professional activity. It is about deepening knowledge, improving skills and expanding functional capabilities without changing the main job profile. Upskilling is a response to gradual changes in the requirements for professions, when traditional roles are transformed under the influence of new technologies. For example, the introduction of digital tools in production or management requires employees to master new software products, analytical approaches and methods of working with data. Thus, upskilling contributes to increasing labor productivity, more efficient use of resources and maintaining employment.

Instead, reskilling involves acquiring fundamentally new competencies necessary to perform a different professional activity or transition to a new field. This concept becomes especially relevant in the context of structural changes in the economy, when certain professions disappear or lose their relevance, and new ones appear in their place. Reskilling allows employees to adapt to such changes, avoid unemployment and integrate into new segments of the labor market. In the context of the energy transition, this may mean retraining employees of the traditional energy industry to work in the field of renewable energy sources, energy efficiency or environmental management. Thus, reskilling performs an important social function, contributing to the preservation of human potential.

Both concepts are closely related to the idea of continuous learning, which involves the constant updating of knowledge and skills throughout life. In modern conditions, knowledge quickly becomes obsolete, so the ability to learn becomes a key competency of an employee. Organizations, in turn, are interested in creating corporate learning systems, developing internal educational platforms and forming a knowledge culture that ensures their adaptability and innovation.

In this context, the concept of human capital, which considers employees as a strategic resource that forms the competitive advantages of the organization, is of particular importance. Human capital includes not only professional knowledge and skills, but also motivation, values, creativity, the ability to innovate and adapt. In the context of economic transformation, the role of human capital is being reassessed: it becomes not just a factor of production, but a key driver of development.

Transformational processes are changing approaches to human capital management. The importance of investing in training and development of personnel, forming flexible organizational structures, supporting innovative thinking and creating a favorable environment for employee self-realization is growing. Particular attention is paid to the development of interdisciplinary competencies, a combination of technical, digital and social skills, which allows you to act effectively in conditions of uncertainty.

Therefore, the concepts of reskilling and upskilling are key tools for adapting human capital to modern challenges. They ensure flexibility and mobility of the workforce, contribute to reducing social risks and increasing the efficiency of economic systems. Combined with a new understanding of the role of human capital, these approaches form the basis for the sustainable development of organizations and society in conditions of deep transformations.

The energy transition from traditional fossil energy sources to renewables is significantly transforming the structure of labor demand, which directly affects the formation of new requirements for personnel competencies. This process is accompanied by profound structural shifts in the economy, in particular, a change in the sectoral structure of employment, the redistribution of labor resources and the emergence of new professional roles. As a result, there is a gradual reduction in the demand for workers in traditional energy sectors, such as coal, oil and gas, and at the same time an increase in the need for specialists in the field of renewable energy, energy efficiency and environmental management.

The change in the structure of labor demand is manifested primarily in the transition from physically oriented work to intellectually and technologically intensive activities. If earlier a significant part of the work was associated with the extraction and processing of natural resources, now the role of knowledge, analytical abilities and digital skills is increasing. This means that companies increasingly need employees who are able to work with modern technologies, manage complex systems and make informed decisions based on data analysis. Accordingly, the structure of competencies is changing: along with traditional technical knowledge, the importance of digital, environmental and interdisciplinary skills is increasing.

Another important aspect is the emergence of new professions related to the development of renewable energy sources, such as solar and wind energy engineers, energy management specialists, energy auditors, energy data analysts. At the same time, existing professions are being transformed, adapting to new conditions by integrating environmental and digital components into their activities. This creates a demand for workers who are able to learn quickly and change their professional trajectory in accordance with market needs.

The changing structure of labor demand also has a regional dimension; as different territories depend differently on traditional energy resources. In regions dominated by fossil energy, there is a risk of employment reduction, which requires the implementation of retraining and support policies for workers. At the same time, in regions focused on the development of "green" energy, new jobs are created, which stimulates economic growth and investment.

In addition, not only the quantitative but also the qualitative structure of demand for labor is changing. Companies are increasingly focusing on employees with a high level of adaptability, the ability to innovate and interdisciplinary thinking. Teamwork, communication and change management skills are becoming important, ensuring the effective integration of new technologies into production processes. In this context, the role of continuous learning and competence development throughout professional life is significantly increasing.

Thus, the energy transition is leading to a profound transformation of the structure of labor demand, which is manifested in changing industry priorities, the emergence of new professions, and increasing requirements for personnel qualifications. This process is shaping a new employment model focused on innovation, environmental responsibility, and digital competence, which determines the directions of human capital development in the context of modern global changes.

The energy transition, accompanied by the introduction of renewable energy sources, digital technologies and sustainable development principles, is not only changing the structure of labor demand, but also actively creating new professions and transforming existing ones. This process is systemic and covers both technical and managerial, analytical and service areas of activity. As a result, a new professional ecosystem is being formed, focused on innovation, energy efficiency and environmental responsibility.

The emergence of new professions is a direct consequence of the development of "green" energy and related technologies. In particular, there is a growing demand for specialists in the field of solar, wind, bio- and geothermal energy, who are engaged in the design, installation, operation and maintenance of relevant systems. Such professions include renewable energy engineers, solar panel maintenance technicians, wind turbine specialists, energy project managers. In addition, the development of intelligent energy systems contributes to the emergence of professions related to digital energy management, such as energy data analysts, smart grid specialists, and cybersecurity specialists in the energy sector.

At the same time, traditional professions are being transformed, adapting to new operating conditions. Workers in the fossil energy sector are forced to master new competencies related to environmental standards, digital technologies and energy-efficient solutions. For example, engineers and technical personnel are moving from working with traditional equipment to managing automated systems, monitoring energy processes in real time and using software to optimize production. This means that even within the same profession, the content of work is changing significantly, its intellectual component and qualification requirements are increasing.

Special attention is paid to the emergence of interdisciplinary professions that combine knowledge from different fields, including energy, information technology, ecology and management. Such specialists are able to

comprehensively solve problems related to the implementation of innovative solutions, assessing their effectiveness and managing risks. For example, energy managers combine technical knowledge with management skills, and ESG strategy specialists integrate environmental and social aspects into business processes.

The transformation of professions is also accompanied by a change in the role of the employee in the organization. If earlier the emphasis was on the performance of clearly defined functions, now the importance of versatility, flexibility and the ability to continuous learning is increasing. Employees must be ready to change their professional trajectory, master new roles and perform tasks that go beyond traditional job responsibilities. In this context, the skills of adaptation, creativity, critical thinking and teamwork become important.

In addition, the process of transformation of professions has a social dimension, as it affects employment, income levels and professional mobility of the population. There is a need to create effective mechanisms for retraining and upgrading of skills of workers, which allows to reduce the risks of unemployment and ensure social stability. Educational institutions and enterprises should closely cooperate to form relevant educational programs focused on the needs of the "green" economy.

The energy transition, accompanied by the active implementation of renewable energy sources, digital technologies and sustainable development principles, is leading to a profound transformation of personnel competencies. In this context, several key areas of change can be identified, among which the development of digital competencies, the formation of green skills, the formation of innovative thinking, as well as increasing the level of adaptability and flexibility of employees are of particular importance.

One of the leading directions of transformation is the development of digital competencies, which are becoming a necessary condition for effective operation in the modern energy system. The introduction of smart grids, automated control systems, Internet of Things technologies and big data analysis is changing the nature of professional activity, requiring employees to be able to work with digital platforms, process and interpret information, and make decisions based on analytical data. In particular, the analysis of energy flows, demand forecasting and optimization of resource consumption are becoming an integral part of the work of modern specialists. This means that even traditional technical professions require the integration of digital knowledge and skills, which increases the requirements for the level of personnel training.

In parallel with digitalization, the importance of environmental competencies, or green skills, is growing, reflecting the ability of employees to act in accordance with the principles of sustainable development. In the context of increasing environmental requirements and the transition to a low-carbon economy, employees must have knowledge of energy efficiency, resource management, waste minimization and the impact of production activities on the environment. Green skills include not only technical knowledge, but also the formation of ecological thinking, a responsible attitude to natural resources and an understanding of global environmental challenges. They are becoming an important component of professional competence in many industries, in particular in the energy, industry, construction and agricultural sectors.

Another important direction is the development of innovative thinking, which involves the ability to generate new ideas, find non-standard solutions and implement innovations in practical activities. The conditions of rapid technological change require employees not only to perform the assigned tasks, but also to actively participate in the processes of improving production, optimizing processes and creating new products and services. Innovative thinking is based on creativity, critical analysis, openness to change and willingness to experiment. It helps to increase the competitiveness of organizations and allows them to effectively respond to the challenges of the external environment.

An important component of the transformation of competencies is also the development of adaptability and flexibility of personnel. In today's conditions of instability and uncertainty, the ability to quickly adapt to change is becoming one of the key characteristics of a successful employee. This includes the willingness to master new knowledge, change professional roles, work in interdisciplinary teams and use new technologies. Flexibility is also manifested in the ability to work effectively in different organizational conditions, including remote formats, project activities and dynamic work environments.

These areas of competence transformation are interconnected and complement each other. Digital skills enhance the capabilities of innovative activity, environmental competences form a responsible basis for decision-making, and adaptability ensures the effective application of this knowledge in a changing environment. Together, they form a new model of professional competence that meets the requirements of the energy transition and the modern economy in general. This, in turn, determines the need to revise approaches to education, professional training and personnel management in order to ensure the sustainable development of organizations and society.

The model of personnel competence transformation in the context of energy transition should be considered as a multi-level dynamic system, formed under the influence of interrelated technological, economic and regulatory factors and implemented at the individual, organizational and national levels. Such a model reflects the complex nature of changes in human capital requirements and allows for a systematic approach to managing competence development in the context of the transition to a low-carbon economy.

At the heart of the model is the process of transformation of competencies, which involves updating, expanding and deepening the knowledge and skills of employees in accordance with the new conditions of the economy. The key factors determining the direction and intensity of these changes are technological, economic and regulatory influences. Technological factors include the development of renewable energy sources, digitalization, automation of production processes, the introduction of intelligent energy systems and data processing technologies. They are the ones that shape new requirements for professional and digital competencies, stimulating the demand for interdisciplinary knowledge and innovative thinking.

Economic factors determine the resource capabilities and motivation for the transformation of competencies. These include changes in the structure of the labor market, increased competition, investment activity in the field of "green" energy, as well as the need for enterprises to increase efficiency and reduce costs. Economic incentives encourage organizations to invest in personnel development, implement training and retraining programs, and employees to increase their own competitiveness by acquiring new skills.

Regulatory factors include government energy policies, environmental standards, international commitments to reduce emissions, and educational and social policies. They create an institutional environment that defines the rules of the labor market and stimulates the development of certain competencies. For example, the introduction of energy efficiency standards or support for "green" energy contributes to the formation of demand for relevant knowledge and skills.

These factors are implemented through a system of levels of competence transformation. At the individual level, the key role is played by the employee's ability to learn, adapt and self-develop. It is here that the direct formation of new competences takes place through the processes of upskilling and reskilling, mastering digital tools, developing ecological thinking and flexible skills. Motivation for learning, openness to change and readiness to change professional trajectory are important.

At the organizational level, the transformation of competencies is associated with the formation of an effective human resource management system, which involves the implementation of corporate training, the development of internal educational platforms, the creation of conditions for knowledge exchange and the support of an innovative culture. Organizations are key agents of change, since they are the ones who define the requirements for competencies, invest in the development of employees and create an environment for the realization of their potential. In this context, strategic planning of personnel development, the integration of sustainable development principles into personnel policy and the use of modern learning technologies are important.

At the national level, the transformation of competencies is ensured through state policy, the education system and the labor market. The state plays an important role in shaping the regulatory framework, supporting educational reforms, developing vocational training and retraining programs, as well as stimulating cooperation between educational institutions and business. It is also important to ensure social support for employees in the transformation process, which helps reduce the risks of unemployment and social tension.

Thus, the proposed model of personnel competence transformation reflects the complex nature of changes occurring under the influence of the energy transition. It emphasizes the need for coordinated actions at all levels — from individual to national — and taking into account key influencing factors that determine the effectiveness of this process. The implementation of such a model contributes to the formation of competitive human capital, capable of ensuring sustainable economic development in the context of global transformations.

In the current conditions of energy transition and rapid technological transformation, enterprises are faced with the need not only to adapt production processes and technologies, but also to form highly qualified human capital capable of functioning effectively in new realities. Practical aspects of staff competency development in the context of these changes are of particular importance, since the organization's ability to innovate, energy-efficient management, and integrate sustainable development principles into its own practice depends on the level of employee training. The main recommendations for enterprises concern the development of personnel training systems and the implementation of the concept of lifelong learning.

The development of personnel training systems is a basic mechanism for forming the necessary competencies in response to changes in the technological, economic and regulatory environment. To effectively implement such systems, enterprises should focus on several key principles. First, training

programs should be comprehensive and include both professional and technical and interdisciplinary components that cover digital skills, innovative thinking and environmental responsibility. For example, employees of energy enterprises should have knowledge of smart grid management, energy data analysis, energy audit and assessment of the impact of production activities on the environment. Such comprehensive training provides the opportunity to effectively adapt to new technologies and market conditions. Secondly, learning systems should be integrated into the internal organizational structure and processes. This involves creating corporate educational platforms where employees can take online courses, participate in workshops and practical training, and receive mentoring from experienced colleagues. Integrating learning into work processes allows you to combine theoretical training with practical application of knowledge, increases motivation for learning, and contributes to the formation of a culture of continuous professional development. Special attention should be paid to adaptive training programs that can be adjusted to the level of training and individual needs of employees.

Third, an effective training system should provide for regular assessment of personnel competencies and feedback. Assessment of knowledge and skills allows you to identify gaps in training and timely adjust training programs. The use of assessment tools, such as testing, simulations, case studies and project tasks, allows you to determine the level of practical training and the effectiveness of mastering new competencies.

The implementation of the concept of lifelong learning is the next critically important aspect of transforming personnel competencies. In today's conditions of rapid technological change, knowledge and skills become obsolete much faster than before, so continuous learning is becoming a prerequisite for maintaining the competitiveness of the enterprise and the personal development of employees. Lifelong learning involves the formation of employees' sustainable motivation for self-learning, the ability to quickly master new technologies, adapt to new professional requirements and actively participate in the process of updating knowledge.

The practical implementation of lifelong learning includes several elements. First, companies should create internal incentives for learning, including a system of bonuses, career prospects and recognition of achievements in the development of competencies. Second, it is important to provide access to a variety of learning resources - online courses, webinars, internal knowledge libraries, the opportunity to participate in industry conferences and professional associations. Third, it is necessary to integrate learning into daily activities through project work, mentoring and knowledge exchange between employees of different departments and levels. This approach contributes to the formation of systems thinking and the ability to quickly adapt to change.

Special attention should be paid to the development of competencies in the field of digital technologies and green skills. Employees should regularly improve their skills in working with intelligent energy systems, data analysis technologies, energy efficiency software, as well as master the principles of environmentally responsible production and resource management. This knowledge ensures the effective integration of innovations and supports the organization's sustainable development strategy.

Thus, the practical aspects of transforming personnel competencies boil down to creating an effective training system that combines corporate educational programs, adaptive training and performance assessment, as well as implementing the concept of continuous learning. This allows enterprises to form highly qualified, adaptive and innovatively oriented personnel capable of effectively responding to changes in the technological and economic environment, supporting the energy transition and contributing to the long-term competitiveness of the organization.

The energy transition, driven by the global drive to decarbonize the economy and develop renewable energy sources, is significantly transforming the requirements for personnel competencies and creating demand for so-called "green" professions. In these conditions, it is important for employees not only to adapt to new technological realities, but also to proactively shape their own trajectory of professional development, focused on the principles of sustainable development. The practical aspects of such an orientation include, first of all, awareness of changes in the structure of the labor market, where the need for specialists in the fields of renewable energy, energy efficiency, circular economy and environmental management is growing. It is advisable for employees to regularly monitor industry development trends, analyze the demand for competencies and identify promising areas of professional implementation.

An important practical step is the development of digital and technical skills, which are becoming basic for most "green" professions. In particular, knowledge in the field of data analysis, automation of production processes, work with energy systems and software for monitoring resources significantly increase the competitiveness of an employee. Along with this, the role of interdisciplinary competencies that combine

technical knowledge with environmental thinking, economic analysis and management skills is growing. Therefore, employees should invest in lifelong learning, including online courses, certification programs and professional training focused on sustainable development and "green" technologies.

Equally important is the formation of environmental awareness and a responsible attitude towards resources, which is manifested both in professional activities and in everyday behavior. Employees must understand the principles of energy efficiency, emission reduction and waste management, as well as be prepared to implement appropriate practices in the workplace. In this context, it is important to develop the so-called "soft" skills, including the ability to adapt, critical thinking, teamwork and innovation, which contribute to effective functioning in conditions of constant change.

Among the recommendations, it is also worth highlighting the need for active interaction with professional communities, participation in industry events, internships and projects related to the green economy. This allows not only to obtain relevant knowledge, but also to expand professional contacts and increase one's own mobility in the labor market. In addition, it is advisable for employees to form individual plans for the development of competencies focused on specific "green" professions, taking into account their own experience and potential.

Summarizing the above, it is appropriate to emphasize that the energy transition is a system-forming factor of deep transformations in global and national economies, labor markets and approaches to human capital management, integrating key imperatives of sustainable development, the ESG paradigm and modern climate policy. Its essence goes far beyond purely technological changes in the energy sector, encompassing the structural restructuring of economic systems, changes in production and consumption models, as well as the transformation of social and labor relations. In this context, the energy transition should be considered as a multidimensional process that forms a new economic reality focused on low-carbon development, resource efficiency and innovation.

It is important to emphasize that the implementation of the energy transition entails significant changes in the structure of labor demand, which is manifested in a gradual reduction in employment in traditional energy sectors and a simultaneous increase in demand for specialists in the fields of renewable energy, energy efficiency, digital technologies and environmental management. This leads to the emergence of new professions, transformation of the content of existing activities and strengthening the role of interdisciplinary competencies. As a result, a new professional ecosystem is formed, dominated by intellectually rich, technologically complex and environmentally oriented types of work.

In such conditions, the key factor in ensuring the competitiveness of both employees and organizations is the ability to transform competencies in a timely and effective manner. A modern employee must possess a set of interrelated competencies, including professional (hard skills), flexible (soft skills), digital (digital skills) and environmental (green skills). It is their synergy that ensures the ability to function effectively in a dynamic, uncertain and technologically saturated environment. In this case, such characteristics as adaptability, the ability to continuous learning, critical thinking, innovation and responsibility for the environmental consequences of professional activity become particularly important.

No less important is the realization that the transformation of competencies cannot occur spontaneously or fragmentarily. It requires a systemic approach that covers the individual, organizational and national levels. At the individual level, the employee's desire for self-development, readiness to master new knowledge and change the professional trajectory are decisive. At the organizational level, an effective personnel management system plays a key role, which involves investing in training, developing corporate educational platforms, forming a knowledge culture and supporting innovative activities. At the national level, it is necessary to create a favorable institutional environment that includes a modern education system, state retraining programs, supporting employment and stimulating the development of a "green" economy.

A special role in ensuring effective transformation of competencies is played by the concepts of upskilling and reskilling, which allow both to deepen existing professional knowledge and to master new types of activities in accordance with the needs of the labor market. In combination with the concept of lifelong learning, they form the basis for ensuring flexibility and mobility of the workforce, reducing social risks and maintaining stability in the face of structural changes. At the same time, these approaches contribute to increasing the efficiency of the functioning of organizations, as they ensure the availability of personnel capable of implementing innovations and effectively using modern technologies.

In addition, the transformation of personnel competencies in the context of energy transition has an important social and value dimension. The formation of environmental awareness, a responsible attitude to natural resources and an understanding of global environmental challenges is becoming an integral part of

professional training. This contributes not only to increasing the efficiency of production processes, but also to the formation of a new management culture focused on long-term sustainability and social responsibility.

Thus, the transformation of personnel competencies in the context of energy transition is not just a response to external challenges, but a strategic prerequisite for the formation of a new model of human capital development. It determines the ability of the economy to innovative development, ensures its competitiveness in the global environment and contributes to the achievement of sustainable development goals. In the long term, it is the effective combination of technological change, human capital development and institutional support that will become a key factor in the successful implementation of the energy transition and ensuring environmentally safe and socially oriented development of society.

4. Mechanisms of capitalization of “green” knowledge in corporate governance

In the context of modern financial globalization, the assessment of a company's market value depends less and less on tangible assets and more and more on the ability of management to effectively manage sustainable development risks, where the key indicator of the quality of Green Human Capital (GHC) is non-financial reporting according to ESG (Environmental, Social, Governance) standards. In this scientific context, investments in "green" education of employees are transformed from the category of operating expenses into a strategic asset, which directly correlates with business capitalization through the mechanism of reducing risk premiums.

The environmental component (E) is due to the fact that personnel with competencies in the field of energy efficiency and waste management minimize the likelihood of environmental fines and man-made accidents, which signals to the investor the low volatility of future cash flows.

At the same time, the management component (G) demonstrates that the presence of educational programs in ethical management and sustainable development indicates a high quality of corporate governance, where the transparency of processes, based on the professional knowledge of the staff, significantly reduces agency costs.

The market value of public companies often significantly exceeds the value of their net assets, and this gap, known as goodwill, is largely filled by intellectual capital, where the signaling function of reporting plays a special role: when a company displays data on the number of hours of “green” training per employee and the percentage of certified eco-managers in an ESG report (for example, according to GRI or SASB standards), it sends a signal to the market about the high quality of its green human capital (GHC), which causes an appropriate reaction from investors, as funds focused on socially responsible investment (SRI) include such companies in their portfolios, creating additional demand for shares and stimulating the growth of their exchange value.

The process of converting employee knowledge into market value can be represented as a logical sequence:

1. investment - in expenses for training on decarbonization, circular economy and eco-design,
2. GHC accumulation - with growth of intellectual potential and change of corporate culture,
3. efficiency - in implementing eco-innovations, reducing resource consumption, improving operational performance,
4. reporting (ESG) - in verification of the achieved results by independent auditors,
5. market valuation - with decreasing cost of capital (WACC) and increasing multipliers (P/E, EV/EBITDA).

The transition from qualitative descriptions (“we care about nature”) to quantitative indicators of knowledge capitalization requires the use of specific metrics:

– ROI in eco-education - with half the ratio of resources saved due to employees' ideas to the cost of their training,

– Green Engagement Index - in knowledge flow on staff turnover (highly qualified specialists are more likely to choose companies with a clear eco-mission, which reduces recruitment costs).

ESG reporting has ceased to be a PR tool and has become a mirror of the quality of human capital. Companies that invest in "green" education receive a double effect: direct resource savings internally and higher external valuation. Thus, GHC is not just an ethical choice, but a fundamental financial asset that determines the winners in the competition for capital in the 21st century.

In the system of modern corporate governance, the concept of L&D (Learning and Development) is undergoing a fundamental transformation under the influence of environmental challenges. Green L&D appears not simply as a set of educational programs on ecology, but as a strategic model for the formation of eco-oriented thinking, integrating environmental responsibility into the professional DNA of each employee.

Knowledge capitalization in this context occurs through the creation of an intellectual environment where the ability to ecological reflection becomes part of the qualification.

1. The “70-20-10” model in the mirror of greening. The traditional 70-20-10 learning model (experience, interaction, courses) takes on a specific “green” color:

- 70 % - practical experience (Green Action Learning). Involving employees in real projects on energy audits, reducing carbon footprints, or transitioning to a paperless office. Knowledge is capitalized directly in the process of solving the organization's environmental problems.

- 20 % - social learning (Green Mentoring). Forming communities of eco-ambassadors within the company. Sharing experience between departments on the implementation of sustainable practices creates a knowledge "cross-pollination" effect.

- 10 % - formal education (Green Micro-learning). Distance learning courses, webinars, and certifications (e.g., ISO 14001 or GRI standards) that provide a theoretical basis.

2. The concept of continuous eco-education (Green Lifelong Learning). Developing eco-friendly thinking requires a transition from discrete learning to a continuous cycle. This is achieved through:

- eco-onboarding - with hiring with the company's environmental values from the first day of work.

- gamification of eco-initiatives - using mobile applications to track an employee's individual contribution to the company's environmental sustainability (for example, collecting points for sorting garbage or saving resources), which stimulates curiosity and engagement.

3. Models of thinking transformation: from anthropocentrism to ecocentrism. The key task of Green L&D is to change mental models. We identify three stages of this transformation that should be supported by educational mechanisms:

- cognitive level - understanding environmental facts and risks,

- affective level - development of empathy for nature and a sense of personal responsibility,

- behavioral level - automation of "green" habits in professional activities.

Modern learning platforms allow for the use of adaptive algorithms to personalize eco-education. Using VR simulators to practice scenarios of responding to environmental risks or simulate the product life cycle allows employees to “feel” the consequences of their decisions, which significantly accelerates the capitalization of the acquired experience.

Green L&D is the main mechanism for reproducing “green” human capital. Continuity of learning ensures that eco-oriented thinking becomes not a temporary trend, but a stable characteristic of organizational culture. Capitalization here is manifested in the company's increased adaptability to changes in the regulatory environment and the ability of personnel to generate innovations that meet the requirements of sustainable development.

In modern strategic management theory, an organization's ability to innovate is considered as a function of its intellectual base. However, in the context of energy transition, a specific dependence arises: the implementation of energy-saving technologies (EST) requires not just a general high level of qualification, but the availability of specialized "green" human and structural capital. Knowledge capitalization in this segment occurs through the mechanism of lowering barriers to the adoption of technological innovations and accelerating the diffusion of eco-efficient practices within the company.

The direct connection between the level of "green" capital and the implementation of EOT is based on the phenomenon of "Absorptive Capacity", according to which a company with a high level of eco-knowledge is able to identify and recognize the potential of new energy-saving solutions (for example, heat pumps, recuperation systems or AI-optimization of energy networks) at an early stage, assimilate and integrate these solutions into existing production cycles without destabilizing processes, and commercialize the results obtained, turning saved energy resources into a competitive advantage in the form of lower product costs.

A high level of "green" capital changes the vector of technological development from reactive, which involves only the implementation of environmental regulations, to proactive, aimed at independently finding ways to achieve energy independence, with the human factor playing a key role, where employees with "green" thinking act as initiators of micro-innovations and kaizen proposals, which together provide a significant energy-saving effect, as well as a structural factor, since the presence of energy audit databases and carbon footprint monitoring systems in the company allows making informed decisions about implementing the latest technologies based on accurate calculations of the return on investment (ROI).

Energy-saving technologies are the material embodiment of "green" knowledge. The capitalization process in this chain looks like this:

1. Investment in intelligence -training personnel in lean production methods (Lean Green).
2. Technological implementation -implementation of closed-loop systems or energy-efficient equipment, which was made possible thanks to the competencies of engineers.
3. Financial result -direct reduction in operating costs for energy carriers (OPEX).
4. Market valuation -capitalization of energy efficiency through net profit growth and improved ESG rating, which makes the company more attractive for "green" investments.

One of the main obstacles to energy modernization is the internal resistance of personnel to new, more complex management systems. "Green" capital acts as an antidote to this resistance. When employees understand the environmental and economic logic of energy saving, they become not just users, but co-developers of innovations. This shortens the implementation period of energy saving projects and increases their actual effectiveness.

Thus, "green" capital is a critical catalyst for eco-innovation. The direct correlation between the level of environmental education of personnel and the intensity of the implementation of energy-saving technologies proves: the capitalization of knowledge in modern corporate management occurs not only in the cloud of intellectual assets, but also in the completely physical dimension of saved joules and kilowatt-hours. Energy efficiency is intelligence frozen in metal and software.

The research conducted within this section allows us to formulate a number of conceptually important conclusions that have both theoretical and applied significance for shaping personnel policy in the context of the global energy transition. In the 21st century, green human capital is a fundamental financial asset and the main guarantor of civilization's ability to develop without destroying the biological platform of its own existence. Further research should be directed toward the development of quantitative methods for assessing GHC, the adaptation of educational programs to the requirements of the green economy, and the formation of institutional mechanisms to stimulate eco-oriented behavior at all levels of management.

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ORGANIC PRODUCTION MANAGEMENT IN THE FRAMEWORK OF SUSTAINABLE DEVELOPMENT: SYSTEMIC AND STRATEGIC DIMENSIONS

Kharchenko Tetyana

PhD in Economics, Associate Professor, Associate Professor of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agrarian University, Ukraine

ORCID ID: 0000-0001-8967-4711

At the beginning of the 21st century, the agricultural sector emerges as one of the key components of the global system, upon which socio-economic stability, food security, and the ecological balance of the planet directly depend. Global challenges – climate change, soil degradation, depletion of water resources, population growth, and geopolitical instability – significantly complicate the ability of global agriculture to ensure food provision for all. Under these conditions, food security policy acquires not only economic and social significance but also a strategic dimension, influencing national security, international cooperation, and sustainable development.

The complexity of modern transformations requires a deeper analysis of the interconnections between global processes in the agricultural sector and the mechanisms for shaping effective food security policy. Understanding these relationships forms the basis for developing effective tools for adapting agricultural systems to new realities – ranging from technological innovations and changes in the structure of agricultural production to the formation of institutional coherence among national, regional, and international policies.

The concept of sustainable development is based on the idea of the systemic integration of economic growth, social equity, and environmental balance as interrelated components of societal progress. Its fundamental principle lies in ensuring the satisfaction of the needs of the present generation without compromising the ability of future generations to meet their own needs.

In response to contemporary global challenges, a new vision of agricultural development is being formed, placing the individual, their needs, and their responsibility to future generations at its core. In this context, the sustainable agricultural sector is viewed not merely as an economic system of production but as an integrated model of harmonious interaction between society, nature, and economic activity.

The sustainable agricultural sector is defined as a model of agricultural functioning that combines the efficient use of natural resources, environmentally safe technologies, and socially oriented rural development. Its strategic objective lies not only in ensuring national food security but also in creating decent living conditions for rural populations, preserving the natural environment, and ensuring the long-term sustainability of agricultural production based on the principles of non-exhaustive resource use.

Formation of a sustainable agricultural sector involves the implementation of a set of interrelated directions:

- rational use of natural resources – preservation, restoration, and enhancement of soil fertility, as well as optimization of water and energy use;
- technological modernization – introduction of innovative, resource-efficient, and environmentally oriented production technologies;
- social orientation of development – stimulation of employment, improvement of labor quality, and ensuring sustainable development of rural areas;
- institutional coherence – integration of agricultural policy with environmental, social, and regional state policies.

A sustainable agricultural sector serves as a key element in the implementation of national and global development strategies, particularly in the context of achieving the United Nations Sustainable Development Goals (SDGs), where agricultural production is considered a fundamental factor in ensuring food security and environmental stability.

It is important to emphasize that organic production represents an applied form of implementing sustainable development principles in the agricultural sector and reflects the transition toward an environmentally oriented model of farming. It is based on the rejection of synthetic agrochemicals, pesticides, growth regulators, genetically modified organisms, and other artificial inputs, instead focusing on the use of renewable resources, natural biological processes, and closed-loop production systems.

Such an approach contributes to the restoration of natural soil fertility, conservation of biodiversity, improvement of water quality, and the formation of an environmentally responsible model of food consumption.

Intensive technologies of agricultural production used today have a negative impact not only on the environment, but and deplete natural resources (soil, water, rocks and varieties of plants, reduce biodiversity, etc.). In turn, organic farming methods improve the condition of soils and increase their fertility without the use synthetic chemical poisons. Weed and pest control is made without the use of chemicals, at the same time, land and water resources are preserved from contamination with toxic chemical compounds. Mandatory application of crop rotation, use of seeds and breeds of animals adapted to local conditions ensures biodiversity and promotes restoration and strengthening of the ecological balance (Nehrei, M., Taranenko, A., & Kostenko, I., 2022).

For effective implementation and development organic agriculture requires the development and mastering of modern organic technologies, in the absence of which, manufacturers may face risks and financial problems.

«Organic agriculture, the most prominent alternative farming system in the market place, offers consumers a different option that reflects well the inherent complexity of achieving sustainable agriculture. However, because conventional agriculture is heavily subsidized and market prices do not yet reflect externalities, organic products remain relatively less affordable to consumers» (Eyhorn et al. 2019).

As a first step, we will consider eco-production in the livestock sector. Of course, we will talk about the production of organic milk. It is worth noting that according to the basic principles of organic agriculture maintenance technology cattle (cattle) during production of organic livestock products should be based on the following basic principles:

- housing system - stable and pasture in summer and stall-walking in winter, the stall system is not allowed;
- method of keeping - untethered, in small technological groups, cows - in sections with boxes for rest; young - in sections with boxes or without boxes; tethering of livestock is not allowed.

Natural balance in crop production during organic farming reduces the spread of pests and diseases, reduces negative influence of natural factors of soil degradation. Compliance with the principles in combination with crop rotation can minimize possible reduction of soil fertility even under conditions of intensification agriculture and stabilize agroecosystems (Hlovyn N., & Pavliv O., 2024). Priorities at work agricultural formations to improve productivity should be considered first of all, to increase the use of organic elements at fertilizers of agricultural crops, which form the first one component. As a result, (Semenda, 2018) agricultural producers will be able to to achieve significantly better indicators of the yield of agricultural crops under the condition of reducing the anthropogenic load on the environment. This will contribute to the environmentalization of agriculture production and creation of opportunities for the development of environmentally safe areas of management.

Organic agriculture offers an alternative food system that can increase agricultural productivity, overcome food shortages even in the poorest regions of the world, and ensure social justice and environmental the poorest regions of the world, ensure social justice and preserve the environment (Самойлик Ю. 2020).

According to the UN Food and Agriculture Organisation (FAO), with organic farming growing by 56% in agricultural production by 56% in developing countries, by 2030 it will be possible to fully meet the demand for food in these countries and overcome the effects of climate change (FAO 2019). According to the study, inefficient agricultural practices in developing countries account for 90% of nitrous oxide and 30% of carbon emissions, which is one of the factors contributing to climate change.

Therefore, organic agriculture should provide a fundamentally new vector for the development of the agricultural sector of Ukraine's economy, exceeding the performance of conventional agricultural production in terms of yield, diversification, economic efficiency and employment of the rural population. The Federation of Organic Movement of Ukraine emphasises that these advantages make organic production particularly attractive for small farmers, who otherwise may be at risk of food and financial crisis.

Today, the organic farming in Ukraine should play a fundamentally new role in economic development, reduce poverty and increase self-employment of the rural population, increase economic growth and help Ukrainian farmers enter foreign markets. According to research, the global organic market is showing an upward trend. Currently, the global organic market is worth USD 62.9 billion. Today, the development of organic farming for Ukraine should play a fundamentally new role in the development of the economy, ensure the reduction of poverty and increase the self-employment of the rural population, increase the rate of economic growth and access to foreign markets of Ukrainian farmers. According to research, the market for organic products in the world shows growing trends. Currently, the size of the global organic market is 62.9 billion dollars. In the USA, according to forecasts, in 2020 it can reach 200–250 billion dollars. USA. The annual

growth of the organic market in European countries is approx 10%. In Ukraine, the main areas of organic agricultural land are used for cultivation cereals (wheat, barley, corn) - 197 thousand ha. Oil crops (sunflower and rapeseed) are allocated 67 thousand ha. Areas for the cultivation of organic vegetables exceed 8 thousand hectares, and for organic potatoes 1200 hectares. According to the areas allocated for the cultivation of organic grain. Cherevko (2018) has argued that oil and vegetable crops, as well as organic potatoes, Ukraine is among the TOP-10 producers in the world. In particular, our country ranks seventh in the area of grain crops, fifth in the area of oil crops, ninth in the area of potatoes, tenth in the ranking of producers of vegetable crops.



Figure 1. Organic map of Ukraine

Source: (Agricultural policy monitoring and evaluation – OECD, 2024)

Based on the military actions in Ukraine, and the fact that it is impossible today to clearly determine the area of agricultural land used for organic production, it can be noted that as of December 31, 2021, the occupied area of agricultural land intended for the production of organic products and the transition period was 422,299 hectares, namely 1% of the total area of agricultural lands of Ukraine (picture 1). Thus, the area of agricultural land for the production of organic products was 370,110 hectares, and the area of agricultural land in the transition period was 52,189 hectares. At the same time, the total number of operators in this field as of the researched period was 528, among which 418 were agricultural producers (Негода і Гузь 2023). In recent years, the domestic consumer market has expanded the range of organic products at the expense of large supermarket chains. The main types of products consumed are milk and dairy products, vegetables, fruits and mushrooms, cereals and cereal products, flour, seeds, juices, drinks, pasta, canned goods, eggs, meat products, bakery products, honey, chocolate and tea. According to the National Economic Strategy for the period until 2030, areas with organic status in Ukraine should be at least 3% of the total area of agricultural land, i.e. 1.26 million hectares (Городняк і Петровський 2023).

The clear leader among trading partners for Ukrainian organic products in 2022 is the Netherlands. 101,000 tons of organic products were shipped to the country, which is almost 45% of organic exports of Ukraine. Among the leading countries are Germany (33.1 thousand tons, i.e. 15% of total exports), Austria (27.3 thousand tons, i.e. 12%), Switzerland (17.7 thousand tons, i.e. 8%) and Poland (13.4 thousand tons, i.e. 6%). Among the types of product nomenclature, almost 40% of the total export of organic products was corn (89.6 thousand tons). The leaders of organic export products in 2022 included soybeans (33.7 thousand tons, i.e. 15%), wheat and spelled (24.2 thousand tons, i.e. 11%), sunflower cake (13.2 thousand tons, i.e. 6%) and

sunflower seeds (13 thousand tons, i.e. 6%), sunflower oil (8 thousand tons, i.e. 3.5%). Regarding the transportation of organic products, the majority of such products were exported by road transport (58.6%). 26.8% was exported by sea and river transport, and 14.6% by railway (Міністерство аграрної політики та продовольства України 2024).

The analysis of the legislative and regulatory base of products was carried out of organic origin made it possible to identify three main groups of normative documents (Khimicheva H., & Sokotun Z., 2023).

1. Intergovernmental framework standards: IFOAM Basic Standards IBS); a joint program of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) regarding food standards products (Commission "Codex Alimentarius" - "Codex Alimentarius. Organic food products");

2. Basic standards and EU Resolutions and Regulations: Council Resolution (EU) no 834/2007; Commission Regulation (EU) No. 889/2008; Commission Regulation (EU) No. 1235/2008, Commission Regulation (EC) No. 1254/2008; Commission Regulation (EC) No. 537/2009; Regulations of the Commission (EC) No. 710/2009; Commission Regulation (EU) No. 271/; American National Organic program - NOP (National Organic Program) of the US Department of Agriculture (United States Department of Agriculture – USDA); JAS (Japanese Agricultural Standard) – The Japanese standard for the quality of agricultural products, which includes "special standard" regarding the production and processing of organic products.

3. Private standards of organic production: Demeter, Naturland, Bioland, Ecoland, Biokreis, Ecovin (Germany); Soil Association (Great Britain); Bio Suisse (Switzerland), Bio Austria, Austria Bio Garantie (Austria), KRAV (Sweden), BIOLan (Ukraine) and others (Recchia et al. 2024).

Let's look at the current policy of the incentive mechanism for organic farming. According to the Law of Ukraine (On Basic Principles and Requirements for Organic Production, Circulation and Labelling of Organic Products), «which defines the basic principles and requirements for organic production, circulation and labeling of organic products, the principles of legal regulation of organic production, circulation of organic products and functioning of the organic market products, the legal bases of the activities of the central executive authorities, the subjects of the organic products market, and the directions of the state policy in the specified areas.

Basic principles and directions of state policy in the field of organic production, circulation and labeling of organic products.

The directions of state policy in the field of organic production, circulation and labeling of organic products are:

- ✓ introduction of innovations, energy- and resource-saving technologies;
- ✓ development of competition and improvement of competitiveness of Ukrainian manufacturers in domestic and foreign markets;
- ✓ increasing the volume of exports of organic agricultural products;
- ✓ development of the internal market of organic products;
- ✓ ensuring genetic safety, biological diversity and rational use of natural resources and their reproduction;
- ✓ control over compliance with legislation in the field of organic production, circulation and labeling of organic products;
- ✓ humane treatment of animals by providing living conditions for animals that correspond to their biological, species and individual characteristics;
- ✓ ensuring environmental safety during organic production;
- ✓ creation of a unified system of certification of organic production and/or circulation and state control of organic production, circulation and labeling of organic products;
- ✓ promotion of organic products;
- ✓ scientific support for organic production;
- ✓ establishment of liability for violations of legislation in the field of organic production, circulation and labeling of organic products.

State regulation in the field of organic production, circulation and labeling of organic products is carried out by:

- definition of the general principles of organic production, circulation and labeling of organic products;
- establishment of appropriate legal regulation;

- improvement of state policy in the field of organic production, circulation and labeling of organic products;
- implementation of state control (supervision) in the field of organic production, circulation and labeling of organic products;
- coordination of training and retraining of organic production specialists;
- promoting the development of organic production;
- promoting the development of the internal market of organic products and meeting the needs of consumers in the range of organic products».

In order to increase the level of development of the production of organic products, the Ministry of Agrarian Policy of Ukraine actively participates in the following international projects (Hlovyn N., & Pavliv O., 2024): the Swiss-Ukrainian program "Development of trade with higher added value in the organic and dairy sectors of Ukraine" (QFTP), the project "German-Ukrainian cooperation in the field of Organic Agriculture" (COA), the program "Organic Trade for Development in Eastern Europe" (OT4D), the EU project "Institutional and Political Reform of Small-Scale Agriculture in Ukraine" (IPRSA), the USAID Program for Agrarian and Rural Development (AGRO). Participation in such programs gives Ukraine the opportunity to receive professional support in the development of a legislative and regulatory framework, implementation of laws in the field of organic production, distribution and labeling of organic products, and also provides support in the implementation of various activities related to organic production (Durán-Lara, Valderrama, i Marican 2020).

(Krajewski et al. 2024) emphasize in their work «The need to develop and implement programs to support and finance organic production caused by a group of economic, social and environmental factors reasons. Depending on the geographical coverage of such initiatives have an international, regional, national and local character. The most influential international organization, responsible for the popularization of organic production in the world, there is an International Federation of the Organic Agricultural Movement, whose programs establish general areas the development of the organic sector, in particular the development of innovations, strengthening cooperation, fair trade, etc. At the regional level, there are EU supranational programs that include methods of financial support and stimulation of organic agriculture. In particular, it is "Joint Agrarian policy for 2014–2020." and «The Vision of the European Movement until 2030».

Thus, in view of the above, it is advisable to single out the dominant factors of the formation of the organic sector by 2030 in Ukraine:

Ecological: (Peigné et al. 2016):

- climatic changes (increasing temperature, strengthening of extreme climatic conditions, scarcity of water resources in some regions);
- ecosystem services (degradation, erosion, decrease in soil fertility, loss of pollinators);
- energy resources (weight from the import of energy carriers, production of shelf gas, new source of energy - nuclear fusion reactor);
- land resources (biodiesel production, land acquisition).

Technological:

- biotechnology, nanotechnology and synthetic biology (Niyommaneerat, Suwanteep, i Chavalparit 2023);
- sensor technologies in agriculture, drones and agricultural works;
- digitization and development of information and communication technologies;
- alternative protein food (insects and algae).

Economic:

- corporate consolidation of companies, emergence of new leaders from developing countries;
- vertical and urban farming;
- an economy based on reputation.

Social:

- the aging of the nation, the dominance of individual farms;
- joint consumption (Nekhai V., 2022).

The "Organic Roadmap to Sustainable" was developed by the international European organic movement Food and Farming Systems in Europe), which includes three programs:

1. "Organic on every table": recognition of the advantages of organic production as legislators, and consumers; active promotion of organic farming; ensuring a high level of availability of organic products; more than half are involved in organic farming

European farms.

2. «Improve - Inspire – Deliver» (Improve - Inspire - Deliver): an organic system is sustainable, constantly improving its activities and inspiring change; knowledge, education and training help establish a link between society and agriculture; organic food provides proper and sustainable nutrition.

3. «Fair play - Fair reward» (Fair play - Fair pay): fair distribution of power and value in the entire distribution system; new models of business and communications, contribute establishment of trusting relations between participants; support organic farming and fair pricing.

To create a formation and development system in our country the market of organic agricultural products needs a systematic one an approach supported by all manufacturers and suppliers, local and central authorities, as well as the higher legislative branch of government (Parizad i Bera 2023). Necessary to consider the issue of improving the state policy of stimulation and by developing the production of organic agricultural products creation of a system of state incentives, regulation and control, because without state support for organic production practically impossible. It is important for the successful functioning of the market of organic products not only to produce quality products, but also to carry out a set of activities for its effective implementation. When choosing sales channels for organic products Ukraine can turn to European experience. The main European ones sales channels for organic products are the retail network (70%); direct sales from businesses and sales through markets that provide approximately 15% of sales; sales through specialized stores: bakeries, butchers benches, restaurants and other catering establishments - up to 15%.

According to our beliefs, right now Ukraine, possessing a significant agricultural potential, can become one of the effective competitors in the foreign market. First, the appearance on the domestic market of large specialized enterprises is able to ensure the development of organic production. Secondly, some scientists emphasize that the reduction in the use of chemicals in previous years will allow Ukrainian farmers to shorten the period of transition to organic production from 5-7 years (as in the vast majority of European countries) to 3 years. Thirdly, the main competitive advantage in both domestic and foreign markets is the reduction of production costs. This is possible due to the use of resource-saving technologies and an increase in the quality of products. This will allow the majority of Ukrainian manufacturers to ensure the high competitiveness of their products. This will not only lead to import substitution of food products, but also improve the quality of the natural environment and the quality of life of the population. A significant impetus to the development of the domestic market of organic products should be the formation of a culture of consumption of organic products among ordinary consumers.

In the context of the transformation of Ukraine's agricultural sector and the gradual development of the organic products market, the study of international experience in effective organic production management is gaining particular relevance. Despite its considerable potential, the Ukrainian organic sector faces a number of institutional, economic, and infrastructural constraints that require systematic improvement.

In this regard, it is appropriate to turn to the practices of European Union countries, particularly Germany, which is one of the leaders in the development of organic production and the formation of effective policy in this field. Germany's experience is characterized by a high level of regulatory support, a well-developed certification system, active state support.

The analysis of the German model makes it possible not only to identify the key success factors of the organic sector but also to determine the prospects for adapting effective management instruments within the Ukrainian economy, taking into account its specific features and the challenges of contemporary development.

Both at the EU level and in Germany, the three main objectives of the food strategy are enshrined in law:

- protection of health (only safe food products may be sold);
- protection of consumers from fraud;
- proper public information.

The implementation of Germany's food security strategy has a strong legal framework (German food legislation includes more than 200 regulations, laws and decisions). Germany's strategic priorities on this issue in the pan-European space are to promote the development and implementation of the Common Agricultural Policy of the EU countries, one of the key goals of which is to ensure food security. It can be concluded that in the EU, supranational mechanisms for strategic food security are combined with 334 state regulation by member states and the EU as a whole. Key elements of the mechanism of strategic regulation of food markets in the EU: - introduction of uniform prices across the EU by the EU authorities to stimulate the development of the agricultural sector and optimal location of production; - setting purchase prices at a level lower than in the domestic market to encourage producers to sell food on the market rather than to the state. In the EU

countries (Quiroga et al., 2017), the policy of strategic food security is based on stimulating the development of domestic agriculture with high production costs for food compared to the world market.

The legislative framework of these countries takes into account the import and export capabilities of commodity producers, although the specifics of the mechanism for strategic support for agriculture in each EU country depend significantly on its production and foreign economic conditions (Halkos & Gkampoura, 2021).

According to experts, global organic production has been growing steadily in recent years. The volume of organic sales in 2020 reached USD 60 billion per year. Consumption of organic products per capita, for example, in Switzerland in 2011 was 153 euros. At the same time, out of 96% of revenues from sales of organic products (Székács et al., 2020), 50% were generated in North America and 46% in Europe (Zhang et al., 2022). The United States accounts for 44% of the retail turnover of organic products, the EU countries - 41% (including Germany - 14%, France - 14%). Germany - 14%, France - 8%, the UK - 4%, Italy - 3%), Canada - 4%, Switzerland - 3%, Japan - 2% (European Commission, 2024).

The goals of organic agriculture are: to achieve a closed production process within the enterprise as far as possible. The main principles of organic farming are: rejection of methods of plant protection with the help of chemical or synthetic preparations; rejection of the use of easily soluble mineral fertilisers, removal of organically bound nitrogen, cultivation of leguminosae; stabilisation of humus content; strict adherence to the principles of crop rotation with a variety of crops and predecessors; rejection of the use of chemical and synthetic plant growth regulators; limited livestock breeding, if possible, rejection of the purchase of fodder from third parties.

Typical arguments for organic farming are: protection of soil resources: activation of humus formation processes, increase of biomass (Otari et al., 2024), stimulation of soil biota activity, reduction of soil erosion; protection of water resources, i.e. reduction of nitrate penetration into ground and surface waters; protection of the diversity of non-farm animal and plant species; protection of farm animals (Recchia et al., 2024). According to EU regulations, a very limited number of additional and auxiliary preparations and substances, which are listed in the so-called Positivlisten, are authorised for use in organic production. For example, out of a list of 320 auxiliary agents allowed for use in Germany, only 50 are authorised for bioproduction.

The key provisions of the Act are: mandatory declaration and registration of a company as a bio-enterprise; transfer of control tasks into the hands of private local associations (currently there are 20 such organisations in Germany); penalties for companies - a monetary fine of up to 30,000 euros and a one-year ban on production. According to statistical data, at the end of 2011 in Germany 22506 enterprises were engaged in ecological production on a total area of 1015626 hectares. This represents 7.5 % of the companies and 5.9 % of the area. The size of an average bio-enterprise is about 45 hectares. Almost all organic and bioproduction enterprises operate within associations or societies. In addition to the large, well-known and oldest Bioland and Demeter, many smaller associations have emerged in recent years - Naturland, Biokreis, ECO-VIN-Bundesverband Ökologischer Weinbau, Gäa, Ecoland, Biopark (Brendler, 2020). The laws adopted by the associations of German bioproducers are stricter in some points than the EU laws for organic farming. For example, according to EU laws, a company can partially, not in all of its units, switch to organic production. German law does not allow German companies to make such a partial conversion.

The state support is provided if the company fully switches to bioproduction. In 2022/2023, the Thünen-Institut conducted a comparative analysis of the profitability of organic and conventional enterprises. The study examined 421 bio-based enterprises and 2,246 similarly situated traditional enterprises. It was found that bio-enterprises made an average profit of 30537 euros, while traditional enterprises made 27694 euros, i.e. 2800 euros or 10 % more. The production of environmentally friendly (Misso et al., 2013) products practically does not harm the environment, conserves water, soil and other resources, and makes a significant contribution to solving climate problems. However, the transition to organic farming is a very difficult process. After 12 months, plant-based products can only be marketed as intermediates, but not yet as organic products. Only two years after the transition, products can be marketed as bio or eco. In addition, companies that have chosen this path must still be able to market their products. These are a few arguments in favour of why such enterprises receive special state subsidies. Enterprises are usually financed in a 60:40 ratio (Hackfort, 2023) for example, if a company is located near Kemnica, which is a Saxon state, 60 % of the subsidy is financed by the state and 40 % from the Saxon budget.

Currently, there are 36,535 organic producers in Germany, accounting for 14.3% of all agricultural producers. They cultivate an area of about 1.94 million hectares, which is almost 12% of all agricultural land. At the same time, the increase in organic areas in 2023 was almost 80.4 thousand hectares (+4.3%).

Almost 2/3 of the total area under organic production in Germany is also certified according to private association standards (e.g. Biokreis, Bioland, Demeter, Naturland), which are usually more stringent. The role of the trade associations is very important in increasing sales of organic food, thanks to the close cooperation of these associations with discounters.

For example, thanks to the cooperation between Naturland and ALDI, the latter plans to increase the share of organic products in the chain to 25% by the end of 2024, compared to 15% last year. Lidl and Kaufland have previously announced strategies to expand their organic product range in cooperation with other associations. In 2023, sales in both discounters and speciality organic stores increased, after having lost significantly in 2022. Overall, from 2019 to 2023, sales of organic products in all outlets increased by 31% (Agricultural Policy Monitoring and Evaluation - OECD, 2024).

Consumption of packaged bakery and confectionery products, frozen foods, as well as spreads, delicatessen and chilled delicatessen products was the highest. Consumption of dairy products, which has been growing rapidly for many years, increased by only 15% in 2023. Consumption of organic fresh produce, cheeses and sausages grew by only 6 and 5% respectively.

At the end of 2023, Germany adopted a national strategy to achieve 30% organic agriculture and organic food production by 2030, which should be accompanied by a national campaign to promote organic food. Therefore, we can expect further growth in both production and consumption of organic products.

In the context of the global challenges of food security, health and climate change, the Greenhouses policy to Reduce CO₂ on Roofs in Birstadt, Germany, is an interesting case study.

In our opinion, the policy of organic farming is close to perfect. The main advantage of German farmers is their responsibility to the consumer and their honesty before the law. It is the mentality and attitude of the population that can set a good example of sustainable agriculture and a responsible attitude to global challenges for the whole society. The essence of organic product management lies in the comprehensive regulation of processes related to production, processing, certification, logistics, and marketing of products in accordance with established environmental standards and principles of organic farming. Such an approach involves the integration of environmental, economic, and social dimensions into a unified system of managerial decision-making, ensuring a balance between production efficiency and environmental sustainability. A distinctive feature of organic product management is the high level of regulation and the necessity to comply with both international and national standards covering all stages of the product life cycle. In this context, the certification system plays a crucial role as a mechanism for verifying compliance with organic production requirements and facilitating access to domestic and international markets. At the same time, quality management of organic products requires the implementation of traceability, transparency, and control principles, which help minimize the risks of fraud and enhance consumer trust.

An important direction of management is the development of efficient value chains that encompass all stages—from raw material production to final consumption. Within these chains, a significant role is played by innovative approaches to production organization, process digitalization, logistics optimization, and the development of local markets. This contributes to improving the efficiency of the organic sector and its adaptability to changes in the external environment. At the same time, organic product management is accompanied by a number of challenges, among which high certification costs, limited access to financial resources, the complexity of compliance with standards, and the insufficient development of organic market infrastructure are particularly significant. An additional factor is the need to foster a culture of organic consumption, which requires active informational and educational policies. The management scheme of organic products (Fig. 2) illustrates a systemic model of organic production management within the framework of sustainable development as an integrated, multi-level structure. At the top of the model, the key target benchmarks are defined—economic efficiency, environmental safety, and social responsibility—which shape the strategic directions of the organic sector's functioning.

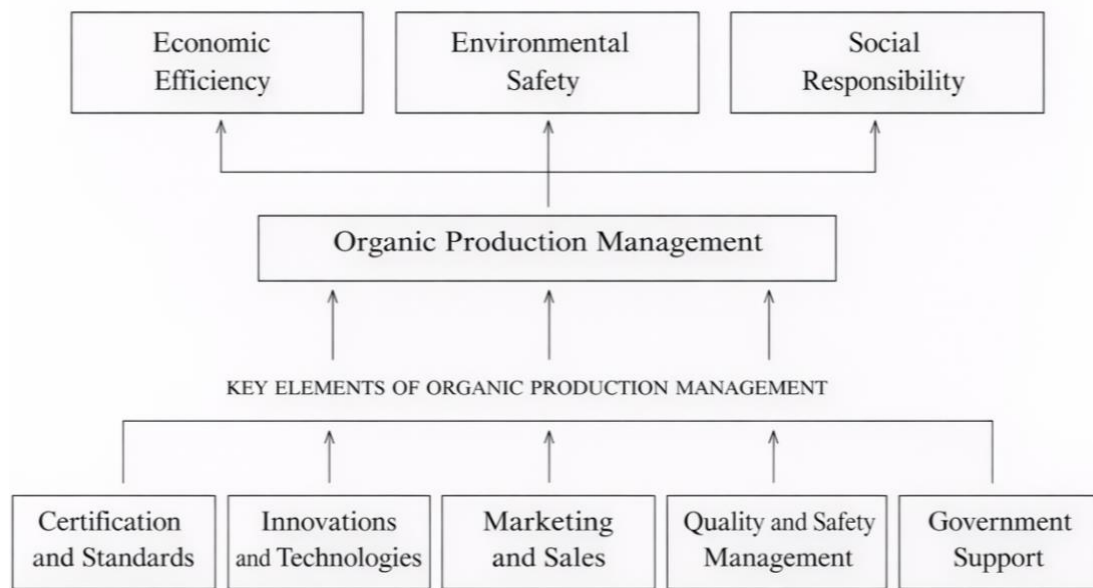


Figure 2. Key Elements of Organic Product Management
Source: Based on the author's own research

The central element is organic production management as the core of the system, ensuring the coordination of all processes and the achievement of defined objectives. The lower level of the model is represented by a set of key management tools, including certification and standards, innovation and technologies, marketing and distribution, quality and safety management, as well as state support.

The key elements of organic product management form an integrated system that ensures the efficiency, quality, and sustainability of the organic sector. These include:

- certification and standards, which ensure compliance with international and national requirements and serve as a tool for building consumer trust;
- innovation and technologies, aimed at implementing resource-efficient and environmentally safe solutions in production processes;
- marketing and sales, which facilitate demand formation, market development, and the promotion of organic products;
- quality and safety management, which ensures control at all stages of production and minimizes the risks of fraud;
- government support, which creates a favorable institutional environment through financial, regulatory, and informational mechanisms.

Organic production, within the contemporary scientific paradigm, is regarded not merely as an alternative model of agricultural practice but as a significant instrument for the implementation of social responsibility toward society. Its essence lies in ensuring a balance between economic efficiency, environmental sustainability, and social equity, which fully aligns with the concept of sustainable development.

From the perspective of social responsibility, organic production is oriented toward meeting societal needs through the provision of safe and high-quality products, the protection of public health, the minimization of environmental impacts, and the rational use of natural resources. The rejection of synthetic agrochemicals, adherence to biodiversity principles, maintenance of soil fertility, and preservation of ecological balance demonstrate the orientation of the organic sector toward long-term societal values rather than short-term profit maximization.

In addition to its environmental dimension, organic production generates significant socio-economic benefits by contributing to rural development, creating employment opportunities, increasing the level of employment, and supporting small and medium-sized producers. Thus, it serves as a factor of social stability and inclusive development.

In this context, organic production can be interpreted as a manifestation of responsible management that integrates the principles of corporate social responsibility into business practices. It shapes a new ethic of interaction among producers, consumers, and society, grounded in transparency, trust, and responsibility toward future generations.

Collectively, these elements ensure the integrated management of organic production and contribute to the achievement of economic, environmental, and social goals of sustainable development. Thus, the scheme demonstrates the interconnection between the strategic goals of sustainable development and the functional mechanisms for their implementation, emphasizing the comprehensive nature of organic production management.

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SCIENTIFIC AND METHODOLOGICAL PRINCIPLES OF FORMING A ROADMAP FOR DIGITALIZATION OF MANAGEMENT IN THE AGRICULTURAL SECTOR

Holub Ivan

Applicant for the third level (PhD) of higher education in the speciality 073 «Management», Sumy National Agrarian University, Ukraine

ORCID ID: 0009-0005-1163-9189

Khromushyna Lyudmyla

Scientific supervisor, PhD in Economic Sciences, Associate Professor, Sumy National Agrarian University, Ukraine

ORCID ID: 0000-0001-9134-9010

In modern conditions, digital transformation of management is an important key factor in increasing the efficiency of business operations, optimizing costs and strengthening its competitiveness. It contributes to the adaptability of enterprises to dynamic changes in the market environment, ensuring flexible, transparent and effective management. In this context, the concept of Management 4.0 is being formed, which combines the latest digital technologies, automation of business processes and modern management approaches (Kravchenko & Salabai, 2023).

Digitalization occupies a central place in modern management, performing a number of important functions; it is a powerful driver of growth, stimulating the development of digital business models both within the core activities of companies and in related areas (Pankratova, 2021). In addition, digitalization allows you to identify new business models and adapt them to changes in the environment, increasing the long-term competitiveness of the enterprise. Another key function is the optimisation of operational processes, which leads to cost reductions, the efficient use of resources and the digitalization of the entire value chain.

Among the main advantages of digitalization of management processes, the following aspects should be noted:

1. Increased productivity through automation of routine tasks and reduction of human intervention.
2. Flexibility and adaptability of management decisions based on the use of Big Data technologies and artificial intelligence.
3. Management transparency, achieved through the implementation of ERP, CRM and other information systems that provide access to up-to-date data in real time.
4. Cost reduction through automation of management and operational processes.
5. Increasing the innovative potential of the enterprise through the use of modern technologies, in particular blockchain, Internet of Things (IoT) and machine learning (Zub & Kalach 2021; Raicheva & Horbanova, 2024).

The concept of Management 4.0 is considered as an innovative approach to management based on digital tools and principles of Industry 4.0. Its characteristic features are:

- automation of business processes through the implementation of ERP, CRM, HRM systems and RPA technologies;
- data-driven decision-making, powered by big data analytics and artificial intelligence algorithms;
- organizational flexibility, which is provided by Agile, Scrum, Lean methodologies, as well as the development of remote work;
- human-centricity and development of digital culture, which involves the formation of digital competencies and «soft» skills of personnel;
- ecosystem management, which consists of interaction based on digital platforms and building partner networks (Khromushyna, 2023).

Digitalization of management and implementation of Management 4.0 principles are fundamental components of the modern business model. They allow enterprises to increase adaptability, efficiency and ability to innovative development.

The Industry 4.0 concept and the active introduction of digital technologies into management activities are leading to new trends in digital management (Derhachova & Koleshnia, 2024). These include:

- development of cloud technology tools for collective documentation management;
- automation of management decision-making in all areas of management;
- implementation of remote access tools that increase employee mobility and engagement;
- integration of industrial IoT technologies into business processes (Hrynko et al., 2022).

Digital transformation is a systemic transformation of the activities of an enterprise or institution, accompanied by the introduction of digital technologies, changes in the business model, organizational structure and culture. At the heart of this concept are not only technological innovations, but also a strategic rethinking of the ways of creating value, interacting with customers, using resources and ensuring management flexibility. The main goal of digital transformation is to form an adaptive, innovative and effective enterprise, capable of quickly responding to the challenges of the external environment (Derhachova & Koleshnia, 2024).

Among the main components of digital transformation, we can distinguish: a digital strategy that forms a vision of change; an organizational culture focused on innovation; data management and analytics that become the basis for decision-making; customer orientation and business process transformation. The technologies most often used in this process are artificial intelligence, machine learning, cloud computing, the IoT, blockchain and robotic process automation (RPA) (Yakovenko et al., 2024).

Implementing digital transformation involves several stages: assessing the digital maturity of the enterprise, developing a digitalization strategy, piloting solutions, scaling and continuous improvement. The effectiveness of this process depends on clear leadership, staff inclusion, the use of Agile approaches and data orientation.

It is also important to distinguish digital transformation from digitalization LLC «Krolevetsky feed mill». While the latter is reduced to the implementation of individual digital tools, digital transformation changes the very logic of the organization's functioning, its strategy and operating models. At the same time, the process of digital transformation faces numerous challenges: resistance to change, insufficient digital literacy of personnel, limited resources, cybersecurity problems and difficulties in integrating new technologies (Oleshko et al., 2022).

In the context of digital transformation research, the TOE (Technology–Organization–Environment) model is of significant methodological value (Holionko & Kondratieva, 2023). This model has gained wide recognition in the field of information technology management and transformation processes, in particular in the study of factors influencing the implementation of innovative solutions in organizations. The TOE model is based on the assumption that the adoption and implementation of technologies in an organization depends on three interrelated contexts: technological, organizational and external environment. It integrates technical, structural-organizational and institutional factors, forming a holistic view of the complex nature of digital transformations.

The technology element encompasses the internal and external technologies available to the organization at the time of the decision. These include the existing IT infrastructure, the level of technological maturity, innovation capabilities, and implementation costs. In digital transformation, this may include technologies such as ERP systems, cloud services, blockchain, AI, etc. The decision to use a particular technology depends on its complexity, relative advantage, and compatibility with existing processes.

The organizational aspect covers the internal characteristics of the enterprise that can affect the adoption of innovations: the size of the organization, the management structure, the development strategy, the level of IT competencies of the staff, the degree of centralization and the corporate culture. The presence of flexible processes, an innovative culture and leadership are critically important for a successful digital transformation.

The external environment context encompasses external factors of influence that an organization cannot fully control, but must take into account. These include competition, the legislative framework, customer requirements, suppliers, industry standards, and government digital policy. In the digital era, the dynamism of the external environment is of particular importance, requiring enterprises to be adaptable and open to change.

Using the TOE model has a number of advantages:

- provides a systematic approach to the analysis of digitalization processes;
- allows you to adapt innovation strategies to the specifics of the industry and organization;
- serves as a theoretical basis for empirical research in the field of technology management;
- used in diagnosing digital maturity and building digital roadmaps.

The TOE model is a universal analytical tool that allows for a comprehensive assessment of an organization's readiness for digital transformation, taking into account both internal and external factors. Its use is appropriate at the stage of strategic planning of digitalization, as well as in the process of monitoring and evaluating the results of the implemented changes (Holionko & Kondratieva, 2023).

In today's environment, characterized by rapid change, technological turbulence, and increasing competition, an organization's ability to adapt is gaining strategic importance. In this regard, the concept of dynamic capabilities, which is considered a determining factor in successful digital transformation. The concept of dynamic capabilities describes the organizational ability to integrate, rebuild and reconfigure internal and external resources in accordance with changes in the environment, which allows organizations not only to respond to changes, but also to actively influence the market, forming new competitive advantages.

Digital transformation requires organizations to be flexible in management, innovative in strategy development, and able to learn quickly based on market feedback (Ciampi et al., 2021). The components of dynamic capabilities are:

- flexibility allows you to quickly change business processes, approaches to customers, and even the business model itself under the influence of new technologies;
- innovativeness provides an opportunity to generate and implement new ideas, including digital solutions that meet the needs of the modern market;
- organizational learning ensures the accumulation and transformation of knowledge necessary for adaptation and improvement (Lokuge & Duan, 2021).

These aspects are critically important in the context of implementing new IT solutions (ERP, CRM, AI, IoT), when changes affect not only the infrastructure, but also the culture, structure, and management practices of the organization.

To develop dynamic capabilities, organizations should form the following management and cultural elements:

- change-oriented leadership that supports digital initiatives and innovation;
- investments in digital competences of personnel, in particular the development of soft skills, analytical thinking and flexibility;
- using digital platforms and data as a basis for strategic decision-making;
- institutionalization of innovations, in particular through the creation of internal incubators, R&D teams and Agile groups (Petrykiva & Malafiiv, 2024).

Organizations with developed dynamic capabilities are able to quickly rethink strategic priorities; adapt products and services; integrate new technologies into operations; and enter new markets.

Thus, an organisation's dynamic capabilities are not merely a means of responding to change, but also a strategic tool for creating new value, making them the cornerstone of successful digital transformation. They form the foundation of digital adaptation and transformation, ensuring that an enterprise is not only technologically flexible but also strategically forward-thinking. In a world where digital change has become a constant feature of business operations, the development of such capabilities is becoming a prerequisite for long-term sustainability and competitive advantage.

Effective implementation of digital technologies in management requires scientifically sound methodological approaches that take into account the specifics of the enterprise, industry and external environment. One of the basic tools is the assessment of the digital maturity of the organization, which allows determining the level of readiness for digital transformation and forming an appropriate digital strategy (Hryshko, 2021).

Digital management is considered as a comprehensive management system focused on the use of digital processes and tools in intra-organizational interaction (Chen, 2023). Particular attention is paid to innovative approaches to personnel management, which include the use of HR analytics, digital recruitment platforms, and automated competency assessment systems.

Methodological approaches to digitalization also include management of innovation activities using system, project and process approaches, which allows optimizing the implementation of digital solutions at the level of the entire organization. In addition, strategic controlling in the context of digitalization allows for feedback and maintaining the effectiveness of change management through digital metrics and KPIs (Dombrowska & Farion, 2024).

An important direction is the design of digital HR systems that combine the functions of strategic and innovative personnel management and create conditions for sustainable development of human capital. Also used are the concepts of design of management technologies focused on the transformation of the organizational structure taking into account digital tools and personnel needs (Khromushyna & Mohylna, 2025).

In general, methodological approaches to digitalization of management are comprehensive in nature and involve the integration of strategic, innovative, project and technological levels of management. Their implementation ensures the transition to flexible digital management structures capable of quickly adapting to external challenges and ensuring sustainable development of the enterprise.

Let us analyze the practical aspects of digital management transformation using the example of LLC «Krolevetsky feed mill» of Sumy region, which is a large agricultural enterprise with an integrated structure that includes crop cultivation, grain trading and elevator capacities. Despite the positive dynamics of asset growth over the past three years, modernization of fixed assets and increase in sales volumes, the enterprise is unprofitable. The main problems are disproportionate growth in costs, high dependence on borrowed capital and low level of solvency. Slow growth in labour productivity and unsatisfactory financial stability necessitate reforms in the field of cost, finance and labour management.

The basis of the digital enterprise management platform is formed by the ERP system (Enterprise Resource Planning), which allows you to integrate all basic business processes: financial planning, accounting, logistics, production management, purchasing, sales, inventory accounting. At LLC «Krolevetsky feed mill», the ERP system provides coordination of the sowing campaign, control over the use of equipment and material resources, and operational analysis of costs and profits (BAS ERP).

To maintain effective communication with clients, particularly in the field of grain trading, a CRM system is used (Customer Relationship Management). It allows you to record and analyze counterparties, create commercial offers, monitor contract execution, automate communication with partners (grain buyers, suppliers of plant protection products, fertilizers, etc.). Using CRM allows you to reduce communication risks and increase customer loyalty.

In conditions of significant document flow (invoices, acts, contracts, invoices, customs documents), the implementation of EDO systems is extremely important. The enterprise under study implemented MEDoc, which reduces the time for document processing, reduces the paper load, ensures the legal significance of digital signatures, and increases the transparency of internal procedures.

GPS monitoring and telemetric of agricultural machinery are also used in production activities in the field of transport operations and the use of agricultural machinery. The use of digital monitoring systems for the machine and tractor fleet allows you to track the location, fuel consumption, load and productivity of tractors, combines, seeders, etc. This optimizes the use of equipment, prevents downtime, improves the quality of agricultural work and reduces costs. The main components of such systems are:

- GPS trackers (GPS bugs), which are installed directly on equipment (tractors, combines, sprayers, trucks, etc.). They collect data on location, speed, and travel route;
- fuel level sensors that are integrated into fuel tanks for precise control of fuel consumption, detection of leaks and refuelling;
- driver (operator) identification sensors, which allow you to track who was driving the equipment at a certain moment and control working hours;
- sensors for the operation of attached equipment, which allow you to monitor when the equipment (for example, a plough, a seed drill, a sprayer) was in working condition and record the amount of work performed;
- monitoring platform (software); a web interface or mobile app that receives all data from trackers and sensors. This is where visualization, analysis, report generation, and notification settings take place.

To manage the elevator infrastructure, a WMS (Warehouse Management System) elevator management system has been implemented. Management System), which allows you to manage grain storage, batch accounting, moisture analysis, clogging, temperature control in silos, and shipment automation. Cloud services and mobile applications are used to access data from any point and organize remote work in the enterprise. Mobile applications for agronomists, machine operators, and managers provide input of primary data directly from the field or machine and tractor fleet, which speeds up the accounting process and reduces errors. Since the enterprise employs a significant number of personnel, an HRM system, in particular BAS Payroll and HR Management is used for effective personnel management, automation of personnel accounting, payroll calculation, work shift planning, and personnel training. It allows you to optimize personnel costs, maintain statistics on vacations, sick leave, certifications, etc.

We will conduct a diagnostics of the digital maturity of the enterprise using the adapted MIT & Capgemini model, which is one of the most famous in the world and was developed by the Center for Digital Business at the Massachusetts Institute of Technology and Capgemini Consulting (global consulting company).

In this model, the level of digital maturity is determined by two main criteria: digital capabilities and leadership capabilities. Digital capabilities are presented:

- customer experience (use of CRM, online services, personalized communications with customers);
- operational processes (ERP, GPS monitoring, electronic document management, production automation);
- business model (new sources of income through digital services, mobile services, integration with partners through platforms);

According to leadership capabilities, digital maturity is assessed through:

- digital vision (availability of a digitalization strategy, support for changes by management);
- culture of innovation (employee readiness for innovation, internal initiatives, development of digital competencies);
- availability of IT infrastructure (cloud services, integrated systems, cybersecurity, mobile access).

The results of the digital maturity diagnostics of LLC «Krolevetsky feed mill» using the MIT & Capgemini model are presented in Table 1.

So, the company is at the initial digital transformation level, digital solutions have already been implemented in the operational sphere, but it needs a systemic digital strategy, personnel development, and business model transformation.

We will also assess the digital maturity of the enterprise according to maturity levels (Table 2).

LLC «Krolevetsky feed mill» according to the scale of Table 2 corresponds to level 3 «Integrated Automation», with a transition to level 4 subject to the implementation of business analytics, digital strategy and personnel training, and in further development to the level of digital leadership.

The digital maturity diagnosis showed that the company has reached an average level of digital integration, is actively implementing IT solutions for management, but has not yet formed a full-fledged digital strategy, does not fully use analytics and needs to develop digital competencies of employees. The next step should be to form a digital transformation roadmap.

Table 1. Results of digital maturity diagnostics of LLC «Krolevetsky feed mill» using the MIT & Capgemini model

Component	Description	Rating (low – medium – high)
Customer experience	Using CRM systems for customer interaction, personalization of communication, electronic order processing	Average
Operational processes	ERP, GPS monitoring, electronic document management, automation of agricultural production and logistics	High
Business model innovation	Using digital platforms for sales, trading, and implementing new digital services	Low
Digital vision	Presence of elements of a digital strategy, management support for digitalization initiatives	Average
Culture of innovation	The level of employees' openness to change, the introduction of innovations, and the digital literacy of staff	Low
IT infrastructure	Cloud services, mobile applications, telemetric, unified information systems	Average

Source: compiled by the author.

Table 2. Results of the digital maturity assessment of LLC «Krolevetsky feed mill» by maturity levels

Level	Name	Characteristic
1	Digital absence	Almost complete lack of digital solutions
2	Fragmentary digitization	There are separate tools: accounting, document management
3	Integrated automation	ERP, CRM, GPS, electronic services
4	Analytical digitalization	BI systems, analytics, digital strategy
5	Digital leadership	Complete transformation of business models, digital culture, digital ecosystems

Source: compiled by the author.

We will determine in which functional areas of management (production, logistics, human resources, finance, marketing) digitalization has already been implemented, and where it is absent or fragmented.

In the field of production management, we assess the state of digitalization at an average level (or partially implemented), since the digitalization of production processes is implemented through GPS-monitoring systems of equipment, fuel accounting, field cultivation control, weather stations, agro-scouting, and precision farming systems. However, management of sown areas, technological maps, and agronomic accounting are often still conducted in a semi-digital format (Excel, local programs), and analytics are fragmented.

At the level of logistics management, truck tracking systems (GPS, telemetric), basic route and cargo accounting, warehouse modules in ERP are used. The planning of logistics chains is not sufficiently automated, there is no end-to-end integration with traders or elevators, and the WMS system for the elevator is partially functioning. Therefore, the state of digitalization of logistics management can be assessed at an average level.

In the field of personnel management, the state of digitalization is fragmented. Timesheets, payroll calculations (in BAS Payroll and HR Management) have been automated, and electronic personnel records are maintained. However, digital modules for personnel adaptation, competency assessment, training, and productivity management have not been implemented.

Since LLC «Krolevetsky feed mill» has been making losses for the last three years, the digitalization of financial management is assessed as fragmented and so far ineffective. The ERP system or accounting software performs only the function of recording transactions, but does not provide strategic financial management. The lack of BI analytics, scenario planning, profitability analysis by crops or areas leads to ineffective decisions. There is no budgeting system with execution control, or it works formally. Financial risks (inflation, seasonality, fluctuations in grain prices) are not compensated by a well-thought-out financial strategy.

In the field of marketing and sales, work with customers is carried out mainly in the form of tables, there are no contacts in CRM or it is not fully functional. Grain sales are organized through personal connections or standard tenders without customer base analytics. Digital communication tools, electronic commercial offers, competitor analysis are absent or used unsystematically. That is, we assess the state of digitalization in the field of marketing as low (or fragmented).

The general state of digitalization in terms of functional areas of management activity is presented in Table 3.

Table 3. Status of digitalization by functional areas of management of LLC «Krolevetsky feed mill»

Functional direction	State of digitalization	Justification
Production	Average	Telemetric, GPS, basic equipment control are used. There is no deep analytics of agricultural production.
Logistics	Average	Transport monitoring has been implemented, but logistics chains are not fully optimized.
Human Resources (HRM)	Fragmentary	Payroll and accounting are automated, but there is no HR analytics and staff development.
Financial management	Fragmented / Ineffective	Despite accounting automation (ERP), analytics, planning, cost and risk management do not work properly, which is confirmed by chronic losses.
Marketing, sales	Low	Lack of CRM, electronic client base, digital promotion, trading analytics.

Source: compiled by the author.

Thus, the most developed areas are production and logistics, where telemetric systems, GPS monitoring, and ERP elements have already been implemented. However, these areas lack end-to-end analytics and data integration, which hinders the improvement of management efficiency. Despite the presence of ERP systems, the lack of strategic financial analytics, cost control, and effective planning has led to long-term losses for the company. This indicates not only weak digital maturity, but also management risks that are not neutralized by digital tools.

The HR function is at a fragmented level, as the implementation of only basic HR solutions (payroll, accounting) without tools for developing competencies, motivation, and staff analytics hinders the formation of an adaptive and innovative corporate culture.

The digitalization of marketing and sales is at a low level: the lack of a CRM system, digital channels of interaction with customers, market analytics, and trading platforms indicates significant losses of potential opportunities in promoting products and building an effective sales system.

The overall level of digital maturity of the enterprise is below average. Although some technologies are implemented, there is no coherent digital strategy, and most functions operate in isolation, without a single information platform and system analytics, which reduces the speed of decision-making, transparency of management, and the enterprise's ability to adapt to market conditions.

So, LLC «Krolevetsky feed mill» is at the stage of integrated automation, having implemented a number of digital solutions in production, logistics and accounting (ERP, GPS, EDM). However, the lack of end-to-end analytics, a full-fledged CRM system, a digital HR and financial strategy limits the effectiveness of management decisions. Financial losses for three years, a low level of digital maturity in marketing and personnel management indicate the need for a comprehensive digital transformation. The enterprise needs to form a single digital strategy, develop business analytics, increase the digital literacy of personnel and integrate digital solutions into all functional areas to achieve sustainable efficiency and competitiveness.

The process of digital transformation in the agricultural sector, despite the active implementation of modern technologies, faces a number of limitations that slow down or complicate the development of digitalization of management processes. For an enterprise that carries out a full production and sales cycle, we classify the restraining factors into groups.

1. Technical factors:

1) outdated material and technical base: the enterprise still uses outdated computers, servers, and equipment without telemetric modules, which makes it impossible to effectively connect to digital systems;

2) lack of high-quality Internet coverage in remote production areas, fields or elevators, which limits the use of cloud solutions and online services;

3) low level of compatibility of existing systems (ERP, accounting, GPS monitoring), which operate autonomously and are not fully integrated with each other.

2. Financial factors:

1) limited funding for digital projects due to the loss-making nature of the enterprise, which makes large-scale implementation of software or modernization of equipment impossible;

2) high cost of implementing complex ERP, CRM, WMS solutions, including their maintenance, updates and licensing;

3) lack of financial support from the state or donor programs, which reduces interest in long-term digital investments.

3. Personnel factors:

1) low level of digital literacy of some personnel, in particular in production units and middle management;

2) employee resistance to change, related to fear of losing their job, reduced influence, or lack of confidence in their own skills.

4. Organizational factors:

1) the lack of a single digital strategy that would define the vision of transformation, priorities, and stages of implementing changes;

2) insufficient level of internal coordination between departments, leading to fragmented implementation of digital tools without proper integration;

3) weak project management, when the implementation of new IT solutions is carried out without clear KPIs, timelines, responsible persons, and risk analysis.

5. Cultural factors:

1) conservative corporate culture, focused on traditional management methods, paper-based document management, and manual reporting;

2) lack of innovative motivation, lack of encouragement for initiatives related to digital change;

3) distrust of digital tools, particularly among the older generation of workers who have no experience working with automated systems.

Table 4 summarizes the factors that hinder the development of digitalization of management at LLC «Krolevetsky feed mill».

The development of digitalization of management at LLC «Krolevetsky feed mill» is constrained by a set of interrelated barriers: technical (infrastructural), financial (lack of investment), human resources (low

digital competence), organizational (lack of strategy), and cultural (resistance to change). Overcoming these barriers requires a systemic approach, strategic vision, staff training, involvement of external resources, and consistent digital leadership from management.

We will identify problems in communication, system integration, and the level of digital literacy of staff, as well as identify risk areas when implementing digital solutions.

Table 4. Main restraining factors of digitalization of management of LLC «Krolevetsky feed mill»

Group of factors	Characteristic
Technical	Insufficient modernity of IT infrastructure, weak Internet coverage in rural areas, low compatibility of existing systems and lack of development telemetric.
Financial	Budget constraints, chronic losses of the enterprise, high cost of licensed programs, maintenance and technical support of digital systems.
Personnel	Insufficient level of digital literacy of staff, resistance to change, low level of motivation for learning.
Organizational	Lack of a digital strategy, fragmented implementation of IT solutions, lack of responsible structures or units for digital transformation.
Cultural	Traditionalism of management approaches, focus on paper processes, low innovation culture, distrust of digital tools on the part of staff.

Source: compiled by the author.

1. Communication problems:

1) lack of a single digital communication platform. Employees of different departments (field, technical, administrative) use disparate means of information exchange (Viber, telephone, e-mail), which leads to data loss or distortion;

2) insufficient transparency of information exchange between management levels. There is information isolation between middle and top management, agronomic services and logistics;

3) lack of clear protocols for transferring digital information (for example, photo reports, equipment tracking, weather data), which reduces the quality of management decisions.

2. Problems with digital systems integration:

1) fragmentation of IT infrastructure: various systems (ERP, GPS monitoring, accounting, fuel accounting, warehouse modules) operate autonomously, without real-time data exchange;

2) lack of end-to-end analytics Data is stored in different formats and cannot be centrally processed in BI systems, which makes effective dashboard analytics impossible;

3) difficulties in connecting new modules. Due to the lack of unified technical standards, the enterprise faces compatibility problems between new digital solutions and the existing system.

3. Low level of digital literacy of staff:

1) difficulties in using new technologies among field and technical personnel. Most machine operators, elevator workers and agronomists have a low level of proficiency in digital tools, which leads to resistance to innovation;

2) lack of training programs. The company does not implement systematic training in digital skills, and training initiatives are limited to briefings when launching a new program;

3) uncertainty in roles and responsibilities for IT processes. Often, IT functions are scattered among several employees without clearly defined areas of responsibility.

Risk areas for further implementation of digital solutions at LLC «Krolevetsky feed mill» are summarized in Table 5.

Table 5. Risk areas when implementing digital solutions at LLC «Krolevetsky feed mill»

Risk zone	Possible consequences
Lack of technical support	Digital system failures, data loss, downtime
Staff resistance	Decreased productivity, conflicts, sabotage of innovations
Incorrect systems integration	Double counting, data inconsistencies, reporting errors
Insufficient training	Using only basic digital tool functions
Financial constraints	Incomplete implementation of solutions, refusal of updates
Lack of a digital strategy	Chaotic actions, loss of focus, duplication of projects
Information insecurity	Risks of data leakage, cyberattacks, lack of backups

Source: compiled by the author.

Thus, for a successful digital transformation of an enterprise, it is necessary not only to implement the latest technologies, but also to ensure a single communication platform, integration of digital systems, development of digital literacy of personnel and risk management. Without overcoming barriers, even the most modern digital solutions may remain ineffective or not fully implemented.

In order to ascertain the current state of digital transformation, identify problem areas and assess the perception of digital change among the management team at LLC «Krolevetsky feed mill», a survey was conducted among managers at various levels

Representatives of the following functional areas were involved in the survey: production, logistics, finance, marketing and HRM (a total of 15 people). The survey results are presented in Table. 6.

Table 6. Generalized results of a survey of the management of LLC «Krolevetsky feed mill» on the state of digital transformation and digital changes, 2025

Question	Key responses from managers
Does your department use digital tools?	ERP – yes, CRM – partially, BI – absent
How integrated are the systems between departments?	Weak integration, each department works autonomously
Does the staff have sufficient digital competences?	Basic level, especially in production and warehousing
What problems arose when implementing the technology?	Resistance to change, lack of training, technical failures
What is the biggest obstacle to digitalization?	Lack of budget and clear strategy
Does management support digital change?	Partially, there is no systemic vision
What areas need digitalization first?	Sales, finance, agricultural planning, analytics

Source: own research.

The survey results show that digitalization in the enterprise is implemented unsystematically: there are separate IT solutions, but there is no coordination between departments, as well as a low level of digital skills of personnel. Managers recognize the need for further transformation, but point to significant barriers.

We believe that at the highest level of management (director, his deputies) with the participation of the chief software specialist, computer systems engineer, a unified digital strategy of the enterprise should be developed and approved; KPIs for digital transformation should be determined and a Digital Development Department should be created. Such management processes provide for financial support in the form of an appropriate budget.

At the functional level of management, in particular financial management, it is advisable to implement BI systems for cost, income, and crop profitability analytics, scenario planning and budgeting. In the field of marketing and sales, it is advisable to ensure the implementation of a fully functional CRM system, online trading platforms, digital customer analytics. In the HRM system, launch modules for competency management, training, personnel assessment, mobile access to HR functions. In the field of logistics, create a single logistics data centre; integrate WMS with ERP and GPS. In production management, it is advisable to introduce agricultural planning, accounting for technological maps, and the use of digital weather stations.

At the technical level of digitalization of the management of LLC «Krolevetsky feed mill», it is necessary to modernize the IT infrastructure (servers, computer equipment, Internet networks); integrate all systems into a single digital platform and implement cloud data storage; ensure a reliable level of information security (backup, cyber protection).

At the level of personnel management, it is necessary to create conditions for systematic training of personnel in digital skills, the formation of a digital culture and motivation for innovation; implement programs for adapting to change.

To promote the digital development of the management of LLC «Krolevetsky feed mill», we offer a version of the digital transformation roadmap for the next three years (Table 7).

Table 7. Roadmap for digital transformation of LLC «Krolevetsky feed mill», 2026–2028

Stage	Period	Main tasks	Expected results
1. Preparatory	1st quarter 2026	Digital strategy approval; appointment of a transformation manager; IT infrastructure assessment; digital budget formation	Organizational readiness for transformation
2. Infrastructure formation	2nd–3rd quarters 2026	Updating equipment; improving Internet connectivity at all locations; establishing a single data «cloud»; ensuring data security	Technical basis for digitalization
3. Systems integration	4th quarter 2026 – 1st quarter 2027	Integration of ERP, CRM, WMS, GPS; automation of accounting and document flow; creation of end-to-end analytics	Unified information system
4. HR and financial transformation	2nd–4th quarters 2027	Implementation of HRM modules; launch of BI system; implementation of budgeting systems	Improving the efficiency of personnel and financial management
5. Marketing and sales	1st–2nd quarters 2028	CRM launch; online interaction with traders; marketing analytics	Digital customer experience and sales
6. Personnel development	Entire period	Conducting training; shaping digital culture; motivating innovation	Digital literacy, engagement, adaptation
7. Evaluation and correction	3rd–4th quarters 2028	Audit of achievements; adjustment of digital strategy; planning for the next cycle	Sustainability and efficiency of digital transformation

Source: suggested by the author.

The map provides for the modernization of IT infrastructure, implementation and integration of key digital systems (ERP, CRM, HRM, BI), development of internal analytics and management competencies. A special emphasis is placed on increasing the digital literacy of personnel and eliminating internal barriers to change. The final phase provides for an audit of the results and adaptation of the strategy taking into account new challenges.

The proposed digital transformation roadmap is a phased action plan aimed at comprehensively updating the enterprise's management processes through the implementation of modern digital technologies in 2026–2028. It covers seven main stages: from preparing the organizational and technical base to the full integration of IT solutions and the formation of a digital culture. Thus, the roadmap is a comprehensive tool for achieving the strategic goal of the enterprise's transition to a sustainable, adaptive and analytically driven digital management model.

It is clear that the implementation of the digital transformation roadmap involves adequate financing and expenditure. In the context of systematic losses observed in the activities of LLC «Krolevetsky feed mill» over the past three years, there is an urgent need to conduct a management audit of financial efficiency. Such an audit is an important tool for identifying internal reserves, shortcomings in accounting, analytical and management subsystems, as well as for formulating practical recommendations for improving the financial condition of the enterprise.

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ADMINISTRATION, ACCOUNTING, REPORTING, AND MONITORING OF VALUE-ADDED TAX SETTLEMENTS WITHIN THE ENTERPRISE MANAGEMENT SYSTEM

Oleksandr Nazarenko

Doctor of economic sciences, Professor, Sumy National Agrarian University, Ukraine

ORCID ID: 0000-0001-7546-174X

Value-added tax (hereinafter VAT) is one of the key revenue-generating taxes in Ukraine and, at the same time, one of the most complex in terms of its administration and accounting treatment. Its evolution—from the classical model of indirect taxation to the modern system featuring elements of electronic administration, automated control, and digital interaction between taxpayers and the state—has led to significant transformations in both tax regulation and accounting methodology. Despite a significant number of academic publications devoted to the economic essence of VAT, issues of its fiscal efficiency, and administration, domestic academic literature lacks a systematic treatment of the comprehensive accounting support for this tax, modern digital tools, and the role of an enterprise's accounting policy as an internal regulator of tax procedures. Under such circumstances, errors in the design of the accounting system or the absence of clearly defined internal VAT accounting rules lead not only to the distortion of financial statements but also to an increase in tax risks, financial penalties, and losses of corporate liquidity. In view of this, there is an objective need for a scientific justification of modern approaches to VAT accounting and their reflection in the company's accounting policy.

The issues surrounding the establishment, development, specific features of accounting treatment, and reflection of VAT in a company's accounting policies occupy a central place in contemporary academic research on the theory and practice of accounting and taxation. These issues are the focus of constant attention from both domestic and foreign scholars, due to the high fiscal significance of VAT, the complexity of its collection mechanism, and the growing role of information technology in tax administration. Scientific publications demonstrate that the effectiveness of the VAT system largely depends on the quality of accounting information, the level of its analytical detail, the timeliness of its preparation, and the accuracy of its presentation in financial and tax reports. Numerous scholars and practitioners have made a significant contribution to the development of theoretical principles and methodological approaches regarding the formation, specific features of accounting support, and the reflection of VAT in the accounting policies of individual enterprises; their works have laid the conceptual foundation for further research in this field: V. Bachynskiy [1], K. Bezverkhyi [2], I. Drozd [4], L. Ebrill [5], M. Keen [5], Y. Kovalenko [6], T. Melikhova [8], T. Melnyk [19], I. Nazarenko [10], H. Nazarova [4], N. Ovcharova [14], V. Plaksienko [15], O. Podolyanchuk [16], M. Shigun [17], and others. Their work focuses on aligning accounting and tax components, developing accounting policies, and documenting VAT accounting processes.

Bachynskiy V. and Pomuleva V. argue for the need for proper regulation and detailed guidelines regarding the accounting treatment of VAT at the national level. This primarily concerns the analytical accounting of this tax, which is linked to the specific nature of certain transactions. Until the relevant unified document is issued, a number of issues require legislative regulation, including the date of accrual of tax liabilities, the tax base, the specification of the procedure for recording offsetting tax liabilities (as part of expenses or initial cost), etc. [1].

Bezverkhyi K. examines the specific features of VAT accounting and reporting in the context of legislative changes. The author analyzes and summarizes amendments to domestic legislation regarding certain aspects of VAT accounting and reporting. The procedure for registering tax invoices in the Unified Register of Tax Invoices is described in detail. The specifics of submitting a request regarding the procedure for registering tax invoices in the Unified Register of Tax Invoices and the procedure for obtaining the corresponding extract are explained. It is argued that a business entity's funds in an electronic account within the VAT electronic administration system should be appropriately reflected in a separate subaccount [2].

Ovcharova N. argues that the effective operation of any business entity is impossible without a thoroughly thought-out accounting policy as a whole and its integral component—tax accounting policy. At the same time, enterprises must formulate their accounting policies in a balanced and thorough manner, taking into account all the specific features of VAT accounting as provided for by current tax legislation. [14].

In his research, Podolyanchuk O. notes that various factors influence the organization of VAT accounting. First and foremost, these include frequent changes in current tax legislation, which can have both positive and negative effects. In the vast majority of cases, these changes concern the organization of analytical

accounting, which is linked to the specific nature of accounting for specific business transactions. Accordingly, the goal of further research should be to clearly justify the methodology for accounting for VAT settlements and to properly regulate specific issues at the legislative level [16].

The Electronic VAT Administration System (EVAS) is a modern tool for state financial control that combines organizational, informational, and technical mechanisms to facilitate transparent, automated VAT accounting. The implementation of this system has become one of the key stages in the reform of tax administration in Ukraine, aimed at minimizing abuses related to the calculation of tax credits and illegal budgetary VAT refunds [10].

In his academic work, Plaksienko V. argues that the introduction of the electronic VAT administration system has led to the emergence of new, specific accounting items that were previously absent in the practices of domestic enterprises. Such objects include, in particular: an electronic VAT account opened with the State Treasury Service of Ukraine (STSU) for each taxpayer, as well as the Treasury's debt to taxpayers arising when the amount of funds transferred to the electronic account exceed the amount of agreed tax liabilities declared for payment. [15].

Research on the internal audit of tax calculations constitutes a distinct field of study. Shygun M. and Ullubieva K. emphasize the fact that, under current economic conditions, value-added tax serves as the primary source of revenue for the state budget (accounting for over 50% of all tax revenues). Consequently, in Ukraine, the development of controls over the accuracy of VAT calculations is primarily focused on improving control measures that will significantly impact the achievement of tax revenue targets. Internal control of VAT calculations can help ensure the completeness of accruals and the timeliness of payments, as well as minimize tax risks and losses and protect the business entity from penalties, which, in turn, will improve the tax compliance of each individual taxpayer. Effective organization of internal control over VAT settlements will allow for a balance of interests between both the state and the taxpayer. However, to achieve such a balance, the availability of adequate internal audit tools for VAT settlements is essential [17].

Yandulska Y. and Melnyk T. note that a comprehensive approach to monitoring VAT payments will help improve the financial condition of individual businesses and minimize the risk of significant violations that could result in financial penalties. The implementation of tax planning methodologies based on a comprehensive approach within the management systems of modern enterprises will reduce tax risk when making management decisions and will have a positive impact on the effectiveness of the further development of individual enterprises [19].

Melikhova T. and Shtepa V. proposed a VAT audit methodology to improve tax planning, which, unlike existing approaches, includes: a questionnaire, a general audit plan, an audit program, and the auditor's working papers. This audit methodology will enable the auditor to: cover all aspects of VAT taxation and accounting at the enterprise; examine the accuracy, timeliness, and legality of VAT accounting entries; promptly identify violations; conduct a high-quality audit; and improve the business entity's tax planning [8].

Drozd I. and Nazarova H. note that, in accordance with the requirements of the Tax Code of Ukraine, all VAT payers, when selling goods, works, or services to customers, must issue tax invoices for the sale amount including VAT in electronic form and must register them in the Unified Register of Tax Invoices (hereinafter the URTI) via the electronic office or using specialized software, such as "M.E.Doc," Art-Zvit Plus, "Accounting Online" from PrivatBank, iFin, and Sonata [4].

The introduction of martial law in Ukraine has led to changes in tax policy, particularly in the area of VAT administration. The problem is that a significant portion of business entities now face limited access to information systems, taxpayers' electronic accounts, and source documentation. This makes it impossible to comply with the deadlines and procedures established by law for determining tax liabilities (TL) and tax credits (TC), leading to violations of tax discipline, financial penalties, and the emergence of tax disputes [10].

Official documents, as amended in 2022–2025 (including the Tax Code of Ukraine, relevant Resolutions of the Cabinet of Ministers of Ukraine, Letters from the State Tax Service of Ukraine, and others). An analysis of scientific sources indicates that despite the existence of a significant body of work in the field of accounting, certain aspects of taxation, and internal audit, the issue of methodological support for the administration of VAT settlements during martial law remains insufficiently explored. Therefore, conducting a systematic study of the specific features of developing the accounting and information components of the administration and internal audit of VAT settlements will help fill this research gap and contribute to the development of practical recommendations for improving tax compliance, ensuring financial transparency, and strengthening the tax security of Ukrainian enterprises.

The purpose of this study is to systematize and critically analyze existing approaches, provide a scientific rationale, and develop practical recommendations for improving the administration, accounting, reporting, and control of value-added tax calculations within the enterprise management system.

VAT plays a leading role in the structure of tax revenues to the Ukrainian budget. The legal basis for its collection is defined in Section V of the Tax Code of Ukraine (Articles 180–211; hereinafter—TCU), which comprehensively regulates the scope of taxpayers, the object and tax base, the procedure for determining tax liabilities and tax credits, as well as the tax administration mechanism. The economic nature of VAT entails a combination of two key functions: a fiscal function, which consists in generating a significant portion of state budget revenues, and a regulatory function, aimed at influencing pricing, consumer demand, investment activity, and the development of specific sectors of the economy. A distinctive feature of this tax is its multi-stage collection mechanism, under which taxation occurs at every stage of the movement of goods, works, and services, while the final tax burden is effectively borne by the end consumer. The implementation of the tax credit principle eliminates the “tax cascade” effect and prevents the double taxation of the same value.

From an accounting perspective, VAT is not recognized as an expense or revenue of the business entity, since the company acts solely as a tax agent of the state, collecting the tax as part of the selling price and remitting it to the budget. In the accounting system, VAT amounts are recorded as current tax liabilities or accounts receivable (the right to a tax credit or budget refund) provided they are directly related to the taxpayer’s economic activity. This approach is consistent with the principle of VAT neutrality. This principle is also enshrined in international tax practice, specifically in Council Directive 2006/112/EC of November 28, 2006, “On the Common System of Value Added Tax” [3], the provisions of which are being gradually implemented into Ukraine’s national tax legislation.

Value-added tax is one of the most important forms of indirect taxation in modern tax systems and a fundamental instrument of fiscal policy in most countries around the world. The development of this tax concept is associated with the name of the French economist and tax inspector Maurice Lauré, who in 1954 justified the feasibility of introducing VAT as an alternative to the turnover tax in order to eliminate the negative “cascade effect” of multiple taxation of goods as they move from the manufacturer to the final consumer [5].

In the second half of the 20th century, VAT became widely adopted in Western European countries and was subsequently implemented in most countries around the world. An important step in its institutionalization was the adoption in 1977 of European Economic Community directives on the harmonization of national consumption tax systems, the provisions of which were codified in Council Directive 2006/112/EC “On the Common System of Value Added Tax” [3]. Today, VAT is applied in more than 160 countries and is considered the dominant model of indirect taxation [13].

In Ukraine, VAT was introduced in 1992 as part of the transformation of the tax system and the transition from a command economy to a market economy. It replaced the turnover tax, which did not comply with the principles of neutrality and economic efficiency. The key characteristics of the national tax model are shown in

Figure

1.

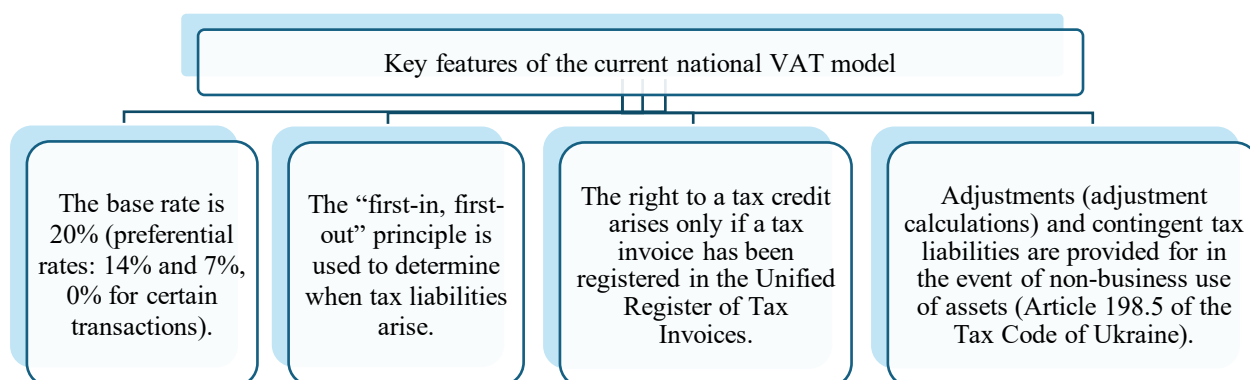


Figure. 1. Key characteristics of the current national VAT model

Source: compiled by the authors based on [6].

In today’s environment of digitized accounting processes, the organization of VAT accounting is characterized by significant variability in methodological approaches, which is due to differences in the scale

of operations of individual business entities, industry-specific characteristics, the structure of business transactions, and the level of development of accounting information systems. The approach to recording VAT in the accounting records of an individual business entity is shaped not only by the requirements of tax legislation but also by the needs of management accounting, internal control, and tax compliance.

The choice of a specific accounting model is directly linked to the existing technical capabilities of the software used by the company to automate its financial and business operations. Modern accounting software products and integrated ERP systems facilitate the implementation of various VAT accounting algorithms—ranging from basic ones focused on generating standardized tax reports to advanced ones that provide detailed analytics by transaction type, tax rates, organizational units, counterparties, and asset utilization categories. From a scientific and practical perspective, the choice of a VAT accounting model should be viewed as a separate component of a company's accounting policy and the result of a trade-off between the costs of tax administration and the required level of reliability, analytical value, and controllability of relevant tax information. Insufficient detail in accounting increases the likelihood of tax errors and financial penalties, while excessive complexity of accounting procedures can lead to higher transaction costs without a proportional increase in the effectiveness of tax control components.

The procedure for accounting for VAT is determined by a set of provisions in tax and financial accounting legislation, with the Tax Code of Ukraine playing a central role. Its provisions establish the rules for recognizing tax liabilities and tax credits, the procedure for adjusting tax amounts, and the mechanism for paying them to the budget. For practicing accountants, the Tax Code of Ukraine serves as the fundamental regulatory framework for organizing VAT accounting and preparing tax returns.

The current provisions of the Tax Code of Ukraine define value-added tax as an indirect tax that is assessed and paid in accordance with the provisions of Section V of the Tax Code. The structure of the components of value-added tax is illustrated in Figure 2.

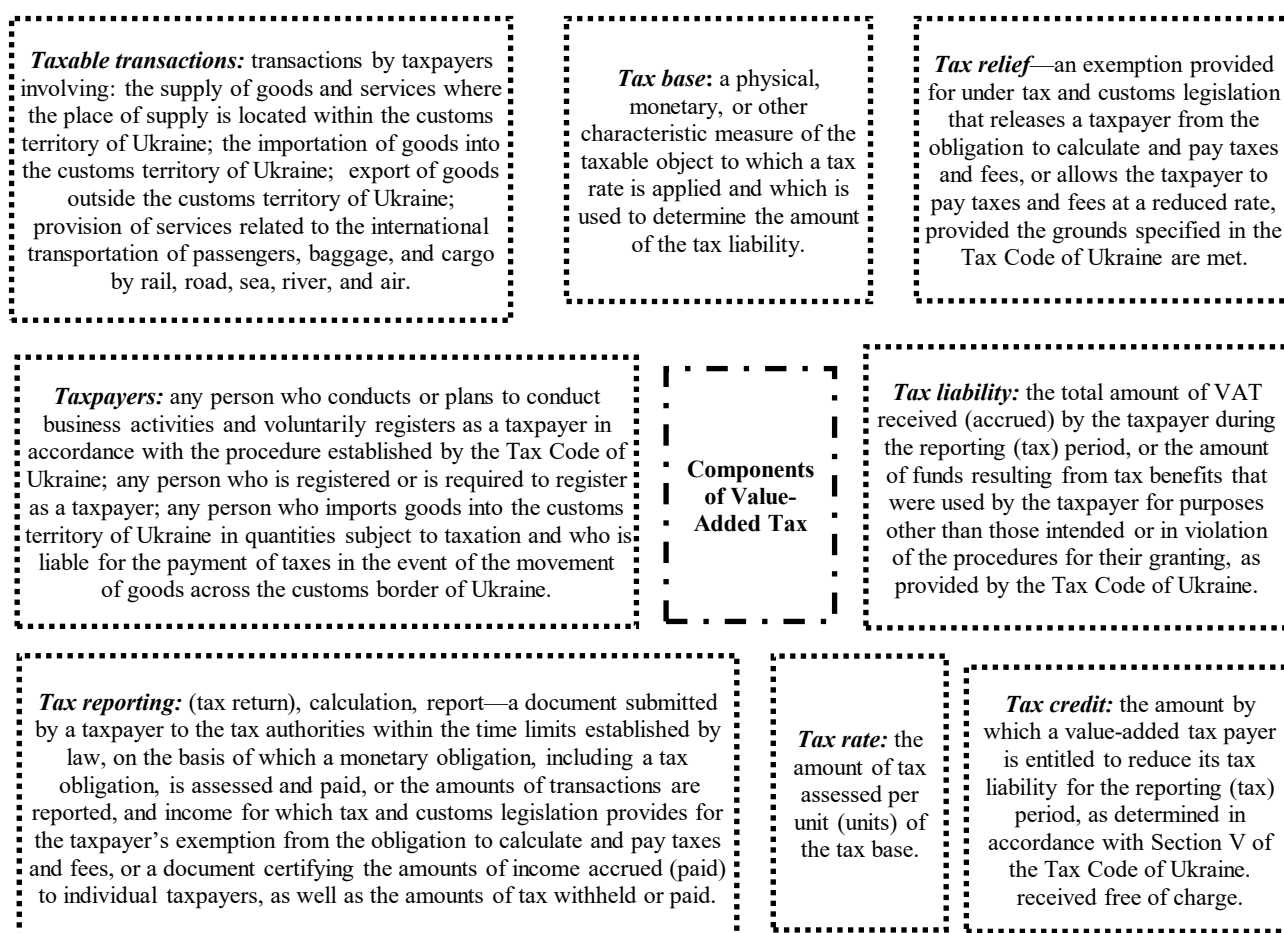


Figure 2. Components of Value-Added Tax
Source: compiled by the authors based on [18]

The Tax Code of Ukraine sets VAT rates as a percentage of the tax base for various business transactions (20%, 14%, 7%, 0%) (Figure 3).



Figure. 3. VAT rates for various business transactions
Source: compiled by the author based on [18]

The VAT tax base for transactions involving the supply of goods or the provision of services is determined, in accordance with paragraph 188.1 of the Tax Code of Ukraine, based on their contractual value,

which includes national taxes and fees. This approach ensures that accounting and tax figures reflect the actual economic conditions of business transactions and contributes to the formation of a reliable tax base.

The legislation provides for a number of exceptions that are not taken into account when determining the tax base. In particular, the following are not included: excise tax on the sale of excisable goods by retail businesses; the mandatory state pension insurance contribution levied on the cost of mobile communication services; VAT amounts, as well as excise tax on ethyl alcohol used for the production of medicines, blood components, and preparations made from them, and others. When determining the tax base, special attention must be paid to transactions for which the Tax Code of Ukraine establishes minimum thresholds. Thus, the tax base cannot be lower than: the purchase price—for goods (services) previously acquired by the enterprise; the normal price—for goods (services) produced in-house; the book (residual) value—for non-current assets being sold, determined based on accounting data as of the beginning of the reporting (tax) period in which the supply takes place.

In accordance with the provisions of the Tax Code of Ukraine, under general circumstances, the supplier's VAT liabilities arise on the date of the first of the following events (Figure 4).

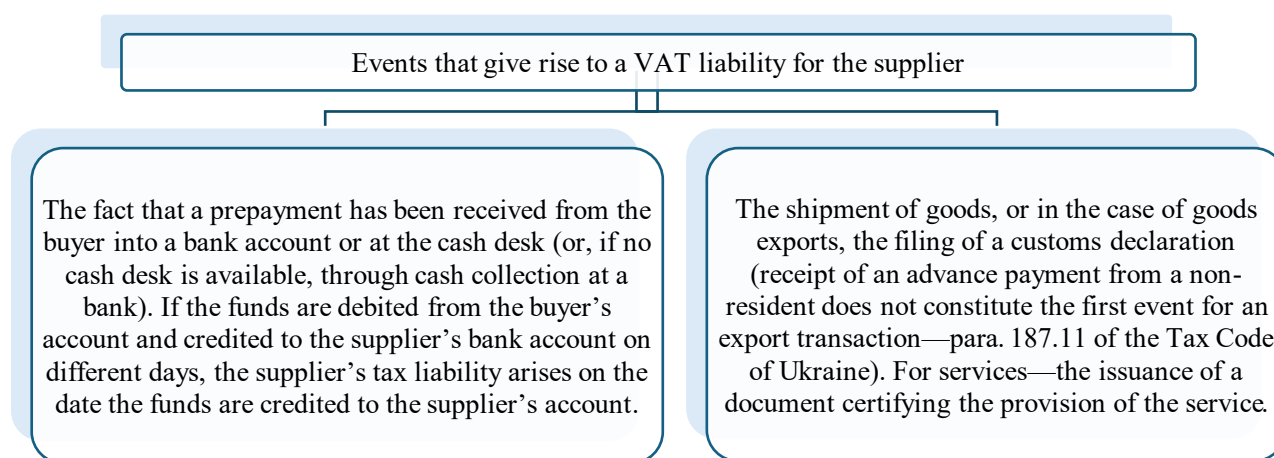


Figure. 4. Events that give rise to a VAT liability for the supplier

Source: summarized by the authors based on [7,18].

The reporting period for preparing and filing a VAT return for all registered taxpayers is the calendar month. The amount of tax liability declared by the taxpayer in the VAT return is payable to the budget within 10 calendar days following the deadline for filing such a return. The Tax Code of Ukraine defines a tax credit as the amount by which a VAT payer is entitled to reduce the tax liability for the reporting period. We will identify the conditions for recognizing the tax credit amount and the date of its recognition. Article 198 of the Tax Code of Ukraine sets forth the rules for the entitlement to a VAT tax credit (Figure 5).

In accordance with the provisions of the Tax Code of Ukraine, a tax credit is recognized regardless of the actual use of purchased goods, materials, works, services, or fixed assets within the scope of taxable transactions during the reporting period, and regardless of whether the taxpayer carried out such transactions during that period. This approach is consistent with the accrual principle established in the accounting system and ensures the continuity of the VAT payer's tax credit accrual.

The main condition for recognizing tax credit amounts is the existence of a tax invoice duly registered in the Unified Register of Tax Invoices (URTI). Registration of such an invoice confirms the payer's right to include the corresponding VAT amounts in the tax credit, regardless of when the goods or services are actually used in their own business activities. In the case of importing goods into the customs territory of Ukraine, the right to a tax credit arises on the basis of a customs declaration confirming the payment of VAT to the budget.

This applies to both primary and temporary, supplementary, and other types of customs declarations prepared in accordance with the requirements of customs legislation. In addition, the Tax Code of Ukraine specifies a list of documents that may serve as a basis for claiming a tax credit without a tax invoice. Such documents include:

✓ transportation tickets, hotel bills, bills for telecommunications or other services (the cost of which was determined based on meter readings) that include the total payment amount, the tax amount, and the supplier's tax identification number (except for international-standard documents);

✓ cash register receipts that include the amount of goods or services received, the total VAT amount, as well as the supplier's fiscal and tax numbers. However, the total amount of such transactions may not exceed 200 hryvnias (excluding VAT) per day [18].

The purchase or production of goods and services.	Receipt of services provided by a non-resident within the customs territory of Ukraine, and in cases where the place of supply of the services is the customs territory of Ukraine.
Amounts eligible for a VAT tax credit:	
The acquisition (creation) of non-current assets (including in connection with the acquisition or importation of such assets as a contribution to the authorized capital, or upon the transfer of such assets to the balance sheet of a taxpayer authorized to maintain records of the results of joint activities).	The importation of goods or non-current assets into the customs territory of Ukraine (including non-current assets under operating or finance lease agreements).

Figure. 5. Amounts eligible for a VAT tax credit
Source: compiled by the authors based on [18].

The date on which the actual right to a tax credit arises is determined according to the “earlier of” rule, i.e., it is the earlier of the following dates: the date on which funds are debited from the taxpayer's bank account to pay for materials, goods, work, or services; or the date on which the taxpayer receives the relevant materials, goods, work, or services. At the same time, the date of the tax credit's formation directly depends on the timing of the tax invoice's registration. If the tax invoice is registered on time, the right to a tax credit arises in the period of its issuance. In the event of late registration, the right to a tax credit arises no earlier than the reporting period in which the actual registration of the invoice in the Unified Register of Tax Invoices (URTI) took place. In accordance with the requirements of the Tax Code of Ukraine, the obligation to prepare and register a tax invoice for transactions involving the supply of goods or the provision of services rests with the VAT payer—the seller. It is the seller who is responsible for the correct preparation of tax invoices, their timely entry into the Unified Register of Tax Invoices (URTI), and the consistency of the invoices' content with the data in the primary accounting documents. Failure to fulfill this obligation gives rise to financial liability and may result in the buyer losing the right to a tax credit. Under martial law, the legislature has established temporary (special) deadlines for the registration of tax invoices and adjustment calculations, which differ from the general deadlines set forth in Section 201.10 of the Tax Code of Ukraine. For clarity, Table 1 provides a comparative overview of the regular and temporary (martial law) deadlines for registering tax invoices and adjustment calculations.

Table 1. Deadlines for filing VAT invoices (VAT adjustment calculations)

Period for issuing tax invoices/credit notes	from the 1st to the 15th of the month (inclusive)	from the 16th to the last day of the month (inclusive)
Temporary registration deadlines in accordance with paragraph 89 of subsection 2 of Section XX of the Tax Code of Ukraine (applicable only during the period of martial law and for 6 months following its termination)	by the 5th day of the month following the month in which the tax invoice was issued	by the 18th day of the month following the month in which the tax invoice was issued
Permanent registration deadlines in accordance with Section 201.10 of the Tax Code of Ukraine (which were previously in effect and will be reinstated six months after the end of martial law)	by the last day (inclusive) of the month in which they were prepared	by the 15th (inclusive) of the month following the month in which they were prepared

Source: compiled by the authors based on [18].

In the VAT system, the correct and timely preparation and registration of adjustment calculations (ACs) for tax invoices are of particular importance, as these documents ensure consistency between the underlying transactions and their tax implications. In accordance with the provisions of paragraph 201.10 of the Tax Code of Ukraine, the procedure for registering an AC depends on the nature of the adjustment (increase or decrease in tax liabilities) and the party making it. If the supplier issues a decreasing adjustment calculation, the obligation to register it falls on the buyer. The exact moment of registration of such a document determines the date from which the adjustment will affect the tax figures of both parties to the transaction. During the period of martial law, the legislation has introduced temporary (extended) deadlines for the registration of decreasing adjustment calculations—within 18 calendar days from the date of their receipt by the buyer. After the end of martial law and the transition period, the registration deadline reverts to 15 calendar days, in accordance with the general peacetime rules. Separate deadlines apply to compensatory and consolidated tax invoices, as well as adjustment calculations related to them. For such documents, registration must be completed within 20 calendar days following the last calendar day of the month in which they were issued.

The Electronic VAT Administration System (EVAS) is a modern tool for state financial control that combines organizational, informational, and technical mechanisms to facilitate transparent, automated VAT accounting. The implementation of this system has become one of the key stages in the reform of tax administration in Ukraine, aimed at minimizing abuses related to the calculation of tax credits and illegal budgetary VAT refunds. The main purpose of creating the VAT Electronic Administration System is to ensure transparency in the movement of tax amounts, improve taxpayers' compliance, and minimize the human factor in administrative processes. Pursuant to Article 200¹ of the Tax Code of Ukraine and the Procedure for Electronic VAT Administration, approved by Resolution of the Cabinet of Ministers of Ukraine No. 569 dated October 16, 2014, the VAT Electronic Administration System provides automated tracking for each VAT payer of the following indicators:

- ✓ tax amounts specified in registered (issued and received) tax invoices and correction calculations in the Unified Register of Tax Invoices;
- ✓ tax amounts paid upon importation of goods into the customs territory of Ukraine;
- ✓ amounts of replenishment and balances of funds in taxpayers' electronic accounts in the VAT EAS;
- ✓ tax amounts for which the taxpayer is entitled to register tax invoices and credit notes in the Unified Register of Tax Invoices (the so-called "registration limit").

A special electronic account is automatically opened for each VAT payer in the VAT Electronic Administration System (SEA VAT), which is intended exclusively for settlements with the budget. Timely funding of this account will ensure the ability to register tax invoices and pay agreed-upon tax liabilities. An important element of the system is the automatic control over the registration of tax invoices and correction calculations. All documents are verified online for authenticity, compliance with the format, and the availability of the registration limit. Within the framework of the VAT SEA, special attention is paid to calculating the registration limit ($\sum \text{Invoices}$)—a conditional (virtually calculated) indicator that determines the amount of VAT for which the taxpayer is entitled to register tax invoices and adjustment calculations in the Unified Register of Tax Invoices. The formula for calculating this indicator is shown in Figure 6.

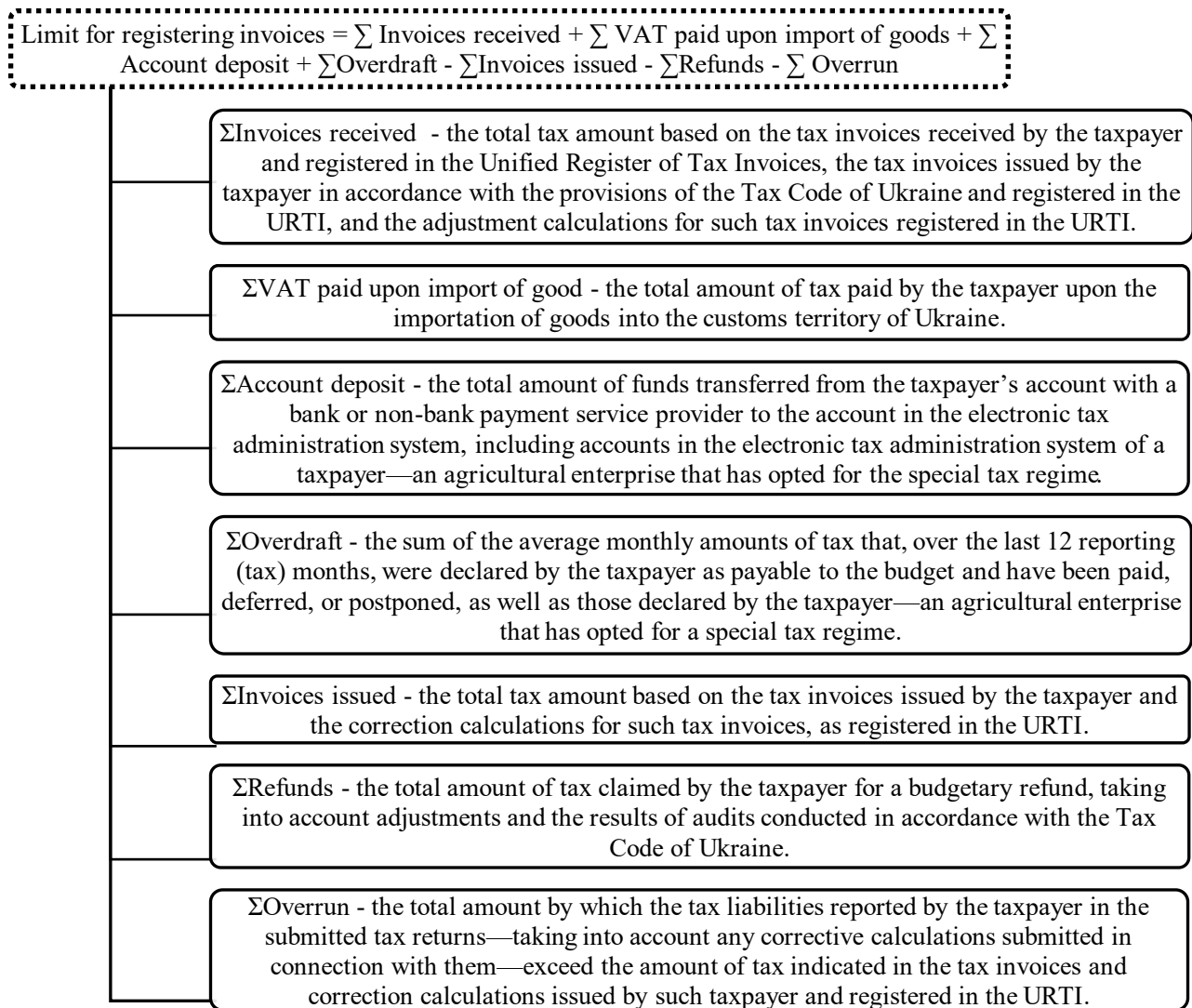


Figure. 6. Formula for calculating the limit within which a taxpayer is entitled to register tax invoices or adjustment calculations in the Unified Register of Tax Invoices ($\sum$ Limit for registering invoices)
Source: summarized by the authors based on [18].

The formula for calculating the registration limit includes a number of indicators, each of which affects the final value in a different way—some increase the available limit for registering tax invoices (correction calculations), while others, conversely, decrease it. Accordingly, the registration limit ($\sum$ Limit for registering invoices) is not a real monetary amount, but a calculated indicator generated automatically in the information system based on data regarding the business transactions of an individual VAT payer. To facilitate control over their own tax indicators, each VAT payer has the opportunity to obtain information about the status of their registration limit in electronic form. To this end, a request is submitted using Form F/J1301206, after which the tax authority generates an extract from the VAT Electronic Administration System using Form F/J1401206. This extract contains detailed data regarding: the balance of funds in the electronic account; the current values of the calculation indicators for the limit formula; the amount of tax for which this taxpayer is entitled to register tax invoices; the amount of account replenishment and tax paid upon importation of goods (works, services).

At the same time, the methodology for recording VAT transactions in the chart of accounts is governed by the provisions of the Instructions on the Application of the Chart of Accounts for the Accounting of Assets, Capital, Liabilities, and Business Transactions of Enterprises and Organizations, approved by Order of the Ministry of Finance of Ukraine No. 291 dated November 30, 1999 [9]. In accordance with the aforementioned

regulatory document, VAT amounts are accounted for using the following subaccounts: 641 “Tax Settlements”; 643 “Tax Liabilities”; 644 “Tax Credit”; 315 “Special Accounts in National Currency.”

Subaccount 641 is used to summarize information on an individual enterprise’s settlements with the budget for all types of taxes and fees, which makes it advisable to break it down in analytical accounting. From a practical standpoint, it is reasonable to open separate analytical accounts for value-added tax (for example, 641.1 “VAT Settlements,” 641.2 “Income Tax Settlements,” 641.5 “Other Taxes”. Subaccounts 643 “Tax Liabilities” and 644 “Tax Credit” serve to temporarily accumulate information on existing VAT amounts subject to payment to the budget or refund (offset) as part of the tax credit. Their use allows for the differentiation of tax figures based on the timing of tax consequences and ensures control over the correct preparation of the VAT tax return.

Business entities independently establish their own accounting policies based on the National Accounting Standards (NAS) or International Financial Reporting Standards (IFRS), as well as other regulatory and legal acts in the field of accounting. The enterprise is responsible not only for determining the methods of valuation and recognition of accounting items but also for establishing the procedure for analytical and synthetic accounting, including the possibility of introducing additional subaccounts. It is advisable to codify the procedure for implementing new subaccounts and specific rules for their application in the accounting policies of individual business entities, which will ensure consistency in accounting methodology, internal consistency of information, and enhance the reliability of accounting data in the event of tax audits or financial audits.

In the practice of value-added tax accounting, it is quite common for business transactions or accounting events not to be supported by source documents in the traditional sense (such as delivery notes, work completion certificates, tax invoices, etc.), yet they must still be recorded in the accounting system. This applies, in particular, to cases of internal settlements, tax credit reallocation, accrual of offsetting tax liabilities, correction of errors, annual recalculation of the proportion of goods/services used in taxable transactions, and other adjustment procedures. In such circumstances, the appropriate instrument for documentation is an accounting certificate, a type of primary document prepared by the enterprise itself. The legal grounds for its use are defined by Article 9 of the Law of Ukraine “On Accounting and Financial Reporting in Ukraine” dated July 16, 1999, No. 996-XIV, according to which the basis for accounting for business transactions is primary documents containing mandatory details and recording the fact of the transaction. Typical cases of using an accounting certificate when performing VAT accounting operations are summarized in Figure 7.

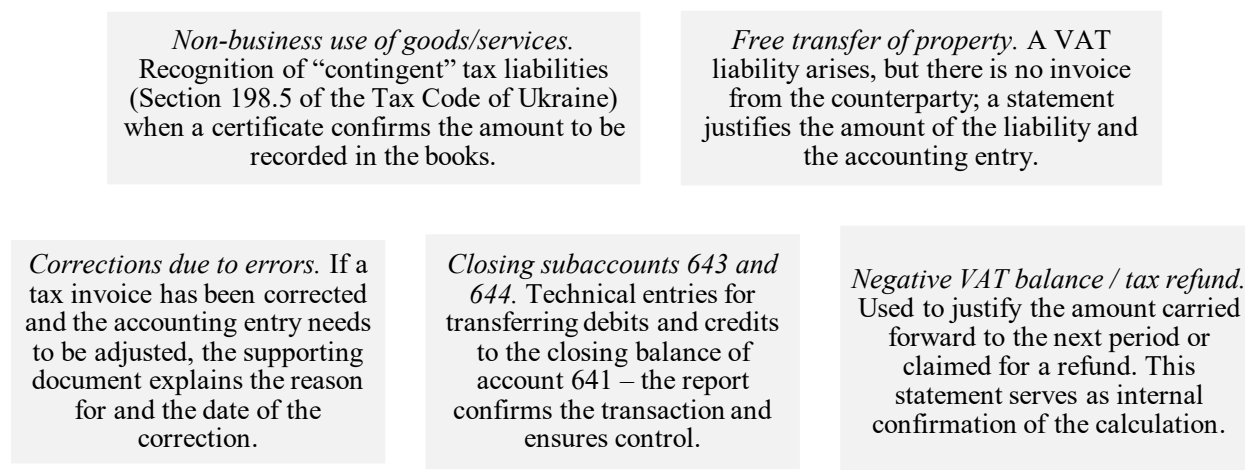


Figure. 7. Typical cases of using an accounting reference when performing VAT accounting transactions
Source: summarized by the author based on [6,18].

In the practice of VAT accounting, an accounting note serves as an important internal source document used to properly document transactions that are not always supported by separate source documents or that require additional calculations and justifications. In such situations, an accounting note serves as a tool for the accountant’s professional judgment, allowing for the formalization of calculations, the recording of the basis and algorithm for determining amounts, and ensuring logical consistency between the financial and tax components of accounting. The need to prepare accounting notes in VAT accounting is illustrated in Figure 8.

<i>Documentary evidence of a business transaction.</i> In the event of a tax audit, an accounting statement serves as valid proof of the legitimacy of entries made in the accounting records. It includes calculations, references to regulatory provisions, and an explanation of the economic substance of the transaction, thereby minimizing the risk of additional tax assessments.	<i>Ensuring the transparency and soundness of accounting decisions.</i> The supporting documentation demonstrates the logic behind the accountant's professional judgment, identifies the sources of the figures, and explains the methods used to calculate them. This enhances the quality of internal controls and promotes the clarity of accounting information for management, auditors, and regulatory authorities.
The Need to Prepare Accounting Documents for VAT Accounting:	
<i>Strengthening the control function of accounting.</i> The systematic preparation of accounting reports helps prevent the accumulation of "unresolved" or economically unjustified balances in subaccounts 643 and 644, enables the timely detection of errors, and ensures the accuracy of VAT analytical accounting.	<i>Legal protection for businesses.</i> An accounting statement serves as a primary document provided that it complies with the established requirements for its preparation. It has evidentiary value in administrative and judicial disputes, confirming the taxpayer's good faith and the proper organization of the accounting process.

Figure. 8. *The need to prepare accounting reports for VAT accounting support*
Source: summarized by the author based on [6,18].

Analytical accounting for value-added tax is maintained by each subaccount and individual accounting objects (counterparties, contracts, tax invoices, adjustment calculations, etc.), for example, in the format "641.1 VAT by Suppliers." This approach helps ensure the ability to identify the source of each tax credit or tax liability, establish a link between accounting entries and the corresponding source documents, and verify the fact and timing of tax invoice registration in the URTI. From a methodological standpoint, analytical accounting performs explanatory and control functions, answering the question "where does the amount come from," while synthetic accounting summarizes the available information in a condensed form to generate financial and tax reporting indicators. The interaction between the analytical and synthetic levels of accounting is a necessary prerequisite for ensuring the accuracy of tax calculations and minimizing the risk of errors when preparing VAT returns.

To optimize the informative value of accounting and strengthen internal tax control, it is advisable to implement a detailed breakdown of additional subaccounts for tax liabilities and tax credits, specifically within accounts 643 "Tax Liabilities" and 644 "Tax Credits" (Figure 9). Such a breakdown should be appropriately reflected in the accounting policies of the individual business entity [11].

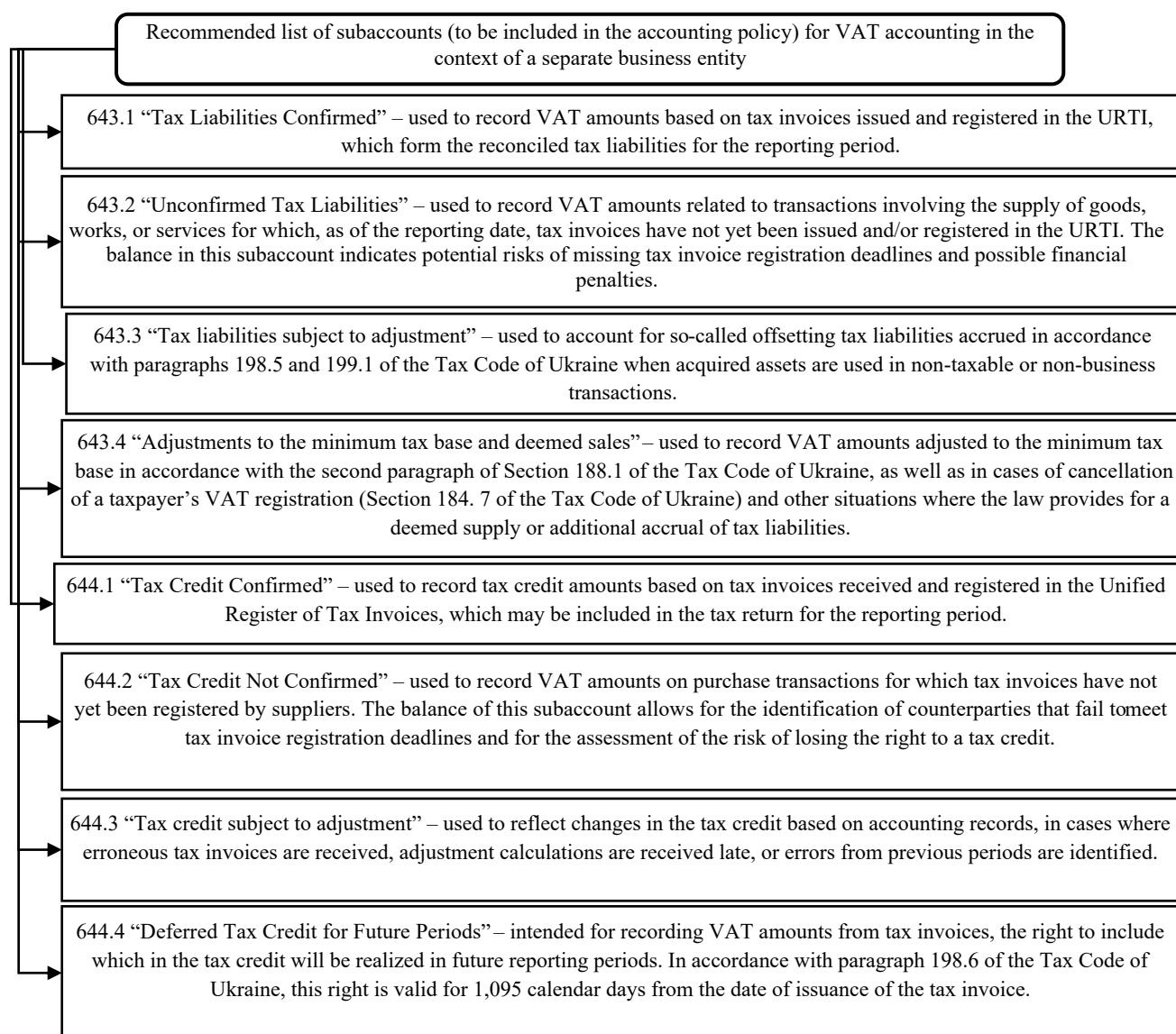


Figure. 9. Recommended list of subaccounts (as reflected in the accounting policy) for VAT accounting in the context of a separate business entity's operations
Source: compiled by the author based on [6,9,18]

The implementation of this system of synthetic and analytical accounts will enable the creation of a structured database tracking VAT transactions, ensure transparency in tax calculations, improve the quality of internal controls, and reduce the likelihood of tax disputes with regulatory authorities.

Subaccount 315, "Special Accounts in National Currency," has taken on particular scientific and practical significance; it was introduced into accounting practice in connection with the implementation of the Electronic VAT Administration System (EVAS). This account records funds held in the electronic VAT account opened by the State Treasury Service of Ukraine for each taxpayer. The economic essence of this account lies in the segregation of funds intended exclusively for settlements with the budget regarding value-added tax, which limits the possibility of their alternative use in the operational activities of an individual business entity. The introduction of electronic VAT administration has significantly transformed both the mechanism of tax control and the methodology of accounting for relevant transactions. As a result, account 315 has become a key element of the tax compliance system, ensuring the interconnection between accounting, tax reporting, and cash flows within the VAT Electronic Administration System. Accordingly, the organization of VAT accounting in Ukraine is based on a combination of current tax legislation, IFRS National Accounting Standards, and the Chart of Accounts. Subaccount 315 is intended exclusively for recording funds in the

electronic VAT account and is not used for direct control of the registered VAT amount. The main transactions on the electronic VAT account are shown in Table 2.

Table 2. Movement of Funds in the Electronic VAT Administration System

№	Operation	Debit	Loan
1	Funds have been transferred from the checking account to the electronic VAT account	315	311
2	The agreed amount of tax liabilities has been debited from the electronic VAT account	641.1	315
3	Funds have been returned to the current account from the electronic VAT account (budget refund or overpayment)	311	315

Source: compiled by the authors based on [9].

Figure 10 illustrates the accounting treatment of input VAT by an individual business entity.

As with the calculation of tax credits, analytical subaccount 643.2, “Unconfirmed Tax Liabilities,” is used to record VAT amounts that have not yet been confirmed by tax invoices registered in the URTI. Figure 11 illustrates the accounting treatment of typical VAT tax liabilities for a separate business entity.

At the same time, compliance with the requirements regarding the minimum tax base is of key importance in the context of VAT taxation. According to paragraph 188.1 of the Tax Code of Ukraine, the tax base for transactions involving the supply of goods and services cannot be lower than: the purchase price—for purchased goods and services; the normal price—for self-produced goods; or the book (residual) value—for non-current assets [18]. Thus, when recognizing revenue and calculating VAT liabilities, the accountant is required to perform a comparative analysis of the contract price against the established minimum tax base. If the contract value is lower than the minimum tax base specified by the Tax Code, there is an obligation to adjust VAT liabilities upward. From an accounting perspective, such amounts must be recorded as part of the company’s expenses. If the adjustment is not related to transactions involving non-current assets, subaccount 949 “Other Operating Expenses” is used. However, in cases where the additional assessment relates to the supply or disposal of non-current assets, subaccount 977 “Other operating expenses” is used.

The procedure for calculating the VAT tax credit is of particular importance. According to paragraph 198.3 of the Tax Code of Ukraine, the amount of “input” tax paid or accrued as part of the cost of purchased goods, works, services, or non-current assets is included in the tax credit in full, regardless of the nature of their subsequent use—whether in economic activities, in transactions exempt from taxation, or in those not subject to VAT. At the same time, if assets acquired subject to VAT are intended for subsequent use in non-business activities or in non-taxable transactions, the taxpayer is required to recognize offsetting tax liabilities, a concept referred to in economic literature and practice as a “conditional sale” (para. 198.5 of the Tax Code of Ukraine). The timing of such liabilities depends on the nature of the assets’ use: upon initial acquisition for non-taxable transactions—on the date of acquisition; upon a change in use from taxable to non-taxable—on the date of the actual commencement of such use. All amounts of “input” VAT are initially reflected as part of the tax credit. However, in the case of partial use of goods, services, or non-current assets in taxable and non-taxable transactions, the enterprise is required to accrue tax liabilities in proportion to the share of non-taxable use. This mechanism is designed to ensure compliance with the principle of VAT neutrality and prevent unjustified tax credits. The final step is an annual recalculation of the proportion of asset usage in taxable transactions, based on the results of which previously accrued tax liabilities or tax credits are adjusted. This adjustment is formalized by preparing and registering the corresponding adjustment calculation in the URTI in accordance with the requirements of paragraph 199.4 of the Tax Code of Ukraine. This ensures the reconciliation of data between the accounting and tax components of record-keeping and enhances the reliability of the figures in the company’s relevant reporting forms.

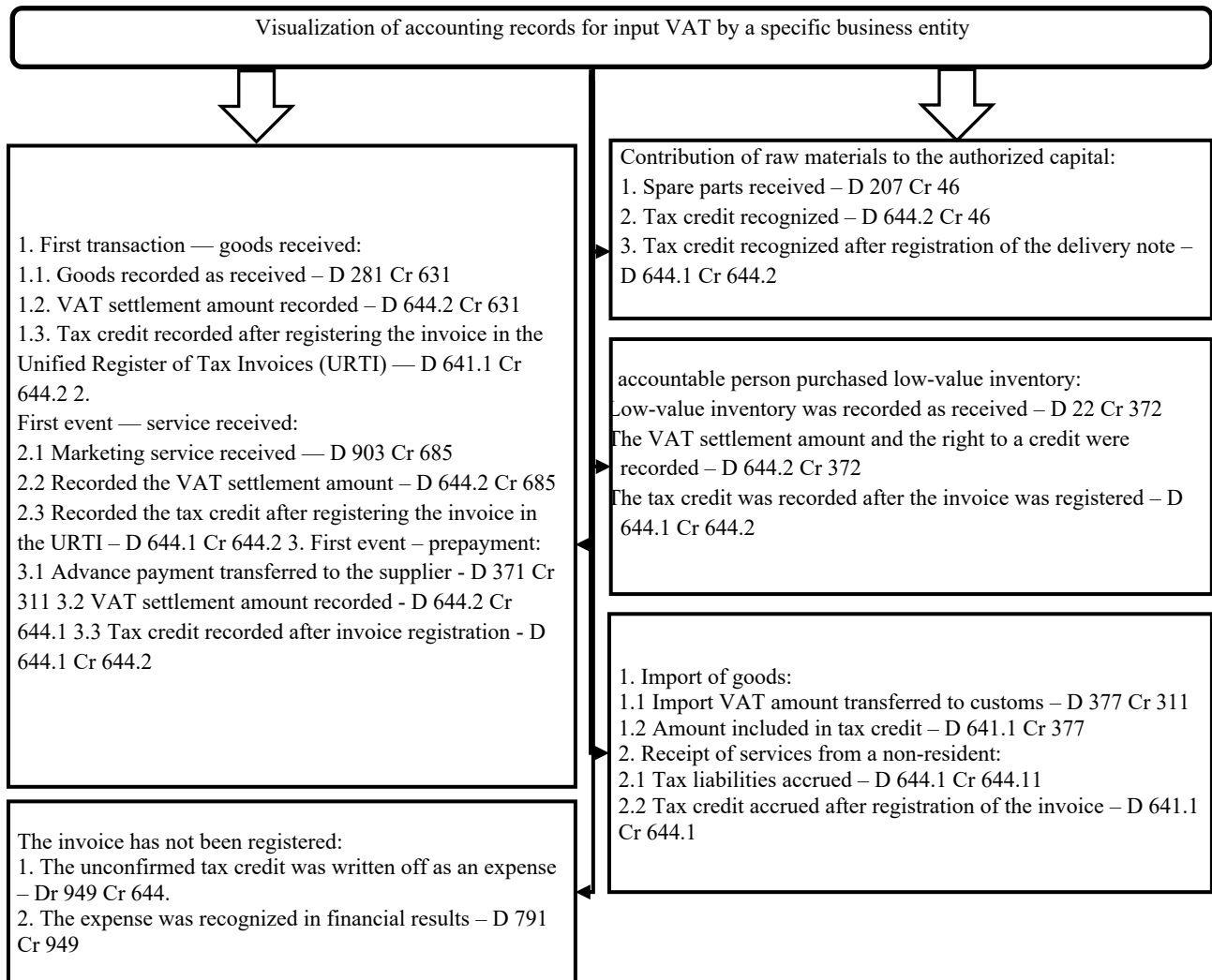


Figure. 10. Visualization of the accounting treatment of input VAT by an individual business entity
Source: summarized by the author based on [9,18].

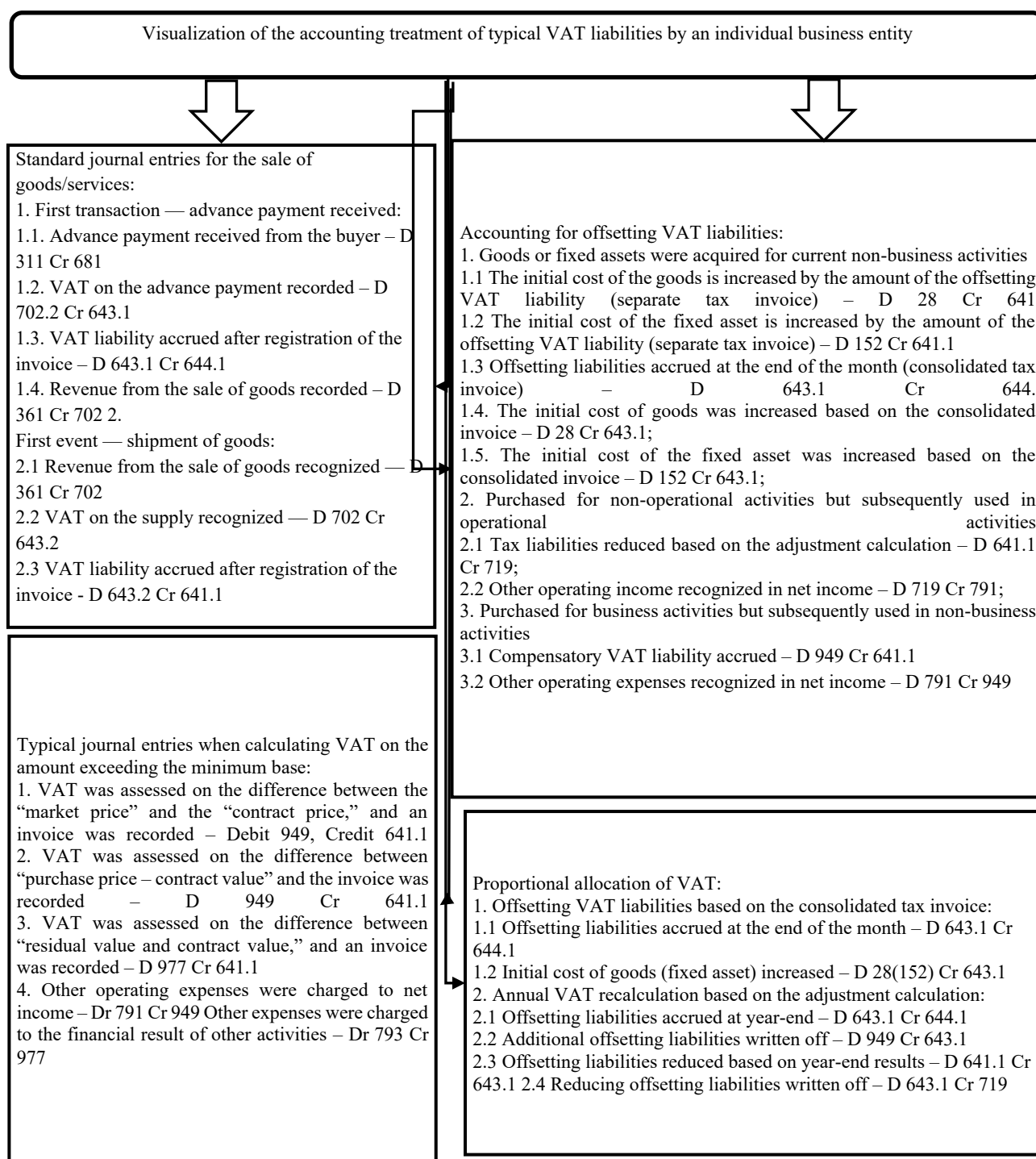


Figure. 11. Visualization of the accounting treatment of typical VAT liabilities by an individual business entity

Source: compiled by the author based on [9,18].

Effective September 27, 2025, amendments to the “Procedure for Suspending the Registration of Tax Invoices and Adjustment Calculations in the URTI,” approved by Resolution No. 1048 of the Cabinet of Ministers of Ukraine dated August 26, 2025, came into force. These changes represent another step by the state toward improving the VAT administration system and enhancing trust between businesses and tax authorities. The primary goal of the updated Procedure is to reduce the number of cases of unjustified blocking of tax invoices, as well as to increase the transparency and predictability of the process for monitoring high-risk transactions. Legislators aim to

ensure a fairer balance between the needs of fiscal control and the rights of conscientious taxpayers. The main transformative changes to this Procedure are grouped and illustrated in Figure 12

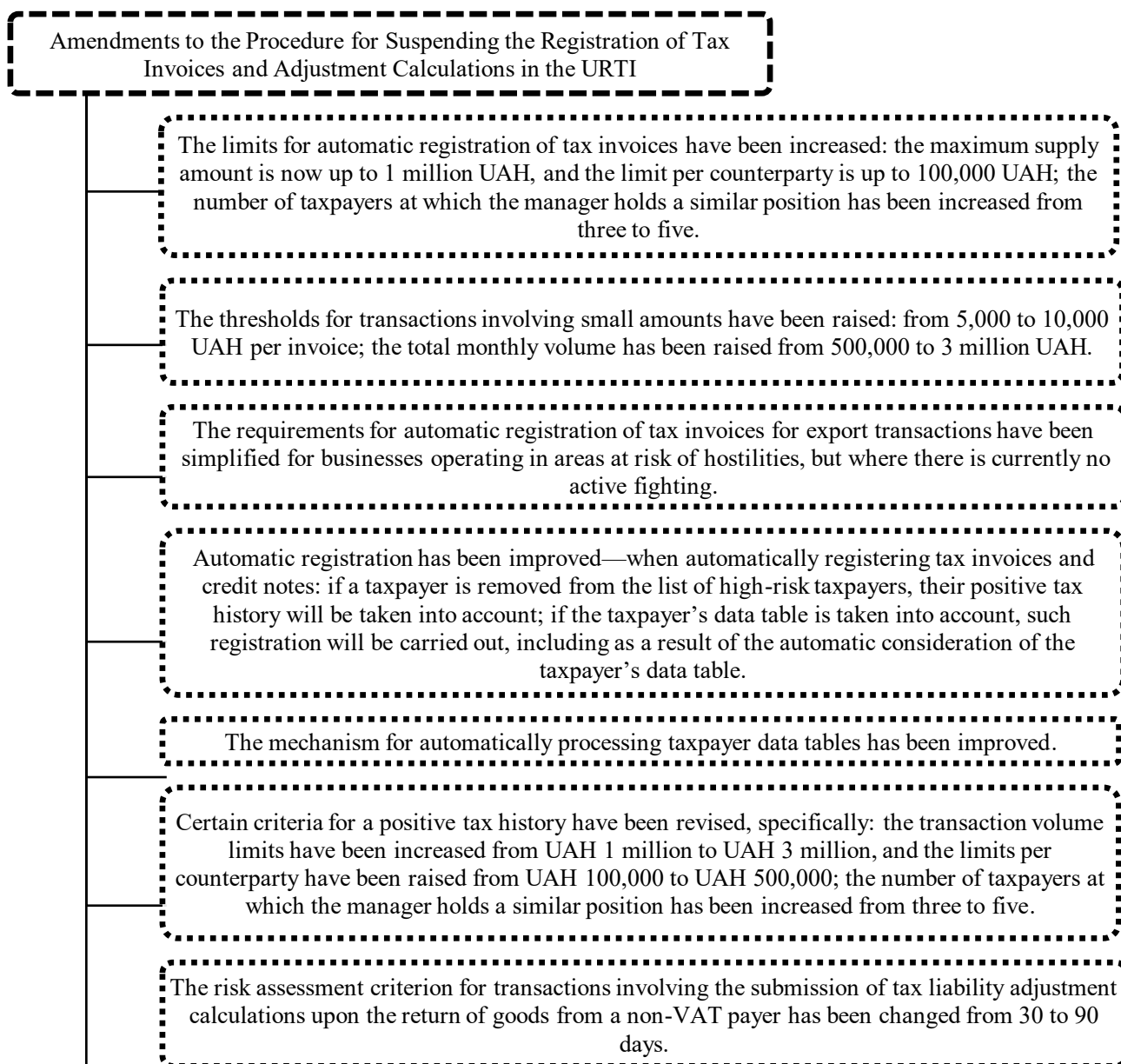


Figure. 12. *Amendments to the Procedure for Suspending the Registration of Tax Invoices and Adjustment Calculations in the URTI*

Source: compiled by the authors based on [18].

In the context of the development of a modern tax administration system, these innovations can be viewed as a step toward the digital transformation of VAT control processes and the creation of a more favorable tax environment for honest businesses. In the face of instability and changes to the regulatory framework during martial law, internal audit becomes a key element of a company's tax security. The main areas of VAT audit for individual modern business entities are illustrated in Figure 13.

Verification of the correctness of determining tax liabilities based on the date of the first event (in accordance with Section 187.1 of the TCU).	Assessment of the validity of including VAT amounts in the tax credit (Sections 198.3–198.6 of the TCU).
Key Areas of Internal Auditing of a Company's VAT Transactions:	
Analysis of the Timeliness of Tax Invoice Registration (Section 201.10 of the TCU).	Verification of the completeness of accounting records and reconciliation with the VAT return.

Figure. 13. Main areas of internal audit of a company's VAT transactions
Source: summarized by the authors based on [18].

The stages of organizing and conducting an internal audit of a company's VAT operations are shown in Figure 14.

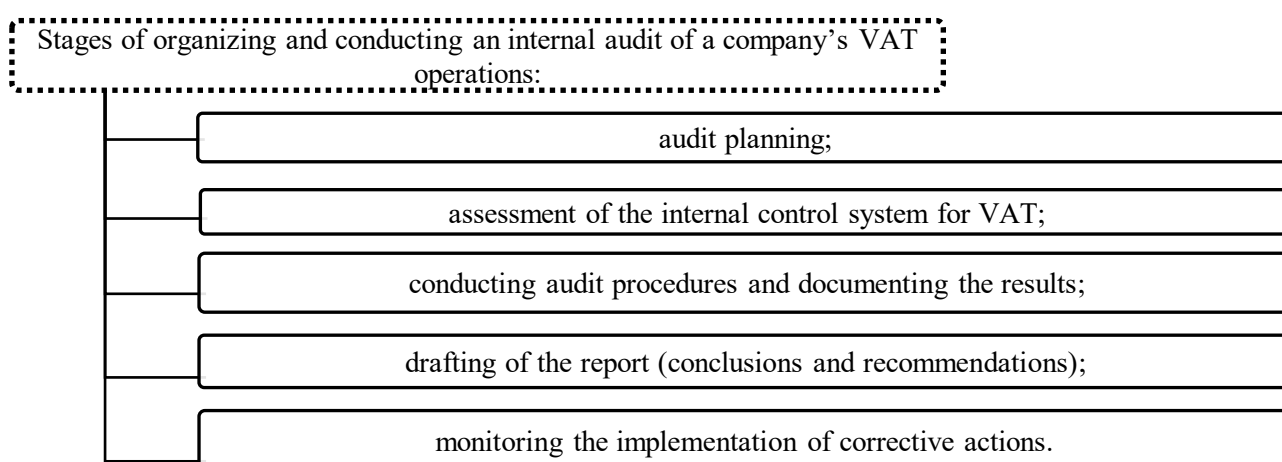


Figure. 14. Stages of organizing and conducting an internal audit of a company's VAT operations
Source: summarized by the author

In the context of war-related risks, the likelihood of errors in tax reporting increases significantly due to limited access to documents, disruptions in electronic systems, and frequent changes to the regulatory framework. Internal audit is designed to identify risks of inaccurate VAT reporting in accounting and financial statements, as well as to improve tax compliance within a specific business entity. The application of analytical procedures at every stage of the internal audit enables the auditor to comprehensively assess the level of audit risk and materiality, determine the entity's ability to continue operations on a going-concern basis, and analyze the impact of internal and external factors on deviations of actual indicators from normative, optimal, or legally established values. This approach allows not only for the timely identification of potential problem areas in the accounting and control system but also for the formulation of well-founded recommendations to address identified deficiencies and improve the effectiveness of managing the enterprise's financial and economic activities. [12]. To facilitate effective quality control of VAT transactions, among other important components, the internal auditor must develop a risk matrix that identifies potential violations, consequences, and appropriate corrective actions. An excerpt from the relevant working document (risk matrix) is presented in Table 3.

Based on the study conducted, we can note that a significant portion of tax compliance violations during martial law are linked specifically to inadequate internal audit processes. It has been established that the timely implementation of control procedures (daily reconciliation of the Unified Register of Taxpayers, audits of debtor-counterparties, and electronic monitoring of tax returns) helps reduce the risk of penalties.

Table 3. Risk Matrix for the Internal Audit of VAT Accounting Records (excerpt)

№	Potential violation	Potential consequences	Auditor's Recommendations
1	Failure to register tax invoices in a timely manner	Fines, loss of the right to a tax credit	Keep a record of tax obligations
2	Lack of proper supporting documents	Denial of a tax credit	Backing up copies to cloud storage
3	Errors in the codes of the Ukrainian Classification of Goods for Foreign Economic Activity	Amendments to tax returns	Automated verification of tax invoices
4	Double-entry bookkeeping	Misrepresentation of financial statements	Breakdown of analytics by counterparty
<i>Other potential violations, consequences, and recommendations from the internal auditor</i>			

Source: compiled by the authors

The implementation of the proposed system of synthetic and analytical accounts for VAT accounting creates the conditions for establishing a comprehensive, logically structured information base regarding the movement of tax liabilities and tax credits. Clear breakdown of accounting indicators by transaction type, counterparties, asset usage categories, and tax periods ensures an adequate level of data analysis and consistency with tax reporting figures. High-quality interaction between the analytical and synthetic levels of accounting is a necessary prerequisite for ensuring the reliability of tax calculations and minimizing the risk of errors when preparing the VAT return. The consolidated accounting and reporting support, as well as the components of control over a specific business entity's VAT calculations, are presented in Table 4.

Table 4. Accounting and reporting procedures, and components of VAT calculation controls for an individual business entity

Accounting and Reporting Support	Individual reconciliation components			
	Tax credit	Tax liabilities	Determining the result	Payment / Reimbursement
Analytical accounting (tax invoices / adjustment calculations, counterparties)	Received tax invoices registered in the URTI	Tax invoices issued and registered in the URTI	Difference: tax liability – tax credit, as shown in the tax invoice register	–
Synthetic accounting (accounts)	Debit 641/VAT (account debit balance)	Credit 641/VAT (account credit balance)	Balance of subaccount 641/VAT	Reversal: Debit 641 – Credit 315/311
VAT Return (Selected Lines)	10 (Acquisition (manufacture, construction, erection, creation) of goods/services and non-current assets within the customs territory of Ukraine), 11 (Goods and non-current assets imported into the customs territory of Ukraine).	1.1 (Transactions subject to the standard tax rate), 1.2 (Transactions subject to a 7% tax rate), 1.3 (Transactions subject to a 14% tax rate); (Appendix 1).	18 (The positive amount of the difference between the tax liability and the tax credit for the current reporting (tax) period, payable to the state budget), 19 (The negative amount of the difference between the tax liability and the tax credit for the current reporting (tax) period), (Appendix 2).	20.1 (Offset against the amount of VAT tax liability) (Appendix 2) / 20.2 (Eligible for budgetary reimbursement), (Appendices 2, 3).

Source: compiled by the author based on [6,18].

Having detailed accounting records makes it possible to substantiate the accuracy of the tax base, tax credit amounts, and tax liabilities, as well as the figures in the VAT return, which significantly reduces the likelihood of tax disputes with the tax authorities.

One of the most common issues in accounting practice is the incorrect recording of tax invoices. In some cases, a tax credit may be recognized immediately upon receipt of goods or services, even if the tax invoice has not yet been registered in the URTI. Such a practice contradicts the provisions of current tax legislation, according to which only a registered tax invoice serves as the basis for claiming a tax credit. The result of such actions is an overstatement of the tax credit and the creation of discrepancies between the data presented in the accounting records and the figures in the electronic VAT administration system.

Errors related to the accounting of VAT transit accounts are quite common. In particular, accounts 643 “Tax Liabilities” and 644 “Tax Credit” are sometimes not closed at the end of a given reporting period. The absence of adjusting or journal entries to transfer the relevant amounts to account 641 “Tax Settlements” leads to the emergence of unjustified balances, which distorts accounting figures and complicates their reconciliation with the tax return. In addition, in practice, the return is sometimes prepared based on auxiliary ledgers or spreadsheets without properly verifying the trial balance for account 641. As a result, discrepancies may arise between accounting and tax data, which regulatory authorities consider a violation during audits.

A separate category of risks involves transactions involving the recognition of contingent tax liabilities that arise when goods or services received are used in non-business activities. If such transactions are not documented with the appropriate accounting documentation and are not recorded in the relevant accounting entries, this leads to an understatement of tax liabilities and potential additional assessments following subsequent tax audits. Significant difficulties also arise when recording adjustment calculations for tax invoices. A common error is recording such transactions in the period when the business transaction occurred, rather than in the period when the adjustment calculation is registered in the URTI. This practice leads to a distortion of the data presented in the accounting records and discrepancies with the information in the generated tax registers. The accounting for transactions involving advance payments received also remains problematic. In some cases, accountants record only the receipt of funds from the buyer as a receivable, without accruing VAT liabilities under the current “first event” rule. This error leads to an understatement of tax liabilities in the business entity’s tax return. Monitoring the balance of funds in the special VAT account, recorded in subaccount 315, is of great importance. In the absence of regular reconciliation with data from the electronic VAT administration system, discrepancies may arise between the company’s accounting data and the corresponding information held by the tax authorities.

Conclusions

This study analyzes the origins and stages of development of the value-added tax (VAT), identifies the key characteristics of the current national VAT model in Ukraine, and concludes that accounting policies, documentation, reporting, and control of VAT settlements are the focus of attention for both scholars and practitioners today, since the effectiveness of the VAT system largely depends on the quality of the accounting information generated. It was established that the operation of the electronic tax administration system has significantly transformed both tax procedures and the accounting methodology for relevant transactions. It is argued that modern accounting software products support the implementation of various VAT accounting algorithms—ranging from simplified models focused primarily on generating standardized tax reports to advanced systems that provide multidimensional analytics by type of business transaction, tax rates, structural units, counterparties, and asset utilization areas. This approach creates methodological prerequisites for increasing the informational value of accounting data and strengthening the control function of accounting. It has been proven that, from a scientific and practical perspective, detailed VAT accounting should be viewed as a component of tax compliance and an element of an enterprise’s tax risk management system.

It has been established that the accurate recording of transactions involving electronic VAT invoices in accounting creates the conditions for improving the reliability of tax calculations, reducing the likelihood of financial penalties, and ensuring an appropriate level of tax compliance among business entities. The paper illustrates the accounting treatment of input and output VAT using the example of a specific business entity, confirming the practical applicability of the proposed approaches.

It is substantiated that the systematic incorporation of provisions regarding VAT accounting support into an enterprise’s accounting policy contributes to increasing the transparency of accounting procedures, unifying methodological approaches, minimizing tax risks, and generating reliable information about financial performance. It is determined that an accounting reference in the field of VAT accounting is not a formal procedure, but an important element of the system of internal control, tax risk management, and legal protection of an individual enterprise. Its proper preparation indicates a high level of accounting organization and the professional responsibility of the accountant.

A list of subaccounts for synthetic and analytical VAT accounting in the context of an individual enterprise's operations is proposed, which can serve as a methodological basis for improving accounting practices and internal tax control.

The study revealed that the main risks in VAT accounting are associated with violations of requirements regarding documentary evidence for tax credits, improper use of transit accounts, a lack of regular reconciliation of accounting data with tax returns, as well as errors in recording adjustments, advance payments, and contingent tax liabilities. To minimize such risks, it is advisable to ensure that tax credits are generated exclusively on the basis of registered tax invoices, to conduct systematic reconciliation of analytical and synthetic VAT accounting with the figures in the return, to close transit accounts 643 and 644 in a timely manner, document all technical and adjusting transactions with accounting notes, and regularly reconcile the balances in account 315 with the data from the electronic VAT administration system.

Improving the VAT accounting system should be viewed not only as a technical element of the accounting process, but as a strategic tool for managing tax risks, increasing the transparency of accounting information, and ensuring the financial security of the enterprise amid growing fiscal control.

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INNOVATIVE DEVELOPMENT OF AN ENTERPRISE IN THE CONTEXT OF THE DIGITAL ECONOMY

Klochko Tatyana

PhD in Economics, Senior Lecturer at the Department of Economics and Entrepreneurship, Sumy National Agrarian University

ORCID ID: 0000-0002-8942-0938

Introduction. In the digital economy, the principles of innovative development are undergoing radical changes: the process is no longer linear, where a product is first developed, then transferred to production, and finally brought to the market. Instead, innovation is becoming ecosystem-based, where the creation, development, and commercialization of ideas occur through the interaction of numerous participants – companies, startups, universities, customers, and partners.

In the modern digital economy, the fundamental principles of innovative development are experiencing profound and irreversible transformations. The traditional approach, in which the process resembled a strictly linear sequence – from the emergence of an idea in closed laboratories to production and final market entry – is becoming obsolete. Previously, this path was lengthy and detached from feedback, which created high risks of product rejection by consumers.

Instead, innovation is becoming ecosystem-based. This means that the creation, development, and further commercialization of ideas now take place within a complex network of interactions among numerous participants. This process simultaneously involves:

- large corporations and agile startups exchanging experience and technology;
- scientific institutes and universities providing the fundamental base;
- end customers and strategic partners participating in testing and refining solutions at early stages.

The digital economy fundamentally changes the paradigm of innovation activity. A large-scale transition is observed from the traditional closed approach, where trade secrets were carefully protected, to the concept of open innovation and global network collaboration. In such an environment, business success no longer depends solely on accumulated internal resources or a limited number of staff members.

Modern companies actively integrate external knowledge flows, attracting talent and breakthrough technologies from around the world. At the same time, a reverse process is also observed: enterprises make part of their developments available to partners or the market through APIs, open platforms, or licensing. This creates synergy, where the joint efforts of multiple market players lead to products that would be impossible to create individually.

Main Part. In the modern conditions, a fundamental shift is taking place in the way value is created: companies not only generate innovations internally but also integrate them into global ecosystems, adapting to a changing market and the rapid development of digital technologies. This approach has become a response to the challenges of globalization, increased mobility of intellectual capital, and the rapid development of digital platforms that open new opportunities for collaboration, accelerate innovation implementation, and enhance the competitiveness of economic entities in the digital economy.

For most of the twentieth century, the so-called closed innovation model dominated the global economy and corporate management. According to this model, the entire innovation process was concentrated exclusively within a single company. Its core principle can be summarized as: “if we want to create a product or technology properly, we must do it ourselves.” This approach assumed that key knowledge, ideas, and competencies should be concentrated within one organization, while the external environment was viewed more as a source of threats than opportunities.

The implementation mechanism of this model involved large-scale investments in internal scientific-research and research-development units, corporate laboratories, research institutes, and centers, as well as the employment of top scientists, engineers, and developers. Companies sought to fully control idea generation, research, prototyping, testing, production, and commercialization. Special attention was paid to intellectual property protection: patents, trade secrets, and know-how were strictly guarded, and knowledge exchange with external actors was minimized.

The logic of this model was based on the priority of control. It was believed that only complete closure of the innovation cycle – from idea generation to market entry – could ensure competitive advantage, reduce information leakage risks, and guarantee monopoly use of research results. Innovation activities were essentially conducted “behind closed doors”, and company success depended on internal resources, investment

scale, and the ability to retain talent. This model was effective in relatively stable markets with slow technological change and high entry barriers, that explains its domination during the XX century.

The term “open innovation” was introduced by Professor Henry Chesbrough in 2003, and since then this concept has become a key approach in modern corporate management and the innovation economy. The main idea is that in a world where knowledge is widely distributed among organizations and individuals, it is inefficient for companies to rely only on internal scientific-research development. Instead of a traditional “closed” approach, when all the stages of innovation cycle are performed inside the company, open innovation involves active exchange of knowledge and ideas between internal and external sources.

The first key principle of this model is the use of external ideas. Companies can integrate knowledge and experience from universities, research institutions, startups, customers, or even competitors to accelerate the development of new products and technologies. This enables a significant expansion of the organization’s innovation potential while reducing internal research costs.

The second principle is the outward transfer of unused internal ideas. If a technology does not fit the company’s strategy, it can be sold, licensed, or used to create a spin-off company. This approach allows companies to generate additional value from underutilized internal resources while fostering the development of the innovation ecosystem.

The third principle is joint commercialization. A product’s path to market may begin internally and end through external channels, or vice versa: External ideas can be utilized at internal stages of development. This ensures flexibility in the implementation of innovations and enables a more effective integration of internal and external resources.

Together, these principles create a model in which company boundaries become permeable and knowledge flows freely in both directions, enabling faster and more efficient innovation, reduced risks, and increased competitiveness. The concept of open innovation differs fundamentally from the traditional “closed” approach and has become central to the strategies of modern technology companies and research organizations.

The modern model of open innovation assumes that a company ceases to be a closed center of research and development and transforms into a kind of “platform” that integrates the best ideas and solutions from various sources. Rather than relying exclusively on its internal R&D department, a company actively incorporates external knowledge, ensuring flexibility, efficiency, and acceleration of the innovation process.

One of the main sources of such knowledge is universities and research laboratories. Businesses fund academic research in exchange for preferential rights to acquire patents or access research outcomes. This creates a mutually beneficial partnership: science gains resources for research, while companies obtain access to new technologies and fundamental discoveries that can be rapidly commercialized.

Another direction is crowdsourcing and interaction with customers. Companies create dedicated platforms or portals where users can propose ideas for new products, modifications of existing ones, or new ways of their use. Examples of such practices can be found in companies such as LEGO and Starbucks, which systematically engage their communities in the innovation process, transforming customers into active participants in the development of brands and products.

A third important element is collaboration with competitors, or co-opetition. Sometimes competing companies join forces to jointly develop industry standards or core technologies, which allows them to share research costs and reduce the risks associated with implementing new solutions. Examples include the joint development of engines by car manufacturers or technological platforms in the IT sector. Such a strategy helps lay the groundwork for subsequent innovations, which can then be pursued individually by competitors.

All these approaches demonstrate that a company, as an innovation platform, becomes a hub that gathers the most valuable ideas and knowledge from the world, integrates internal resources with external ones, and creates conditions for the rapid, flexible, and efficient development of new products and technologies. This fundamentally changes the logic of the innovation process, making it open, dynamic, and interactive with the external environment.

Large corporations often accumulate a vast number of patents, prototypes, and other developments that effectively “gather dust” because they do not align with the current strategy or business profile. Traditionally, such assets remained unused, resulting in lost potential revenue and reduced effectiveness of research and development investments. The open innovation model proposes transforming these unused resources into additional income and strategic advantages through various commercialization mechanisms.

The first of these is licensing, where a company grants other organizations the right to use its technology in exchange for royalties or other forms of compensation. This allows financial returns from developments that do not fit into the current business model while simultaneously stimulating the growth of adjacent markets.

The second approach is the creation of spin-offs – separate subsidiary companies that focus exclusively on a specific idea or technology. Often, internal corporate experiments evolve into fully-fledged business units; examples include numerous Google services that began as internal prototypes and later received their own structure and resources for large-scale development. This mechanism enables the effective use of existing technologies, their development outside the core business, and the testing of new markets without risking the company's key operations.

The third mechanism is open source, where a company publicly makes its technology available to anyone interested. This may seem contrary to traditional approaches to intellectual property protection, but strategically it allows for the stimulation of the market in which the company intends to generate revenue through other means. An example is Tesla, which opened its patents on electric vehicles to accelerate the adoption of electric transportation infrastructure and create a favorable environment for its business.

Thus, the open innovation model transforms unused internal developments into tangible economic and strategic benefits, providing additional revenue streams, stimulating technological advancement, and creating new opportunities for market collaboration.

The contemporary concept of open innovation entails not only using internal and external knowledge but also actively integrating the company into a broad ecosystem of partners, where value creation occurs collectively. Such a hybrid approach enables the optimization of development processes, reduction of time-to-market, and minimization of risks by combining the strengths of various ecosystem participants.

One mechanism for implementing this approach is joint ventures. In this case, two or more companies pool their resources: one may provide technology or intellectual products, while the other offers market access and distribution channels. This type of collaboration allows for faster market entry, shared development costs, and reduced risks associated with demand uncertainty or technological challenges.

A second important tool is the use of external sales channels. Even if the development occurs entirely within the company, market entry can be achieved through established platforms and partner brands. For example, a small software developer can distribute its product via the Apple App Store or Microsoft Azure, leveraging their infrastructure, customer base, and marketing support. This enables rapid product scaling and a focus on technological improvement without expending resources to build proprietary distribution channels.

A third direction is the reverse innovation pathway, in which a corporation acquires a promising startup at the prototype stage and facilitates its scaling through its own resources, marketing capabilities, and infrastructure. This approach allows for the rapid integration of new ideas, risk reduction in development, and accelerated commercialization of promising technologies, while simultaneously supporting an innovative environment and the growth of the startup ecosystem.

Taken together, this hybrid approach demonstrates that a modern innovation strategy involves close collaboration and resource sharing within an ecosystem, allowing companies to effectively combine internal developments with external opportunities to create additional value and competitive advantages (Table 1).

Table 1. Differences between Models

Characteristic	Closed Innovation – Traditional (Linear) Model	Open Innovation – Contemporary (Ecosystem) Model
Source of ideas	Own R&D centers (closed)	Crowdsourcing, startups, customers (open)
Source of talent	Only internal employees	Top specialists worldwide (external and internal)
R&D	Internal research ensures success	Success achievable by combining internal and external R&D
Intellectual property	Strict control and patenting	Shared use, licensing in/out
Role of the market	Market entry only through own channels	Multiple market entry channels
Role of the consumer	Passive consumer of the final product	Co-creator, tester, source of data
Risks	Risks borne entirely by one company	Risks distributed among ecosystem participants

**Source: compiled based on [7]*

In the digital economy, several primary models can be identified, such as platform-based models, data-driven models, efficiency-enhancement models through automation, and distribution models via digital networks. Each of these models opens up new opportunities for businesses, alters competitive dynamics, and imposes new requirements on the management of economic processes.

Thus, understanding the main economic models of the digital economy is essential for forecasting its development and for the effective implementation of digital innovations at all levels of economic activity. This process influences competition, productivity, the labor market, and the innovation potential of enterprises and countries as a whole.

In platform economies, digital platforms play a crucial role as intermediaries between different user groups or business participants. Such platforms can span various sectors, from e-commerce (Amazon, eBay) and financial technologies (PayPal, Revolut) to rental and ridesharing services (Airbnb, Uber). These platforms often operate based on network effects, meaning that the greater the number of participants on the platform, the higher the value for all its users (Table 2).

Table 2. Main Peculiarities of Digital Platforms

Peculiarities	Characteristic
Network effects	Platforms become more valuable to users as their number increases.
Minimization of transaction costs	Platforms reduce the costs of searching, verification, and contracting, significantly simplifying economic interactions between market participants.
Access to the global market	Through platforms, businesses can enter new markets without the need to establish physical offices or stores. This enables small and medium-sized enterprises to globalize their services or products.
Dynamic pricing and personalization	Digital platforms leverage large volumes of data to adapt prices and offers to specific user needs. With big data analytics, platforms can provide personalized recommendations and discounts, significantly increasing sales efficiency and customer satisfaction.
Financial infrastructure and payment processing	Platforms not only connect suppliers and consumers but often provide financial infrastructure to facilitate transactions. Examples include platforms such as PayPal or Stripe, which process payments between buyers and sellers, reducing the need for traditional banking services.
Changes in business models	The platform economy transforms traditional business models, where companies had vertically integrated supply chains and production, into a new model in which the intermediary role is played by the platform. Consequently, companies shift strategies from developing internal resources to maximizing the use of external networks, reducing costs and accelerating business scaling.
Changes in competition	Platforms change competitive mechanisms, as companies no longer compete solely at the level of products or services but also in terms of access to the largest user audience. Technologies with network effects allow the creation of monopolies or “giants” that dominate the market, which can limit competition.
Changes in the labor market	The platform economy creates new opportunities for flexible employment. Increasingly, people work on contracts or perform short-term tasks via platforms such as Upwork, Freelancer, Uber, or TaskRabbit. This leads to changes in traditional approaches to labor relations, giving rise to new employment models, such as the gig economy.
Lowering barriers to market entry	Platforms enable small businesses and startups to quickly enter the market without significant capital investment in physical points of sale or marketing campaigns. This creates new opportunities for entrepreneurs and fosters innovation across different economic sectors.
Social and economic challenges	Alongside these advantages, the platform economy also carries risks. These may include data privacy and security issues, as platforms often collect vast amounts of personal user information. Additionally, labor market challenges may arise regarding the flexibility of employment relationships, social protections for gig workers, and potential abuses of monopolistic positions by large platforms.

* Source: *compiled by the authors based on [2, 3, 5]*

The platform economy radically transforms traditional markets and business models. It creates new opportunities for entrepreneurs and consumers, lowers barriers to market entry, and stimulates innovation, while simultaneously altering competition and labor relations. Platform-enabling technologies continue to evolve, allowing them to increasingly influence various aspects of the economy, reshaping interactions among consumers, businesses, and other market participants. However, this process requires careful oversight and regulation to ensure fair conditions for all participants in the digital economy.

The digital economy not only transforms traditional business models but also enables new approaches to customer interaction, revenue management, and business process organization. One of the main trends is the implementation of subscription-based business models, e-commerce, and online services. Each of these models has its own characteristics, advantages, and challenges, but overall, they simplify interactions between businesses and consumers, reduce operational costs, and allow for the most efficient use of digital technologies.

Digitalization leads to significant changes in the labor market, creating new professions and competencies requirements for employees. There is an increasing demand for specialists capable of working with the latest technologies and driving digital transformation within companies. At the same time, these changes require constant adaptation by both employees and educational institutions, which must develop new training programs to cultivate the necessary competencies. Success in the context of digitalization depends on the ability to effectively leverage new opportunities, continuously improve professional skills, and actively engage with technology (Table 3).

Table 3. New Competencies in the Context of Digitalization

Competence	Characteristic
Technical skills and knowledge	As most emerging professions are associated with the use of advanced technologies, knowledge in areas such as programming, data analysis, machine learning, cybersecurity, cloud computing, and other digital tools becomes particularly important.
Critical thinking and problem-solving	Digitalization involves working with large volumes of information and often requires decision-making based on data analysis and interpretation. Therefore, it is essential to possess critical thinking skills, the ability to find innovative solutions, and adaptability to change.
Adaptability and learning ability	As digital technologies are constantly evolving, employees must be able to quickly adapt to new tools and processes. This requires continuous learning, self-improvement, and flexibility in professional development.
Interpersonal skills and collaboration	Despite the fact that digitalization involves the use of technologies, the importance of interpersonal skills – such as effective communication, leadership, and teamwork – remains unchanged. In the context of remote work and online collaboration platforms, these skills become even more significant.
Digital literacy and media literacy	The ability to work with digital tools, assess the reliability of information, interact through social media, and protect one's privacy in the digital environment are skills that are becoming essential for any profession in the digital economy.

Source: *compiled by the authors considering current digital trends*

Digitalization is radically transforming not only the way business is conducted but also the very structure of the economy, reshaping traditional industries and fostering the emergence of new ones. The implementation of innovative technologies such as artificial intelligence (AI), Big Data, the Internet of Things (IoT), blockchain, as well as robotics and automation, opens up new horizons for business and economic development.

These changes have a profound impact on many sectors – from manufacturing and agriculture to finance and healthcare. At the same time, digital technologies contribute to the creation of new industries, such as the platform economy, cybersecurity, new media, financial technologies (FinTech), blockchain services, and many others.

The following practical examples illustrate these transformations:

1. Tesla and patent openness:

- in 2014, Elon Musk announced that Tesla would not initiate patent lawsuits against those who use its technologies in good faith. This is a classic example of open innovation: the company realized that the development of the electric vehicle market requires a shared infrastructure and competitors that stimulate demand.

2. The Apple ecosystem:

- Apple does not merely sell devices but creates a platform where thousands of third-party developers (through the App Store) generate value for its products. This represents network-based collaboration, where the company's success is directly dependent on the success of its partners.

3. Linux and Open Source in business:

- most modern cloud computing and servers operate on Linux. Companies such as IBM and Red Hat do not exclusively own the code but invest in its collective development, integrating external talent to improve their commercial solutions.

Summarizing the above, it can be stated that in the digital era, competition occurs not between individual products but between entire business ecosystems. The winners are those who are best able to build connections and integrate external ideas into their own context.

Open innovation is impossible without the development of innovation ecosystems. A company ceases to be an "island" and becomes part of a dynamic economic network.

Crowdsourcing: the use of collective intelligence (for example, platforms such as LEGO Ideas, where users themselves propose new product sets).

Crowdsourcing (from "crowd" and "sourcing") is a model of problem-solving that involves engaging a large group of people (a community), typically via the Internet, on a voluntary basis or for compensation.

At the core of crowdsourcing lies the concept of collective intelligence – the idea that a group of people can generate better and more creative solutions than even highly paid in-house experts.

The mechanism of crowdsourcing involves engaging a wide range of participants in solving specific tasks or generating new ideas, enabling companies to leverage collective intelligence to enhance their innovation potential. The process typically consists of four key stages:

The first stage is task definition, when a company clearly formulates the problem to be solved, whether it is the design of a new product, the identification of bugs in software code, or the selection of a brand name.

The second stage is crowd engagement, during which the task is published on an open platform accessible to a large audience with diverse experience and competencies.

The third stage is idea generation, when participants propose solutions, discuss them with others, and build upon each other's ideas, creating a collective intellectual output.

The fourth stage is the selection of the optimal solution, which may be carried out either by the company itself or by the community through voting or expert evaluation. Through this mechanism, crowdsourcing enables the rapid discovery of unconventional solutions, enhances creativity, and engages external resources for innovation development.

The concept of open innovation, introduced by Henry Chesbrough, is based on the idea that in today's economic environment knowledge is so widely distributed that no company can afford to rely solely on its own research.

Depending on its purpose, crowdsourcing can be divided into several categories (Table 4).

Table 4. Types of Crowdsourcing by Direction

Type	Essence	Example
Crowd creativity	Searching for creative ideas, design solutions, and naming concepts.	Logo design contests (e.g., 99designs).
Crowd wisdom	Using community knowledge to create content.	Wikipedia – the world's largest knowledge base.
Crowd testing	Identifying software bugs by real users.	Beta testing of new games or applications.
Crowdfunding	Raising funds for project implementation.	Kickstarter, where people fund startups.

*Source: *compiled based on* [5] Crowd creation (crowd creativity)

Crowdsourcing is the practice of obtaining ideas, services, or solutions from a large group of people, particularly from online communities. It is a powerful way to leverage the collective intelligence, creativity, and skills of millions of people worldwide. Crowdsourcing can be used for various purposes, such as problem-solving, innovation, data collection, content creation, and more (Figure 1).

Crowdsourcing and co-creation provide businesses with a range of strategic advantages that form the foundation of modern marketing and innovation management.

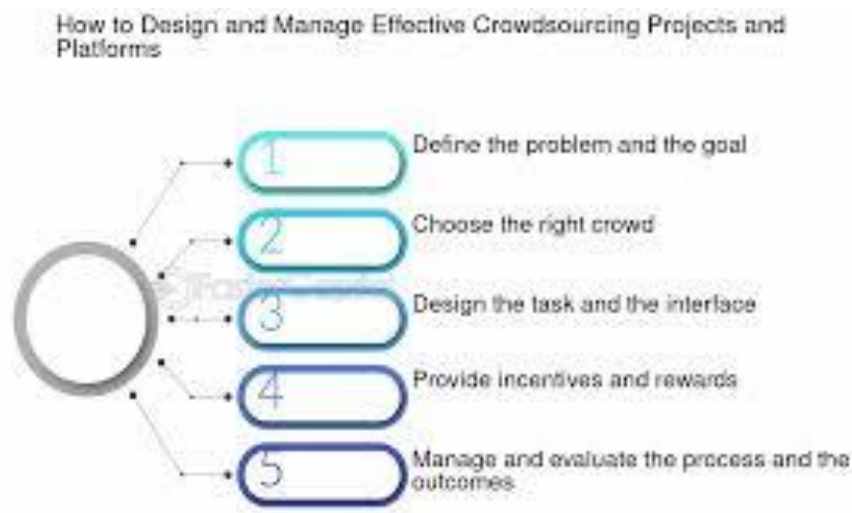


Figure 1. Crowdsourcing: How to Use It for Problem Solving and Rapid Innovation Implementation

First, the company gains access to talent – thousands of professionals and amateurs from around the world can contribute their ideas and solutions without the need to hire them as staff. This significantly expands the company's innovation potential and allows for resource savings.

Second, this approach reduces the risks associated with launching a new product: for example, if 10,000 people vote for a design on the LEGO Ideas platform, the company already obtains practical confirmation of demand for the product, minimizing the risk of unsuccessful investments.

Third, brand loyalty increases because users feel involved in the creation of the product, shaping them as brand advocates and encouraging repeat purchases and positive feedback. Together, these three aspects make crowdsourcing an effective tool not only for idea generation but also for developing mutually beneficial relationships with consumers and enhancing competitiveness.

The European Investment Bank identified three main reasons for transitioning to a circular economy:

1. Limited resource base usage. Demand for raw materials and resources increases every year, leading to a growing shortage of critically important types of resources.
2. Continuous development of technologies and production methods. The implementation of new technologies creates opportunities for developing and adopting circular economy business models.
3. Development of the socio-economic sector. Circular models play an important role in the context of increasing urbanization. In cities, it is possible to design, implement, and maintain systems that transform various goods, materials, and other resources in an economically efficient and environmentally safe way.

The main strategies that entrepreneurial entities in Ukraine should apply to implement the objectives and principles of the circular economy are summarized in Figure 2.

Reducing the use of primary resources: Waste recycling, Efficient use of resources, Use of renewable energy sources,

Preserving the highest value of products and materials: Remanufacturing and reuse of products, Extending the product lifecycle

Changing product usage models: Product as a service, Shared-use models, Changes in consumer behavior

Figure 2. Key Strategies for Implementing a Circular Economy

To implement a circular economy strategy, it is necessary to prepare a grant proposal.

Developing a high-quality grant proposal is an art that requires a combination of deep understanding of the problem, knowledge of donor needs, and the ability to clearly articulate the proposal. This is especially true for proposals aimed at supporting circular solutions, as they often require innovative approaches and interdisciplinary collaboration.

Examples of successful projects and their key features:

Agro-economy:

- Project “Smart Farming”:

Implementation of a precision agriculture system that optimizes the use of water, fertilizers, and pesticides.

- key elements: use of sensors, drones, and big data analysis.;

- “Solar Greenhouses” Project:

- construction of greenhouses equipped with solar panels for electricity generation and heating.;

- key elements: integration of agriculture and renewable energy.

Within the framework of the grant program, support will be provided to initiatives that contribute to increasing sales of organic products, expanding the organic product range on store shelves – particularly by extending the shelf life of organic products – and establishing new supply chains.

Areas of support and forms of activity within the Organic Sector Grant Program include:

- promoting the sale of organic products and opening new sales channels for organic products in the domestic market;

- shortening supply chains from producer to consumer in the domestic market;

- improving the presentation of organic products on store shelves in the domestic market, including through the extension of product shelf life.

Eligible applicants for Grant No. 1 under this grant program are Ukrainian certified organic market operators who are already present in the domestic market or are ready to enter the Ukrainian market.

Resource optimization is one of the key directions of modern development, particularly in the context of the transition to a circular economy. Grant programs aimed at supporting energy efficiency and recycling provide a valuable opportunity to implement innovative solutions and reduce environmental impact.

Conclusion: Flexibility is the antidote to “death by success.” Companies that cling too long to their old, successful models lose out to those willing to disrupt their own achievements in pursuit of new technological opportunities.

The circular economy provides mechanisms for creating value that do not rely on the consumption of finite resources. Consumption occurs within efficient biocycles, or usage displaces consumption, with resources being regenerated within the biocycle. Today, globalization offers significant advantages for businesses: the ability to explore new markets, benefit from reduced trade barriers, and adapt more quickly to technological progress. However, due to intensified competition, it is increasingly challenging for enterprises to achieve, maintain, and strengthen their competitiveness. The transition to circular business models represents a substantial competitive advantage for any enterprise, as modern consumers place great emphasis on product quality, environmental sustainability, and corporate social responsibility.

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IMPROVEMENT OF ENTERPRISE PERSONNEL MANAGEMENT BASED ON CLOUD HRM TECHNOLOGIES

Mohylna Liudmyla

PhD in Economic Sciences, Associate Professor, Sumy National Agricultural University, Ukraine

ORCID ID: 0000-0002-9053-5177

Human resource management is an important component of the successful functioning of any enterprise, and this is especially true for private transport companies, where efficiency depends not only on the technical condition of transport, but also on the human factor. It should be emphasized that personnel is the main criterion for the enterprise's ability to compete.

Human resource management as a science began to take shape in the 20th century, when the need for a systemic approach to human resources became apparent. Modern theories of human resource management are based on research in psychology, sociology, economics and other sciences. Classical management theories, such as Frederick Taylor's school of scientific management, focused on rationalizing work and increasing productivity through standardization of processes. However, in the context of private motor transport enterprises, it is important to also consider humanistic theories that emphasize the importance of motivation, communication and personnel development.

First, let us justify the terms used in the constructed definition. An analysis of scientific publications related to this topic makes it possible to assert that the authors use different terminology in their works: we are talking about human and labor resources, personnel, staff. The correlation of terms used in the studies of economists can be represented using Euler circles (Figure 1). Labor resources include people both employed in the economy and not employed, but able to work. Personnel is the personnel of the enterprise. That is, these are all employees who take a direct part in the activities of the organization in order to achieve its goals. Staffs have a "tie" to the industry or enterprise, institution, organization in which they carry out labor activities, and they are hired.

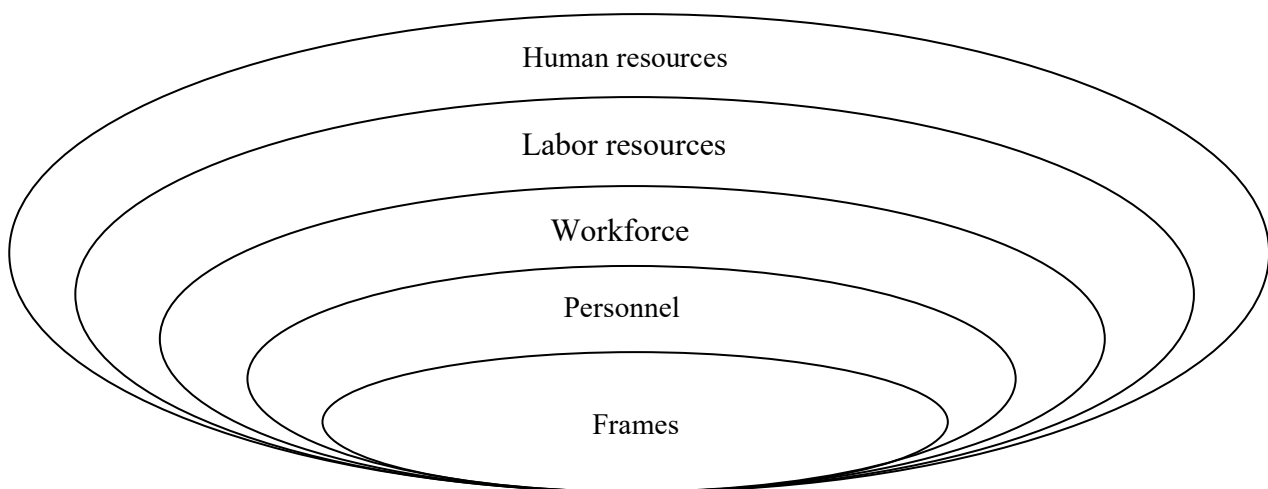


Figure 1. Correlation of definitions of "human resources", "labor resources", "workforce", "personnel" and "staff"

Source: generated by the author

Enterprises with the same type of activity have, first of all, different production environments, which are presented as a set of conditions in which work is performed and include physical, social, psychological and environmental factors, that is, everything that surrounds a person in the process of work: technical equipment of the organization, features of technological processes and production, condition of buildings, structures and engineering communications, sanitary-hygienic and aesthetic conditions, relationships in the work team, etc.

In order for an employee to be able to work successfully at a certain enterprise, he needs to go through the stage of industrial adaptation. This process includes familiarization with the specifics of the company's work, integration into communication networks, getting to know the team, mastering the corporate culture and

rules of conduct. The employee must also practically master his duties and requirements set by the enterprise, and establish interpersonal relationships with colleagues. He gradually overcomes industrial and social difficulties in order to move on to stable and productive activities. Even if a new employee has special training and experience in similar departments of other companies, in the new organization there may be different approaches to solving tasks that are already familiar to him.

The issue of personnel management is given much attention in the scientific economic literature, however, there is no single unified definition of this concept and there are many interpretations. In general, the essence of personnel management is the human resource acquired in a certain struggle on the labor market, which constitutes the value of companies. That is why in order to achieve economic benefits and goals of the enterprise, from the use of knowledge to the skills of its employees, it is necessary to stimulate, motivate and develop them.

We would like to emphasize that after thoroughly researching and studying the essence of the considered definition, we have proposed the following vision of it. In our opinion, human resource management is a strategic process of planning, attracting, developing and retaining employees. This term includes recruitment and selection of personnel, training and development, as well as performance evaluation.

The goals of personnel management, including a private enterprise, are key to its success and sustainable development (Figure 2). They help ensure that the qualifications of employees meet the requirements of the enterprise, increasing work efficiency, and also contribute to the formation of a motivational system that stimulates the productivity and loyalty of employees. The implementation of such goals ensures the competitiveness of the enterprise in the market through the optimization of human resources.

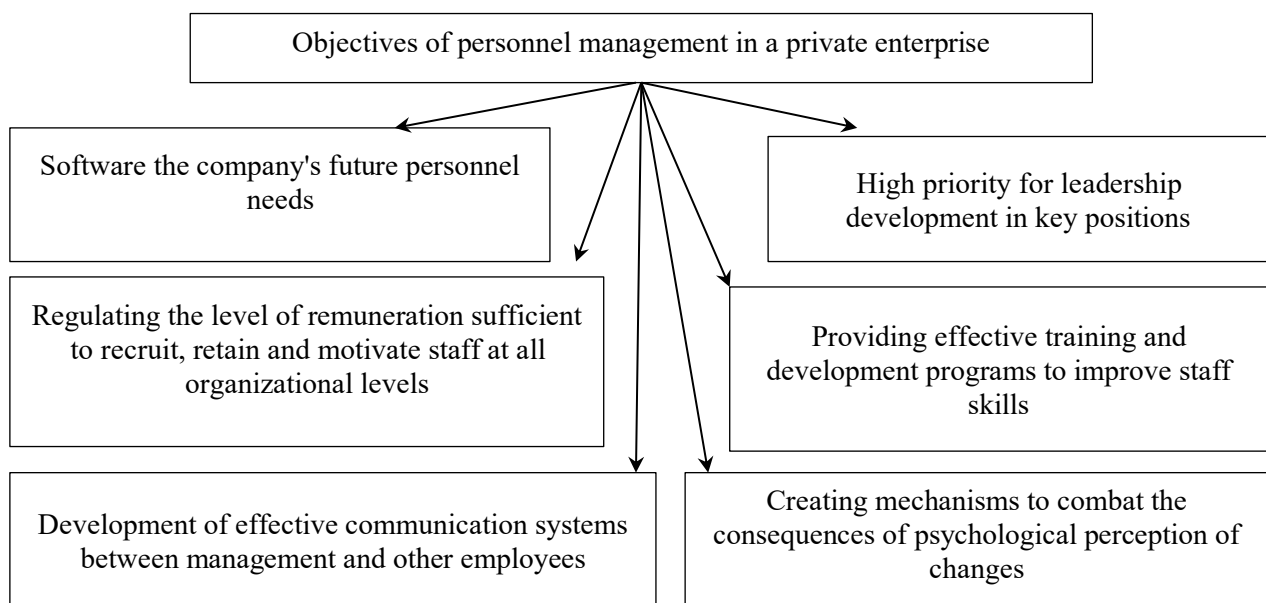


Figure 2. Objectives of personnel management in a private enterprise
Source: generated by the author

The main goal of personnel management is to organize the team in such a way that joint efforts achieve an effective result. The main goal of the human resources management strategy is the development of the employee and the achievement of goals by the organization. This is achieved through: first, training and professional development of employees; second, improving the creative capabilities of employees; third, ensuring the social needs of employees. The organization's personnel management is subject to certain principles.

Thus, the enterprise's personnel management is aimed at the optimal use of personnel and time for the purpose of successful organization of its activities and comprehensive development of the individual. In general, the enterprise's personnel management is a function of line management.

The process of personnel management is aimed at achieving specific goals of the organization. The effectiveness of the organization's management activities is determined by the real results of its activities. In

general, the practice of developing effective methods of personnel management in economic science has a long history, but the relevance of this task does not decrease today. The dynamism of the external environment of the enterprise, innovative changes in production and implementation lead to the fact that previously productive personnel management systems do not guarantee the expected return. This leads to the idea that sustainable personnel management efficiency can be achieved only by integrating performance factors in a single systemic mechanism of personnel management, which is potentially capable of adapting to inevitable changes.

Personnel is becoming one of the key types of resources with a constantly updated productivity potential, on which the sustainable economic activity of the enterprise depends. Discussing the issue of synchronicity of personnel strategy and the general strategy of enterprise development, scientists came to the conclusion that personnel strategy can be subordinated to the general strategy of the enterprise and, in the case of ensuring the interests of personnel, is implemented through the participation of personnel management in strategic management. It can also act as an autonomous means of solving management problems with its own principles, but at the same time should not contradict the general strategy of the enterprise. A systematic approach as a tool for increasing the efficiency of personnel management of the enterprise is achieved through deep integration of the interests, goals and objectives of all participants in economic activity during the development of a personnel management strategy. This process provides a harmonious complement to the key measures of the general strategy of enterprise management. Creating an effective human resources management strategy is one of the main factors in the successful functioning of the enterprise. Such a strategy involves a set of management actions aimed at maximum use of the potential of employees.

The development of a human resources management strategy includes an analysis of the characteristics of the enterprise, determining the possibilities for its development in both the short and long term (Figure 3). These actions must be consistent with tactical and operational plans that directly relate to the main areas of business activity. It is also important to take into account the impact of the external environment on management processes and adapt the personnel strategy accordingly.

The HR strategy plays an important role in achieving the business goals of the enterprise, optimizing the processes of hiring, adapting and developing personnel. It contributes to improving the qualifications and motivation of employees, as well as establishing effective relations between management and employees. Successful implementation of the HR strategy allows you to increase the efficiency of personnel work, improve the quality of products or services and increase profits. The implementation of the HR strategy is a key condition for the enterprise to adapt to external changes and increase its overall efficiency.

Personnel management implies not only the formal organization of work with people (planning, selection and placement), but also a number of social factors of a social nature: a democratic management style, concern for people's needs, taking into account their individual characteristics, and others. In unstable conditions, personnel management (with an unstable situation in the country) should take into account a whole range of problems that adapt the employee to the external and internal conditions of the organization's work. Personnel management in the field of anti-crisis management should include the use of effective measures, namely: to reduce the organizational structure of management, it is necessary to reduce management levels, not jobs; it is also necessary to strengthen the personnel reserve for the highest level of the organization; at the same time, one should not engage in mass staff reductions. It is necessary to create a structure of employees with the best characteristics for the current situation and the financial recovery plan; in order to assess the staff, it is necessary to regularly conduct quantitative and qualitative assessments; it is recommended to support and train employees of the organization who have leadership qualities or are inclined to managerial activities; Based on the creation of a strategic and tactical personnel reserve, it is necessary to prepare potential candidates for key management positions; it is necessary to give priority to the team, rather than individual efforts of the company's personnel; it is necessary to identify and preserve the core of the organization's human resources potential.

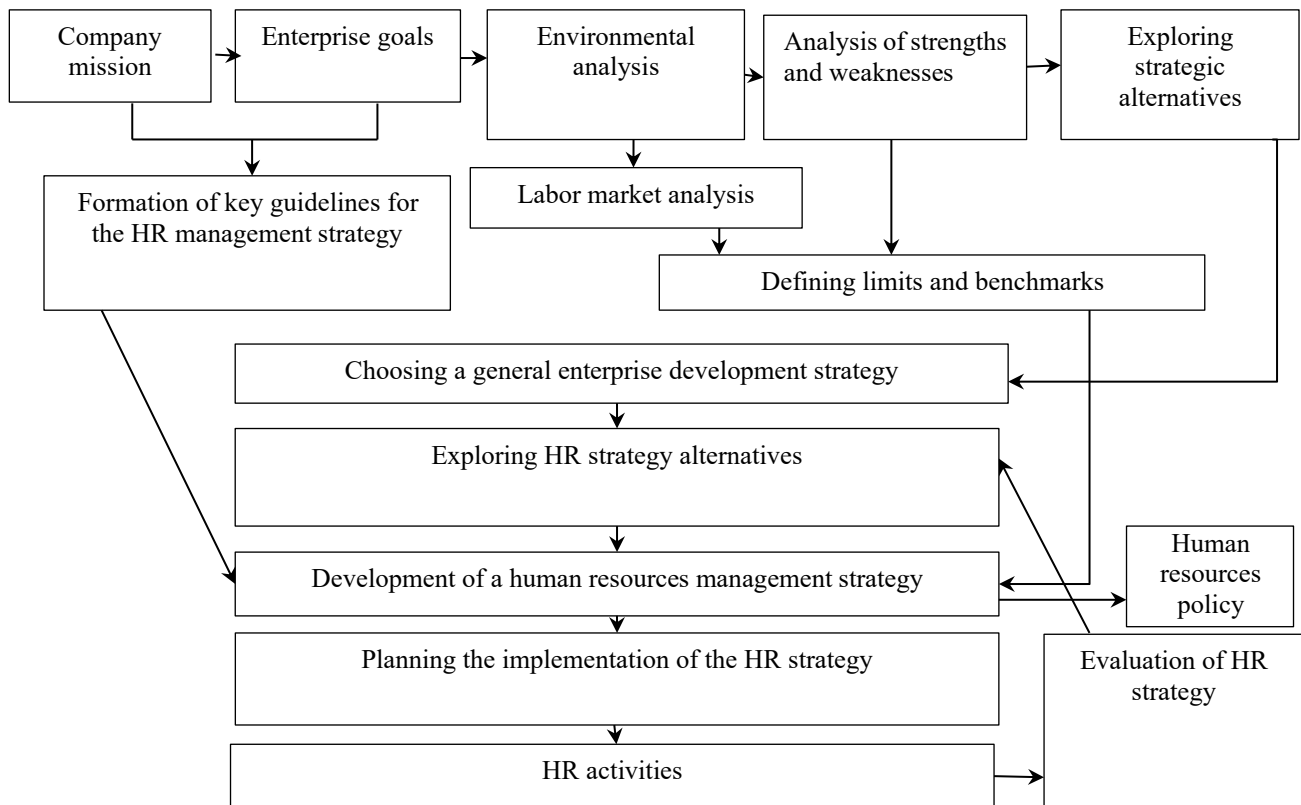


Figure 3. The main stages of forming and implementing a human resources management strategy for a private enterprise

Source: generated by the author

According to the anti-crisis personnel policy, it is necessary to form such a personnel system to achieve not only economic and social consequences, but also subject to compliance with current legislation. Today, when hostilities are observed in the country, personnel management is forced to change its policy. There are several reasons for their organization: limited financial resources and the need for organizational measures, which is accompanied by a reduction in a number of social development programs or a reduction in the number of personnel. The main ideological principle of the anti-crisis intervention policy is to survive with minimal losses of personnel potential and ensure the maximum possible social security for personnel. Thus, in modern realities at Ukrainian enterprises, a crisis situation often arises, which primarily indicates insufficiently effective and high-quality personnel management.

In recent years, a number of changes have been observed in the practice of human resources services, primarily related to changes in personnel strategies, the introduction of innovative technologies in personnel management, as well as the automation of procedures that are easily algorithmized: the introduction of electronic document management, personnel accounting, as well as working time accounting, drawing up vacation schedules and shift schedules, salary calculations and accrual of additional payments, organization of employee training in a distance format, etc. That is why human resources management in the information society has certain trends, the characteristics of which are given in Table 1.

When identifying key trends in HR management, it is necessary to highlight the main fundamental changes in HR management of enterprises that contribute to increasing the efficiency and effectiveness of commercial activities of enterprises of various forms of business.

Table 1. Trends in HR Management in the New Economy

Trend name	Brief description
Changing the psychology of the employer and employees	Enterprise specialists in the new economy must possess key qualities: the ability to work in a team, awareness of the need for continued education, readiness for change, knowledge of the basics of self-management and communication skills, and the ability to adapt to the current situation.
Shaping the knowledge economy	Based on the collective intelligence, qualifications and ingenuity of employees, modern tools, freedom of creativity and business, and instant response to ongoing changes.
Competition for resources and workers	The competitiveness of personnel in the conditions of growing competition is of crucial importance for the effective operation of the enterprise; therefore it is necessary to pay special attention to the factors that ensure it. Global competition in the labor market has strengthened the demand for workers and increased wages. Competition for workers increases the cost of labor.
Managing and embracing change	The readiness of staff to realize the need for individual and group awareness of change, behavioral change, and belief in the success of the change, which depends on their level of competence and enthusiasm for change.
The new role of the HR manager	The HR manager acts as a mentor and consultant, brings the technology of enterprise HR management to each employee, and contributes to the inclusion of personnel in the list of strategically important factors of activity.

Source: [6, p. 165]

These include: the formation of a personnel ecosystem, increased attention to corporate social responsibility, active implementation of new work methods and new places to work, digitalization of recruitment technologies, digital transformation of employee training, HR marketing, increased attention to external and internal HR branding tools (Table 2).

Table 2. Fundamental changes in the field of personnel management

Change	Content
1 Forming a personnel ecosystem: managing employees outside the enterprise	Over the past few years, "alternative employment" such as freelancing, project work, part-time work or gig work has become increasingly common. The ecosystem includes both full-time and part-time employees, as well as contractors, remote workers, partners, agents, freelancers, gig workers and crowdsourcing workers, focused on various projects and individual tasks. As a rule, "alternative workers" have little interest in the overall strategy of the organization and do not seek to understand it. Among the problems faced by HR managers, one can single out the lack of HR software and effective tools that help employers manage such non-traditional employees, as well as training and performance evaluation systems for such employees.
2 Increasing attention to corporate social responsibility implementing new	In EU countries, the following criteria for assessing the level of development in the organization of corporate social responsibility have become widespread: absence of discrimination in personnel selection; level of employee integration; degree of integration into the team of employees with disabilities; availability of a system of support for employees employed in "critical positions" and their retraining; quality of dialogue with trade unions; observance of correct working conditions; – formation of hyperconnected workplaces;
3. working methods and new places to work	– formation of flexible and adaptive workspaces. Along with the traditional "corridor-office" system of workplaces, the concept of an open office, aimed at improving employee communications within the company's structural divisions, as well as the flexible office system (flex-office), are becoming increasingly widespread. The implementation of a flexible office system is advisable for companies that employ many employees who work remotely or have a flexible work schedule. Within the framework of the flexible office system, several work zones are distinguished, which are determined by the specifics and direction of activity, the duration and complexity of the work performed, individual or collective decision-making, etc.; - use of Agile and Scrum approach. The mission of Agile can be formulated as follows: we constantly discover more advanced and attractive methods of work and help other people in this. The Scrum methodology is based on a simple idea — "test and adapt". When developing a project, according to its author J. Sutherland, it is necessary to systematically check the progress of work and answer the questions: is the movement in the right direction; what does the customer really want to get; are there ways to improve the methods of development and work execution; how can the work be done more efficiently and quickly; are there factors that hinder your tasks

4 Digitalization of recruitment technologies	digitalization of recruitment technologies. Key trends in this area are automation of screening and the hiring process. The main tools of digital recruiting are: robot recruiter, chatbots, business process automation (the most popular services are VCV, Navicon, Preinterview and Skillaz), predictive analytics and work with big data, aggregation and uberization, cognitive selection (Design Thinking)
5 Digital transformation of employee training	Its main features can be considered: – constant exchange of experience and knowledge, learning while working on real work processes; – formation of personalized digital learning content; – ensuring access to training programs at any time, in any place and with any type of device (implementation of a mobile learning system and cross-platform solutions); – formation of an electronic distance learning system: massive open online course, for example, through the Coursera, EdX platforms, corporate open online course, small private online courses, webinars; – creation of virtual platforms for learning (solving cases and exercises in a virtual environment, creating virtual simulations); – providing the possibility of receiving instant feedback (automated verification of work using Big Data technology, implementation of microlearning technology with time-distributed assessment of granular knowledge, skills and abilities)
6 HR marketing, increased attention to external and internal HR branding tools	aimed at attracting potential candidates and forming a loyal, broad audience for the company. Among the current tools for attracting talented employees, one can note the technology "HR Ambassador" (HR brand ambassador)

Source: compiled by the author

It should be noted that most modern enterprises, and the automotive industry is no exception, tend to use digital tools for recruiting personnel more often than using traditional sources. One of the most promising digital tools that allows you to optimize mass recruitment in an organization, which involves the largest number of employees in a short time for positions that do not require high qualifications is chatbots. These are programs for interactive interaction between the employer and candidates. Currently, two main types of chatbots are used: text and telephone. Text chats are presented in the form of a chat with written answers from candidates. Telephone chatbots are an automatic call by a robot to candidates and recording oral answers to questions recorded in advance by the employer. This format allows HR staff to save a significant amount of time, since communication with candidates occurs without their personal participation.

It is worth noting that instead of the usual placement of job advertisements on the Internet, modern enterprises use the modern digital tool Clickme, created on the basis of the popular HeadHunter service. Clickme is a service for self-placement of smart advertising, which shows vacancies only to targeted candidates based on the interests and requests of the user. The recruiter selects the audience independently, setting the desired settings according to the criteria: region, gender, age, income, language skills, professional field, education. Thus, there is a transformation of the traditional source of recruitment – advertising in the media – into a modern and more effective recruitment technology. Also used are such tools as: robot recruiters; chat bots; targeted advertising of vacancies, etc.

Personnel management in a motor transport enterprise is an important element of ensuring its effective work and competitiveness and has its own characteristics. It is recruitment that plays a key role in forming a highly qualified workforce. The selection of professional drivers, mechanics, dispatchers and administrative staff is carried out taking into account their qualifications, experience and responsibility. Psychological testing and in-depth interviews help to select the best candidates. Training and development of personnel is the next important aspect. Regular advanced training, courses on road safety and vehicle maintenance allow employees to update their knowledge and skills. This contributes to improving the quality of work and safety on the roads. It should be emphasized that employee motivation is another critical factor. The introduction of a system of rewards and bonuses for high productivity and safe work stimulates employees to perform their duties qualitatively. Social guarantees, such as medical insurance and pension programs, increase staff loyalty to the enterprise. Favorable working conditions, including comfortable workplaces and modern equipment, reduce the risk of occupational diseases and accidents, which also contributes to increasing work efficiency. Personnel management in a transport enterprise requires a systematic and comprehensive approach. Such an approach

ensures not only the efficient operation of the enterprise, but also high quality of services and employee satisfaction, which ultimately has a positive effect on the overall efficiency of the company.

It should be noted that the successful functioning of the enterprise largely depends on a well-developed personnel policy. This assessment is the main tool for analyzing employee productivity and satisfaction. It involves analyzing key indicators such as productivity, staff turnover, and job satisfaction. Regular surveys, feedback, and periodic assessments allow you to identify strengths and weaknesses in personnel management, which allows management to take timely corrective measures to improve the working environment, increase staff motivation, and productivity. Effective personnel management is the key to the stable development of the enterprise and increase its competitiveness in the market.

The availability of labor resources and the completeness of their involvement give some enterprises absolute and comparative competitive advantages over others. The role of labor potential in ensuring and increasing the competitiveness of enterprises is particularly significant. It is no coincidence that more and more attention is now being paid to the personnel component of enterprises, since today it is impossible to achieve successful development and stable competitive advantages, remaining within the framework of the former system of personnel management. It is necessary to radically change the attitude towards this area, develop progressive approaches to personnel management of enterprises, and organize large-scale training in the skills of their practical use. And the primary stage of this process is the development of a competitive personnel policy.

The personnel policy of any motor transport enterprise is largely determined by a number of specific factors such as: the peculiarity of transport products, the heterogeneity of motor transport enterprises in terms of structure, scale, areas of activity and forms of ownership, the specifics of the drivers' labor process, etc. It should be noted that the level of solving the problems of the personnel policy of a motor transport enterprise is quite low, due to the level of general culture of employees in this industry, the low proportion compared to other areas of the national economy of specialists with higher education, insufficient professional training of personnel service employees, bureaucratization of structures that carry out personnel activities, etc.

Using various methods of collecting information, as well as based on data obtained through personal observation and assessment, it is possible to structure the main problems of the personnel policy of passenger transport enterprises regarding individual categories of employees (Table 3).

Obtaining high results of the enterprise's activity (decent profit/revenue) by optimizing personnel costs is the main direction of the personnel policy of passenger motor transport enterprises. Moreover, as a tactic of behavior in a crisis situation, such a measure as job reduction was taken. Thus, it turns out that the same amount of work must be performed by fewer people, for the same amount of salary. In addition, the staff is forced to stay overtime to perform this amount of work, but the employees are not paid for this time. The personnel management style of state passenger motor transport enterprises can be characterized as authoritarian, with minimal consideration of the needs of employees, provided that the maximum possible powers and completeness of information are concentrated at the upper levels of management.

Table 3. Main problems of personnel policy of passenger transport enterprises regarding certain categories of employees

Personnel category	Main problems
Drivers	Forced rework; non-compliance with work and rest schedules; unfair wage structure; low level of driver qualifications; loss of prestige of the profession
Technical service employees	Low level of training of repair workers (quite often, repairs of the car fleet are carried out by "self-taught" people); difficult working conditions in the absence of an appropriate technical and technological base
Administrative and managerial staff	Lack of participation in management decision-making; low professional potential compared to personnel in other sectors of the economy; bureaucracy of those structures that implement personnel policy for the enterprise; low level of professional training of personnel services employees

Source: own research

Although training qualified employees and maintaining their qualifications require significant financial investments, modern companies view these costs as investments that should provide a return in the form of increased efficiency. From this point of view, one of the main tasks of personnel policy is to maximize the

results of these investments. Therefore, the theoretical and practical aspects of assessing the effectiveness of personnel development are of great importance not only for business, but also for all enterprises that seek to rationally use their resources.

Effective human resource management is critically important for the success of any company. Evaluating the effectiveness of this process allows us to understand how productively PE "KOMPOL" (hereinafter referred to as a PE) uses its personnel. Such an assessment helps to identify weaknesses in personnel management and provides an opportunity to eliminate them. Attracting and retaining qualified employees ensures stable growth and development of the company. Personnel management, based on an objective assessment of its results, allows not only to retain important employees, but also to quickly respond to changing personnel needs. Currently, there is a problem of providing passenger transport enterprises with specialists with appropriate qualifications. There is an acute need for working personnel. The personnel of the enterprise can be conditionally divided into two groups: the first is managers and specialists responsible for organizing passenger transportation; the second is bus drivers and mechanics engaged in technical maintenance of transport. It is the number of this second group that determines the volume of transportation.

Effective management of both groups of personnel is an important condition for ensuring the stable operation of the enterprise and its further development. First of all, the results of the work of a research private enterprise and high quality of service provision are achieved with the presence of highly qualified management. It is the professional competencies and extensive knowledge base of the manager that allows the organization to adjust the process of service provision taking into account existing socio-economic conditions and increase the profitability of enterprises.

In quantitative terms, the structure of the enterprise's personnel is dominated by working professions, mainly drivers. This professional group has a rather low level of education and has great professional mobility. The main personnel problem of transport is that the quality of services depends on the work of low-skilled workers. Accordingly, special attention of the personnel service should be paid to forming a core of personnel from highly qualified employees and gradually increasing the qualification potential of employees of organizations as a whole, as well as forming a personnel reserve. In the management of personnel of a motor transport enterprise, the so-called "technocratic approach" prevails, which is based on the philosophy of positivism (one of the founders is F. Taylor). This approach is the basis for an authoritarian management style, in which a person is not distinguished as a separate personality, but is perceived as a part ("cog") in a man-machine system. Improving the performance of a private enterprise is achieved through rationalization – increasing the level of exploitation of all the components of these systems, in particular human resources.

This style of enterprise management is now outdated and ineffective for objective reasons. The most effective approach to personnel management is humanistic, which involves creating conditions for comfortable work, allowing employees to feel their significance for the enterprise, see the results of their activities and link them with the achievements of the motor transport enterprise as a whole. This approach allows reducing staff turnover, increasing the level of employee satisfaction. Thus, in motor transport enterprises, it is necessary to change the personnel policy towards a humanistic approach, to pay more attention to personnel as the main driving force of the enterprise. Due to the high level of personnel turnover, it is necessary to analyze the reasons and motives for employee dismissals. The composition and number of employees are influenced by a system of factors, which can be divided into external and internal by the form of influence (Figure 4).

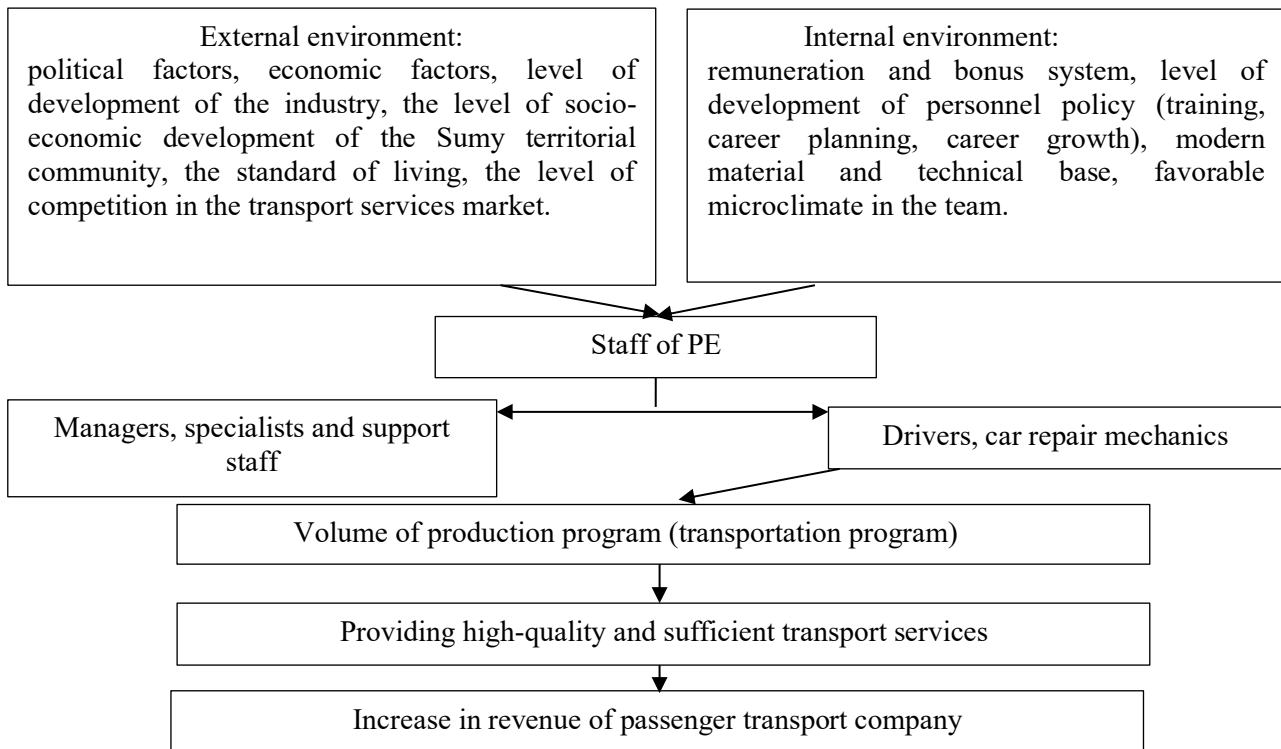


Figure 4. Personnel of a motor transport enterprise: formation factors and dependence of achieving the goal of PE on its characteristics
Source: own research

External factors have an indirect effect on the employee's desire to change the place of work; internal factors depend on the level of organization of the labor and production process in PE.

The number of support staff depends on the number of main workers (mainly minibuses drivers), as well as such an important indicator of the work of a motor transport enterprise as the volume of the transportation program. The larger the transportation plan, the more the need for transport services is satisfied and, accordingly, the quality of service provision increases.

The quality is also greatly influenced by the qualification level of the staff. In turn, the improvement of transport services contributes to the growth of passenger traffic and the increase in the income of PE. There is a direct relationship between the number of main workers and the volume of the production program – the more workers, the larger the program, and vice versa, with a decrease in the number of staff, the transportation program also decreases.

It should be emphasized that the principles of personnel management in PE are closely related to the assessment of the effectiveness of personnel management, since they determine the approaches and methods that affect the results of personnel work and the overall success and goal of the enterprise (Figure 5). Each of the principles of personnel management creates the basis for the effective functioning of the enterprise.

The assessment of the effectiveness of personnel management is based on the analysis of how successfully these principles are implemented and allows you to adjust management approaches to achieve better results. It shows how effectively the principles of management are implemented in practice and what results this brings to the enterprise. Improving the staffing of the enterprises of the motor transport complex is facilitated by the application of a number of basic principles of personnel management.

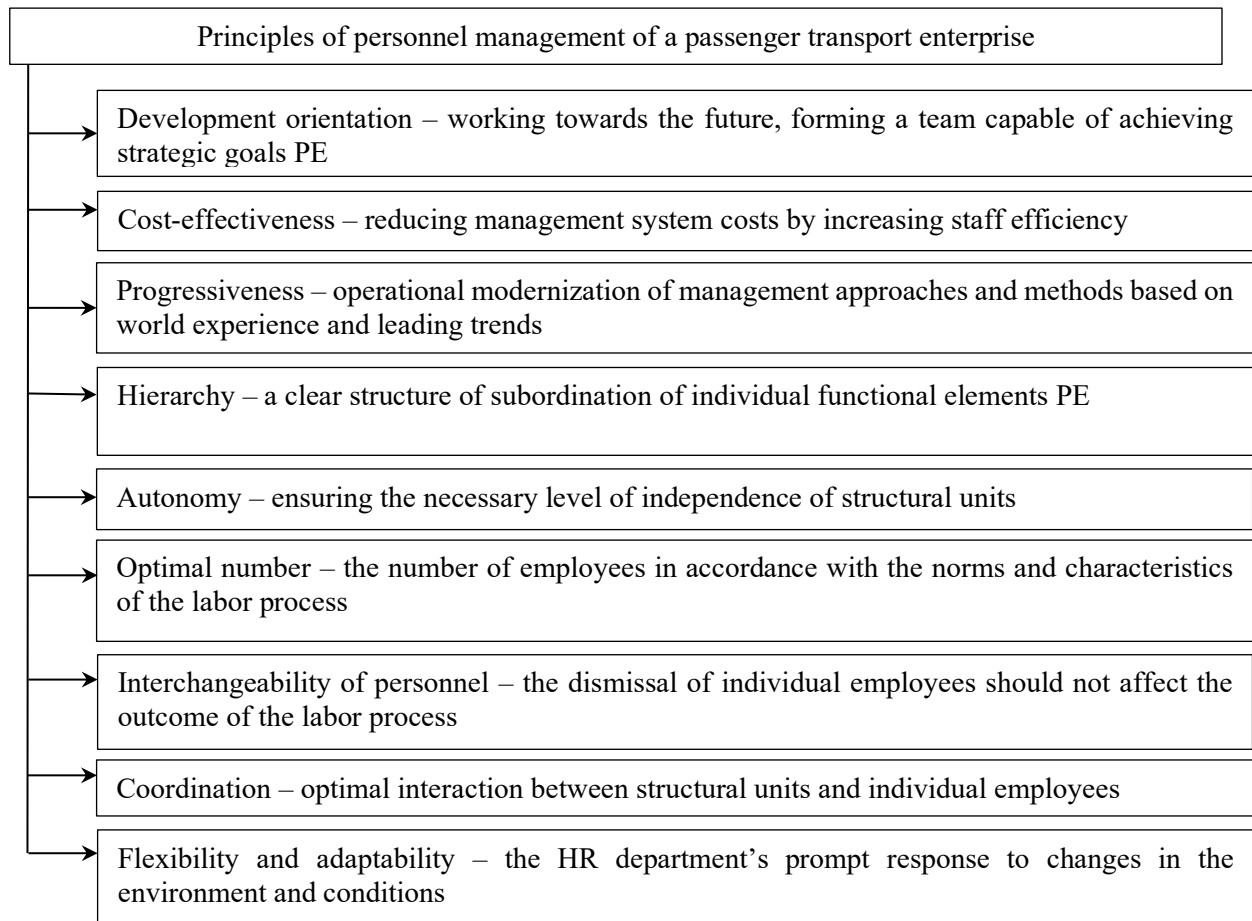


Figure 5. Principles of personnel management of the private enterprise PE
Source: own research

In our opinion, the most important principle is the orientation towards development, since it is he who sets the necessary vector, the direction of development, which is achieved subject to compliance with other principles as a result of the coordinated work of the entire team of a private motor transport enterprise. The principles of personnel management are aimed at forming the necessary personnel structure, filling vacant positions taking into account the professional and qualification characteristics of candidates and, importantly, maintaining the stability of the team and its development. Implementation of the listed principles will allow enterprises to reduce the number of layoffs, contribute to increasing labor productivity and maintaining a favorable microclimate in the team, these principles are the basis for improving the quality of services. Therefore, it is necessary to solve the problems of personnel shortage taking into account existing factors while using the experience of past years, applying modern methods and principles of personnel management. It is necessary to take into account that personnel is the main and most important resource of motor transport enterprises and the level of service quality depends on its quantitative and qualitative characteristics.

Based on the analysis of the economic activities of PE, it is possible to identify negative and positive aspects in the organization of personnel management (Table 4). The indicated shortcomings indicate problems in the organization of the company's personnel management system. Management should pay attention to these shortcomings, since they negatively affect the overall results of the enterprise.

Table 4. Advantages and disadvantages of the personnel management system in PE

Advantages	Disadvantages
Training of personnel before assuming official duties.	Lack of long-term human resources planning.
When hiring, preference is given to a candidate with experience, which allows you to avoid spending money on additional training.	Lack of personnel reserve due to the military situation in the country.
Rapid adaptation of personnel to an informal environment.	Lack of professional advancement of staff.
	Lack of encouragement for staff initiative.
	Partial lack of decent financial incentives.

Source: own research

Let us consider in more detail these shortcomings in the personnel management system. First of all, this is the lack of long-term personnel planning. Personnel selection is carried out only when there is a need to provide the enterprise with the necessary personnel, which leads to the hiring of employees only in case of urgent need. This approach gives rise to a number of problems, including delays in the selection of suitable candidates due to the urgency of the situation.

Everyone knows about the benefits of system analysis, study and research of business processes, especially about SWOT analysis of the personnel management system. No one has ever managed to build an enterprise that functions effectively and actively develops without feedback: analysis of the current state of affairs and achieved results, adjustment of goals and objectives in accordance with the strategy and mission, constant monitoring of indicators – what was planned and what turned out as a result – analytical methods are indispensable here. All this, of course, applies to the HR sphere, to which SWOT analysis of personnel assessment in the enterprise also belongs (Table 5).

Of course, that Using SWOT analysis allows an enterprise to objectively review its positions on the HR management system, identify strategic priorities and develop effective solutions to achieve long-term goals. It is a tool that helps turn potential challenges into new opportunities, ensuring stable and sustainable development of a private enterprise. SWOT analysis allowed us to form a complete list of strengths and weaknesses, opportunities and threats necessary to improve the human resources management strategy.

In summary, the assessment of the effectiveness of personnel management in PE in Sumy is not just a tool for determining the current state of affairs, but also an important element of strategic management. It allows you to identify the strengths and weaknesses of management, develop measures to improve efficiency and ensure sustainable development of the enterprise in the future. The management of PE should consider personnel management as a key factor of success, investing in the development of its employees and forming a corporate culture that contributes to the achievement of the enterprise's ambitious goals.

Table 5. SWOT analysis of the personnel management system

Strengths	Opportunities
Management's readiness for development Management, through informal sources, is interested in the climate in the team and the problems that concern the majority. Availability of professional development programs The presence of elements of a program to increase staff motivation – corporate New Year's holidays, bonuses, etc. Regular assessment of employee performance, income dependent on work results Extensive social package	Improve the company's image Innovative processes in the personnel management system Increasing the level of professionalism of personnel Regulate and implement a formal practice of surveying staff regarding satisfaction with working conditions and other motivational factors
Weaknesses	Threats
Insufficient professionalism of staff Increasing staff turnover Lack of career growth Stressful nature of the work. Insufficient staff to cover all passenger needs There is no practice of formal questionnaires, staff surveys regarding satisfaction with working conditions and other motivational factors. Limited budget for staff training	Instability of the economic situation in Ukraine There is strong competition for the best employees with other enterprises providing passenger services Limited financial resources Low efficiency of the personnel motivation system Low interest of ordinary employees in the development of the enterprise Unpreparedness to perform a large volume of passenger services

Source: author's own development

In essence, the specific content of enterprise personnel management is the process of effectively optimizing the allocation of human resources for a private enterprise engaged in passenger transportation. Based on this, in the enterprise personnel management system, it is necessary to make a reasonable distribution of all employees in the enterprise, taking into account their personal qualities and abilities, to ensure the effective use of human resources in the enterprise. In addition, in the process of personnel management, the comprehensive level of the enterprise's personnel team is improved through the development of human resources, which provides a stronger driving force for the long-term and stable development of the enterprise.

Analysis of problems existing in personnel management of PE:

1. Lack of awareness of innovation in enterprise management. Some modern elements have been incorporated into the enterprise development process, but there is no innovation consciousness, and some traditional management models are still used. This is mainly because the relevant management personnel of the enterprise are not familiar with the latest management innovations, do not pay attention to the important value of human resource management, and only focus on the short term.

2 Incomplete enterprise management system. In the process of enterprise development, a corresponding institutional system is needed as an important basis for the development of work. On this basis, the enterprise should innovate its own personnel management system and promote the efficiency of personnel managers in specific work through specific norms and standards, accurately analyze the specific reasons for the existence of various personnel management problems, and be able to solve them according to the actual situation.

3 The personnel composition of PE is not sufficiently optimized. The main content of the enterprise's personnel management is the need to achieve effective management and development of human resources, through the relevant personnel management work to comprehensively analyze and compare the actual working capacity and level of specific employees, and combine the actual status of the personnel with the work. The level is assigned to more reasonable work positions, which can effectively enhance the interest of the personnel, ensure the full fulfillment of the role of the personnel, and realize the long-term development of the enterprise.

The strategy of enterprise personnel management in modern conditions:

1 Create a modern concept of personnel management. PE should continue to create a new concept of personnel management based on traditional concepts of personnel management, emphasizing the importance of specialists. In the strategic goal of the enterprise, personnel management should take the initiative to influence its implementation. PE needs to spend a certain amount of time and money on personnel management.

2 Formulate a systematic performance appraisal and an effective incentive mechanism. The private enterprise should conduct in-depth consultation with employees when implementing appraisal plans. The content of the appraisal should be suitable for all employees who hold the same position. The appraisal standards should be clear and understandable. The appraisal results should be made public, and at the same time, it is necessary to point out the shortcomings of employees. In addition to suggestions for improvement, employees who excel in the appraisal should be encouraged. Usually, if large-scale appraisals are formal in nature and accompanied by a written report, each employee should be informed of this. From the formulation of the appraisal plan to the announcement of the appraisal results, everything should be honest, fair and transparent.

3. Create a flawless personnel management system. A perfect personnel management system is one of the conditions for the enterprise to be an industry leader. PE must create a set of intelligent systems for recruiting, assigning, training, promoting and dismissing personnel to ensure the smooth development of the service provision process at the enterprise.

4 Improving the personnel training mechanism. In the work on human resources management, the studied enterprise needs to pay attention to the effective development of human resources and the use of professional skills of employees, therefore, it is necessary to pay attention to timely training of employees. In addition to the selection of more professional personnel, it is also necessary to regularly train employees in PE so that the overall quality and professional level of the enterprise's personnel can be constantly improved and fully meet the requirements of the enterprise in its long-term development.

In conclusion, it can be said that it is necessary to further optimize the personnel management structure of the private enterprise under study, make personnel management work more important, and promote the long-term development of the private enterprise itself.

It should be emphasized that key problems in personnel management were identified at the experimental enterprise, and we developed recommendations for their elimination. To improve the personnel management

system in PE, a number of measures can be implemented (Table 6). The effectiveness of the enterprise's activities largely depends on how coherently the personnel management policy is implemented.

We would like to emphasize that due to the difficult military situation in the enterprises of Sumy, there is a high turnover of personnel. Our enterprise is no exception. At the same time, new personnel are coming to replace them. That is why employee adaptation is a critically important process for the successful work of PE, because it ensures the rapid integration of new employees into the corporate culture, increases their motivation and productivity.

Proper adaptation reduces the level of stress, helps newcomers to master their duties faster and minimizes the risk of errors. This also contributes to the formation of a positive working environment, which increases employee loyalty to the enterprise.

By investing in adaptation, the enterprise ensures stable development, improves teamwork and reduces staff turnover, which will ultimately have a positive impact on financial results. If we talk about innovative improvements to the mechanism for managing the personnel adaptation process, they can be implemented using the following tools:

- Buddying – a new employee is supported by an employee who is at the same level of the hierarchy as him, as a result of which adaptation takes place in a relaxed and informal manner. This situation helps to establish interpersonal relationships faster and helps create comfortable conditions for the newcomer, which ensures the new employee's quick entry into the position and acceptance into the team;

- Jobshadowing – a new employee becomes a "shadow" of an experienced specialist and observes him. The advantage of this method over mentoring and buddying is the release of an experienced specialist from the direct process of training a new student as such, according to which he can effectively perform his professional duties, bringing income to the enterprise;

- immersion – a method in which the adaptation of a new employee occurs as they master current job duties. This approach can be chosen only for experienced employees and allows a private enterprise to have no additional costs or to minimize them.

Table 6. Recommendations for improving the personnel management system in PE

Direction	Recommendation
Clear and interesting information	Conduct training to convey to employees the mission and goals of PE, ensuring that employees are aware of and responsible for their activities.
Recruitment and training	Provide the opportunity to send your employees to educational centers where they will improve their skills their professionalism and qualifications at the expense of PE.
Systematic training and retraining of employees	Systematic improvement of the professional level of personnel and, as a result, increased efficiency of the enterprise. Competent introduction of innovations and their application in PE.
Adaptation and mentoring programs	Improving the image indicators of a private enterprise in the labor market, maximizing the use of the professional abilities of personnel.
Implementation and expansion of motivational tools	Ensuring occupational safety, discipline, and teamwork skills.
Certification aimed at identifying basic skills, abilities, abilities, as well as the ability to learn	Adjust the management strategy of PE to its capabilities and requirements.
Work to reduce conflict situations and prevent them. Improving the social climate in the team	The formation of a permanent team interested in the strategic goals of the enterprise, understanding them as their own.
Increasing the education of the team	Opportunity for career growth, implementation of new ideas for optimizing processes by employees involved in direct activities.
Implementation of social programs	Full interaction with the employee and understanding of his aspirations and desires within the framework of work activities. The emergence of corporate culture.
Social motivation	Various celebrations can be organized at the company's own expense, such as anniversaries. Organizing various holidays, you can help improve the corporate culture of the staff, thanks to which employees will feel involved in their work and the relationships they have with their colleagues.

Source: own research

For each employee who comes to work at PE it is necessary to select his own tool for rapid adaptation in the team, depending on his experience and psychological characteristics. It should be emphasized that drivers are constantly faced with stressful situations due to various passengers, and therefore, among the general measures aimed at improving their working conditions, the following can be distinguished: regular medical examinations and medical check-ups of employees; implementation of social programs that promote health; creation of a favorable psychological atmosphere in the team to reduce stress. This may include organizing corporate events, trainings, developing corporate social networks, arranging rest rooms, as well as creating psychological support centers or including a psychologist in the staff, monitoring the level of stress among employees and other initiatives.

In PE it is necessary to improve another aspect of effective personnel management – delegation of responsibility. It allows managers to distribute tasks among employees, giving them the opportunity to demonstrate their abilities and develop skills. Delegation of responsibility contributes to the development of a sense of independence and initiative among employees, which is important for cultivating leadership qualities and strengthening teamwork. It also allows employees to make more thoughtful and effective decisions in their workplaces. Ultimately, support and encouragement of employees are critically important for maintaining a high level of motivation and job satisfaction. Recognition of employees' efforts and their achievements contributes to the creation of a positive and productive working climate. In confirmation of the uncompromising impact of human resource development on the effectiveness of PE, we will compile a Table 7.

Table 7. The impact of personnel development on the efficiency of PE

Personnel development impact indicators	Impact description
Labor productivity	Trained and motivated employees work more efficiently and productively.
Quality of services	Trained employees are able to provide better services.
Passenger satisfaction level	A high level of service thanks to trained and motivated employees increases passenger satisfaction.
Reducing staff turnover	Trained and motivated employees feel great loyalty to a private enterprise and stay at work longer or may take additional time off in case of force majeure.
Reputation of PE	A private enterprise that invests in the development of its employees has a better reputation as an employer and attracts qualified candidates.

Source: compiled by the author

Therefore, all the above recommendations will directly contribute to increasing labor productivity. In addition, the growth of the professional level of employees will improve the quality of passenger services, which, in turn, will strengthen passenger satisfaction and loyalty. As a result, a positive image of a private enterprise as an employer that invests in its personnel will increase its attractiveness in the labor market and help attract highly qualified personnel. Thus, systematic and targeted development of human resources is a strategically important direction for any enterprise that seeks to increase its efficiency, competitiveness and ensure sustainable long-term development.

We have established that the technology of searching, selecting and hiring employees working at the enterprise is regulated and includes a number of stages, at each of which the actions of specialists are implemented using appropriate methods and within the time limits specified for each performer. Thus, at the first stage, an application for the search for a specialist is received from the manager. An employee of the human resources department begins processing and checking the data, while discussing the details of the vacancy, selecting search strategies and work procedures. After 1-2 weeks from the moment of receiving the application, the person responsible for the search must propose candidates for consideration. If the decision is positive, individual candidates are assigned an interview, the results of which form an opinion about the candidate's compliance with the requirements and working conditions. At the second stage, the candidate is checked. At the third stage, the applicant's data is again transferred to the manager for a decision on the possibility of hiring, after which the applicant is offered employment. In general, the procedure takes a long time; sometimes closing the vacancy is delayed up to two months. In addition, specialists are involved in the work, which are constantly forced to interact with each other to coordinate actions. The process of personnel adaptation in the enterprise is aimed at solving several tasks: minimizing financial and time costs for an

employee to enter a position and team; acquiring the necessary professional skills and abilities; accepting the values and rules existing in the enterprise by the employee.

Thus, employees, albeit to varying degrees, express dissatisfaction with the organization of selection, hiring and adaptation at the enterprise, with the main problem being the large loss of time. Interviews with specialists in the personnel selection department showed that they have to solve the problems of rapid and mass selection, work with a large flow of candidates, while routine tasks take up about 30% of working time. This negatively affects the speed and quality of closing the vacancy, the duration of adaptation and its content. The timing of the working day of the HR specialist confirmed our observations (Table 8).

Table 8. Indicators of working time spent on individual recruiting operations in traditional work

Operation name	Time costs	
	minutes	% of working day
Posting information about a vacancy	40	8.33
Conducting telephone interviews with potential candidates	45	9.38
Working with mail and writing emails, letters, notifications	130	27.09
Formation of a candidate base	145	30.21
Search for candidates from the database	30	6.25
Conducting an interview	75	15.63
Other actions	15	3.11
Together	480 (8 hours)	100.00

Source: according to own research

Thus, during the working day, a specialist can productively work on only one or two applications for closing a vacancy, despite the fact that, as a rule, he can have up to 15 applications for various positions in his "order portfolio". In this situation, recruitment specialists express a positive attitude towards the automation of work processes, since this leads to a significant reduction in working time spent on standard, repetitive operations, facilitating their implementation, better storage and use of data for prompt personnel decision-making. In the practice of personnel management today, many automated systems of both domestic and foreign production have begun to be actively used. One of the most frequently used by enterprises is the E-Staff platform [7]. E-Staff is a full-cycle system that automates most routine operations in recruiting. However, it has a significant disadvantage for a small passenger company – high cost (15,000 USD or 620,387 thousand UAH) [3]). There are cloud technologies that cost less. These include the following cloud technologies, namely: HURMA System, Zoho People, BambooHR, Workable, SmartRecruiters, CakeHR, ADP Workforce Now [2]. Table 9 presents the three largest HRM systems.

Table 9. Comparison of the best HRM systems

Parameters	HURMA System	Zoho People	BambooHR
Free trial period:	Yes	Yes	Yes
Linkedin integration	there are	there are	there are
Integration with Google Calendar	there are	there are	there are
Performance management:	Yes	Yes	Yes
OKR module:	there are	no	no
Integration with job portals:	Yes	Yes	Yes
Interface language	Ukrainian, English and Spanish.	English, German, French, Portuguese and over 10 different languages	English, French, Spanish, Italian and others
Knowledge base	there are	no	there are
Mobile format	mobile version and AI Parther chatbot	mobile application	mobile application

Source: [2]

For example, the ATS system and cloud HRM platform HURMA 45 USD or 1861 UAH per month. They also offer to conclude an agreement to use this cloud technology for a year. This will cost 432 USD or 36 USD per month [4].

This platform is characterized by flexible settings, convenience of many operations for personnel selection, which fully meets the set goal. The functionality of the system is extensive and includes solutions to a number of tasks: working with candidates for vacancies, using external job sites, hiring, adaptation planning, etc. (Figure 6).

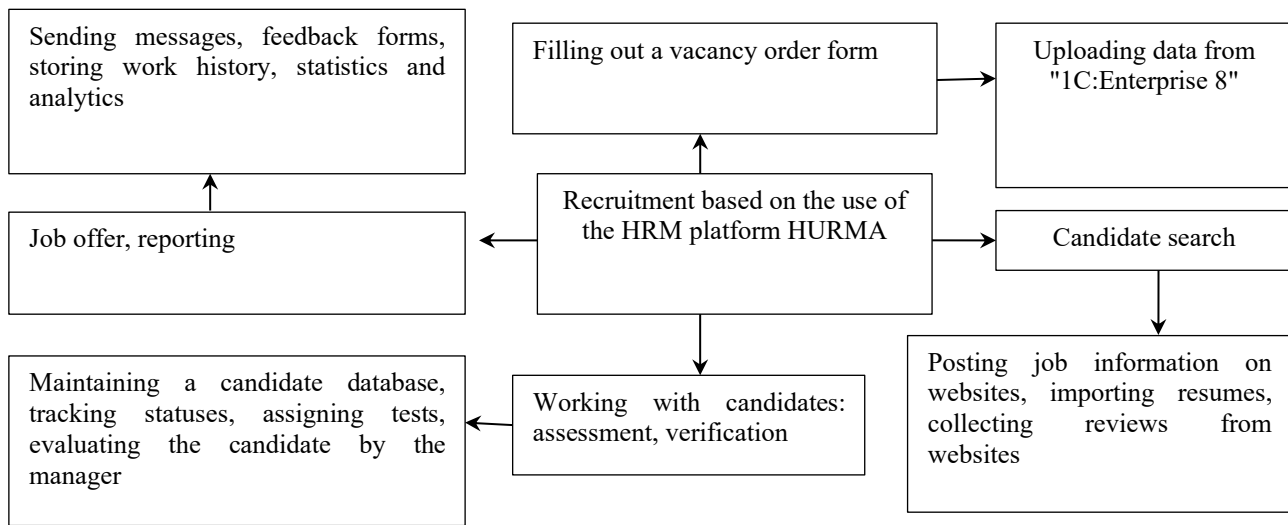


Figure 6. Recruitment automation using the HURMA cloud HRM platform
Source: own development

Let's consider the sequence of actions during the implementation of the technology of personnel selection and adaptation during the implementation of the HURMA platform for optimizing personnel process data. In order to automate the selection of resumes, it is necessary to set certain parameters by keywords so that the most valuable candidates, whose experience and qualifications meet the stated requirements, are not missed through the workflow and redirected to a folder for priority consideration. It is necessary to develop notification letters to candidates for vacancies for their automatic distribution. This notification must be used at the stage of completing the initial telephone interview in case of a positive result. The letter to the candidate should contain: information about the company; description of the compensation package and the procedure for receiving remuneration for work; travel plan; contact person details. Before the interview, the candidate will have the opportunity to familiarize himself with complete and reliable information about the company, its scale and development opportunities in it, which constitute the compensation package, etc. The text should be motivating so that the applicant can quickly decide on a place of work. This will allow the recruitment specialist to increase the intensity of work, increase the number of interviews, especially during mass recruitment. For candidates who have been accepted for employment, you can create an SMS message about their upcoming start of work. Since a sufficient amount of time can pass from the approval of the candidacy to the date of their start of work, it is expected that such a message will have a positive effect on the attitude towards the company and will strengthen the decision made. A few days before the start of work of a new employee, the HR department employee creates a message to the manager, to which they attach a photo of the employee, a list of materials necessary for work, their competencies, etc. It is necessary to automate this mailing by creating a template for it in advance and uploading the entire list of necessary information.

The construction of the newsletter is carried out depending on the category of personnel, since the organization of the workspace of each of them has significant differences. For the centralized organization of the adaptation process of newly hired employees, it is necessary to introduce them with adaptation instructions on production equipment, social relations, etc. The developed instruction should contain frequently asked questions from employees; the organizational structure of the enterprise, information on who to contact in case of problems, infrastructure opportunities for recreation; a description of traditional activities for employees. This will allow recruitment specialists, as well as managers, not to waste time on these organizational issues. The regulations for the adaptation process are necessary not only for employees, but also for the manager. In order to optimize the process, an adaptation program should be developed that allows you to systematize work with newly hired employees and contains an adaptation plan, a goal map and a memo for the mentor. In

addition, a newsletter informing about the end of the employee's probationary period will be useful for the manager. Since during a long probationary period (90 days), information about its end date may be lost sight of, its automation by generating a corresponding letter will solve the problem of providing the employee with feedback on the results of the trial. It is possible to automate conducting surveys based on the results of the initial adaptation, also sending reminders to the recipients. In current practice, each employee is invited to participate in a survey two weeks after the date of his employment, which is dedicated to identifying the level of his professional adaptation and socio-psychological comfort in the company's team. At the same time, a questionnaire is sent to the employee's manager, in which he evaluates the employee who is on probation and the recruitment specialist who recommended this candidate. Optimization of the selection and adaptation technology is facilitated by synchronization of the HURMA software product with the existing «1C: Enterprise 8» system. When combining 1C: ZUP and HURMA, data upload to the personnel selection program is automated. The uploaded data includes departments, employees, staffing positions, and vacancies. When synchronizing the two systems, only one platform – HURMA – will be required for a full-fledged recruitment process, which will lead to a single, simplified system for the work of recruitment department specialists.

Synchronization of HURMA with work sites will lead to the fact that the necessary vacancy and application for the selection of a specialist can be promptly placed on the specified sites. As part of the study, we tested this technology at one workplace of a HR specialist of the demonstration (Demo) version of the HURMA platform. Repeated timing of the costs of a working day for the execution of applications showed a significant reduction (almost 50%) and the possibility of increasing the specialist's labor productivity (Table 10).

In addition to increasing work efficiency, we have noted an increase in the satisfaction of both specialists themselves and candidates, employees and employers with the improvement of the quality and efficiency of personnel procedures. Thus, the automation of a number of processes of personnel selection and adaptation technology will help save time resources of personnel selection specialists and reduce financial costs. It should be recalled that in 2023 the average number of employees There were 22 people, and the net income from the sale of services was UAH 3,519,000. The cost of using the HRM platform HURMA is UAH 1,488.6 per month, which is UAH 17,863.2 per year (provided that a contract is signed for a period of 1 year).

Table 10. Time consumption indicators for individual recruiting operations while working on the HURMA platform

Operation name	Time costs	
	minutes	% of working day
Posting information about a vacancy	10	2.08
Conducting telephone interviews with potential candidates	45	9.38
Working with mail and writing emails, letters, notifications	30	6.25
Formation of a candidate base	55	11.46
Search for candidates from the database	15	3.13
Conducting an interview	75	15.63
Other actions	15	3.11
Together	245 (4.09 hours)	51.04

Source: own research

According to our research, the time spent on routine tasks is 30% of working time, and after the implementation of HURMA, there was a reduction in time spent on routine tasks by 50% and the possibility of increasing labor productivity. In 2024, there are 261 working days. The working day lasts 8 hours. The total working time of one employee (HR specialist) per year is $261 \times 8 = 2088$ hours. Time spent on routine tasks before the implementation of HURMA: $2088 \text{ hours} \times 30\% / 100\% = 626.4$ hours per year. Time spent on routine tasks after the implementation of HURMA: A 50% reduction means that: $626.4 \text{ hours} \times 0.5 = 313.2$ hours per year. Total saving of working time of one HR specialist: $626.4 \text{ hours} - 313.2 \text{ hours} = 313.2$ hours per year. The average salary of a HR officer is 15,000 UAH per month. For a year, we have the amount of $15,000 \times 12 = 180,000$ UAH per year. That is, the cost of one hour of work of this employee is $180,000 \text{ UAH} / 2088 \text{ hours} = 86.2$ UAH per hour. Savings in monetary equivalent: $313.2 \text{ hours} \times 86.2 \text{ UAH} = 26,997.84$ UAH. Thus, using the HURMA platform allows you to save and receive a net financial gain of $26,997.84 - 17,863.2 = 9,134.64$ UAH per year.

Let's consider another cloud platform – Zoho CRM. The Medium technical support package costs \$37 per month. However, if the company is only interested in HR management, then Zoho People Plus is offered, which will cost \$9 per month with an annual cooperation [5]. The annual cost of using the Zoho CRM HRM platform is UAH 4466.4 or USD 108 [3]. Using the Zoho CRM platform in the Zoho People Plus offer allows you to save and get a net financial gain of $UAH\ 26997.84 - 4466.4 = UAH\ 22531.44$ per year. It is clear that comparing the two cloud HRM platforms; we can say that the net financial gain from using Zoho People Plus will be more effective by UAH 13396.8. But there is one significant disadvantage – there is no Ukrainian-language version. To work with this platform, a human resources employee must have perfect English or German, but not all HR specialists in a regular enterprise can boast of this, and therefore we are not considering other cloud HR platforms.

It is clear that when using the HURMA cloud platform, the net financial gain is small, but if the company expands again in the future and provides passenger services on suburban routes, the HR specialist will be entrusted with more and more routine functions. It should be emphasized that if an employee works with this cloud platform, the company will receive additional benefits in the form of: increased productivity of HR specialists, the possibility of faster and more efficient recruitment, a reduction in the number of errors and increased accuracy in maintaining personnel documentation. The implementation of the HURMA HRM platform is advisable, since it allows not only to offset its costs, but also brings additional cost savings, increasing the productivity of specialists. In addition, it contributes to the optimization of business processes, which is especially important for an enterprise that works with a significant flow of candidates and is engaged in personnel recruitment.

PE is an organization, which is responsible for the life and health of people – not only those transported, but also for the safety of others in the process of providing passenger services. In addition to direct services for transporting people, this researched enterprise carries out repair operations in the event of a breakdown of motor vehicles. Thus, it becomes obvious that increasing the motivation of the personnel of a passenger enterprise is one of the main areas of management activity of its management. However, in the process of forming an effective system of motivation of labor of PE, one cannot ignore such a type of motivation as an intangible form. As a rule, such stimulation depends on the personal effectiveness of the work of a particular employee and is expressed in a handshake and personal gratitude of the manager, reducing the high significance of the work of drivers of a private enterprise to an axiom. As already noted in the work, the driver must bear and realize personal responsibility for his own work. In particular, there must be an understanding that he may lose bonus payments, as well as not receive a certain part of his salary and even be fired if the following events occur: facts of non-compliance with the rules for operating the vehicle entrusted to the employee are discovered; the route is disrupted due to the driver's fault; the rules for working with passengers are grossly violated, etc. Thus, we can talk about an effective system of motivation for drivers at PP only if the management manages to form a system of motivation for drivers, in which their personal goals coincide with the strategic goals of the automobile enterprise. At the same time, the legitimate interests of the employees themselves will be strictly observed.

In addition to the basic salary, an important element of the motivation system is additional remuneration, which includes material and non-material incentives. It allows for maximum individualization of remuneration, taking into account many factors, including the competence and contribution of the employee himself. The remuneration covers everything that is valuable to the employee or can become so. It can be internal or external. Internal remuneration reflects psychological satisfaction from work, the joy of creativity and the awareness of the importance of one's activities, which can arise through recognition of merit, achievement of goals and benefit to society.

Intangible incentives that do not require investment from the company but have a great impact on employee efficiency and the socio-psychological climate in the team:

- recognition of the driver's merits in the form of praise and thanks, announced publicly;
- congratulations on significant dates – anniversaries, birthdays, weddings, birth of a child, retirement, etc., corporate holidays and parties contribute to team cohesion and strengthening organizational culture;
- a gallery of honor where the results of work are displayed.

Thus, the proposed measures can be used to improve the labor incentive system. The proposed measures will allow not only to take into account the tariff (permanent) part of the salary, but also to make the income of the employee dependent on labor productivity and the final results of the private enterprise. This approach seems to be the most progressive in the field of employee incentives, which provides both a guarantee of receiving a permanent salary and the possibility of a significant increase in income based on the results of

work. In order to increase the labor productivity of the enterprise, it is necessary to pay special attention to such an intangible incentive factor as improving working conditions, namely, providing employees with the necessary equipment, the lack of which does not allow them to quickly and efficiently perform their duties. In addition, it is necessary to convince employees that the work they perform is very important for the enterprise, that the quality of their work directly affects the image.

In the modern business environment, an important factor in the success of an enterprise is its ability to maintain high motivation. That is why for the implementation of the project to improve the system of non-material motivation of employees of PE, the following costs can be proposed, which are given in Table 11. The table below reflects the distribution of financial resources for measures aimed at increasing morale and employee satisfaction.

Each item has a specific goal and justification, which indicates the desire of PE to create a favorable working environment. The first item is the design of a greeting board with expenses of 3,000 UAH. This event will allow the enterprise to demonstrate attention to employees, celebrate their achievements and important events in life. The importance of this item lies in increasing the sense of belonging to the team, which will contribute to strengthening the corporate culture. Corporate events, for which 45,000 UAH are provided, are a powerful tool for bringing the team closer together. They promote informal communication; reduce barriers between employees and management, which will positively affect teamwork. The regularity of such events (three times a year) will ensure constant support for a positive atmosphere in the team.

Table 11. Costs for the implementation of the project to improve the system of non-material motivation of employees of PE

No	Expense item	Expenses per year, UAH
1	Greeting board design	3000
2	Corporate events (3 times a year)	45000
3	Organization of sporting events	10000
4	Board of Honor	5000
5	Gifts for the best employees	15000
6	Caring for employees' children (sweet gifts for all children for the New Year and for children on September 1 – for those going to first grade – a first-grader gift set)	22000
	Total	100000

Source: own development

Organizing sports events, which requires 10,000 UAH per year, will contribute to the physical health of employees and strengthen team spirit. Involving employees in sports events will also affect the development of leadership qualities and team interaction. The Board of Honor, which will cost 5,000 UAH, is another important element of intangible motivation. It will allow PE to publicly recognize the achievements of its employees, which will stimulate others to achieve high results. Recognition of employees' merits will contribute to their professional growth and increase loyalty to the enterprise.

Gifts to the best employees, for which 15,000 UAH are provided, are a manifestation of individual attention to the results of work. They demonstrate that the private enterprise appreciates the diligence and contribution of everyone and additionally motivates employees to achieve new heights. Finally, caring for the children of employees (22,000 UAH) will emphasize the social responsibility of PE. Gifts for the New Year and September 1 will create a positive emotional connection between the enterprise and its employees, which will increase the level of employee satisfaction with work. Thus, the costs provided for in Table 11 are an important investment in creating a stable, satisfied and motivated team, which, in turn, will contribute to the success of PE.

Another suggestion is to use the savings from the bonus fund to pay an annual bonus. Due to the fact that some employees may not receive a monthly bonus for various reasons (dismissal, vacation, sick leave, de-bonus), the bonus fund in the current month may not be used in full. The saved part can be planned to be credited to the bonus fund at the end of the year. An employee can receive a bonus at the end of the year provided that:

- 1 If his work experience is 11 months or more.
- 2 If the employee has no disciplinary sanctions at the time the bonus is accrued.

This use of the bonus fund savings will reduce staff turnover, increase discipline and interest in the results of their work.

In addition to improving the compensation system for motivating the personnel of PE, attention should also be paid to non-compensatory ones. In non-material incentives, the main direction of work is to raise the status of an individual employee and increase employee loyalty. To do this, it is necessary to introduce a system for registering employees who have distinguished themselves. The manager must develop criteria for the effectiveness of the work of his subordinates and determine the best employee of a certain unit every week and every month. The photo of the "best" should be placed on the Honor Board. It is necessary to hold monthly meetings with the presentation of symbolic gifts to the leaders. It is planned to hold corporate evenings every year, where the results of the work of PE should be highlighted and certificates, awards and gifts should be presented to employees who have distinguished themselves.

However, along with bonuses, de-bonuses play an important role in the personnel management system. This is a mechanism that is used in cases of failure by employees to fulfill their duties or violation of labor discipline. De-bonuses are intended to point out to the employee their mistakes and stimulate him to improve his work results. It serves as a kind of reminder of responsibility for fulfilling job duties. The relationship between bonuses and de-bonuses is that they complement each other. If a bonus encourages reaching new heights, then de-bonuses remind of the consequences of failure to fulfill duties or violating standards. Together, these mechanisms form a balanced motivation system that takes into account both incentives and responsibility. Companies that effectively combine these two approaches are able to create a culture in which employees understand that their contribution is important, but at the same time they are responsible for their actions. Thus, bonuses and de-bonuses are interdependent elements of an effective motivation system that promotes the development of professionalism and discipline among employees. Only through the correct combination of these tools can PE achieve maximum results and ensure stable development.

It is proposed to divide the de-bonus indicators into two types: indicators that apply to all categories of employees; indicators that apply to individual positions. Table 12 presents the de-bonus indicators for all categories of employees. This system of measures is aimed at reducing the number of facts of violation of labor discipline, will contribute to improving the quality of service to the population, and trust in public transport, increasing the prestige and competitiveness of PE.

Table 12. De-bonus rates for all categories of employees of PE, UAH.

Violation	Amount, UAH
Being late for work	200
Absence from work	500
Chatting with friends while working	250
Rudeness when communicating with a passenger	600
Absence from work without a valid reason	8000

Source: own development

In order to maintain the natural level of staff turnover, it is necessary to conduct a survey every six months to identify those employees who plan to leave and are actively looking for a new job. The survey should identify changes in the basic needs and motivators of employees. The data obtained should be used during the annual review of the labor motivation system. We also presented a questionnaire to study the socio-psychological climate in PE, because the psychological well-being of employees is a state of satisfaction, confidence and general well-being of the employees of the enterprise. It should be emphasized that in the modern world, many enterprises pay attention to the psychological aspects of work no less than to the material ones, which requires studying the peculiarities of work, motivation and attitude of employees to the enterprise. A motivated and satisfied employee is very responsible for his job duties, is ready to work overtime with less resistance, is proactive, and is also more loyal to innovative changes. To determine the level of socio-psychological climate in the team, you can conduct questionnaires, surveys, tests, and interviews. A competent manager can independently assess the state of the socio-psychological climate. The main indicator for him may be high staff turnover and low levels of labor discipline. Analysis of the identified indicators can serve as an impetus for taking measures to eliminate factors that have a negative impact.

In conclusion, it should be emphasized that an effective motivation system will allow PE to stimulate employees to their professional growth, reduce staff turnover and create a favorable corporate culture. The

implementation of the elements of improving motivation that we have proposed will increase employee satisfaction, their involvement and productivity. Ultimately, this will contribute to strengthening the company's position in the market and ensuring its long-term development.

Thus, we have considered the essence of the theoretical and methodological principles of personnel management in a private enterprise. In our opinion, personnel management is a strategic process of planning, attracting, developing and retaining employees. Personnel development management plays an important role in improving the efficiency of an enterprise's operations and increasing its competitive advantages over similar enterprises in the same industry [1]. Using Euler circles, the correlation of the basic concepts of personnel management was considered, namely: human resources, labor resources, labor force, personnel and staff. The main stages of the formation and implementation of the personnel management strategy in a private enterprise were highlighted.

We at the experimental enterprise identified key problems in personnel management and developed recommendations for their elimination. The conducted research allowed us to find out that the current system of personnel selection and adaptation has a fairly large range of routine operations that can be automated, minimizing the possibility of making mistakes and freeing up part of the working time of specialists to solve significant tasks. In order to optimize personnel management technologies through automation, you can use the HURMA cloud HRM platform. Using the HURMA platform allows you to save and get a net financial gain of $26997.84 - 17863.2 = 9134.64$ UAH. per year.

It is proposed to spend 100 thousand UAH per year on the implementation of a project to improve the system of non-material motivation of employees of PE, because this will be an important investment in creating a stable, satisfied and motivated team. Another proposal is to use the savings of the bonus fund to pay an annual bonus to employees. Along with bonuses, de-bonuses play an important role in the personnel management system. Only through the correct combination of these tools can PE achieve maximum results and ensure stable development.

The proposed measures will help PE improve personnel management, increase motivation, reduce turnover, and create a favorable corporate culture for long-term development.

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DEVELOPMENT OF AGRIBUSINESS IN THE POST-WAR RECONSTRUCTION OF UKRAINE

Kovbasa Oleksandr

PhD in Economics, Associate Professor, Head of the Department, Sumy National Agrarian University

ORCID ID: 0000-0003-2593-0362

The agricultural sector of Ukraine is traditionally one of the key structural elements of the national economy. However, the full-scale invasion of the Russian Federation in February 2022 formed an unprecedented complex of structural shocks, simultaneously hitting the land fund, production infrastructure, logistics chains, personnel potential and foreign trade positions of the sector. Thus, the problem of the development of agribusiness takes on not only an economic, but also a geopolitical dimension: both the country's food security and its place in the global food system depend on the ability of the agricultural complex to recover and modernize.

So, agribusiness occupies a special place in the structure of the national economy of Ukraine, determining not only domestic food security, but also the position of the state in global markets. Agricultural production forms about 7% of the country's GDP, and agricultural exports account for almost 60% of all foreign trade. These indicators are not static - they reflect the long-term structural transformation of the industry, which over the past decade has turned from a traditional sector of the agricultural economy into a full-fledged competitive industry integrated into global value chains.

The strategic role of agribusiness for Ukraine is due to several interrelated factors:

- favorable natural and climatic conditions - more than 40 million hectares of agricultural land, a third of which falls on fertile chernozems of the world - form a powerful natural resource potential;
- the existing production and processing infrastructure, formed over decades, provides opportunities for increasing volumes and diversifying the range of products;
- the growing international importance of Ukraine as a guarantor of food security for a number of regions - from the Middle East to Africa - turns the agricultural sector into an instrument of geopolitical influence [1].

Therefore, understanding the dynamics of agribusiness development in modern conditions acquires not only economic, but also strategic importance.

To analyze structural shifts in the domestic agricultural sector, it is necessary to consider the key macroeconomic indicators of the industry in dynamics. Comparison of 2020 and 2024 indicators makes it possible to establish the nature and directions of transformation processes, identify stable trends and identify factors that determine the competitiveness of the domestic agro-industrial complex (Table 1).

Table 1. Agribusiness performance

Indicator	2020, billion (UAH/dollar) USA	2020,%	2024, billion (UAH/dollar) USA	2024,%
Share of agricultural products in the country's GDP	318,0	8,3	464,0	6,8
Share of agricultural exports in the country's exports, billion dollars USA	22,2	45,0	24,7	59,0
The share of the agro-industrial complex in loans to all sectors of the economy	130,0	18,0	190,0	24,0

Source: compiled by the author based on [1; 17; 27]

These data indicate a contradictory, but generally positive dynamics of the development of the agricultural sector in the context of the national economy. On the one hand, the share of agricultural products in the country's GDP decreased from 8.3% in 2020 to 6.8% in 2024, which, however, is explained not by an absolute drop in the industry, but by a faster growth in nominal GDP at current prices compared to agricultural production. The absolute indicator of production volume increased from 318 to 464 billion UAH, that is, increased by 46%.

The dynamics of export indicators is indicative: the share of the agricultural sector in the total volume of Ukrainian exports increased from 45% in 2020 to 59% in 2024, while the absolute volume of agricultural exports increased from \$22.2 to \$24.7 billion. USA. This means that in the face of shrinking industrial and

other sectors due to military destruction, agribusiness has become the main sector of the national economy generating foreign exchange earnings, bearing a disproportionate burden of ensuring the country's balance of payments. In general, it can be stated that the agricultural sector has shown itself to be the most stable component of the Ukrainian economy in the face of unprecedented military and humanitarian challenges.

The dynamics of lending also deserves attention: the share of the agro-industrial complex in the total loan portfolio of the banking system increased from 18% to 24%, and the absolute volume of loans to the industry increased from UAH 130 to 190 billion. This indicates a growing financial interest in the agricultural sector from institutional investors and the banking system, reflecting its perception as a relatively reliable borrower even in wartime conditions.

The full-scale invasion of the Russian Federation in Ukraine, begun on February 24, 2022, caused enormous damage to the country's agro-industrial complex, which are both direct - material and indirect - operational and profitable.

Thus, analytical studies of the Kyiv School of Economics, the Ministry of Agricultural Policy and international analytical centers (FAO, OECD, World Bank) make it possible to systematize these losses into six key categories, which is reflected in Table 2.

Table 2. Main categories of losses of Ukrainian agribusiness due to full-scale invasion

Loss category	Volume/Metric	Main regions of defeat	Impact on production
Agricultural land (de-occupied/war zones)	~ 5.0 million hectares withdrawn from circulation	Kherson, Zaporizhzhya, Donetsk, Lugansk regions.	Reduction of sown areas by 25-30%
Machinery and equipment	More than 100 thousand units destroyed or damaged	Front-line and front-line zones	Mechanization reduction to 60% of pre-war level
Grain infrastructure (elevators, warehouses)	~ 30% of capacity is damaged	South and East of Ukraine	Storage deficit - 10-15 million tons
Irrigation systems	Kakhovskaya system - 584 thousand hectares of irrigation lost	Kherson, Nikolaev regions	Threat of desertification of southern agrozones
Human capital (mobilization + migration)	Up to 3 million employed in the sector left the country or mobilized	Nationwide scale	Personnel deficit 35-45% in crop production
Logistics corridors and ports	Black Sea exports blocked for ~ 18 months	Odessa, Nikolaev region	Overloading of land and river routes

Source: compiled by the author based on [1; 4; 11; 19]

The analytical data presented indicate that the most critical are not so much direct material losses as systemic failures in the functioning of the production and logistics chain. The withdrawal from circulation of about 5 million hectares of agricultural land - primarily due to mine pollution, physical destruction and occupation - means a long-term reduction in production potential even in the conditions of the complete liberation of these territories. The destruction of the Kakhovsky reservoir in June 2023 dealt a particularly heavy blow to the irrigated agriculture of the South, where irrigation is not an option, but a necessary condition for a stable harvest. Summarizing the above indicators, it can be stated that the cumulative regressive impact on industry productivity is estimated at 25-40% relative to the pre-war baseline.

A comprehensive assessment of these losses is crucial for understanding the real state of the industry and justifying its recovery strategy [1; 19]. Structured accounting of direct losses of the agro-industrial complex for the period from February 24, 2022 to December 31, 2024 is shown in Table 3.

Table 3. Losses of the Ukrainian agro-industrial complex during the war, (from February 24, 2022 to December 31, 2024)

Group	Amount, billion dollars USA	In% of total
Volume of losses, total billion dollars USA:	11,2	100,0
incl. damage to machinery and equipment	6,5	58,0
- damage to storage facilities	1,9	17,0
- theft of material and technical resources and products	1,9	17,0
- other	0,9	8,0

Source: compiled by the author based on [1; 19]

The total volume of direct losses of the agro-industrial complex for the analyzed period amounted to \$11.2 billion. USA. The largest share is 58%, or \$6.5 billion. USA - make up losses from damage to agricultural machinery and equipment. This position is critical due to the fact that the complete or partial loss of technical fleet directly limits the production potential of the industry and is the first condition for the restoration of normal functioning of farms. Firstly, destroyed or disabled tractors, combines, seeders and other equipment make it impossible to comply with agrotechnical deadlines critical for preserving yields. Secondly, the restoration of the technical base requires significant investments and time, because there is a shortage of equipment on the market due to pan-European demand and disruptions in supply chains.

Equal shares - 17% each, or \$1.9 billion each. USA each - distributed losses from damage to warehouse facilities and from theft of material and technical resources and products. The first component reflects the destruction of elevators, granaries, refrigeration facilities and processing plants, which directly complicates the storage and sale of crops. The second component - kidnapping - is a special form of losses associated with the occupation of agricultural land and production facilities, where large-scale thefts of equipment, fertilizers, fuel resources and finished products have been recorded. The rest - 8%, or 0.9 billion dollars. USA - accounts for other categories of losses, including damage to irrigation systems, drainage infrastructure and agricultural buildings. As of December 2024, the volume of losses in the sector increased by 9.2% compared to December 2023, which indicates the continuing impact of hostilities on the material base of the industry.

Along with direct losses subject to direct value measurement, agribusiness suffered significant indirect losses, which cover lost revenues of producers due to production cuts, unfavorable price conditions and rising costs. The cumulative picture of indirect losses is reflected in Table 4.

Table 4. Volume of indirect losses (from February 24, 2022 to December 31, 2024)

Group	Amount, billion dollars USA	In% of total
Volume of indirect losses, total billion dollars USA:	72,8	100,0
including production reduction - annual crops	37,1	51,0
- perennial	1,5	2,0
- animal husbandry	3,6	5,0
Decrease in purchase prices	24,7	34,0
Increase in production costs	4,4	6,0
Other	1,5	2,0

Source: compiled by the author based on [1; 19]

The total volume of indirect losses amounted to \$72.8 billion. The United States is more than six times higher than direct losses and clearly illustrates how destructive the impact of armed conflict is on the operations and income of agricultural producers. Indirect losses are the difference between the actual revenues and the revenues that agricultural producers would have received in the absence of invasion. It is fundamentally important that these losses will be incurred by farmers throughout the country, and not just in areas of active hostilities.

The dominant item of indirect losses is the reduction in the production of annual crops - \$37.1 billion. USA, or 51% of the total. This reflects the combined impact of the removal of significant areas from cultivation in war zones, mass mining of farmland, labor shortages through mobilization and migration, and the destruction of irrigation systems. The second most significant article is a decrease in purchase prices - \$24.7

billion. USA, or 34%. The blockade of the Black Sea ports during the initial stage of the invasion, disruption of logistics routes and general instability led to a significant depreciation of agricultural products in the domestic market. The increase in production costs amounted to 4.4 billion dollars. US (6%), reflecting increases in fuel, fertilizer, plant protection and insurance costs. The greatest indirect losses were recorded in the Kherson, Zaporizhzhya, Kharkov and Donetsk regions, which is a natural consequence of active hostilities in these regions.

Analysis of structural shifts in the production base of the agricultural sector is a prerequisite for understanding the long-term consequences of armed conflict and assessing the adaptation capabilities of the industry. Comparison of the production volumes of the main product groups at constant prices in 2021 for 2018 and 2024 makes it possible to separate cyclical fluctuations from structural transformations (Table 5).

Table 5. Agricultural products, UAH billion (at constant prices in 2021)

Commodity goods	Year		In dynamics
	2018	2024	
Cereals and legumes	413,0	353,0	-60,0
Technical cultures	387,0	373,0	-14,0
Fruits and vegetables	211,0	133,0	-78,0
Livestock products	256,0	211,0	-45,0
Total, UAH billion	1267,0	1070,0	-197,0

Source: compiled by the author based on [1; 27]

The total volume of agricultural production decreased from UAH 1267.0 billion in 2018 to UAH 1070.0 billion in 2024 - that is, by UAH 197.0 billion, or 15.5%. This decline reflects not only the immediate consequences of hostilities in 2022-2024, but also the gradual erosion of production capacity due to systemic imbalances that accumulated even before the start of the active phase of the conflict.

Firstly, most of all, in absolute terms, reductions were recorded in the production of grain and legumes - from 413.0 to 353.0 billion UAH (-60.0 billion UAH, or -14.5%). Cereals remain the basis of crop production, so their reduction has a multiplicative negative impact on the entire industry - from the feed base of animal husbandry to the workload of processing facilities. In 2024, grain production in Ukraine fell to the lowest level in a decade, which is primarily due to the low yield of spring crops, in particular corn, due to unfavorable weather in the summer of 2024.

Consequently, the production structure has undergone internal shifts: farmers have reoriented sown areas to soybeans and other oilseeds because of their higher profitability. The production of industrial crops decreased relatively less - only by UAH 14.0 billion (-3.6%), which reflects the higher adaptability of this segment. The largest relative drop was in the production of fruits and vegetables - from 211.0 to 133.0 billion UAH (-37%), which is explained by the occupation of the main production zones in the southern regions (Kherson region, Zaporozhye) and logistical restrictions that make it difficult to supply to sales markets. The livestock industry reduced production from UAH 256.0 billion to UAH 211.0 billion (-17.6%), although poultry production partially compensated for the drop in other subsectors due to the growth of industrial poultry farming [1].

Summarizing the industry dynamics, it should be noted that despite significant challenges, the agricultural sector has shown relative stability, retaining 84.5% of the pre-war production potential. A key feature of the current transformation is the geographical movement of production centers: occupation and hostilities in the traditional agrarian regions of the South and East led to a reorientation of production to the central and western regions.

Despite significant internal challenges, Ukraine retains a significant position in the global agricultural market.

It is advisable to start the analysis of the development of foreign trade in agri-food products by assessing the overall dynamics of the main indicators of the trade balance, which reflects structural shifts in the production chains of the domestic agricultural sector. The formation of a positive balance of foreign trade is one of the key indicators of the competitiveness of the industry, while the dynamics of imports and exports makes it possible to identify trends in attracting enterprises in cooperation chains for the production of value-added products [1; 17].

The data below illustrate the dynamics of Ukraine's trade balance in the agri-food sector during 2023-2025 (Chart 1).

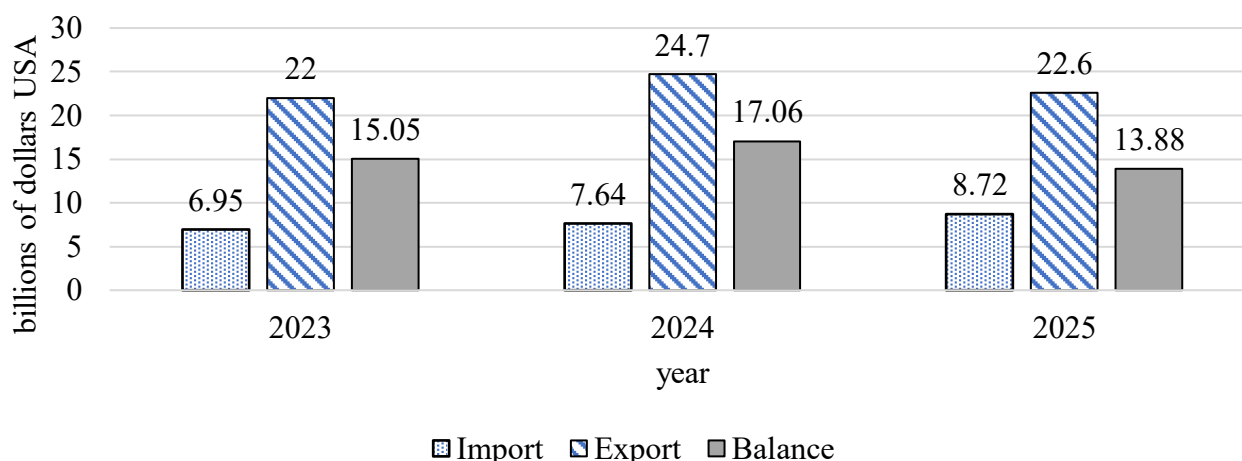


Figure 1. Indicators of foreign trade in agri-food products of Ukraine, billion dollars USA
Source: built by the author based on [1; 17]

Analytical data indicate a contradictory nature of trends in foreign trade in agri-food products. On the one hand, imports show stable growth: from \$6.95 billion. USA in 2023 to \$8.72 billion in 2025, which corresponds to an increase of \$1.77 billion or 25.5%. This growth is primarily due to an increase in the needs of the processing industry for raw materials and ingredients that are not produced domestically, as well as the revival of domestic consumer demand in the context of a partial normalization of economic life.

On the other hand, the dynamics of exports is less unambiguous. After growing from \$22.0 billion in 2023 to a record \$24.7 billion in 2024, in 2025 there is a decrease to \$22.6 billion, which ultimately gives only a slight increase (+ \$0.6 billion) compared to the base year. Consequently, the corresponding reduction in the positive trade balance - from \$17.06 billion in 2024 to \$13.88 billion in 2025 - indicates an increase in pressure on Ukraine's foreign trade positions. At the same time, a decrease in the balance is not an exclusively negative signal: it may reflect structural transformations in the direction of increasing imports of means of production and technologies necessary for the production of products with higher added value.

Summarizing the analysis of the dynamics of the trade balance, it can be stated that the preservation of a positive balance with a simultaneous increase in imports indicates the preservation of competitive positions of domestic agricultural exports, however, the lack of stable growth in export indicators indicates the need for qualitative changes in the commodity structure of supplies.

The assessment of Ukraine's share in global agricultural exports is fundamental for understanding the international dimension of domestic agribusiness and its importance for global food security (Figure 2).

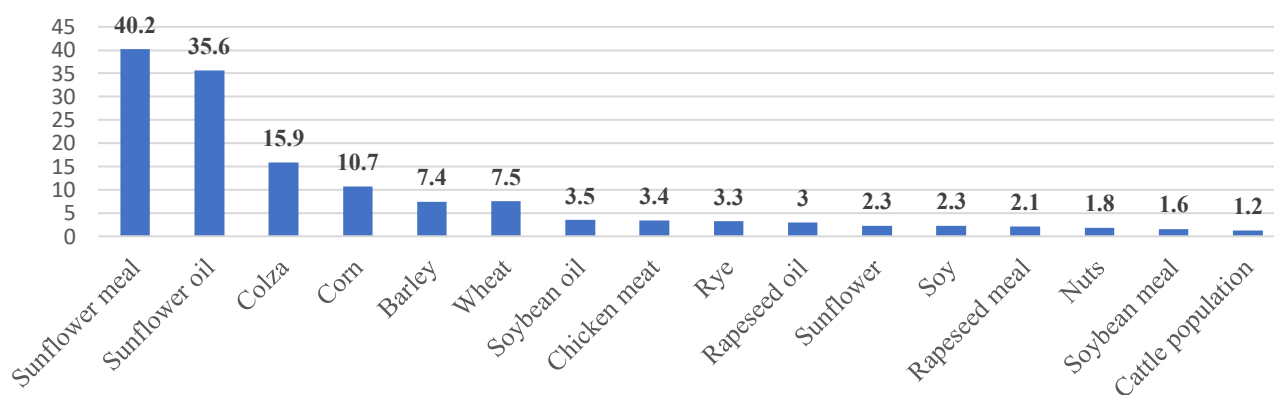


Figure 2. Ukraine's share in global exports of basic agricultural products, % (2024/25 MY)
Source: built by the author based on [1]

These data indicate an exceptional concentration of competitive advantages of the domestic agricultural sector in individual product niches. The undisputed leader is the production and processing of sunflower: Ukraine controls 40.2% of the world sunflower meal market and 35.6% of the sunflower oil market. This means that more than a third of the world's supplies of key oil and protein products are formed by Ukraine, which gives it the status of an indispensable player in the respective markets.

The second strategic direction is grain crops: Ukraine's share is 10.7% in world corn exports, 7.5% in wheat and 7.4% in barley. These indicators are significant in absolute terms, but they have decreased compared to pre-war years due to production cuts and time logistical constraints. The resumption of the work of grain corridors - first within the framework of the "Grain Initiative," and then through the Danube and railway routes - contributed to the preservation of market share, but did not fully compensate for the losses caused by the fall in yields.

The position of Ukraine in the rapeseed market is also indicative - 15.9% of the world market, which reflects the rapid growth of domestic rapeseed. Firstly, rapeseed is becoming increasingly important as a raw material for biodiesel production in the European Union, which forms a stable demand from European buyers. Secondly, the expansion of rapeseed areas is part of the overall strategy of diversification of sown areas, which is carried out by domestic farmers in the face of price volatility in the wheat and corn markets. The share of Ukraine in the chicken market is also noteworthy - 3.4%, which indicates the competitiveness of the domestic industrial poultry industry at the international level.

Summarizing the competitive profile of the domestic agricultural sector, it can be argued that Ukraine occupies a leading position mainly in the production and processing of oilseeds, while in the markets of grain and livestock products its share, although it remains significant, is inferior to individual competitors. Consequently, the agribusiness development strategy should take into account the need to protect existing competitive niches, primarily sunflower processing, and to purposefully increase its presence in promising segments.

Ensuring sustainable economic development in wartime and post-war reconstruction of Ukraine requires fundamentally new approaches to organizing production and creating competitive advantages in foreign markets. The agricultural sector is faced with a paradox of commodity orientation: despite significant export volumes, the level of added value in domestic products remains significantly lower than potentially possible. This contradiction determines the relevance of the study of mechanisms of inter-business cooperation as a tool to increase the degree of product processing and increase profitability along the entire production chain [23].

Cooperation of enterprises in its various forms - vertical integration, horizontal alliances, contract production, cluster associations - allows you to concentrate the resources and competencies necessary for the manufacture of products with higher added value. Therefore, the question of how organizational interaction between the subjects of the agricultural market affects the structure and competitiveness of Ukrainian agricultural exports acquires not only theoretical, but also purely practical significance in the context of European integration aspirations and the need to diversify foreign trade relations [21-25].

This problem becomes especially acute given the instability of global food markets, volatility in commodity prices and increased competition from other agricultural exporters. With commodity margins declining and demand for deep processing products growing, the survival and development of domestic enterprises directly depend on the ability to form effective cooperative ties and integrate into global value chains.

The problems of cooperation between enterprises and the formation of added value in production chains are being developed by a wide range of domestic and foreign scientists. The conceptual foundations of the theory of value chains are laid in the writings of M. Porter [10], who substantiated the importance of vertical integration and specialization in ensuring the competitive advantages of enterprises. These ideas were further developed within the framework of the Global Value Chains approach, which was formed thanks to the research of G. Gereffi, J. Humphrey, T. Sturgeon [5-6], K. Fernandez-Stark [5] and their followers, who proved that participation in global chains is a key factor in technological and institutional upgrade for enterprises in developing countries.

In the national scientific literature, a significant contribution to the study of cooperation in the agricultural sector was made in the works of V. Andriichuk [12], Yu. Lupenko, M. Malik, A. Shpykuliak [22], L. Moldavan [24]. In particular, the researchers focus on the need to move from primary production to deep processing as a condition for increasing the profitability of agricultural enterprises. The issues of forming clusters in the agri-food sector of Ukraine are covered in the works of M. Kropyvko [21], I. Kaitanskyi et al. [18], which consider clustering as an effective tool for increasing the competitiveness of regional agri-food systems.

The results of the analysis of the commodity structure reveal the dominance of two commodity items, which together form more than 54% of agricultural exports: corn (29.5%) and sunflower oil (25.0%). It is necessary to note the fundamentally different degree of processing of these products. Maize is predominantly a primary raw material with a minimum degree of processing and, accordingly, a low level of added value. But sunflower oil is a product of industrial processing of oilseeds, the production of which provides for the use of complex technological chains and the participation of several business entities - seed producers, elevator enterprises, oil and fat factories, logistics operators (Figure 3).

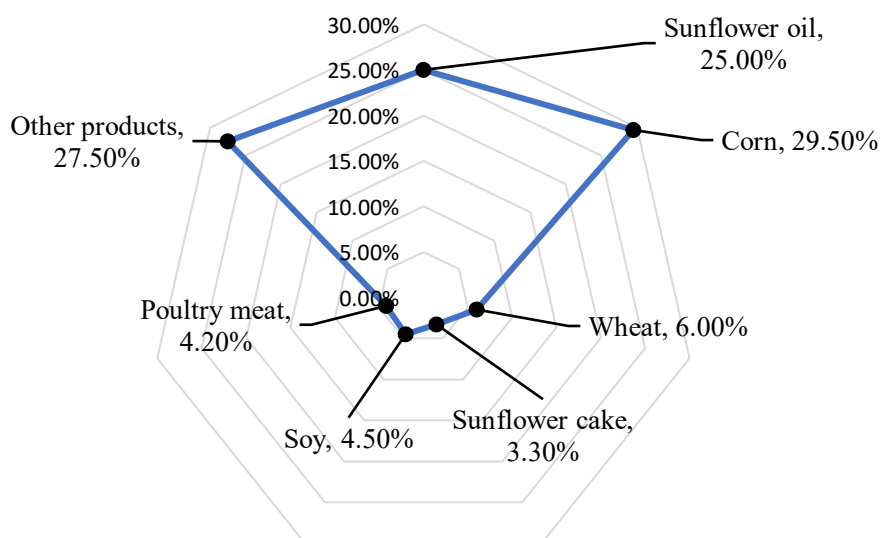


Figure 3. Commodity structure of agricultural exports, as of January 2026
Source: built by the author based on [17]

We can state that a high share of vegetable oil (25%) indicates the presence of effective production cooperation in the processing sector, because the production of this product requires coordinated interaction between different levels of the production chain. It should also be noted that the participation in the structure of products such as poultry meat (4.2%), sunflower cake (3.3%) and soybeans (4.5%) indicates an increase in the level of processing in the livestock and crop segments. Consequently, even despite the dominance of grain, the structure of domestic agricultural exports is gradually acquiring the features inherent in more diversified and technologically saturated value chains. The presence of 27.5% of "other goods" in the structure additionally indicates an expansion of the range of products produced and sold in foreign markets.

A more detailed analysis of foreign trade flows by individual product groups allows us to identify specific points of growth and decline associated with the effectiveness of cooperation relations in the relevant industries of the processing industry. To quantify these trends, we turn to actual data, which reflect the comparative dynamics of exports and imports in the context of commodity groups (as of January 2026) relative to the same period in 2025 (Table 6).

The presented actual export and import indicators reveal a significant differentiation of growth rates among different commodity groups, directly correlates with the degree of involvement of enterprises in processing cooperation chains. The most noticeable trend is the outstripping growth of vegetable oil exports (+ 27.5%) - to \$601.1 million - against the background of a slight decrease in the volume of exports of grain crops (-1.0%) and primary oilseeds (-2.8%). This asymmetry is a significant evidence that cooperation between farmers, elevators and processing enterprises can effectively convert primary plant raw materials into processed products, which are distinguished by significantly higher price competitiveness and more stable demand in international markets.

So, it should be noted that the oil and fat complex of Ukraine occupies one of the key places in the structure of the national economy, providing a significant share of foreign exchange earnings and forming the basis for the development of related industries. At the same time, despite the strong production potential and favorable agroclimatic conditions, the domestic industry still remains predominantly focused on the export of raw materials and oil with a minimum degree of processing. This situation leads to inefficient use of resource

potential and leads to significant losses of added value, which is realized not in Ukraine, but in importing countries, where further advanced processing is carried out [28].

Table 6. Dynamics of exports and imports of agricultural products in January 2026 relative to January 2025

Merchandise category	Export		Import	
	Cost, million U.S. dollars	Changes: January 2026 to January 2025	Cost, million U.S. dollars	Changes: January 2026 to January 2025
Cereals	712,5	-1,00%	12,6	-9,90%
Oilseeds	158,9	-2,80%	39,4	+20,20%
Vegetable oil	601,1	+27,50%	9,39	+30,30%
Meat and meat products	92,7	+11,10%	13,7	+83,20%
Milk and milk products	18,2	-6,10%	22,4	-1,20%
Fish and fish products	2,45	-24,20%	86	+16,40%
Fresh vegetables	1,13	-5%	26,8	-36,40%
Fresh fruits and berries	2,24	+32,40%	98,1	+4,80%
Honey, sugar and products from it	51,9	+0,80%	6,89	-26,10%

Source: Author based [17]

Analysis of the structure of the value chain of oilseeds reveals a systemic problem: individual participants in the chain - producers of raw materials, processing enterprises, logistics operators, research institutions - function in fragments, without proper coordination and institutional interaction. The lack of integrated cooperation mechanisms leads to unjustified losses at the stages of storage, underuse of by-products of processing, which contain valuable components - lecithin, tocopherols, phytosterols, protein fractions - and can serve as raw materials for the pharmaceutical, food and cosmetic industries. Technological backwardness and low level of innovation activity of enterprises in the industry further limit the possibilities of diversifying the product portfolio and entering markets with higher margins.

In this context, the question of which model of organization of interaction between participants in the oil market can comprehensively solve these problems and become an effective tool for the transition from a raw material to an innovative technological model of sectoral development acquires particular scientific and practical relevance. The concept of a cluster approach offers an answer to this request through the synergistic integration of producers, processors, scientists and institutional actors within a single spatial cooperation system. Wartime provides additional urgency to the problem: the destruction of the logistics and processing infrastructure, the reorientation of export flows and the change in market conditions form new challenges, but at the same time new windows of opportunity for the structural restructuring of the industry on a cluster basis in the process of post-war recovery [29].

The problems of forming clusters and value chains in the agricultural sector cover a wide range of scientific areas. Yes, Bartolucci S. et al.. [2] examine the correlation between upstream and downstream positions of enterprises in global value chains, which is the theoretical basis for assessing Ukraine's place in the international division of labor in the field of oilseeds. Michael E. Porter [10] laid the conceptual foundations of the cluster approach through the prism of competitive advantages of countries, which remains the basic theoretical framework for all further research in this area. Mario Davide Parrilli [8] develops cluster theory regarding the challenges of the 2020s, focusing on the transformation of cluster politics in the face of global change. K.V. Zheludenko [16] considers clusters as an innovative tool to ensure the competitiveness of agricultural enterprises, emphasizing their potential for the modernization of agribusiness. I. Kaitanskyi, K. Harbazzhii and I. Hladkyi [18] systematize theoretical approaches to the management of agrarian clusters, which is important for developing practical recommendations for organizing cluster structures in an oil subsequence. I. Chekhova [28] examines the regional aspect of oilseed production in Ukraine, forming an analytical base for assessing the clustering potential of the industry. The materials of the European Cluster Platform [3, 9] and the European Commission [15] outline the best EU practices for supporting clusters.

The cluster approach, as a paradigm for the organization of economic activity, is based on the recognition of the fundamental role of geographical proximity, specialization and networking in the formation of competitive advantages. The basic concept formulated by Michael Porter defines a cluster as a geographic concentration of interconnected companies, specialized providers, service providers, firms in related industries, and related institutions in certain industries that compete but also collaborate. Unlike traditional industrial areas or simply sectoral agglomerations, clusters are characterized by the presence of complex vertical and horizontal connections, institutional support infrastructure, and a culture of cooperation that promotes knowledge exchange and collective learning.

In the context of the agro-industrial sector, the cluster approach takes on specific characteristics related to the nature of agricultural production. Agro-industrial clusters bring together not only processing enterprises and producers of raw materials, but also suppliers of seeds, fertilizers, plant protection products, agricultural machinery, logistics companies, research institutions in the field of agronomy and food technology, financial institutions specializing in agricultural lending, as well as local governments and industry associations. A feature of agro-industrial clusters is their close relationship with the natural and climatic conditions of a certain territory, which determines the possibilities of specialization and differentiation of products. Studies by the European Commission show that successful agro-industrial clusters contribute to 15-25% higher productivity compared to isolated enterprises through effects of scale, specialization and knowledge sharing [3; 9; 15].

The concept of value chains, which derives from Michael Porter's work on enterprise-level value chains and has been developed by researchers of global production networks, focuses on the sequence of activities through which a product or service is created, distributed, and delivered to the final consumer. Each link in this chain adds a certain value to the final product, and the overall efficiency of the chain is determined not only by the performance of individual participants, but also by the quality of coordination and integration between them [10; 18].

In the case of oilseeds, the value chain includes the production of seeds and other raw materials, the cultivation of oilseeds, storage and logistics, primary processing, oil refining and fractionation, food production and technical applications, and marketing and distribution of final products [28].

For Ukraine, which seeks to move from exporting raw materials to creating high value-added products and integrating into global production networks on more favorable terms, the development of an effective oil cluster model can become a strategic lever for regional economic development and strengthening food security (Table 7).

Table 7. Dynamics of exports of oilseeds from Ukraine for 2022-2025, million dollars USA

Culture	2022		2025*		In dynamics	
	Seeds	Oil	Seeds	Oil	Seeds	Oil
Soy	863,1	304,7	1002,4	434,2	139,3	129,5
Sunflower	1256,2	5464,2	36,5	3703,2	-1219,7	-1761
Colza	1540,5	83,6	619,7	169,4	-920,8	85,8
Others	61,3	8,77	46,8	3,83	-14,5	-4,94
Together:	3721,1	5861,3	1705,4	4310,6	-2015,7	-1550,6
Ratio of oil export to seed export, %	157,5		252,8		-	

* Note: As of September 2025

Source: Author based [17]

Particularly promising is the development of areas related to the advanced processing of oilseeds, including the production of functional food ingredients, biofuels, biopolymers and other products with high added value. Studies show that deep processing can significantly increase value added compared to crude oil exports (Table 7) and (Figure 4).

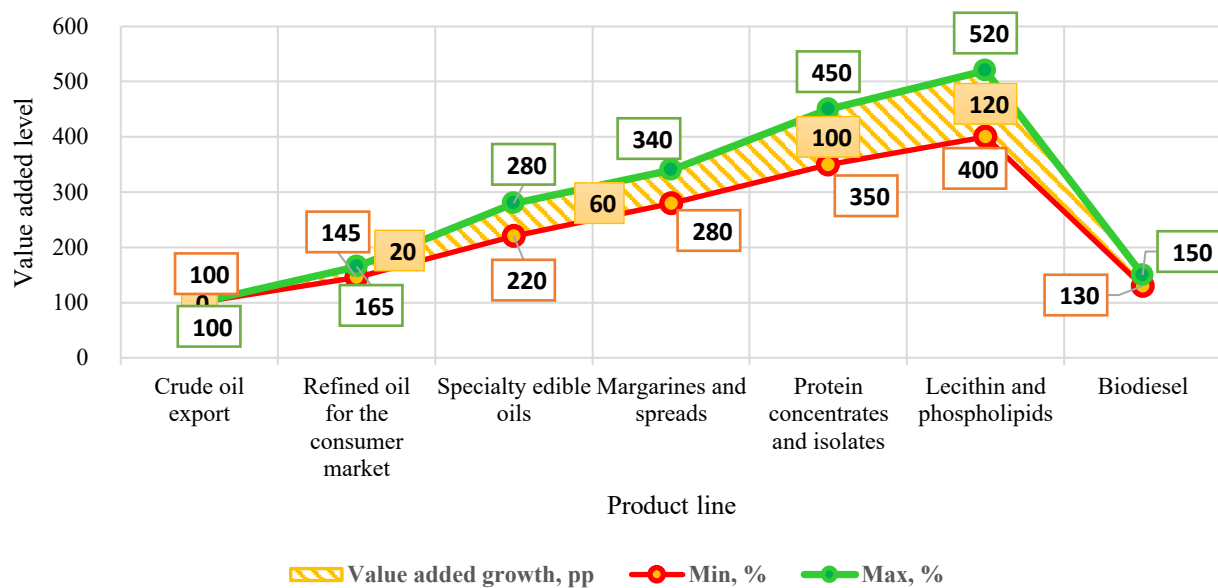


Figure 4. Level of added value in relation to raw materials, %
Source: built by the author based on [8; 13; 20]

Thus, protein concentrates, lecithin and specialized food ingredients demonstrate the highest level of added value, but these areas require significant technological competencies and investments in specialized equipment. The cluster model can facilitate the development of these high-margin directions through the creation of a joint research infrastructure, the exchange of technologies and the coordination of investments between cluster participants.

The choice of the optimal model of the oil cluster for Ukraine requires taking into account the specific conditions of the national economy, industry characteristics and strategic development goals. In international practice, several basic cluster models are distinguished, each of which has its own advantages and limitations in various contexts:

- a regional cluster is characterized by a geographical concentration of interconnected enterprises within a certain region, which ensures maximum use of the advantages of spatial proximity;
- industry cluster unites enterprises of a certain industry regardless of their geographical location, focusing on common technological and market challenges;
- the innovation cluster focuses primarily on the creation and commercialization of new knowledge and technologies through intensive cooperation between business, scientific institutions and educational institutions [16; 21; 29].

The analysis of the Ukrainian context indicates the advisability of using a hybrid model that combines elements of regional and innovative approaches. Such a model provides for the formation of several regional oil clusters in the most suitable areas for this, while creating a nationwide innovation network that will provide technology transfer, coordination of scientific research and the exchange of best practices between regional clusters. The regional component is critical for the fat and oil industry due to the significant role of logistics and the need for close coordination between raw material producers and processing plants [28]. At the same time, an innovative component is needed to ensure long-term competitiveness through the constant updating of technologies, the introduction of new products and adaptation to changes in global value chains.

The structure of the regional oil cluster for Ukrainian conditions should include three main groups of participants. The core of the cluster is formed by enterprises for the production and processing of oilseeds, including agricultural enterprises, elevators, oil extraction plants, refineries and manufacturers of food products based on vegetable oils. The supporting infrastructure covers suppliers of seeds, fertilizers, plant protection products, agricultural machinery and equipment for processing, logistics companies, financial institutions, consulting and engineering firms. The institutional component includes research institutions, educational institutions, standardization and certification laboratories, industry associations, local governments and regional development agencies (Figure 5).

A key element of a successful cluster model is a management and coordination mechanism that ensures effective communication between heterogeneous participants. International experience demonstrates the effectiveness of creating a specialized cluster organization or agency that acts as a coordinator, facilitator of cooperation, representative of the interests of the cluster in relations with authorities and external partners, organizer of joint projects and initiatives. Such an organization can function as an independent non-profit structure funded by membership fees of cluster members, government support and income from joint projects. It is important for Ukrainian conditions to ensure a balance between private initiative and state support in the formation of a cluster organization, avoiding both complete dependence on state funding and insufficient institutional capacity due to limited resource attraction [16, p. 104; 18].

The innovative component of the cluster model provides for the creation of mechanisms for systematic interaction between business and research institutions. This may include joint research projects, internship programs for scientists in enterprises, the creation of technology platforms for the exchange of knowledge, support for startups in the field of agrotechnology and food innovation.

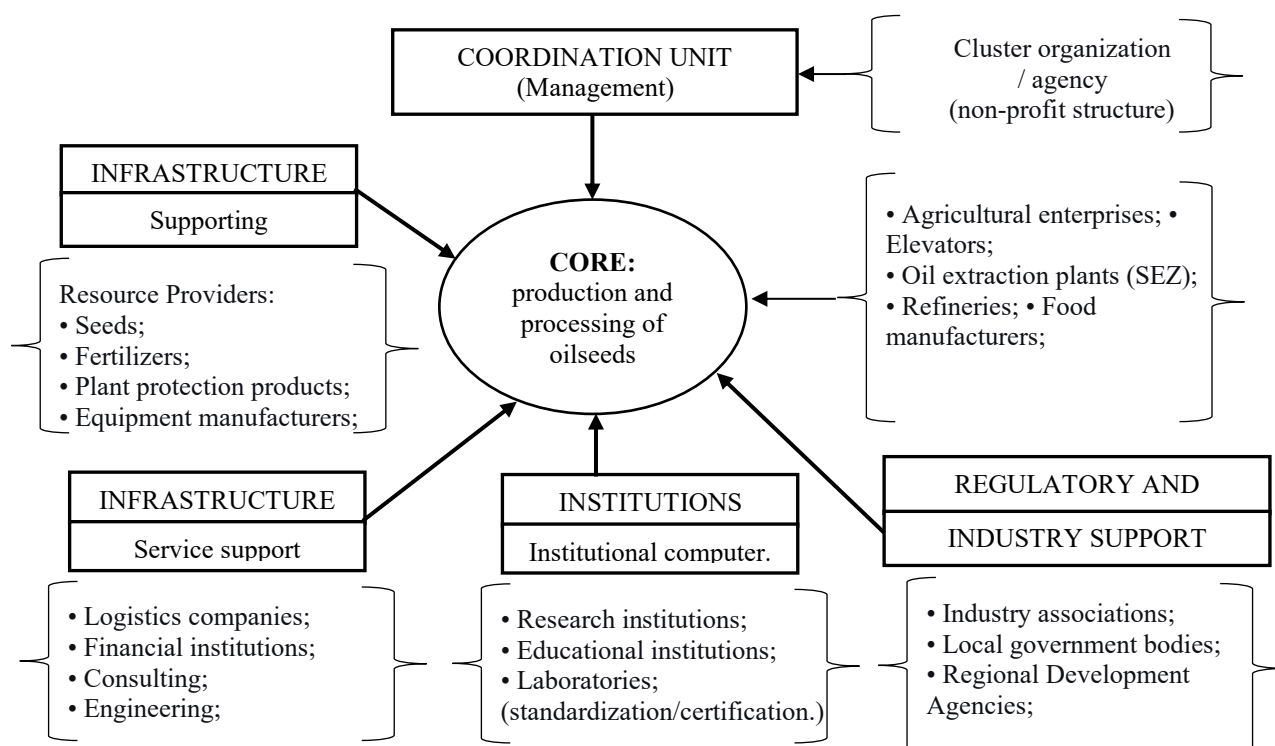


Figure 5. Regional oilseed cluster structure

Source: built by the author

A cluster organization creates specific opportunities to add value at each stage of the chain from growing oilseeds to selling the final product to consumers. During the growing phase, the cluster approach allows for increased productivity and raw material quality through better access to innovation, specialized consulting services and quality seed material. Concentration of production creates economic incentives for suppliers of seeds, fertilizers and plant protection products to invest in the development of products adapted to the specific soil and climatic conditions of the region.

The organization of collective storage and logistics systems within the cluster can significantly reduce product losses and transportation costs. Investments in modern elevator capacities with controlled environment, active ventilation and quality monitoring systems can significantly reduce these losses. A cluster organization makes such investments economically viable because of the ability to ensure stable capacity utilization and the distribution of fixed costs among a large number of participants. The creation of a common logistics infrastructure, including railway access roads, vehicles and transshipment terminals, makes it possible to realize economies of scale and reduce transportation costs [16, p. 106; 18].

In the downstream phase, the cluster approach opens up opportunities for technological modernization, product diversification, and increased utilization of by-products. Conventional seed oil extraction technology

involves the production of crude oil and meal as primary products, while other seed components such as lecithin, tocopherols, phytosterols, and other valuable compounds are often lost or underutilized. The introduction of advanced processing technologies makes it possible to extract these expensive components and create products for specialized markets, such as functional food ingredients, dietary supplements, cosmetic ingredients and pharmaceutical applications.

The key advantage of a cluster organization is the ability to implement the concept of industrial symbiosis, in which by-products or waste from one enterprise become the raw material for another. In the context of the fat and oil industry, this may include:

- the use of sunflower seed husks for the production of pellets as fuel or raw material for the production of furfural;
- processing of glycerol formed during biodiesel production into chemical products or feed;
- use of protein fractions for the production of animal feed or food ingredients.

The geographical proximity of businesses in the cluster reduces the transport costs of moving by-products and facilitates coordination between members of the symbiotic network.

The marketing and sales phase also benefits the cluster organization through collective branding opportunities, co-marketing products in international markets and building the region's reputation as a producer of high-quality oilseeds. Creating a regional brand or geographical indication can be a powerful tool for differentiating products and getting a premium to the price. Successful examples of this approach include the French Appellation d'Origine Contrôlée system for olive oil, Italian regional brands of oils and other forms of collective trademarks [14]. For Ukraine, the development of brands of organic sunflower oil, premium rapeseed oil or specialized products with a high content of oleic acid or other functional components may be promising.

A systematic analysis of the potential for value addition at different stages of the chain through a cluster organization is presented in a summary table (Table 8).

Table 8. Mechanisms to add value at oilseed chain stages through cluster approach

Chain stage	Traditional approach	Cluster approach	Value increase potential, %	Key mechanisms
Cultivation	Standard agronomy	Precision farming, breeding	15-25	Access to innovation, consulting
Storage	Basic elevators	Modern grain terminals	8-12	Loss reduction, quality
Logistics	Retail delivery	Overall Logistics System	20-30	Economies of scale
Primary processing	Oil extraction	Complex processing	40-60	Getting expensive components
Refinement	Basic refining	Fractionation, modification	30-45	Specialty Products
Production of products	Standard products	Functional foods	50-80	Innovation, Premiumization
Marketing	Individual sales	Collective brand	15-25	Reputation of the region

Source: developed by the author based on the analysis of international practices and expert assessments

It should be noted that the presented estimates of the potential for cost increase are approximate and may vary depending on the specific conditions for implementing the cluster approach. It is important to understand that the maximum effect is achieved not through individual initiatives at certain stages of the chain, but through system integration and coordination of activities at all stages, which allows you to realize synergistic effects and optimize the value chain as a holistic system.

In general, based on the study, it can be argued that the cluster approach is one of the most promising organizational and economic tools for the systemic transformation of the oil and fat complex of Ukraine - the transition from a model of raw material exports to the creation of products with high added value and integration into global value chains on more favorable terms. The study confirmed that fragmentation of production links, technological backwardness of individual links in the processing chain and insufficient level of institutional coordination between industry participants are the main structural shortcomings that hinder the realization of the potential of oilseeds as a strategic resource of the national economy. The cluster model is able to address these deficiencies through the formation of an integrated environment where geographic proximity, shared infrastructure, and networking among producers, processors, scientists, and institutional actors generate synergistic effects unattainable for isolated businesses.

So, we can state that the traditional raw material model of agricultural exports of Ukraine, which is based on the mass export of grain and sunflower oil in unprocessed or primarily processed form, demonstrates systemic restrictions in terms of both income generation and resistance to external shocks. Analysis of global trends shows that each dollar of added value in the processing chain generates 2.5-3.5 times more GDP and provides 4-6 times more jobs compared to raw materials sales of a similar volume of agricultural products. Firstly, this means that the shift in emphasis from "selling grain" to "selling flour, cereals, pasta, feed mixtures, food ingredients" is not just desirable, but a strategically imperative transformation.

Critical tools for increasing added value are: development of capacities for deep processing of grain (flour, starch, glucose-fructose syrups, bioethanol); expansion of oil and fat processing from raw oil to margarines, mayonnaise and specialized fats; development of production of organic and functional products (the market of which is growing in the EU by 8-10% annually); promotion of niche crops - flax, buckwheat, hemp, echinacea, spelts - with direct contracts for the markets of Central and Western Europe. A special role is played by the strategy of geographical designations (GI) on the model of the EU, which allows you to monetize the uniqueness of the regional origin of the product, adding from 15 to 80% of the price premium compared to unmarked counterparts.

The dynamics in the meat products segment is also indicative (Table 6). The growth of meat and meat products exports by 11.1% - to \$92.7 million - testifies to the gradual strengthening of cooperation ties in the livestock industry, where feed producers, farms, slaughterhouses and meat production enterprises form a relatively closed value chain. At the same time, a sharp increase in imports of meat products (+ 83.2%) indicates unsecured domestic demand and insufficient capacity of cooperation ties in this segment, which signals a significant potential for the development of intra-industry cooperation.

At the same time, the negative dynamics in certain product groups - milk and milk products (-6.1%), fish and fish products (-24.2%), fresh vegetables (-5%) - indicates the fragmentation of cooperation chains in the relevant sub-sectors and the insufficient level of their integration. But the positive dynamics of fruits and berries (+ 32.4%), as well as honey, sugar and products from it (+ 0.8%), indicates the formation of new niches for cooperative specialization (Table 6).

Geographical diversification of sales markets is one of the key indicators of the maturity of cooperation structures and their ability to produce products in accordance with the requirements of various international markets. The study of the geographical distribution of agricultural exports reveals both established partnerships and new strategic directions reflecting the growing competitiveness of processed products [1; 17].

Analytical data indicate a significant differentiation of dynamics between individual geographical sales markets, which directly reflects changes in the competitive position of Ukrainian manufacturers and the success of cooperation strategies aimed at meeting the requirements of specific markets. The most significant result is the rapid growth in supplies to Turkey - from 116.5 to 235.7 million dollars. USA, or almost twice (+ \$119.2 million). This growth reflects the effectiveness of interaction between Ukrainian oil and grain producers and Turkish trading partners, which act not only as end consumers, but also as re-exporters of processed products (Figure 6).

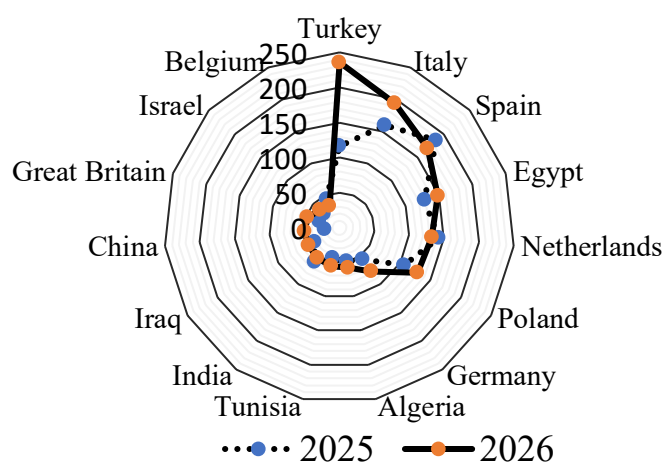


Figure 6. Rating of countries for the export of Ukrainian agricultural products (as of January 2026)

Source: built by the author based on [17]

A significant increase in supply volumes is also recorded in China (+ \$28.8 million, or + 137%), which is evidence of the development of a new strategic market, access to which is possible only if there are certified, technologically mature cooperation chains capable of providing quality standards and volumes that meet the requirements of Chinese importers. Significant growth was also recorded in Poland (+ \$22.1 million), Germany (+ \$21.2 million) and the UK (+ \$17.3 million), which indicates the gradual penetration of processed products into the demanding markets of the EU and the UK with their strict standards of quality and food safety.

At the same time, the decrease in supplies to Spain (-17.2 million dollars), the Netherlands (-9.63 million dollars) and Belgium (-10.8 million dollars) is due to competitive pressure from other suppliers and a partial reorientation of resources to markets showing higher demand. This trend indicates the need to strengthen cooperation specialization on products with specific competitive advantages that can withstand competition in the most saturated markets. Consequently, the geographical structure of agricultural exports in 2026 reflects both successes and challenges for the domestic system of inter-entrepreneurial cooperation in the field of agricultural processing.

Summarizing, it can be argued that cooperation between enterprises is not only an organizational, but also an economic phenomenon that directly affects the profitability and competitiveness of participants in agricultural chains.

The scale of the damage caused and the volume of indirect losses naturally raise the question of the formation of a comprehensive strategy for the recovery of the agricultural sector. Realistic planning for redevelopment requires a detailed consideration of funding needs by focus area and time horizon. Table 9 summarizes the recovery needs for 2025-2035.

Table 9. Recovery needs, billion dollars United States (2025-2035)

Direction	Amount, billion dollars USA	In% of total
Service recovery, total	38,9	100,0
Promoting climate-oriented technologies	15,0	38,6
Value chain development	10,0	25,7
Investment grants	10,0	25,7
Support for agricultural institutions	3,0	7,7
Other	0,9	2,3
Recovery, total	10,5	100
Agricultural equipment and machinery	7,2	68,6
Warehouse facilities	2,3	21,9
Perennial, animal husbandry, fish farming	1,0	9,5
Production support, total	6,0	100
Program 5-7-9%	3,1	52
Grants for small FGs	1,1	18
Recultivation	1,1	18
Other	0,7	12
Total, billion dollars USA	55,4	—

Source: compiled by the author based on [1; 19]

The total need to restore the agricultural sector over the ten-year horizon is \$55.4 billion. US, which is structured in three main components: restoration of services (\$38.9 billion USA), physical recovery (\$10.5 billion US) and production support (\$6.0 billion USA).

The largest share is \$38.9 billion. The United States, or 70% of the total, falls on the restoration of services. The leading article of this component is the promotion of climate-oriented technologies - \$15.0 billion. USA (38.6% of service recovery). This figure reflects the recognition that simply restoring the pre-war production model is insufficient: the agricultural sector needs to be structurally modernized to address increasing climate risks. Sunflower production in 2024 decreased significantly due to drought - a fact that clearly illustrates the vulnerability of production systems without appropriate climatic adaptation. \$10.0 billion each The United States (25.7% each) is provided for the development of value chains and investment grants.

Restoration of the material and technical base requires \$10.5 billion. USA. The dominant item is the restoration of agricultural equipment and machinery - \$7.2 billion. USA (68.6%), which directly corresponds to the structure of direct losses, where damage to equipment accounted for the largest share. Therefore,

restoration of the technical fleet is a critical priority, as without it any other restoration measures will have limited effect. \$2.3 billion is provided for the restoration of warehouse facilities. USA (21.9%), for the revival of perennial plantings, animal husbandry and fish farming - \$1.0 billion. USA (9.5%).

Production support is estimated at \$6.0 billion. USA. Half of this volume is \$3.1 billion. USA (52%) - provided for the program of cheaper loans "5-7-9%," which is the main financial instrument to support agricultural production in Ukraine. Equal shares - \$1.1 billion each. USA (18%) each - planned for grants for small farms and for the reclamation of contaminated and mined land. Reclamation is a particularly important article, given the scale of mine pollution: according to various estimates, from 174 to 250 thousand square kilometers of Ukrainian land need demining, which directly limits the restoration of processing.

It should be noted that the recovery of the industry has already begun: in 2022-2024, the state budget and donors allocated \$873 million. USA, mainly for interest rate compensation (49%) and grants for small producers (22%). However, this amount is only 1.6% of the total need, which indicates the need to attract significant amounts of private capital and international funding. In particular, private investment has significant potential to become an engine of recovery, which requires the formation of an appropriate investment climate.

The question of the optimal structure of agricultural production in the post-war conditions is one of the most controversial in the professional environment. Researchers disagree on whether large agricultural holdings retain a dominant position, or whether the crisis opens a window of opportunity for restructuring in favor of small and medium-sized entities. The answer to this question is not unambiguous, since different models show a different stability profile depending on the specific operating conditions, which is summarized in Table 10.

Table 10. Comparative resilience of post-war agribusiness patterns

Model	Resilience in Crisis	Benefits for recovery	Risks and limitations
Large agricultural holdings (> 50 thousand ha)	Average	Access to capital, technology scaling, international certification	High vulnerability to assets in the war zone, dependence on foreign markets
Medium farms (500-5000 ha)	High	Flexibility, rapid reorientation of cultures, local employment	Limited access to credit resources, lack of agro-consulting
Cooperatives and associations of small farmers (<500 ha)	High (in a well-developed network)	Food security of the region, preservation of rural communities, diversification of products	Need for government support, low capitalization
Mixed partnerships (holding + cooperative), clusters	High	Synergy of capital and local knowledge, risk allocation	Management complexity, need for legal settlement

Source: compiled by the author based on [20-25; 29]

These data strongly suggest that medium-sized farms and cooperative or cluster structures demonstrate higher operational resilience in crisis conditions compared to large holdings. This is due to their ability to quickly reorient to alternative crops, a smaller share of assets in high-risk zones and an organic connection with local food systems. At the same time, large agricultural holdings remain indispensable in terms of access to international capital and technology, which is critical for the implementation of large-scale investment recovery projects. Therefore, the optimal structure of the post-war agricultural sector does not provide for the dominance of one model, but a synergistic combination of all three forms within a regulated system with clear government incentives for each segment.

The blockade of the Black Sea ports in 2022-2023 exposed the key structural vulnerability of Ukraine's agricultural exports - its critical concentration in one geographical node. Before the invasion, about 75-80% of grain and oilseed exports passed through the Odessa, Black Sea and Nikolaev ports. But in wartime conditions, there was an urgent need for operational diversification, which is also a strategic task for the post-war period. A comparative analysis of alternative logistics routes is presented in Table 11.

Table 11. Alternative logistics routes and tools for diversification of agricultural exports

Route/tool	Current throughput	Development potential	Priority actions
Danube ports (Izmail, Reni, Kilia)	Up to 3-4 mln t/month	Expansion to 8-10 million tons/month. for overload investments	Deepening of the fairway, new terminals, railway communication
EU rail corridor (broad/narrow gauge)	~ 30-35 million tons per year (2023 estimate)	Up to 50-60 million tons/year when upgrading gauge transfers	Acceleration of gauge conversion, simplification of customs procedures
Black Sea Grain Corridor (restored)	Temporarily restored in 2022-2023, suspended	Full de-escalation recovery	International guarantees, insurance, demining
Baltic routes (via Poland, Lithuania)	Limited (~ 5-8 million tons per year)	Growth in Polish port infrastructure	Coordination of tariffs, compatibility of standards
Direct contracts with Asian and African countries (without intermediaries)	Develops	Formation of stable bilateral agreements for 3-5 years	Diplomatic support, digital trading platforms

Source: Author based [19]

The results of the study of alternative logistics routes demonstrate that no single route can completely replace the Black Sea corridor in conditions of hostilities or constant threats. Danube ports, despite a significant expansion of capacity in 2022-2024, are limited by the depth of the fairway and the throughput potential of the river itself. Rail corridors across the EU are promising, but require a solution to the problem of gauge differences and harmonization of customs procedures. In general, the diversification strategy should be based on the principle of a "portfolio approach": the simultaneous development of several routes of various modalities ensures geopolitical resilience regardless of the development of specific regional conflicts or protectionist trends of individual countries.

Digitalization of the agricultural sector acquires a fundamentally new meaning in the context of post-war recovery, when there are two critical deficits at the same time: personnel (through mobilization and forced migration) and financial (due to the need to effectively use limited resources). A comparative analysis of the main digital technologies and their impact on production indicators is systematized in Table 12.

Table 12. Agribusiness Digital: Functionality, Efficiency, and Barriers to Adoption

Technology/Tool	Functional purpose	Effect on performance	Barriers to implementation
Precision farming (GPS, IoT sensors, drones)	Crop monitoring, differentiated fertilization	15-25% reduction in resource costs, 10-20% increase in yield	High initial cost of equipment, need for trained operators
Remote sensing of the Earth (satellites, UAVs)	Mapping of damaged land, mine pollution assessment	3-5 times faster land inventory	Dependence on cloud services, the question of data sovereignty
Electronic document management (USRP, agro-ERP)	Digital land registration, subsidies, reporting	30-40% reduction in administrative costs	Digital divide in small communities, cybersecurity
Agro-information platforms and marketplaces	Connecting manufacturers with buyers, insurance companies	12-18% increase in income for small farmers	Distrust of platforms, the need for a legal framework
Automated farming (robots, autopilot technology)	Compensation for personnel shortages in the fields	40-60% reduction in manual labor in some operations	Critical dependence on power supply and service

Source: Author based [26]

These data allow us to draw several fundamental conclusions. First, digital technologies are able to compensate for 30 to 60% of the personnel deficit in individual operational processes - in particular, automated agriculture and remote monitoring of crops. Secondly, the systemic effect of the integrated implementation of digital solutions exceeds the simple sum of individual effects: the integration of satellite monitoring with

precision fertilization and automated technology allows achieving synergistic productivity growth by 25-35%. Third, the key barrier is not technological accessibility, but the digital divide between large farms and small farmers, which requires targeted government support in the form of subsidized access to digital platforms and operator training programs.

Ukraine's food security is an integral part of its national security and an important factor of stability in global markets. We have summarized the key factors that form the contour of food security in Ukraine in war conditions (Table 13).

Table 13. Key Factors Affecting Ukraine's Food Security (2022-2025)

Category	Indicator/Impact factor	Quantification/Trend
Production potential	Change in total output of agricultural products	Reduction by 15.5% (from 1267 to 1070 billion UAH per post. prices 2021)
	Reduction of acreage	Withdrawn from circulation ~ 5 million hectares of agricultural land
	Losses of irrigation systems	Lost Kakhovskaya irrigation system for 584 thousand hectares
Key Product Groups	Production of cereals and legumes	Reduction by 14.5% (from 413 to 353 billion UAH)
	Fruit and vegetable production	Reduction by 37% (from 211 to 133 billion UAH) - the largest relative drop
	Production of livestock products	Reduction by 17.6% (from 256 to 211 billion UAH)
Export potential (ability to generate revenues)	Share of agricultural exports in the country's total exports	Increased from 45% (2020) to 59% (2024)
	Share in global exports (sunflower oil)	35.6% - critical role in the global food system
	Dynamics of vegetable oil export	+ 27.5% growth (Jan 2026 vs Jan 2025)
Logistics and market access	Logistical constraints	Blockade of Black Sea ports for the ~ 18 months, reorientation to land and river routes
Industry losses	Direct losses of the agro-industrial complex	\$11.2 billion USA (58% - destroyed equipment)
	Indirect losses (lost revenue)	\$72.8 billion USA (51% - due to a decrease in the production of annual crops)
Resilience to crises	Comparative stability of business models	Medium-sized farms and cooperatives show higher sustainability than large agricultural holdings

Source: compiled by the author based on [1; 17; 19]

The war caused not point, but systemic defeats of the agricultural sector, which simultaneously covered the production base, logistics, personnel potential and sales markets. The most long-term effects are land mine pollution and loss of irrigation systems, which will take decades to recover. Despite colossal losses (total direct and indirect losses exceed \$84 billion. USA), the agricultural sector not only survived, but also increased its share in the country's economy, becoming the main source of foreign exchange earnings. This indicates the high adaptation potential of the industry, but at the same time indicates its critical importance for macroeconomic stability. Successful restoration and strengthening of food security in Ukraine is impossible without significant amounts of external funding (the need is estimated at \$55.4 billion. USA), technological support and security guarantees to restore the full operation of marine export corridors.

The speed of recovery of destroyed agricultural enterprises and their long-term competitiveness directly depend on how much the recovery process integrates innovative solutions, and not just reproduces the pre-war technical and technological base. This thesis is confirmed by international experience in the post-war recovery of agricultural sectors: In particular, the experience of Rwanda after the 1994 genocide and Vietnam after 1975 indicates that enterprises that combined recovery with the introduction of new technologies, after 7-10 years exceeded pre-war productivity indicators by 1.5-2 times.

The climatic measurement is gaining special weight due to the fact that the average annual temperature in Ukraine over the past 30 years has grown by about 1.2 ° C, and droughts in the South and East have become more frequent and prolonged. Therefore, the restoration of agricultural enterprises without taking into account climate adaptation will mean their repeated vulnerability in 10-15 years. Key innovation areas include: introducing drought-resistant and heat-resistant varieties; transition to water-saving irrigation technologies (drip irrigation); development

of agroforestry and restoration of forest belts destroyed over decades of agricultural plowing; using AI-based predictive analytics systems to make crop rotation and risk management decisions.

The agricultural sector is traditionally considered mainly in the production and economic dimension. However, in conditions of de-occupation of significant rural areas, it is able to play the role of a systemic "anchor" for the restoration of all social and physical infrastructure. This phenomenon can be described through the concept of an "agrarian multiplier": each stably functioning agricultural enterprise in a de-occupied territory generates demand for transport infrastructure (roads, bridges), energy, telecommunications, housing services for staff, education and medicine for families employed. World Bank research shows that every dollar invested in rural agribusiness in post-conflict economies generates \$2.0-3.2 of growth in related industries [11].

Practical mechanisms for realizing this synergy include: the tool of "agro-infrastructure packages," under which large agricultural holdings receive benefits (subsidies, land concessions) in exchange for commitments to invest in the restoration of local roads, schools and medical facilities; corporate social responsibility programs supported by tax incentives for investments in the social infrastructure of the communities of presence; model of "agricultural parks" - integrated complexes that combine production, processing and logistics functions with housing and educational infrastructure, creating self-sufficient centers for the revival of rural communities.

The global food system is in a state of structural turbulence caused by a combination of factors: increased protectionist trends among key importers, restructuring of supply chains after COVID-19, growing climate risks in traditional production regions and geopolitical fragmentation. In this context, Ukraine has a unique "window of opportunity" associated with its natural production potential, but it is possible to use it only if it is actively strategic positioning, and not passive expectation of a recovery in demand.

The grain sector remains the foundation, but requires a transition from the sale of raw materials to contract trade with fixed supplies, which ensures price stability and long-term relations with importers. The oilseed sector - due to the preserved processing potential - may occupy a niche of premium oils (cold-pressed sunflower, linseed, rapeseed) in the EU and Asian markets. Niche and organic crops are the segment with the highest growth rate of value: the demand for organic products in the EU is growing by 8-10% annually, while Ukraine is already one of the ten world producers of organic grain. Therefore, the positioning strategy should be based on a three-tier model: mass crops and oilseeds - as a stable base; deep processing - as the main generator of added value; organic and niche products - as a premium growth segment.

A comparative analysis of three fundamentally different conceptual approaches to post-war reconstruction - the reproduction of the pre-war model, forced modernization and the construction of a fundamentally new agrarian architecture - is the central theoretical and analytical task of this study. Each approach has its own benefit and risk profile, which is summarized in Table 14.

Table 14. Comparative analysis of conceptual models of post-war agribusiness recovery

Evaluation criterion	Restoring a pre-war model	Forced modernization	New agrarian architecture
Production recovery rate	High (3-4 years)	Average (5-7 years)	Inferior (7-10 years)
Food security (short-term)	High	Average	Low
Competitiveness in 2035-2040.	Low	Average-high	High
Climate resilience	Low	Average	High
Value added and diversification	Low (feed model)	Average	High (processing, niche crops)
Need for external financing	Moderate	High	Very high
Social effect (employment, communities)	Moderate	Moderate	High
Integral score (score 1-10)	5,5	7,0	8,5*

* Evaluation in conditions of sufficient external funding and consistent public policy.

Source: compiled by the author

The benchmarking results demonstrate the undoubted advantage of the "new agrarian architecture" model in most strategic criteria, despite its lower performance in the short term. This model provides for simultaneous action in three planes: structural (restructuring of land relations and the ownership system in favor of a diversified farm structure); technological (large-scale implementation of digital, precision and biological technologies as a standard, not an exception); institutional (building a new system of agrarian

education, meeting, financial intermediation and market infrastructure). Therefore, the key issue is not the choice between these three models in its pure form, but the determination of the correct balance between them in different time horizons: in the first 2-3 years, priority should be given to elements of "forced modernization" to ensure food security, while at the same time the institutional foundations of the "new architecture" are being laid, the results of which will manifest themselves in a 7-15-year perspective.

Conclusions. The study suggests that the agribusiness of Ukraine, despite the unprecedented challenges caused by the full-scale invasion, has retained the status of a backbone element of the national economy. The analysis showed a contradictory, but generally stable dynamics of the industry: despite the reduction in the share of GDP to 6.8% in 2024, absolute production volumes increased by 46%, and the share of agricultural exports in total foreign trade reached 59%. This testifies to the transformation of the agricultural sector into a key guarantor of foreign exchange earnings and a balancer of the country's balance of payments in a military economy.

At the same time, the study revealed that this sustainability is achieved at the cost of colossal structural losses. The total volume of direct losses of the agro-industrial complex reached \$11.2 billion. USA, with the greatest damage caused to the technical park (58% of total losses). Indirect losses, which are estimated at \$72.8 billion, turned out to be even more destructive. The United States, which is six times more than direct losses and indicates a deep operational decline, especially in the production of annual crops. The production potential of the industry decreased by 15.5% compared to 2018, with the most critical drop recorded in sectors tied to the occupied southern regions, in particular in the production of fruits and vegetables (a drop of 37%).

The key conclusion of the study is the confirmation that the raw material model of agricultural exports has exhausted itself. Despite maintaining a leading position in global exports of sunflower oil (35.6%) and meal (40.2%), the commodity structure of exports demonstrates a high concentration on products with a low degree of processing (corn - 29.5%). A direct correlation was revealed between the development of cooperation ties and the growth of exports of products with higher added value. In particular, the outstripping growth in the export of vegetable oil (+ 27.5%) against the background of a decrease in the export of oilseeds is an empirical confirmation of the effectiveness of vertical cooperation in the oil and fat complex. But the fragmentation of ties in the livestock and dairy sectors leads to the loss of markets and an increase in imports, which indicates reserves for the development of intra-industry integration.

It has been proven that a cluster model of production organization is an optimal tool for overcoming structural imbalances. A hybrid model combining regional concentration (to optimize logistics and use natural advantages) with an innovative component (for technology transfer and deep processing) can provide a synergistic effect. Calculations show that the introduction of the cluster approach allows to increase the added value at different stages of the production chain: from 15-25% at the stage of cultivation (thanks to precision technologies) to 50-80% at the stage of production of functional food products. This confirms the thesis that the strategic transition from the export of raw materials to the export of deep processing products is not only desirable, but also an economically justified vector of development.

Summary of recovery needs (\$55.4 billion) US 2025-2035) and comparative analysis of agribusiness patterns demonstrate that simple reproduction of the pre-war structure is the least effective in the long term. The highest integral assessment (8.5 points) was received by the model of the "new agrarian architecture," which provides not just physical restoration, but high-quality modernization based on climate adaptation, digitalization and cooperation development. It was revealed that medium-sized farms and cluster structures demonstrate higher operational stability in crisis conditions compared to large holdings, which actualizes the issue of revising the state support policy in favor of a more balanced structure of the agricultural sector.

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TRENDS OF SMALL BUSINESS DEVELOPMENT IN UKRAINE UNDER DISPROPORTIONALITY OF ECONOMIC GROWTH

Larysa Poliatykyina

Candidate of Economic Sciences, Associate Professor, Associate Professor, Department of Accounting and Taxing, Sumy National Agrarian University, Ukraine

ORCID ID: 0000-0003-1548-934X

Small business is an integral part of a market economy, which gives it flexibility, mobilizes financial and production resources, accelerates the pace of scientific and technological progress, solves the problem of employment of the population, and also forms an economically independent and stable middle class. Therefore, multilateral support for the development of small business and the construction of a socially oriented economy should become the main vector of reforms in Ukraine, which will serve as a factor in raising the standard of living of the population and will contribute to the processes of integration of the national economy into the world global economy.

Modern market economy encourages enterprises to implement the latest equipment and technologies, expands the range of possibilities for using newer financial instruments and mechanisms. Issues that require further research include: the issue of determining the original cost of objects of means of labor obtained from various sources; the issue of determining the liquidation and revalued value.

Problem statement. The purpose of the study is the conditions for the functioning of small business in Ukraine in the context of its support by the state and substantiation of the main prospects for its development.

Research results. Small business is the most massive, dynamic and flexible form of business life with its own development patterns and specific advantages, which under certain conditions become disadvantages that hinder its development. For example, relatively small capital for starting a small business narrows the scope of production and limits the possibility of attracting additional resources: scientific and technical, financial, production, labor, etc. The instability of a small business due to limited resources, as well as increased sensitivity to changes in the economy, is much higher than that of large and medium-sized business structures. About 80% of small businesses exist for a year or two, and more than a third are unprofitable

The reason that small businesses in many sectors of the economy are in debt dependence is the difficulty of obtaining bank loans. As a rule, banking institutions provide short- and medium-term lending against collateral that far exceeds the loan provided. The financial assistance provided by the Ukrainian Entrepreneurship Support Fund and the State Innovation Fund is quite insignificant. Therefore, an important measure of state support should be the provision of preferential loans to small entrepreneurs and their state guarantee.

In conditions where the state financial policy to support small businesses is unable to create conditions for the necessary development of infrastructure, which would stimulate more effective functioning and penetration of small businesses into new sectors of the economy, the volume of international support is increasing every year. New business centers and credit lines are being created, but investments by international funds in the development of small businesses in the domestic economy are still several times smaller than in other European countries.

In the conditions of market transformation of the Ukrainian economy, the development of entrepreneurship, in particular small business, should become one of the most important factors of socio-economic growth. Realizing the innovative role of entrepreneurship, the state provides it with comprehensive support.

After the declaration of independence, Ukraine began a multi-stage and complex process of market transformation. It involves the formation of a currency and monetary system, its own legislative institutions, privatization, land reform, etc.

The process of formation of small business in the young Ukrainian state is especially relevant today. In the conditions of gigantism, extremely poorly developed economic relations and the crisis economy as a whole, small business acts as one of the means of solving many socio-economic problems. It contributes to the weakening of monopolistic tendencies by developing intra-industry competition in the national economy.

The special role of small businesses is to support and develop some industries, in particular, trade, services and public catering. During the command economy, these industries developed extremely poorly, as the state focused on large-scale production. The deformation of the sectoral structure of the national economy can be largely corrected with the help of effective small private business.

However, despite all the positive developments, small business faces a large number of obstacles. Its development is uneven, chaotic and contradictory, it is not given due attention by state authorities: support

programs are declarative, there is no coordination in the actions of central and local authorities, weak financial assistance, etc.

The process of formation of small private business in the economy of Ukraine requires further in-depth research. This topic is especially relevant today, when the processes that accompany the formation of entrepreneurship are still insufficiently studied. Western economic science has been studying small business in depth for more than one decade. Domestic economists have only begun to study this phenomenon during the independence of Ukraine.

However, even modern studies do not provide an exhaustive assessment of the profound transformations that are taking place in the small private business sector, since it is in constant dynamics. Each time, scientists-researchers of the phenomenon of entrepreneurship encounter qualitatively new manifestations of it. Further research is required on the problems of determining the optimal size of small enterprises, developing an effective system of state regulation and support for domestic entrepreneurship, and the experience of Eastern and Central European countries in the development of private business with a projection on the specifics of the Ukrainian market.

The starting point is the category of ownership and one of its forms - private ownership. The property relations that prevail in society affect the socio-political system, economic development, and the formation of interests of various social strata. They form the country's economic system and the network of institutions that support its functioning.

The concepts of "business" and "entrepreneurship" are synonymous. Entrepreneurship is considered as an innovative, risky activity of individuals to create goods, the purpose of which is to make a profit. Accordingly, an entrepreneur is a strong-willed, energetic, creative, purposeful, ambitious and persistent leader who is able to organize his own business, involve other people in its implementation, effectively combine various resources, etc. Attention is focused on a certain synonymy of such terms as "firm", "company", "enterprise" and "small entrepreneurship" and "small business".

Until recently, Ukrainian small businesses were assessed according to the criteria formulated in the Law of Ukraine "On Enterprises". As practice has shown, these indicators were significantly overestimated and economically impractical and therefore were not widely used. Ukraine uses the criteria formulated in the Decree of the President of Ukraine "On State Support for Small Entrepreneurship".

The use of two indicators of the above-mentioned document: the number of employees and the volume of annual revenue is quite sufficient for practical purposes. In our opinion, there is no need to differentiate the indicators of the number of employees by industry, since it is very difficult to objectively assess the optimal size of small businesses in different sectors of the economy. A single universal criterion greatly simplifies the characteristics of small businesses.

The role that small businesses will play in Ukraine will largely depend on the country's economic model. The individualistic and cooperative values of Ukrainians correspond to a multi-party system of political rule and a market economy with limited state intervention. The Ukrainian model should be formed evolutionary, based on the political, economic, natural and climatic, historical, cultural features of the country's development, and in no case be a copy of another model.

In our opinion, it is inappropriate to make calculations to determine the exact number of SMEs that is necessary for the competitive development of the domestic economy. It is much more important to direct the state's attention to implementing radical economic transformations. After some time, as a result of this tactic, such a number of small firms will appear in Ukraine that will be optimal for the effective functioning of the national economy. In its activities, small domestic businesses encounter various macro- and microeconomic obstacles. The first group includes the following:

- tax policy,
- lack of proper legislative and regulatory support.

Today, the country's tax system has an extremely negative impact on business development. According to our estimates, more than 80% of an enterprise's income is withdrawn in the form of various taxes and payments. The modern tax system does not allow enterprises to make investments, and also creates the most favorable conditions for their departure into the shadow economy. Entrepreneurial activity cannot fully develop due to the absence or imperfection of the laws that regulate it.

Administrative barriers. A large number of laws, regulations, instructions confuse entrepreneurs, they are forced to spend a lot of time studying changes to the legislation and implementing them in their activities. Enterprises are subject to frequent and groundless inspections by various government agencies.

Limited domestic demand and the presence of a sales crisis in the domestic market. As a result of massive unemployment, increasing arrears in wages and pensions, and recent inflationary jumps, citizens' incomes are decreasing. Small businesses are losing their main consumers of their products.

Insufficient state support. Today, Ukraine has not yet developed an effective system of state support and protection of small businesses. There is a weak financing and lending mechanism, inadequate information and consulting support, and an imperfect system of training and retraining personnel for entrepreneurial activity.

Low investment activity. Instability deters entrepreneurs from investing. Most SMEs do not have the funds to make capital investments, since loans are too expensive and short-term, and most of the profits are directed to paying taxes.

Underdeveloped infrastructure. Despite the large number of infrastructure facilities, their role in the development of small businesses is still very insignificant. Effective cooperation and information exchange has not yet been established between various organizations supporting SMEs and SMEs themselves.

Underdevelopment of the financial sources market. The high cost of credit resources and the limited state financial funds significantly limit the possibilities of SMEs. Firms are forced to rely mainly on their own funds and the capital of private individuals.

Shadow economy. Small businesses are increasingly using the practice of working without contracts, and are also trying to transfer their operations to cash turnover in order to minimize taxation. Most often, SMEs are forced participants in the shadow economy, "driven" there by tax pressure, state bureaucracy, etc.

Ineffective privatization. Although small-scale privatization is almost complete, it has not given a significant impetus to the development of private entrepreneurship. The process of small-scale privatization was subject to many restrictions. As a result, with a non-functioning secondary market for privatization objects, many enterprises are in the hands of those who are unable to manage them, but cannot sell them.

General economic crisis. The development trends of small business are directly affected by the negative dynamics of the main macroeconomic indicators. The constant decline in GDP leads to a decrease in the internal financial resources of the state, working capital of business entities, and a decrease in the purchasing power of the population of Ukraine. The opportunities of small enterprises in the market are significantly limited by the high share of barter in turnover.

Underdevelopment of the real estate market. Small enterprises are catastrophically short of office space. Rent is very high, rental rules are confusing, in many cases the facility is not allowed to be privatized together with the premises.

Underdevelopment of leasing and franchising significantly narrows the range of business financing. Due to the high cost of leasing payments, small businesses in Ukraine are unable to lease equipment. Therefore, it is necessary to create conditions for the emergence and development of leasing companies, as well as encourage banks and other financial institutions to participate in leasing relations. Among the microeconomic factors that most influence the development of small business, the following can be distinguished: the method and time of its emergence; form of ownership; financial capabilities of the enterprise; range of products it manufactures, their quality and demand for them; the chosen strategy of the enterprise, its organizational structure; personnel policy; the possibility of access to commercial information; the manager's skills to professionally manage the business; the degree of compliance by clients with the terms of contracts and payment discipline.

Approximately until the 70s, SMEs were "considered" unpromising and were not given due attention by the state and researchers, since large enterprises prevailed in Western economies. However, during the 70s, the center of gravity of business activity gradually began to shift to the small business sector, which was manifested in a significant increase in the number of small enterprises, an increase in their influence on the creation of national income, ensuring employment and developing competition.

Small enterprises in Ukraine are in private, collective, state and mixed forms of ownership. In 1997, the largest number - almost 65% - were collective, 31% - private and 0.9% - state.

One of the ways of emergence of small private enterprises is small privatization. More than 45 thousand SMEs were privatized. In fact, small privatization did not become a significant catalyst of entrepreneurial activity, as in other countries, because it was often carried out inefficiently, without taking into account the interests of new owners and was not supported by a number of necessary economic reforms.

The share of SMEs in almost all sectors of the economy is decreasing, with the exception of trade, public catering and logistics. Almost 52% of all SMEs operated in these three areas. Small companies are concentrated in sectors where capital is quickly repaid and large material costs and investments are not required for doing business. Many SMEs are simultaneously engaged in several types of activity.

In Ukraine, there is a very uneven distribution of small businesses across regions. It is due to different territorial conditions: economic potential, resource provision, specialization of regions, level of investment activity, state of market infrastructure, relations between state bodies and business structures. These regional features should be taken into account in the process of developing state support measures.

A number of regulatory acts have been adopted and are in force in Ukraine, which laid the foundation for the formation and development of entrepreneurship. According to these regulatory acts, state support for entrepreneurship is aimed at creating favorable organizational and economic conditions for its development. This is the provision of land plots to entrepreneurs; transfer of state property necessary for entrepreneurial activity; assistance to entrepreneurs in organizing material and technical support and information services, training personnel; implementation of the initial arrangement of undeveloped territories with production and social infrastructure facilities with their sale or transfer to entrepreneurs in accordance with the procedure prescribed by law; stimulating technological modernization, innovative activities, development of new types of products and services and other types of assistance.

To ensure the development of free entrepreneurship in Ukraine, the rights, obligations and responsibilities of business entities, which are oriented towards effective management, have been legally defined. Entrepreneurship is incompatible with economic incompetence, losses, irresponsibility, failure to fulfill obligations and contracts with counterparties.

A particularly negative phenomenon is that a significant number of registered small businesses are not operating, and most of the operating ones are engaged in such quickly profitable types of business activities as trade and intermediary services. This is explained by the fact that small business entities develop in an unfavorable investment climate, which makes long-term production investments unprofitable.

An analysis of the state of business activity in Ukraine shows that the small and medium-sized business sector needs effective financial support at both the national and regional levels.

World practice of development and protection of entrepreneurship shows that an accessible source of financing for small businesses is the provision by the government of guarantees for the repayment of loans in the event of insolvency of small enterprises. This reduces credit risks and eliminates the main obstacle to providing loans to small business entities, especially to small business starters. But this requires appropriate credit resources from banks. Unfortunately, credit resources in Ukraine for small businesses are very limited. For most business entities, bank credit remains inaccessible due to excessively high interest rates. This is explained by the fact that the mechanism for guaranteeing loans is actually not in place in the national economy.

One of the significant obstacles to the development of domestic entrepreneurship is the imperfection of the current tax system and excessive tax pressure and a burdensome reporting system, which lead to an increase in the volume of products sold that are hidden from taxation, as well as entrepreneurs' uncertainty about the stability of the conditions for conducting commercial activities.

According to the entrepreneurs themselves, the main barrier to the development of small businesses in Ukraine is excessive tax pressure. This problem has become particularly urgent in connection with the adoption of the new Tax Code, according to which single tax payers are now divided into 4 groups by type of activity and other criteria with different tax rates. As a result, some small entrepreneurs of many types of activity who used the simplified taxation system will now pay large payments in an amount sometimes exceeding their profit. Such a policy of inadequate replenishment of the state budget to the economic situation will not only not solve the problem of the shadow economy, but will even deepen it. In addition, small businesses will begin to close en masse, since the main incentives for entrepreneurship - profit and wages as an attribute of material well-being - are disappearing. The economy of Ukraine remains highly monopolized, since the terms of tax legislation are aimed more at supporting large businesses, which are characterized by discipline in paying a significant amount of taxes and partially provide financial assistance in important projects of state and regional importance.

In the conditions of new forms of labor organization, the activities of business entities under various forms of ownership have significantly increased the role of control over the use of labor resources and the preservation of property. Given that non-current assets play a significant role in the general property of the enterprise, at the current stage of development, the problems of their effective use and preservation are becoming important issues. This largely contributes to effective control over the condition and use of these objects.

The study of theoretical provisions and modern practice of organizing accounting for non-current assets in the conditions of the transformation of accounting to international standards allows us to identify a number of problems that hinder the process of production management and reduce the efficiency of the use of labor

resources. These problems include different approaches to determining the nature of non-current assets and the methods of their reflection in accounting and tax accounting, the lack of constant certainty in the composition of labor resources, etc.

Along with the disclosure of the nature and methods of accounting for non-current assets, which are of particular importance, the study of the problem of depreciation, the development and improvement of the depreciation system as a whole, the clarification of its role in the reproduction process, as well as financial control of the efficiency of the use of labor resources in the production process.

Accounting in Ukraine in the context of adaptation to international standards should be aimed at providing operational information to all business entities, as well as for the preparation of informative accounting statements for use by investors and creditors. One of the important factors affecting the efficiency of each enterprise is the availability of fixed assets, without which it is impossible to produce products (goods and services). The entire subsequent process of their use at the enterprise depends on the correct organization of accounting for labor resources. Well-known domestic and foreign scientists have studied the problems of organizing accounting and effective use of non-current assets at the enterprise: Chernenko S.K., Yugas E.O., Turlakova O.V., Chaly I.Ya., Tarasova I.P., Orlov V.M., Korniychuk G.V., Kovalev A.I., etc. Analysis of the works of these authors showed that, along with a fairly deep, there is a contradictory approach to this problem. The purpose of the study of non-current assets, the state of fixed assets and the efficiency of their use.

The problem of increasing the efficiency of the use of non-current assets and production capacities is the main stage of creating a market management mechanism. Determining the location of the company in the system of market relations, its financial condition, level of competitiveness, etc. Depends on its solution. Increasing the efficiency of the use of labor tools is an important factor in increasing the efficiency of the enterprise.

In a broad sense, the concept of accounting means the observation, measurement, recording of certain natural or social phenomena. It is important for humanity to monitor all phenomena that affect members of society, but the object of special attention is economic activity, which is based on the production of material goods.

Economic activity - any activity related to the production, exchange and consumption of tangible and intangible goods. Economic activity, which is carried out for the purpose of making a profit, is entrepreneurial activity (business). The subjects of economic activity are individuals (citizens) and legal entities (enterprises, organizations, institutions). To carry out entrepreneurial activity, enterprises must have the necessary means of production, which consist of tools and objects of labor.

By means of labor is meant a thing (or a set of things) that the worker places between himself and the object of work, so that he was the leader of his actions on this issue. Means of earnings by their nature can be of two types: tools and objects that provide working conditions.

Tools are means by which material and spiritual values are realized (i.e. machines, equipment, machines, tools, etc.). They are designed to act on objects of labor and change them in the production process.

The entities through which enterprises create conditions for the organization and normal behavior of the production process (structure, buildings, devices, vehicles, etc.) belong to the second type of means of labor - they create conditions for work in production. The construction of accounting for non-current assets is determined by the features of their functioning in the process of activity. A feature of non-current assets is that they are used repeatedly during the operation for a long time during the operation, gradually wear out, while maintaining their natural form.

A characteristic feature of non-current assets is that they do not have the general interchangeability characteristic of potential labor and activity reserves. Therefore, their efficiency depends on the industry, enterprise and individual types. This difference for each specific work depends on its technical and moral deterioration. The characteristic features of all non-current assets are as follows: they participate in the process of preserving the natural (material) form and gradually (parts) by transferring value to a new manufactured product in the form of depreciation. The amount of depreciation of one or another means of labor is determined by the degree of its wear in the process of use.

Enterprises are constantly replenished with new means of labor in accordance with the level of production technology, the nature and volume of products produced. Awareness of the availability of work and constant monitoring of their effective use are important factors in managing the activities of each enterprise. This should be facilitated by well-structured and organized accounting. Important conditions for the rational organization of such accounting are scientifically based classification of these instruments and their evaluation.

In the financial system, in planning and accounting, all means of labor are divided into two large groups - negotiable and non-negotiable. The basis of such division is: on the one hand, the limits of the purchase price, and on the other - the term of use.

Non-current assets include means of labor that are operated for more than one year and cost up to a certain limit (except for laboratory equipment, for which the limit is much higher); fully and repeatedly participate in the production process, transferring their value to finished products in parts, as they are. These are: land; capital expenditures for improvements; buildings and structures; machinery and equipment; conveyors; tools, consumables and consumables; animals; perennial plantings; other fixed assets.

The group "Other non-current tangible assets" includes: library funds; non-current assets of low value; temporary (non-hotel buildings); natural resources; inventory packaging; hire; other non-current tangible assets.

The group "intangible assets" includes: rights to industrial property objects, copyrights and related rights, trademark rights, rights to use natural resources, rights to use property, partial capital investments in intangible assets, other intangible assets.

In addition to the above-mentioned non-current means of labor, there is also a group "Long-term biological assets", which are divided into the following groups:

- long-term biological assets of crop production;
- long-term biological assets of livestock production;
- immature long-term biological assets.

Accounts are designated for accounting and summarizing information on the availability and movement of means of labor: 10 "Fixed assets", 11 "Other non-current tangible assets", 12 "Intangible assets", 15 "Capital investments", 16 "Long-term biological assets", 184 "Other non-current assets", 21 "Current biological assets" and 22 "Low-value and perishable items".

The information reflected in the accounting registers and the General Ledger at the end of the reporting period is transferred to the forms of annual financial reporting in a general summary. Information on the means of labor of the enterprise is also reflected in statistical reporting. The theoretical and practical principles of the organization of accounting for non-current assets must be improved in the direction of expanding its management capabilities, adapting as much as possible to the practical needs of business entities that arise in the process of making management decisions regarding the movement of means of labor and the efficiency of their use. The main ways to improve the organization of accounting for non-current assets are the rationalization of each form of documents and accounting registers, as well as methods and ways of collecting, processing and summarizing accounting information, adapted to modern conditions.

The current stage of development of accounting in Ukraine has a characteristic feature of harmonization, which is embodied in the concept of building a new internal accounting system based on the approximation of the world of theory and practice. Leading methodologists of Ukraine are doing a lot of work on solving the problems, but their final implementation will undoubtedly depend on their practical development and implementation by young accountants who will leave the walls of higher educational institutions tomorrow at enterprises, institutions and organizations in cities and villages of Ukraine. The level and quality of their training will directly affect the success of organizational accounting procedures and, as a result, the quality of the reproduction of the accounting system itself at the micro- and macroeconomic levels of the economic model of Ukraine.

The process of modern training of accounting specialists takes place against the background of Ukraine's integration into the pan-European educational space, on the one hand, and, on the other hand, with careful study for further development and application not only of world methodological and methodological accounting records, but also of international experience in training professional accountants. Although teachers faced these problems, the discussion of the need for such implementation in general and its quantitative and qualitative degree, in particular, unfolded on the pages of periodicals.

Long-term assets are tangible assets of various types that are an integral part of the production process and are the basis for capital creation, a dynamic, complex, comprehensive and multifaceted concept that requires a balanced approach to determining the areas of its position.

P(C) BO 7 "Fixed Assets" has significantly changed the existing procedure for accounting for fixed assets, but despite the fact that it has been used for sixteen years, during this time the characteristic forms of primary accounting for transactions with fixed assets have not undergone any changes.

In modern conditions, with the presence of thousands of fixed assets at the enterprise, it is difficult to talk about an effective solution to the problems of their accounting and control when using the manual method

of information processing. The enterprise faces the issue of automating the accounting of non-current assets for the implementation of system accounting and control operations. Automation of university management based on economic and mathematical methods, computer tools and information technologies is an integral part of the process of increasing the productivity of almost all enterprises. Recently, a qualitatively new stage has appeared, characterized by the desire to create integrated automated systems that combine all management tasks. This is facilitated by distributed computing systems and networks, database management tools, development and implementation of functional subsystems.

To solve the problems of automation of individual areas of accounting, you can use the concept of "task", which means an algorithm for converting input data by processing data into output indicators that have a certain functional purpose for accounting and management.

We can distinguish the following tasks of automation of non-current assets:

- accounting and control of non-current assets by storage location and classification groups;
- accounting and control of the correctness and timeliness of the movement of non-current assets (income, disposal, transfer);
- accounting for depreciation of non-current assets and control over the correctness of its accrual and reflection;
- accounting for costs of repairs, modernization of non-current assets and control over the rational use of funds for these purposes;
- accounting for the revaluation of non-current assets (revaluation, impairment);
- accounting for operating and financial leasing of non-current assets;
- Identification of obsolete non-current assets.

A beneficial factor of automation is the stability of permanent accounting information, which is formed at the enterprise. This creates conditions for its multiple use and thereby contributes to increasing the efficiency of using computer technologies in this area of accounting. Characteristic for this area of accounting is the possibility of obtaining in the information system environment a complete set of accounting registers necessary for organizing rational management of fixed assets of the enterprise.

Intensive improvement of the use of labor means increasing the degree of loading of production capacities per unit of time, which can be achieved by modernizing existing machines and mechanisms, establishing the optimal mode of their operation. Work in the optimal mode of the technological process ensures an increase in output without changing the composition of fixed assets, without increasing the number of employees and with a decrease in the cost of material resources per unit of output.

In P(S)BO 7, it is advisable to refer to P(S)BO 28 "Impairment of Assets" regarding the establishment of the procedure for impairment of assets. Therefore, the theoretical and practical principles of organizing accounting for labor resources must be improved in the direction of expanding its management capabilities, maximally adapting to the practical needs of business entities that arise in the process of making management decisions regarding the movement of fixed assets and the efficiency of their use.

P(S)BO 7 contains significant discrepancies with international standards, therefore the proposed ways to improve the regulatory framework for accounting for labor resources and non-current assets will allow harmonizing domestic accounting with international standards, since they are currently an effective tool for increasing the transparency and clarity of information that discloses the activities of business entities, creating a reliable basis for assessing assets and liabilities. Harmonization of national standards with international ones will also reduce inconsistencies and problematic issues in accounting for non-current assets.

The debatable nature of many theoretical provisions, the practical significance of accounting, analysis and control of labor resources, the insufficient level of their research from the point of view of modern management needs requires their further improvement. Changes are necessary primarily in terms of increasing the efficiency of information support for the management of non-current assets, which requires solving the following tasks:

- study of the essence of non-current assets, their composition and classification in various branches of economic science;
- generalization and systematization of the classification of non-current assets;
- study the current methodology for calculating depreciation and accounting for wear and tear of non-current assets, establish its effectiveness and feasibility of application at enterprises;
- analyze the current organization and methodology for accounting for non-current assets, the impact of changes in tax policy on them and identify ways to improve it;

- improve the methodology for analyzing the material and technical base of the enterprise and non-current assets;
- develop recommendations for improving the methodology for controlling the effectiveness of non-current assets.

To solve problems of automating certain areas of accounting, you can use the concept of a task, which means an algorithm for converting input data using data processing procedures into output indicators that have a specific functional purpose for accounting and management.

When applying progressive automation methods at the enterprise, the following issues will be resolved:

- providing all management entities with operational information
- conducting non-cash payments through the "Client Bank" system
- integration of operational, accounting, statistical accounting into a single system.

It should be noted that a comparison of the regulatory and legal support for accounting and tax accounting in Ukraine, IFRS and the approaches of accounting specialists revealed the lack of a clear definition of the concept of "improvement" with a single classification of types of improvement in various regulatory documents. This causes inconsistency between the P(S)BO and the tax legislation of Ukraine, and also slows down the adaptation of national accounting and reporting provisions to international standards. To eliminate these discrepancies, it is necessary to initiate the introduction into the P(S)BO 7 and the tax legislation of Ukraine of the definition of improvement of fixed assets as a set of measures aimed at increasing future economic benefits initially expected from the use of such objects, and measures aimed at maintaining fixed assets in working condition with elements of improving the initially expected economic benefits from their use in the future. Such an interpretation of improvement will allow to attribute to it repairs and maintenance with elements of modification or modernization of individual parts of the object, which meets the needs of modern production and increases the objectivity of assessing the value of fixed assets that have undergone the corresponding improvement.

The considered approaches and the provided proposals for disclosing the concept of "improvement of fixed assets" with the classification of types of improvement serve as the basis for continuing research in the direction of improving the methodology for accounting for costs for improving non-current assets and increasing the analytical value of enterprise reporting in terms of reflecting such costs.

Tax accounting of fixed assets and non-current assets is entirely and completely based on accounting (paragraph 134.1.1 of the Tax Code of Ukraine). The question arises due to the absence in the Tax Code of Ukraine of rules for determining the initial cost of new fixed assets. The updated tax rules indicate that it is sufficient to focus on the requirements of accounting standards. The legislator's dream of converging tax and accounting for fixed assets and non-current assets has come true.

According to the provisions of the Tax Code, when calculating the depreciation of fixed assets and intangible assets in accordance with clause 138.3 of Article 138 of this Code, their book value must be equal to the book value of such assets according to tax accounting data, which is determined. In tax accounting, the same depreciation methods are allowed as in accounting, with the exception of the production method. Section III of the Tax Code in the new edition does not contain specific rules for tax accounting of current expenses for maintenance, improvement and repair of fixed assets. Therefore, the corresponding amounts are taken into account as part of expenses according to accounting rules. In the event of sale or liquidation of fixed assets, the financial result before taxation is increased by the residual value of such an object, determined in accordance with the P(S)BU, and is reduced by the residual value of such an object, determined in accordance with tax accounting rules.

Thus, it is necessary to improve the theoretical and practical principles of accounting organization in the direction of expanding its management capabilities, maximally adapting to the practical needs of business entities that arise in the process of making management decisions regarding the movement of non-current assets and the efficiency of their use. The main ways to improve the organization of accounting for non-current assets are the rationalization of both each form of accounting documents and registers, and methods and means of collecting, processing and summarizing accounting information, adapted to modern conditions. As a result of ignoring the interests of small business, the number of hired workers increases, and the number of self-employed people is constantly decreasing. These processes negatively affect the social activity of citizens, and, consequently, the willingness and ability of the population to realize specific interests associated with the active activities of an independent business entity is suppressed. Therefore, to implement an effective mechanism for supporting small businesses in Ukraine, it is necessary, first of all, to take certain steps towards the democratization of market relations and the mitigation of social tension in society. It is necessary that the

interests of small entrepreneurs be protected not only by state structures, but also by individual organizations created to lobby the business community, whose opinion would have weight in decision-making by the state, especially in matters relating to tax payments and contributions to funds.

The development of entrepreneurship is negatively affected by complex and lengthy post-registration procedures for business entities, excessive interference by state authorities in their activities.

The main directions of accelerating the development of entrepreneurship in modern conditions of transformation, transition to an innovative model of economic development of Ukraine are:

1. Further improvement of the legislative and regulatory framework for creating favorable conditions for the development of small and medium-sized businesses.

2. Improvement of credit policy, namely: organization of state credit institutions for the purpose of preferential lending to business entities, especially small business startups.

3. Improvement of tax policy, i.e. ensuring the functioning of a simplified taxation system with preference for a single tax and the right of those working in the small business sector to social and pension security.

4. Further strengthening of state support for small and medium-sized businesses (financial and credit, property, information and personnel*). Creation and support of a network of business centers, business incubators, etc.

5. Stimulating the development of entrepreneurship in industries that ensure the highest efficiency of social production and its competitiveness through the use of achievements of scientific and technological progress, resource-saving technologies, and the production of fundamentally new types of products.

6. Ensuring the implementation of measures to create a single automated system of state registration of business entities.

7. Implementing measures to gradually create a network of training centers for training entrepreneurs from among the unemployed at employment centers.

8. Strengthening the responsibility of executive authorities and civil servants for the implementation of relevant laws on the development of business, in particular small businesses.

Conclusions. Thus, in the modern market economy of Ukraine, a small business is forced to overcome a number of macroeconomic obstacles, the main reason for which is ineffective financial support, excessive tax pressure and other restrictions established at the legislative level. That is why a promising way to overcome these barriers should be to reach a consensus that the interests of entrepreneurship should be protected by entrepreneurs themselves. The role of the state should only be to improve the necessary infrastructure and create an effective legal framework that would create space for the development of public organizations and other associations aimed at solving the problems of small business development in Ukraine.

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INFORMATION SUBSYSTEM FOR THE RECORD-KEEPING OF ENVIRONMENTAL PROTECTION MEASURES

Viunenko Oleksandr

PhD in Economic Sciences, Associate Professor, Sumy National Agricultural University, Ukraine

ORCID ID: 0000-0002-8835-0704

Against a backdrop of growing environmental challenges, caused by both human activity and the consequences of armed aggression, the issue of automating the recording of environmental protection measures is becoming particularly important. Effective recording, rapid analysis and reporting of environmental data enable a swift response to changes in the environment and the adoption of informed management decisions at all levels of government.

The vast amounts of information received by local authorities and government bodies make it difficult to manually process and analyse environmental measures and data on waste resulting from the destruction. This highlights the need to develop an integrated information system that will automate the entry, processing, storage and generation of reports in accordance with current legislation and the minutes of government meetings. This task is of particular relevance in light of the introduction of new reporting requirements regarding environmental protection measures, waste and operational plans, in accordance with resolutions of the Cabinet of Ministers of Ukraine, orders of the Ministry of Environmental Protection and current state environmental policy strategies. Consequently, the development of an effective information subsystem is a practically significant and timely task.

In line with the stated objective, the following tasks have been formulated: 1) to review recent research and publications in the field of ‘accounting for environmental protection measures’; 2) to analyse existing information subsystems for the automated accounting of environmental protection measures; 3) to formulate the problem statement and select the means for its implementation; 4) to develop a design for an information subsystem for the accounting of environmental protection measures; 5) to implement the database and the user interface in the selected software environment. The object of the study is the information processes involved in the accounting of environmental protection measures. The subject of the study is the automation of the accounting of environmental protection measures.

For the first time, a concept for an information framework to record environmental protection activities has been proposed and substantiated to meet the practical needs of local environmental authorities; this framework provides for:

- the integration of the documentation of environmental programmes and the recording of residues from destructive processes into a single digital space, in line with the latest Ukrainian legislation and approved government directives;
- the introduction of a structured layout for information databases, brought into line with the definitions of waste components, documentation forms and classification rules established by Government Resolution No. 1073 of 27 September 2022;
- the proposed data warehouse architecture helps to eliminate redundant data and ensures data reliability when working with large volumes of records;
- the implementation of proprietary mechanisms for the automatic generation of reports, which take into account specific environmental metrics and the relevant requirements of government regulatory bodies;
- creation of visual user interface layouts that simplify data entry and analytical processing, thereby improving the efficiency of the specialist’s interaction with the software suite;
- identifying the critical operational and hardware characteristics necessary for the further development and expansion of this system within regional or national environmental information networks.

Building on the results achieved, scientifically sound principles have been formulated for the design of modern information systems for recording environmental protection activities, which can serve as a foundation for the development of more comprehensive digital environmental platforms.

1. Review of recent research and publications. Under the Law of Ukraine ‘On the Protection of the Natural Environment’ (Articles 20 and 22), provision is made for the development of the State Environmental Monitoring System (hereinafter referred to as the SEM) and for the monitoring of the state of the environment, in particular the level of pollution. The performance of these functions has been delegated to the Ministry of the Environment and other central executive authorities that are participants in the State Environmental

Monitoring System, as well as to enterprises, institutions and organisations whose activities cause or may lead to a deterioration in the state of the environment.

The main principles of the SESM's activities are set out in Resolution No. 391 of the Cabinet of Ministers of Ukraine dated 30 March 1998 "On the Approval of the Regulations on the State Environmental Monitoring System".

Currently, within the State Environmental Monitoring System (hereinafter referred to as the SEM), the functions and tasks of observation and information provision are carried out by eight entities of the monitoring system: the Ministry of the Environment, the Ministry of Emergencies, the Ministry of Health, the Ministry of Agrarian Policy, the Ministry of Housing and Communal Services, the State Water Management Agency, the State Forestry Committee and the State Land Committee.

Each entity within the State Environmental Monitoring System monitors those environmental components specified in the Regulations on the State Environmental Monitoring System and in the procedures and regulations governing the state monitoring of specific environmental components.

Key regulatory acts governing the monitoring of environmental objects:

- Resolution of the Cabinet of Ministers of Ukraine No. 343 of 9 March 1999 'On the Approval of the Procedure for the Organisation and Conduct of Monitoring in the Field of Atmospheric Air Protection';
- Resolution of the Cabinet of Ministers of Ukraine No. 815 of 20 July 1996 'On the Approval of the Procedure for the Implementation of State Water Monitoring';
- Resolution of the Cabinet of Ministers of Ukraine No. 661 of 20 August 1993 'On the Approval of the Regulations on Land Monitoring';
- Resolution of the Cabinet of Ministers of Ukraine No. 51 of 26 February 2004 'On the Approval of the Regulations on Soil Monitoring on Agricultural Land' [9].

Thus, the regulatory framework for state monitoring covers the main components of the environment, ensuring a systematic approach to their observation and assessment. However, the current challenges posed by the full-scale war in Ukraine necessitate an update to monitoring approaches, particularly with regard to controlling the environmental consequences of destruction. The devastating effects of the war affect absolutely all areas, including the need to find ways to prevent and minimise the negative impact on the environment and human health of waste generated as a result of damage (destruction) to buildings and structures, unfinished construction projects, and public amenities due to hostilities, terrorist acts, sabotage or the elimination of their consequences — on the environment and human health.

The Government has proposed the relevant Procedure, approved by Resolution of the Cabinet of Ministers of Ukraine No. 1073 of 27 September 2022 (as amended). The Procedure applies during the performance of a range of restoration works to eliminate the consequences of armed aggression and hostilities during martial law and in the reconstruction period (within 90 calendar days following the cessation or lifting of martial law on the territory of Ukraine).

The management of demolition waste involves a range of organisational and technical measures and operations. These are carried out to ensure the environmentally safe collection, transport, sorting, storage, processing (recycling), disposal, removal, neutralisation and burial of such waste. These measures are coordinated by the executive body of the village, settlement or city council, or by the military administration of the settlement (settlements).

The organisation of operations involving demolition waste may be carried out in areas where active phases of hostilities are absent or have already concluded:

- by the owner/manager of the facility that has suffered damage (demolition), as a result of which this waste was generated;
- by the owner or user of the land plot on which such waste is located;
- by the authorised body — in respect of waste from destruction located on the streets and roads of settlements, public roads, in public areas such as parks, squares, open spaces, embankments, areas adjacent to buildings, beaches and cemeteries (in particular, those displaced to the aforementioned areas by a shock wave resulting from the impact of weapons, explosions, fires, etc.).

The identification and recording of demolition waste shall be organised by the competent authority on the basis of: 1) inspections of damaged (demolished) properties; 2) consideration of applications (reports) from citizens, enterprises, institutions and organisations, other legal entities, the media, central executive authorities, military formations, or receipt of information regarding the identification of demolition waste.

The recording of demolition waste is carried out directly at the site of its generation or at temporary storage sites or other waste management facilities using the specified form shown in Table 1.1.

Waste generated as a result of demolition includes: 1) main components — parts (fragments, debris) of building structures, fillings from door and window units, utility systems, plumbing fixtures and the like; 2) additional components — materials and items that were inside or near the structure at the time of damage (destruction) or during its demolition, for example, equipment, personal belongings, everyday items (furniture, household appliances), and organic compounds [7].

Table 1. Form for recording demolition waste

Serial number	Names of waste components resulting from demolition	Unit of measurement	Volume	Location (temporary storage of demolition waste/other waste management facilities)
Notes	1. Information shall be provided regarding demolition waste stored at a temporary storage site for demolition waste or at another waste management facility. 2. The names of the components of demolition waste in accordance with Annex 1 to Resolution No. 1073 of the Cabinet of Ministers of Ukraine of 27 September 2022 No. 1073 ‘On the Approval of the Procedure for the Management of Waste Generated in Connection with the Damage (Destruction) of Buildings and Structures as a Result of Hostilities, Terrorist Acts, Sabotage or the Conduct of Work to Eliminate Their Consequences, and on Amendments to Certain Resolutions of the Cabinet of Ministers of Ukraine’. 3. The volumes of waste from destruction shall be stated in tonnes or cubic metres; the relevant unit of measurement shall be indicated when completing the form.			

Source: [7]

The destruction of infrastructure and residential buildings, on the one hand, generates a large volume of waste, and on the other, leads to mass population displacement. Internal displacement in Ukraine is one of the most significant humanitarian consequences of the armed conflict. According to the Ministry of Social Policy, as of 1 February 2022, over 1.4 million internally displaced persons (IDPs) had been registered in Ukraine, and during the year this figure exceeded 6.6 million. These are people who were forced to leave their homes and possessions due to threats to their lives and health.

Firstly, it is important to recognise that internally displaced persons (IDPs) face numerous difficulties and challenges in their new region, namely: 1) inadequate social and economic adaptation; 2) limited access to housing, education, healthcare, social services and justice; 3) discrimination, stigmatisation and rejection by the local population; 4) psychological distress, anxiety, depression, post-traumatic stress disorder (PTSD), suicidal thoughts and behaviour; 5) loss of a sense of purpose, self-identity, heritage and cultural values.

Given these circumstances, psychosocial support for IDPs is required, aimed at alleviating their situation, improving their psychological well-being and facilitating their social integration.

Secondly, psychosocial support, as a crucial element in the adaptation of IDPs, can be provided by various stakeholders, amongst whom non-profit organisations (NGOs) play an important role. NGOs are capable of delivering such psychosocial support to IDPs, but they are not the only ones:

- psychosocial support that NGOs can provide to internally displaced persons in their new region of residence;
- providing information on available services and resources in the new region, such as education, healthcare, social assistance, legal support and more;
- organising group and individual counselling and psychotherapy sessions for internally displaced persons suffering from stress, anxiety, depression or other psychological problems;
- creating safe and welcoming spaces for internally displaced persons where they can socialise, receive social support, pursue their interests and develop their skills;
- engaging internally displaced persons in community initiatives and voluntary work, which promotes their social integration and a sense of belonging;
- conducting training sessions and workshops for internally displaced persons on self-help, stress management, building peaceful relationships and constructive conflict resolution [25].

Given the sheer volume of such waste and the potential risk it poses to the environment, it is of the utmost importance to have a clear system for recording, sorting and managing it in accordance with current legislation. Since 1 January 2018, a ban on the landfilling of untreated (unrecycled) household waste has been in force in Ukraine. In addition, waste sorting has become a direct responsibility of every resident of Ukraine.

Particular attention should be paid to the problem of unauthorised disposal at landfills of bulky waste, waste requiring repair, and waste hazardous to the environment.

How should waste be sorted correctly? As regards recyclable materials, there are two main sorting principles: 1) Waste bins must be dry and clean; 2) All packaging must be compressed as tightly as possible.

In accordance with the law, hazardous waste must be collected, sorted and immediately handed over to specialised companies licensed to process it. Transporting this type of waste is permitted only by vehicles with special equipment. Household waste may only be disposed of at landfills or waste disposal sites specifically designated for this purpose.

Local authorities or the state administration must give priority to waste management schemes that enable higher levels of recovery or recycling to be achieved.

Waste incineration is permitted only at specialised facilities, exclusively for the generation of energy (thermal or electrical).

The law prohibits the construction and use of landfill sites for household waste where the designs do not include mechanisms to protect against groundwater contamination, as well as systems for the collection and utilisation of leachate and biogas.

Recyclable materials are generally divided into the following categories:

- Waste paper. This includes books, magazines, newspapers, paper packaging, etc. To save space, cardboard and paper items should be flattened as much as possible and then placed in a paper bag or tied with string. The following are not considered waste paper: receipts, cigarette packets, Tetra Pak cartons, products that have already been recycled, and various types of soiled or damp paper.

- Tetra Pak refers to multi-layered packaging made of polyethylene, cardboard or foil. The packaging should be thoroughly washed inside and compressed;

- polyethylene: food bags, gloves, cling film;

- plastic. There are seven types of plastic, five of which are recyclable. To determine which type a plastic item belongs to, look closely at the marking. It shows a triangle with a number from one to seven; sometimes the marking consists only of letters. If there is no marking, or if it shows the numbers 7 or 3, such items are not recyclable.

- metal: tin cans, lids, other metal items. These must be cleaned of dirt and tightly compressed;

- glass: bottles from medicines and cosmetics, drinks, etc. Broken glass is also recyclable. Porcelain and particularly tough glass (which withstands heavy impacts and high temperatures) are not recyclable;

- waste containing toxic substances: energy-saving light bulbs, mercury thermometers, batteries, solvents, paints, ABS plastic. Such waste must not be disposed of in a standard bin;

- organic waste: wood, plants, food scraps;

- residual waste: this is what remains after waste sorting (adhesive tape, 'shur-shik', sanitary towels and wipes, wrappers and unlabelled products, broken items). This portion of waste must be sent to a landfill. Old clothing that can still be used;

At first glance, sorting rubbish may seem like a complicated task. But if you practise and commit the above-mentioned types of waste to memory, it is easy to learn [24].

2. Analysis of software products and alternatives. The market offers a wide range of software solutions designed for environmental monitoring. Their functionality varies, including the collection, processing and visualisation of collected data. However, not all of them feature an intuitive interface and flexible settings tailored to individual user needs. Despite the availability of such products, information systems for monitoring environmental conditions are few in number and not widely used by internet users. The following were selected for the analysis of comparable products:

- eco.gov.ua [8];

- saveEcoBot [10];

- globalForestWatch [1];

The first example is the 'EcoSystem' website. The site contains information on:

- administrative services;

- registers;

- news;

- about the project;

- ecoThreat;

- e-Cabinet;

- online services: e-Exits, e-Forest, e-OVD, e-Control and others;

- Information panel on resources: water, forest fires, geological portal.

This resource was created to gather information on various activities (Figure 1).

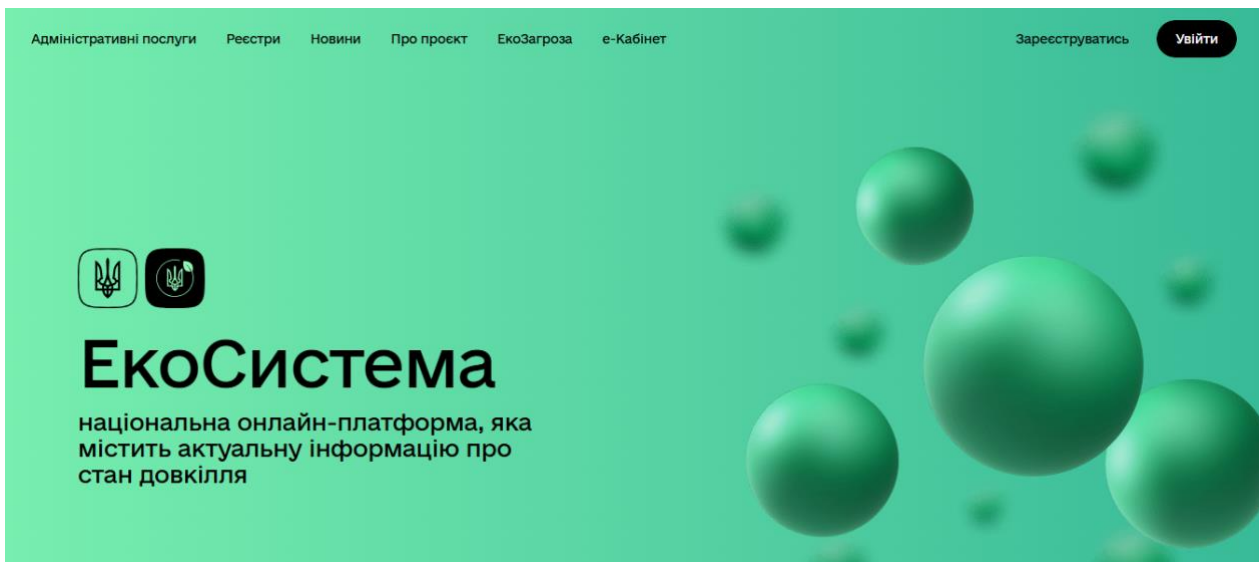


*Figure 1. The 'EcoSystem' homepage
Source: [8]*

To view the waste data that has been entered, you must first register with the system and log in using a file key or via IDGOVUA (Figure 2). If using IDGOVUA, you can use an electronic signature: a physical token, a USB token, or cloud storage. It is also possible to use the NBU Bank ID, in which case you will need to log in via your chosen bank.

*Figure 2. System login page.
Source: [8]*

Once registration is complete, the user is redirected to a selection page: tasks, services, registers, account. To view the waste declarations submitted by companies, go to the 'Registers' section and click 'Waste Declaration 3.0' (Figure 3).

Зверніть увагу	Задачі	Послуги	Реєстри	Обліковий запис
Q Пошук по назві реєстру				
Перелік дозволів на викиди забруднюючих речовин в атмосферне повітря стаціонарними джерелами об'єктів 1, 2, 3 груп				
Декларація про відходи 3.0				
Перелік Декларацій про поводження господарської діяльності				
Реєстр РВПЗ				+
OVD				+
Реєстр Дозволів на здійснення операцій з оброблення відходів				+

Figure 3. Registry selection webpage.

Source: [8]

A separate page has been created for businesses, which ordinary users cannot access; therefore, the standard waste reporting for businesses has been revised (Figure 4). The reporting consists of:

- date of submission;
- name of the company or full name of the sole trader;
- company's EDRPOU number or sole trader's RNOKPP number;
- place of registration of the applicant;
- region of operation;
- city or district of operation;
- village, settlement or city district;
- reporting year;
- email address;
- application number;
- telephone number.

The generation of waste or the acquisition of ownership of waste is divided into:

- name of the waste (code [11] is used);
- volume of waste accumulated at the start of the reporting year, tonnes;
- details of the waste producer;
- volume of waste, tonnes;
- details of the waste producer (specify the name and country of registration of the counterparty);
- volume of waste, in tonnes;
- code under List A or B of the Basel Convention;
- notification or decision number;
- volume of waste generated by the declarant, in tonnes.

Carrying out waste treatment operations, including those involving hazardous waste. Information on waste used by the declarant for the purposes of reuse, recycling, recovery or disposal, and information on waste generated as a result of the reuse, recycling, recovery or disposal of waste by the declarant:

- name of the waste;
- volume of waste, tonnes;
- code of the planned waste operation [13];
- description of waste operations;
- name of waste;
- volume of waste, tonnes;
- number of the treatment permit and/or number of the licence decision;

- code under List A or B of the Basel Convention;
- code of the operation resulting in the generation of waste;
- description of the waste operation.

Дата подання (не обов'язково)
31.03.2025

Назва компанії або ПІБ ФОПА заявника (не обов'язково)
ТОВАРИСТВО З ОБМЕЖЕНОЮ ВІДПОВІДАЛЬНІСТЮ "СУМСЬКИЙ ОБЛАС...

ЄДРПОУ компанії або РНОКПП ФОПА (не обов'язково)
41685165

Місце реєстрації заявника (не обов'язково)
Україна, 40035, Сумська обл., місто Суми, вул.Сірка Івана, будинок 7/1

Область провадження діяльності (не обов'язково)
Сумська обл., місто Суми

Місто або район провадження діяльності (не обов'язково)
Сумська обл., місто Суми

Село, селище або район міста (не обов'язково)

Figure 5. Waste declaration
Source: [8]

Waste transfer:

- name of the waste;
- details of the producer;
- volume of waste;
- details of the producer;
- volume of waste;
- code under List A or B of the Basel Convention;
- notification number or decision number;
- name of waste;
- volume of waste remaining at the end of the reporting year, tonnes.

This report can also be downloaded or viewed in PDF format (Figure 6).

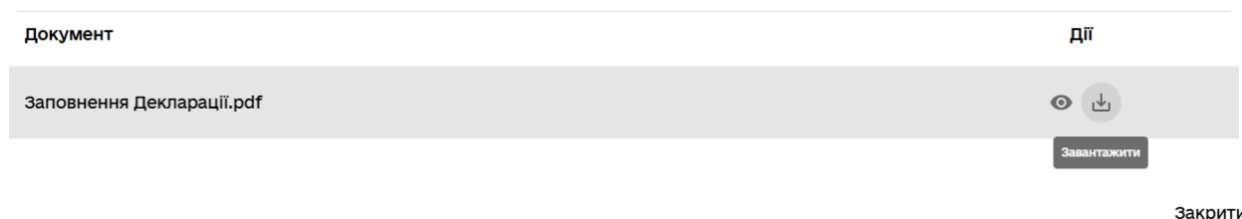


Figure 6. Download as PDF
Source: [8]

General features of the EcoSystem website:

- Public access and transparency of data – data can be viewed by any user without the need to create an account or log in;
- Registry structure – the website is organised as a registry containing information on various environmental documents, permits, licences, businesses and other relevant data;
- Search and filtering – the interface allows users to search and filter data by key parameters, such as object name, region, status and other relevant criteria;
- Pagination – results are displayed in batches, with the option to configure the number of records per page (rowsPerPage) and page navigation (page);

- API-oriented – URLs contain parameters (keyId, page, rowsPerPage), indicating a REST architecture and enabling potential integration with other systems;
- Up-to-date information – information is regularly updated in line with changes made to government registers;

- machine-readability
- data is presented in the form of clearly structured tables, allowing it to be parsed, analysed and integrated with business intelligence (BI) systems or other analytical tools;

Another example of environmental monitoring is ‘SaveEcoBot’ – an eco-friendly chatbot and online platform designed for public monitoring of the state of the environment in Ukraine, specifically air emissions, air quality, environmental impact assessment (EIA) procedures, companies’ environmental documentation, and citizens’ actions (Figure 7).

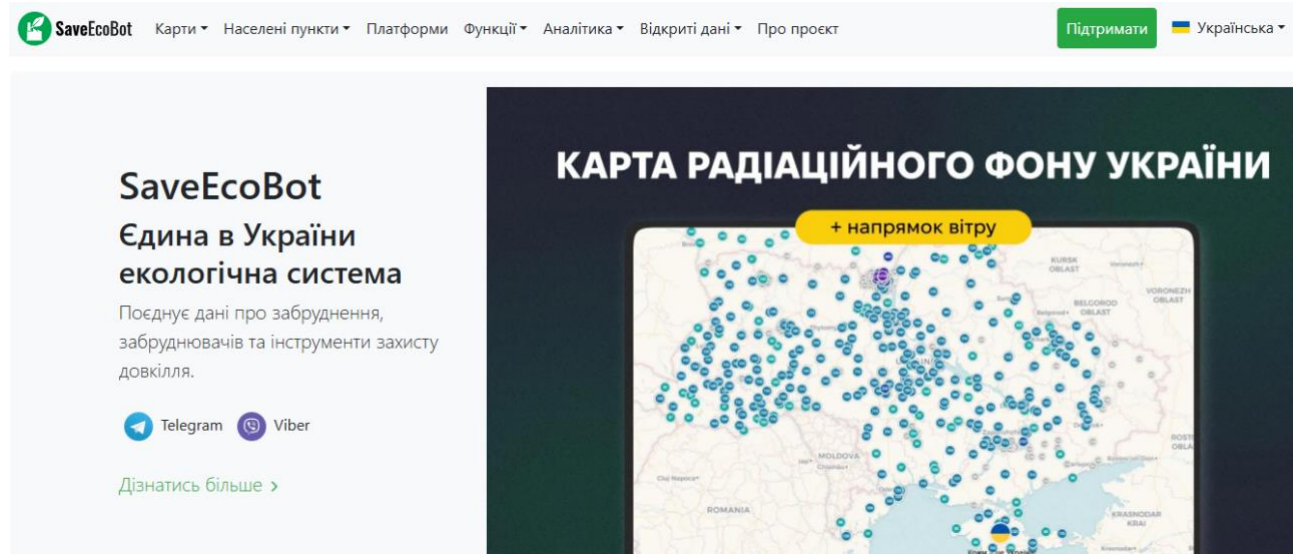


Figure 7. The ‘SaveEcoBot’ homepage
Source: [10]

Key features and capabilities:

1. Real-time air quality monitoring:

- display of data from automatic monitoring stations;
- sources: government stations, Sensor.Community, Airly, and citizens’ own stations;
- pollutants: PM2.5, PM10, CO₂, NO₂, O₃ and others;
- interactive map.

2. Access to environmental permits and documents:

- register of atmospheric emission permits;
- permits for special water use;
- waste management licences.
- EIA (Environmental Impact Assessment): public consultation and project archive.

3. Notifications (bot feature):

- via Telegram, Viber, Facebook Messenger or the web platform;
- subscription to companies, regions or types of environmental documents;
- notifications about new permits, changes to document status, the start of public consultations, etc.

4. Public participation tools:

- templates for submitting comments on EIA reports;
- the ability to monitor a specific enterprise (environmental threats, permits, changes);
- public pressure through appeals to the authorities.

Who is it for:

- for citizens — to monitor air pollution levels in their local area;
- for environmental activists — to monitor the activities of businesses that harm the environment;

- for journalists — a platform for accessing environmental information that is open to the public;
- for public authorities — a tool for ensuring transparency and gathering feedback from the public;
- for developers — providing data via API.

Another example of environmental monitoring is ‘Global Forest Watch’ – an online platform that provides open-access, satellite and analytical data on the state of the world’s forests in near real time (Figure 8). The platform allows users to track deforestation, fires, degradation and other threats to forest ecosystems.

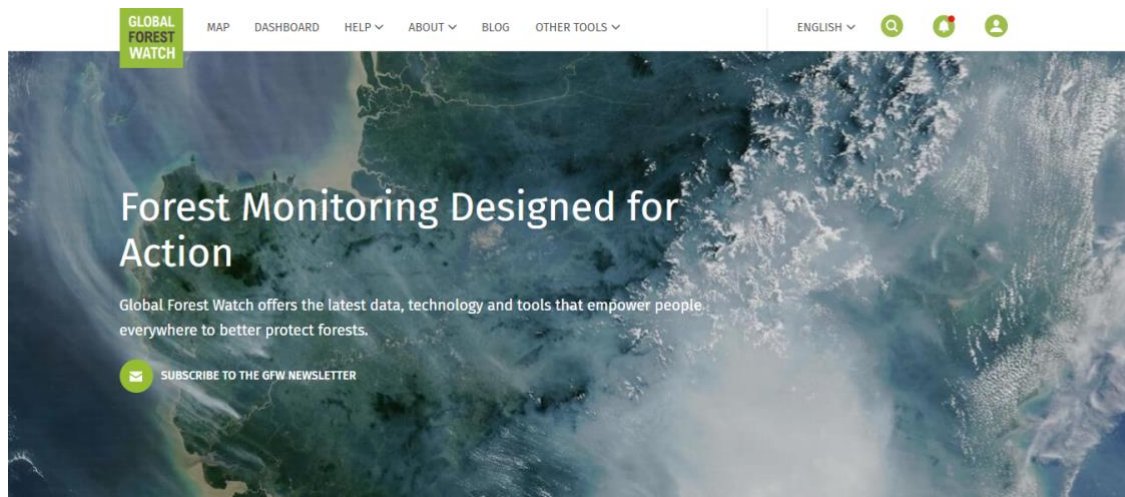


Figure 8. Global Forest Watch homepage
Source: [1]

Key features:

1. Monitoring of deforestation:

- data is updated weekly or monthly, depending on the source;
- visualisation of deforestation from 2001 to the present;
- identification of illegal logging, including the intensity and scale of changes.

2. Fire detection:

- integration with NASA (MODIS, VIIRS) – fire hotspots;
- information updated several times a day;
- alerts regarding forest fires in specific regions;

3. Interactive map:

- a map with over 100 layers;
- forest cover;
- deforestation;
- humid tropical forests;
- agricultural land;
- biodiversity, legal status of territories;
- you can create your own maps, export them or share them.

4. Data downloads and API:

- Geodata can be downloaded in CSV, GeoJSON and SHP formats;
- An open API is available for automatic integration.

5. Alerts

- Creating monitoring zones: the user selects an area (e.g. their neighbourhood or a nature reserve);
- Receiving email or SMS alerts about new fires, deforestation or changes in land cover.

6. Analytics tools:

- a dashboard for each country, region or even specific area;
- statistics by year: area of forest loss/regeneration, trends, causes of deforestation;
- integration with databases on logging licences, nature reserves and commercial zones.

An analysis of the subject area has revealed that environmental monitoring plays an extremely important role in assessing and predicting changes in the environment. Current trends in its development are closely

linked to the implementation of smart technologies, such as the Internet of Things (IoT), artificial intelligence, wireless sensor networks and remote sensing. An analysis of existing software products (Ecomonitoring.hlr.ua, Monitoring.davr.gov.ua, Acres, Esri) has shown that, despite their significant functionality, most of them are either designed to address a limited range of tasks or are insufficiently adapted to the needs of local authorities. This highlights the relevance and necessity of developing a new web application that will provide a user-friendly interface, flexibility, automation and adaptability to the specificities of environmental data collection and analysis in local communities.

3. Defining the task and selecting implementation methods. The creation of an information subsystem for recording environmental protection measures ensures the automation and optimisation of processes relating to the collection and processing of environmental monitoring data, the register of environmental protection measures, waste from demolition works, and the implementation of operational action plans.

In accordance with job descriptions and the composition of the executive committee, the entry of this information is carried out by responsible persons entrusted with the relevant duties for implementing environmental protection measures, reporting on demolition waste and operational action plans, with the main Department of Environmental Protection and Natural Resources housing senior specialists who collect this information from local authorities.

The basis for the development of software and information systems for the purpose of preparing information for the Ministry of Environmental Protection and Natural Resources of Ukraine regarding the implementation of environmental measures, in accordance with Article 20 of the Law of Ukraine ‘On Environmental Protection’ and taking into account the requirements of Resolution No. 106 of the Cabinet of Ministers of Ukraine dated 16 February 2011 ‘Certain Issues Concerning the Accounting of Taxes, Fees, Payments and Other Budget Revenues’ [5]. The data is compiled from reports on measures that have been carried out, planned or not implemented, covering areas of environmental conservation, nature conservation measures, nature conservation effects, as well as the reasons for the non-implementation of these measures. This is used for the conservation of the nature reserve fund, the protection of atmospheric air, the rational use of natural, plant and animal resources, and other activities throughout the entire period of regulatory activity. A database of environmental protection measures is established, characterising the environmental situation of local authorities. Reports are generated promptly based on overall indicators. Reporting is carried out at the following intervals: 1st quarter, half-year, 9 months, and annually. Once the measures have been recorded, the report is removed from the register and transferred to the archive.

Furthermore, in the development of the software and information infrastructure for the information system—designed to ensure compliance with the requirements of paragraph 2 of Section IV of the minutes of the meeting chaired by the Prime Minister of Ukraine, Denys Shmyhal, on 9 February 2023—the Ministry requests that monthly reports be provided on the management of waste generated as a result of damage (destruction) to buildings and structures, unfinished construction projects and public amenities as a result of hostilities, with the aim of preventing and reducing the negative impact of such waste on the natural environment and human health [15]. The data is compiled from reports on waste generated by destruction, information on damaged facilities, the management of hazardous waste, details of existing equipment or the need for such equipment, and details of operations involving the management of waste generated by destruction. This is used to monitor environmental situations that may involve hazardous materials. Tracking this data enables the identification of: the level of threat to the environment, the detection of critical environmental impacts, and the planning of measures to mitigate the consequences of destruction. Management of disposal processes: data on damaged facilities, the volume and composition of waste, the availability of disposal equipment, and information on the transfer of hazardous waste to licensed enterprises. Ensuring effective planning and response: assessments of the need for additional funding and equipment, and coordination of actions between local authorities and central government bodies. Reports are produced on a monthly basis. Once the measures have been recorded, the report is removed from the register and transferred to the archive.

Furthermore, as part of the development of the software and information infrastructure for the information system, an operational action plan has been drawn up in accordance with Order No. 312-r of the Cabinet of Ministers of Ukraine dated 7 April 2023, approving the implementation of the State Policy Strategy on Internal Displacement for the period up to 2025 during 2023–2025 [16]. The data is generated from reports on the provision of information regarding the operational action plan, including the names of measures and

tasks. This is used to develop the Strategy's plans and measures. The data is collected and processed automatically on an annual basis.

The vast volume of incoming information results in a significant time investment for carrying out this work. The automation of data entry operations within the information subsystem for recording environmental protection measures serves to improve the productivity of the relevant specialist.

This information is collected by all local authorities and by the Department of Environmental Protection and Natural Resources itself. To this end, the option is provided to receive reports automatically, using a filter of their choice; certain fields have been restricted for standard users.

The functional structure of reporting on environmental protection measures is shown in Figure 9 [22].

Description of the system's functions. The entry of data on environmental protection activities by local government bodies – code ПРИРОДОХ1 – facilitates the monitoring and management of actions taken to protect the environment and ensures effective management of the process at the level of local councils and their surrounding areas.

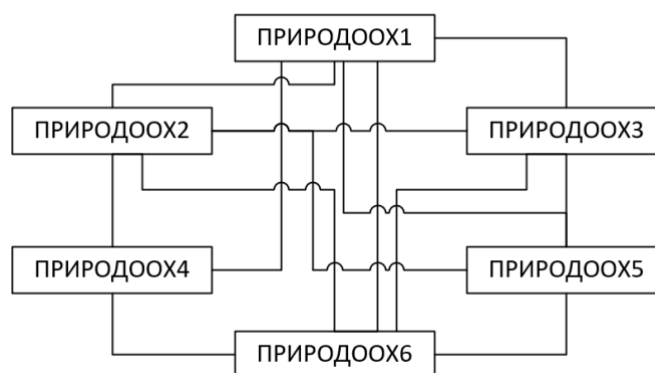


Figure 9. Diagram illustrating the interrelationships between the tasks involved in these environmental protection measures.

Entry of reference information on environmental protection measures – task code ПРИРОДОХ2. A list of reference information on environmental protection measures is compiled, covering: environmental protection programmes, ecological initiatives, energy-saving measures, and the protection of biodiversity.

Creation of reports on planned environmental protection measures, task code ПРИРОДОХ3. A list of planned environmental protection measures is being compiled. It is presented in MS Excel table format. The list shows funding amounts and sources of funds. The information is broken down by budget items and organised by areas of work and environmental protection measures. The total funding for the planned environmental protection measure is indicated, as well as the expected environmental impact. Summaries are provided separately for each area and in total.

The generation of reports on implemented environmental protection measures, task code ПРИРОДОХ4, involves compiling a summary of the environmental protection measures carried out. This summary is generated in the form of an MS Excel spreadsheet. It contains data on funding amounts and sources. The information is structured by budget items, grouped by areas and specific environmental protection measures. It shows the total amount of actual expenditure, as well as the environmental impact achieved as a result of the environmental protection measures. Results are summarised both for each individual area and in aggregate.

The preparation of reports on planned and unimplemented environmental protection measures, task code ПРИРОДОХ5, involves the creation of a list of unimplemented environmental protection measures. This list is generated in MS Excel table format, showing funding volumes and their sources. The information is structured by budget items, grouped by areas of environmental protection activity and specific measures.

The total funding allocated for each environmental protection measure is specified, and the reasons for its non-implementation are identified. The report's findings are summarised separately for each area, as well as in aggregate.

The generation of user queries to the database is designated by task code ПРИРОДОХ6. All specified tasks are implemented in the appropriate mode with clearly defined deadlines and types of results. In addition, this database allows for the execution of certain non-standard queries:

- by period;
- by year;
- by quarter;
- by contractor's full name;
- by local authority;
- by field values in the list of areas form;
- by field values in the list of measures form;
- by criteria in the fields of the list of outcomes form;
- by criteria in the fields of the list of reasons for non-completion form;
- by adding or updating data;
- by deleting individual or all records;
- by exporting to MS Excel;
- by editing existing records;

The functional structure of reporting on demolition waste is shown in Figure 10.

Overview of the system's functions. The entry of data on demolition waste by local authorities – code BI/X1 – facilitates the preparation of reports on the composition, volumes and sources of waste generated as a result of demolition; it also ensures that central authorities are kept informed in a timely manner and supports decision-making in the field of environmental safety.

Entering reference information on waste from destruction (task code BI/X2) generates a list of reference information on waste from destruction, which includes: types of data on damaged objects, names of operations involving the management of waste from destruction, and names of components of waste from destruction.

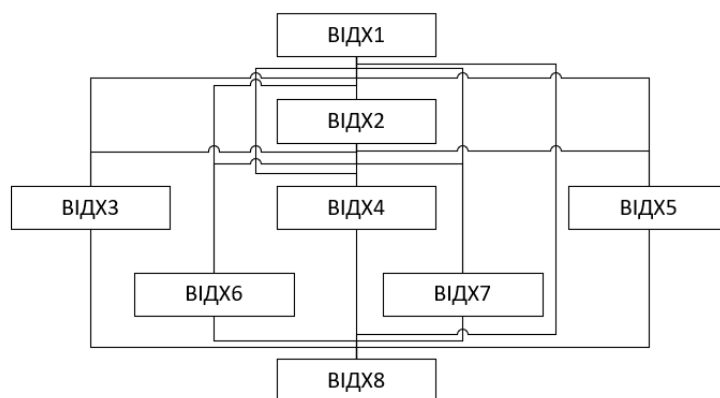


Figure 10. Functional structure of reporting on demolition waste

Preparation of reports on the provision of information regarding demolition waste (task code BI/X3): a report is generated from the form for providing information on demolition waste and is presented in tabular form on the website and as a downloadable MS Excel file, showing: the names of the components generated during demolition, the volume in tonnes of the demolition waste itself, the location of the temporary storage site / other waste management facility, the address or coordinates, and the total area of the storage sites. The information is sorted by the date of reporting, as well as by district and the name of the local authority. Filtering is available for the chief specialist of the Department of Environmental Protection and Natural Resources by local authority and district, as well as by month, several months or year; for ordinary users, filtering is available by month, several months or year. The summary is based on the volume of waste from demolition in tonnes.

Generation of reports on damaged objects (task code BI/X4): a list is generated from data on damaged objects and presented in tabular form on the website; when downloaded to MS Excel, it displays: the type, number and volume (in tonnes) of damaged objects resulting from destruction. Filtering is available for the chief specialist of the Department of Environmental Protection and Natural Resources by local authority and district, as well as by month, several months, or year; for ordinary users, filtering is available by month, several months, or year. The summary is based on the volume of waste resulting from the destruction.

Generation of hazardous waste management reports (task code BI/X5): a summary of hazardous waste management data is generated and presented in tabular form on the website; when downloaded to MS Excel,

it shows: whether hazardous waste is separated from demolition waste, locations for the separate storage and disposal of hazardous waste (site for the temporary storage of demolition waste/other waste management facility, address, coordinates), the number of temporary storage sites for hazardous waste within demolition waste, whether hazardous waste is transferred to enterprises licensed to carry out economic activities involving the management of hazardous waste, and the business entity to which the hazardous waste has been transferred. The information is sorted by the date of reporting, as well as by district and the name of the local authority. Filtering is available for the chief specialist of the Department of Environmental Protection and Natural Resources by local authority and district, as well as by month, several months, or year; for ordinary users, filtering is available by month, several months, or year.

Generation of a report on existing equipment or the need for such equipment (task code BI\X6): a list of existing equipment or the need for such equipment is generated; this is presented as a table on the website and, when downloaded to MS Excel, displays: the type of existing waste disposal equipment, the quantity of existing waste disposal equipment, the type of equipment required, the quantity of equipment required, the expected quantity of equipment and the means of obtaining it (purchase, transfer), and proposals. The information is sorted by the date of reporting, as well as by district and the name of the local authority. Filtering is available for the chief specialist of the Department of Environmental Protection and Natural Resources by local authority and district, as well as by month, several months, or year; for ordinary users, filtering is available by month, several months, or year.

Generation of reports on waste management operations relating to demolition waste (measure code BI\X7): a report on waste management operations relating to demolition waste is generated in the form of a table on the website and, when downloaded to MS Excel, displays: the names of the operations, the volume (in tonnes) covered by the operation, the volume (in tonnes) remaining to be processed, the funding sources used to carry out the operation, whether there is a need for additional funding (with an approximate indication of the amount required), and whether there is a need for specific equipment (specifying the type). The information is sorted by the date of reporting, as well as by district and the name of the local authority. Filtering is available for the chief specialist of the Department of Environmental Protection and Natural Resources by local authority and district, as well as by month, several months, or year; for ordinary users, filtering is available by month, several months, or year.

User queries to the information database are identified by task code BI\X8. All such tasks are carried out in a regulated manner, with specified deadlines and types of results. In addition, a number of non-regulated queries can also be performed in this database: 1) by type of data on damaged objects; 2) by name of operations for the management of demolition waste; 3) by name of demolition waste components; 4) by month; 5) by year; 6) by contractor's full name; 7) by local authorities; 8) by field labels in the form for the list of names of operations for the management of demolition waste; 9) by field labels in the form for the list of names of demolition waste components; 10) by fields in the form for the list of names of demolition waste components; 11) by inserting or updating data; 12) by deleting individual or all records; 13) by exporting to MS Excel; 14) by editing existing records.

The functional structure for reporting data on operational action plans is shown in Figure 11.

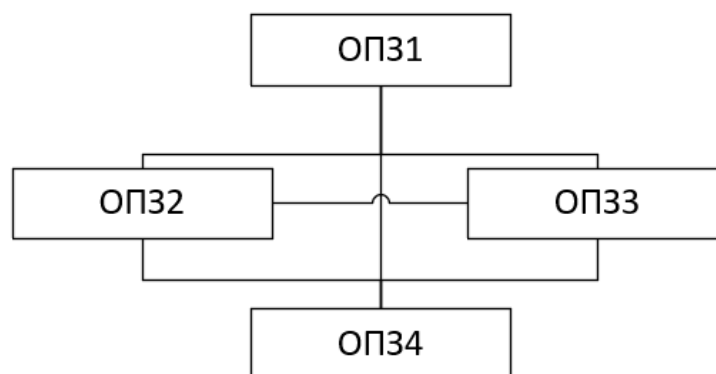


Figure 11. Diagram showing the interrelationships between tasks in operational action plans

Description of the system's functions. Entering data on operational action plans by local authorities – code OII31 – facilitates the implementation of action plans and tasks for internally displaced persons.

Entering reference information for operational action plans – code OII32 – generates a list of reference information from operational action plans, which includes: task names and action names.

Generating reports on operational action plans (task code OII33) is generated as a table on the website and, when downloaded to MS Excel, displays: task name, action name, completion deadline, and implementation status (expected outcomes, indicators). The information is sorted by the quarter in which the report is submitted, as well as by the persons responsible for its implementation. Filtering is carried out by quarter and year.

Generation of user queries to the information database – code OII34. All the tasks listed are carried out in a regulated manner, with specified deadlines and types of results. In addition, a number of non-regulated queries can also be performed in this database: 1) by event name; 2) by task name; 3) by quarter; 4) by year; 5) by contractor's full name; 6) by local government bodies; 7) by values entered in the fields of the list of event names form; 8) by values entered in the fields of the list of task names form; 9) by inserting or updating data; 10) by deleting individual or all records; 11) by exporting to MS Excel; 12) by editing existing records.

4. Choice of implementation tools. Visual Studio Code (VS Code) [3] was selected as the development environment for implementing the web application. This is an open-source editor from Microsoft, chosen for the following reasons:

- Extensibility and customisation: VS Code adapts extremely easily to the needs of a project, thanks to its support for a wide range of extensions. You can easily extend its functionality by supporting various programming languages, configuring debugging, implementing version control, and integrating other developer tools. Extensions are installed via the built-in manager;

- Cross-platform compatibility: VS Code works equally well on different operating systems, including Windows, macOS and Linux. Developers can work on their preferred platform without changing their development tool. This provides convenience and flexibility during the development process;

- Integration with version control systems: VS Code has built-in support for Git and other similar systems. This allows you to conveniently manage code changes, perform revisions and collaborate with your team. Integration with GitHub, Azure Repos and other services makes developing and deploying applications significantly easier;

- Powerful debugging and testing tools: VS Code comes with built-in debugging tools that support most popular programming languages and platforms. This allows you to quickly identify and fix errors, thereby improving productivity. In addition, it offers the ability to configure an environment for automated testing;

- Speed and performance: VS Code is characterised by fast start-up and high performance. The editor's lightweight nature and optimised use of system resources ensure stable and fast operation, which is critical for large projects;

- Community and support: VS Code has a large and active user community. A wealth of resources is available, including documentation, tutorials, forums and conferences. The community's activity contributes to the tool's rapid development and improvement.

In addition, HTML (HyperText Markup Language) [21] was chosen for building the web application as a means of structuring web applications, owing to a number of advantages:

- Versatility: HTML is a universal standard for all web pages and works in all browsers. This means that web pages written in HTML open and display without any issues in any browser on any platform, whether it be a desktop computer, laptop, tablet or smartphone;

- Ease of learning: HTML is one of the easiest programming languages, making it the ideal choice for beginners. It features a simple syntax structure and does not require an in-depth understanding of programming to create basic web pages;

- multimedia support enables the use of various multimedia formats, utilising tags for images, audio and video. This makes it easy to embed images, videos and audio files directly into web applications, making them more engaging and interactive for users;

- free to use – no need to purchase specialised software to work with HTML. You can create and edit HTML files in any editor, and view them in a web browser.

JavaScript [19] was chosen to create dynamic, interactive pages, given that it allows the page to be updated in real time. The main areas of application for JavaScript are:

- Client-side development: JavaScript runs directly in the browser, enabling developers to integrate interactive components such as animations, modal windows, sliders and dynamic data loading. This significantly improves user interaction, making web pages more ‘responsive’;

- Server-side development (Node.js): The Node.js platform has enabled JavaScript to move to the server, allowing server-side applications to be written using a single language for both client-side and server-side components. This reduces training costs and simplifies the integration of different parts of a project;

- mobile app development: using technologies such as React Native or Apache Cordova, JavaScript enables the development of cross-platform mobile apps that run on Android and iOS;

- using tools for creating desktop applications, such as Electron, developers can build apps for Windows, macOS and Linux from a single JavaScript codebase.

Advantages of JavaScript:

- interactivity and responsiveness: JavaScript plays a key role in creating websites that respond instantly to user commands, as this gives web pages a more ‘lively’ feel;

- Versatility: it works on both the client-side and server-side of a project, allowing a single programming language to be used throughout the project, which minimises the complexity of the development and integration process for all components;

- A thriving developer community and a wide selection of libraries and frameworks (e.g. React, Angular, Vue) significantly simplify the process of developing complex interfaces and applications, allowing new functionalities to be implemented quickly;

- Asynchronous data processing, mechanisms such as AJAX, the Fetch API and Promises, enable efficient handling of large volumes of data without disrupting the user’s interaction with the site. This is extremely important for modern web applications that require high performance;

- Easy integration with HTML and CSS; JavaScript works seamlessly with existing web technologies, making it the logical choice for creating interactive elements on existing websites;

- Regular language updates; ECMAScript standards are constantly being improved (e.g. ES6, ES7 and others), enabling developers to use modern programming approaches, thereby improving performance and code quality.

CSS [20] has been chosen for styling, as it defines how elements written in the markup language should appear on web pages. Thanks to CSS, it is possible to control the layout, positioning, colour palette, fonts, spacing and many other visual aspects, which significantly improves the user experience and makes the website harmonious and attractive. Key features and applications of CSS:

- Separation of content from presentation: CSS allows the document structure (HTML) to be separated from its visual styling. This helps keep the code clean and simplifies the process of making changes. Visual styling is controlled via one or more CSS files, which are automatically applied to all pages using these styles;

- Responsive design: thanks to CSS media queries, it is possible to develop designs that automatically adapt to the screen sizes of various devices — from mobile phones to desktop computers. This is a key aspect of modern web development, as it ensures a comfortable viewing experience regardless of the user’s device;

- flexible layout methods: the use of CSS Grid Layout and Flexbox allows you to build complex layouts and provides flexibility in positioning elements on the page without the need for additional elements or complex calculations. These approaches make the creation of complex yet intuitive interfaces more efficient;

- animations and transitions: CSS enables the creation of animations, transformations and effects that add dynamism to web pages. Modern capabilities allow for smooth transitions between styles, the definition of keyframes, and the development of interactive effects without the need for JavaScript;

- Support for a component-based approach: thanks to methodologies such as BEM (Block Element Modifier), SMACSS or ITCSS, CSS becomes more organised and modular. This enables developers to create isolated components that are easy to maintain and extend in large-scale projects.

MySQL Server [4] has been selected for data storage, given its reliability and efficiency in data management:

- is renowned for its outstanding performance. It demonstrates the ability to process large datasets and provide simultaneous access for a large number of users. This makes it suitable for large-scale projects that require the processing of significant volumes of information;

- is notable for its ease of scaling, allowing the volume of data and the number of users to be flexibly adapted to the current needs of the project. You can start with a smaller database and gradually expand it as the application’s functionality grows;

- offers a robust security system that provides granular control over data access at the user level. The ability to set permissions at the database, table or individual row level allows you to flexibly determine who can view or modify information;

- is open-source, allowing you to freely use and modify it. This enables you to flexibly configure MySQL to meet the specific needs of your project without licensing restrictions;

- supports a wide range of programming languages, including PHP, Java, Python, Perl and C++. This expands its potential for integration with various systems;

- is compatible with various platforms, including Linux, Windows, Mac OS and Solaris. This makes it a versatile solution that can be deployed on a variety of operating systems and servers.

PHP was chosen as the programming language for the web application [23] due to its numerous advantages, which make it the ideal choice for developing dynamic web applications:

- recognised as one of the easiest programming languages to learn;

- PHP is an extremely versatile programming language. It can be used to create a wide range of projects – from basic web pages to complex web applications – as well as for writing command-line scripts and developing applications;

- It integrates easily directly into HTML code, allowing you to combine PHP code with HTML markup;

- It supports MySQL, PostgreSQL, SQLite, Oracle and many other databases;

- PHP is open-source software. This means it is free to use and you are free to modify it to suit your requirements;

- PHP runs on most web servers and major operating systems, including Linux, macOS and Windows.

To implement the information subsystem for recording environmental protection measures, the selection of technical and software components was justified by taking the following aspects into account: functionality, stability, scalability, cross-platform compatibility, integrability, and active support from the developer community. The Visual Studio Code environment was chosen due to its adaptability; a wide range of extensions and seamless integration with HTML, CSS and JavaScript ensure a comfortable, responsive and interactive user interface. PHP was used for the server-side – a language that is easy to learn and interacts well with HTML and databases. The Microsoft SQL Server database management system ensures high performance, security, flexible access control and the ability to process large volumes of data.

5. Development of functional diagrams for the software tool. A use case diagram is an important tool in the process of system design and development [2]. The system's functionality models the services, tasks and functions it is required to perform. Interactions are defined that reflect the external entities (actors) interacting with the system, and helps to visualise how a user or another system will interact with the diagram, which aids in defining the requirements for the functional behaviour of the system under design, and the definition of boundaries, which establishes the general limits and context of the modelled domain in the early stages of design.

In this context, actors can be considered as follows:

- user: a representative of a local authority within a territorial community who uses the software product;

- administrator: a person who has extended access to the product's features and manages the system.

- Department of Environmental Assessment, Monitoring and Natural Resource Management; Department of Air Quality Standards, Water Resources, Waste Management and Air Quality Control: senior specialists within the state administration who review and compile a consolidated report based on the data submitted by users.

The creation of functional diagrams (also known as functional block diagrams or system block diagrams) is an important part of the system analysis and design process [12]. These diagrams help to visualise the interaction between the functions and components of a system. Figure 12 shows a context model of the information subsystem for environmental protection measures.

The input data for the environmental protection measures accounting information subsystem include:

- username;

- password;

- data on environmental protection measures;

- data on demolition waste;

- data on the management of operational action plans.

The input data includes:

- updated database;

- automated management of environmental protection measures;

- automated management of demolition waste;
- automated management of operational action plans.

The managed properties include:

- environmental protection guidelines;
- guidelines on demolition waste;
- guidelines on operational action plans;
- authorisation;
- input database.

These mechanisms include:

- administrator;
- end user;
- software and hardware.



Figure 12. Contextual model of the information subsystem for recording environmental protection measures

The architecture of the information subsystem for monitoring environmental protection measures defines the structure, organisation and interaction of the components required to ensure the functionality and effective operation of the system [6].

The architectural model is designed with a focus on scalability, ensuring the reliability and uninterrupted operation of the information system, whilst guaranteeing flexible deployment in both on-premises infrastructure and cloud environments. Interaction between components is carried out via well-documented API interfaces, which facilitates the simple integration of new modules and updates without the risk of disrupting the functionality of existing parts of the system. The databases are designed with backup capabilities and fault tolerance in mind, and data exchange channels are protected by modern encryption and user authentication methods. Access rights to the system's functionality are organised according to a role-based model, allowing permission levels to be set depending on the rights of each user type, from administrators to representatives of local authorities.

The deployment diagram of the information subsystem for recording environmental protection measures illustrates the physical structure of the system, including the location of its components on a physical server, and demonstrates scenarios for their interaction (see Figure 13) [18].

This diagram clearly shows how the various elements of the system — the web server, database, file storage, processing modules and user interfaces — are situated within the physical environment, forming a coherent and interconnected structure. Interconnections between components are provided via an internal

network and the use of communication protocols, which allows for the optimisation of system response times and the maintenance of stable data exchange.

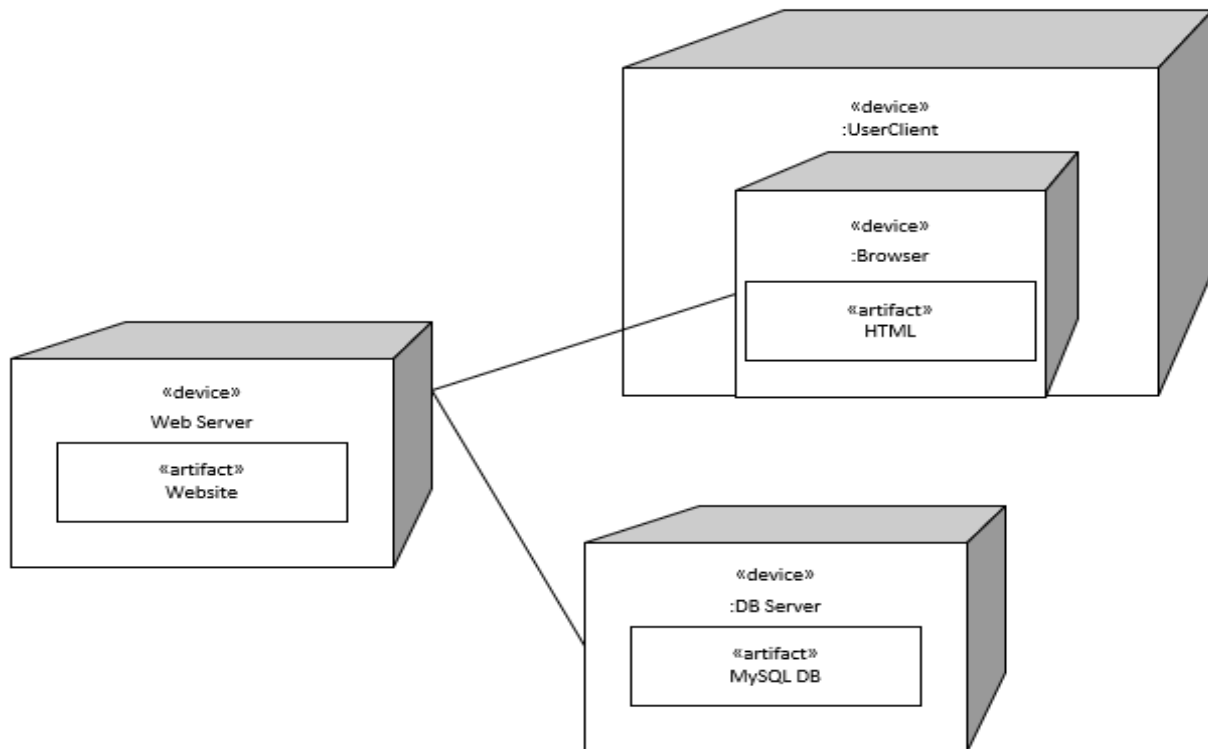


Figure 13. Block diagram of the information subsystem for recording environmental protection measures

The diagram includes components such as web servers, databases, additional services and integration modules. It illustrates the principles of interaction between these components, communication protocols and data processing logic.

6. Design of the database for the information subsystem for monitoring environmental protection measures. The database of the information subsystem for recording environmental protection measures is compiled on the basis of input documents and reference guides [14]. The list of documents and reference guides is given in Table2.

Table 2. Information entities

№	Name of the information object	Document type
1	2	3
1	Form for providing information on demolition waste	Register of information on waste resulting from demolition
2	Information on damaged properties	Recording details of damaged properties
3	Management of hazardous waste	Registration of hazardous waste management
4	Information regarding existing equipment or the need for such equipment	Registration of details regarding existing equipment or the need for such equipment
5	Information on waste management operations relating to demolition waste	Registration of details regarding operations involving the management of demolition waste
6	Operational Action Plan	Registration of operational action plans
7	Information on environmental protection measures that have been implemented	Registration of information on environmental protection measures that have been implemented
8	Information on environmental protection measures that were planned but not implemented	Registration of information regarding environmental protection measures that were planned but not implemented

9	Information on environmental protection measures, taking into account the changes planned for implementation	Registration of information on environmental protection measures, taking into account planned changes
10	Local authorities	Guide
11	Data types for damaged objects	Guide
12	Names of operations for the management of demolition waste	Guide
13	Names of waste components resulting from demolition	Guide
14	Areas of environmental conservation	Guide
15	Environmental benefits	Guide
16	Environmental protection measures	Guide
17	Reasons for the failure to implement environmental protection measures	Guide
18	Names of events	Guide
19	Task titles	Guide

Describing the structural relationships between information objects in a database allows relationships to be established between information objects, i.e. between tables. These relationships are established using a key. The established relationships allow simultaneous access to information across multiple tables. A description of the structural relationships between information objects relating to environmental protection measures is provided in Table 3. This description provides a clear understanding of how different information objects interact within the database and which key fields are used to establish these relationships.

Table 3. Description of the structural relationships between information objects relating to environmental protection measures.

№	Information objects		Type of relationship	Communication key
1	2		3	4
1	Local authorities	Information on environmental protection measures that were planned but not implemented	1:B	Territorial_communityCode
2	Environmental protection measures	Information on environmental protection measures that were planned but not implemented	1:B	Event_Code
3	Areas of environmental conservation	Information on environmental protection measures that were planned but not implemented	1:B	Direct_Code
4	Reasons for the failure to implement environmental protection measures	Information on environmental protection measures that were planned but not implemented	1:B	Reason_code
5	Guide to Environmental Effects	Information on environmental protection measures that have been implemented	1:B	Effect_code
6	Areas of environmental conservation	Information on environmental protection measures that have been implemented	1:B	Direct_Code
7	Environmental protection measures	Information on environmental protection measures that have been implemented	1:B	Event_Code
8	Local authorities	Information on environmental protection measures that have been implemented	1:B	Territorial_communityCode
9	Areas of environmental conservation	Information on environmental protection measures, taking into account the changes planned for implementation	1:B	Direct_Code
10	Environmental protection measures	Information on environmental protection measures, taking into account the changes planned for implementation	1:B	Event_Code
11	Local authorities	Information on environmental protection measures, taking into account the changes planned for implementation	1:B	Territorial_communityCode
12	Guide to Environmental Effects	Information on environmental protection measures, taking into account the changes planned for implementation	1:B	Effect_code

Table 4 provides a description of the structural relationships between information objects relating to demolition waste, comprising the information object's serial number (primary or subordinate), the relationship type and the relationship key.

Table 4. Description of the structural relationships between information objects relating to demolition waste

№	Information objects		Type of relationship	Communication key
	Primary	Subordinate		
1	Data types for damaged objects	Information on damaged properties	1:B	Damaged_object_data_code
2	Local authorities	Information on damaged properties	1:B	Territorial_communityCode
3	Types of data on damaged objects	Form for providing information on demolition waste	1:B	Code_components
4	Local authorities	Form for providing information on demolition waste	1:B	Territorial_communityCode
5	Local authorities	Management of hazardous waste	1:B	Territorial_communityCode
6	Local authorities	Information regarding existing equipment or the need for such equipment	1:B	Territorial_communityCode
7	Names of operations for the management of demolition waste	Information on waste management operations relating to demolition waste	1:B	Operation_Code
8	Local authorities	Information on waste management operations relating to demolition waste	1:B	Territorial_communityCode

Table 5 provides a description of the structural relationships between information objects in operational event plans. It includes: item number, information object (parent, child), relationship type and foreign key. These relationships form the foundation of the logical database model. They ensure the integrity and consistency of information stored in different tables. It is these relationships that define the interactions between the entities: 'Operational Action Plan', 'Event Names', 'Task Names' and 'Local Authorities'. This approach enables database queries to be executed taking into account related parameters. The foreign key acts as an intermediary between tables, allowing data to be joined based on specified attributes.

Table 5. Description of the structural relationships between information objects in operational action plans.

№	Information objects		Type of relationship	Communication key
1	Local authorities	Operational Action Plan	1:B	Territorial_communityCode
2	Event title	Operational Action Plan	1:B	Meas_Code
3	Task titles	Operational Action Plan	1:B	Task_Code

The names of the relationships between information objects relating to environmental protection measures are listed in Table 6.

Table 6. Names of relationships between information objects

№	First information item	Second information object	Connection name
1	Local authorities	Information on environmental protection measures that were planned but not implemented	Create Create
2	Local authorities	Information on the environmental protection measures that have been implemented	Create
3	Local authorities	Information on environmental protection measures, taking into account the changes planned for implementation	Create
4	Information on environmental protection measures that were planned but not implemented	Reasons for the failure to implement environmental protection measures	They explain
5	Information on environmental protection measures that were planned but not implemented	Environmental protection measures	Includes
6	Information on environmental protection measures that have been implemented	Environmental protection measures	Includes
7	Information on environmental protection measures, taking into account changes that are planned to be implemented	Environmental protection measures	Includes
8	Environmental protection measures	Areas of environmental conservation	Belongs to
9	Environmental protection measures	Guide to Environmental Effects	Have
10	Information on environmental protection measures that were planned but not implemented	Guide to Environmental Effects	Describe
11	Information on environmental protection measures that were planned but not implemented	Guide to Environmental Effects	Describe
12	Information on the environmental protection measures that have been implemented	Guide to Environmental Effects	Describe

The structure of relational tables is based on keys: primary and foreign keys, which form the basis of data integrity.

Primary keys uniquely identify each record in a table, enabling the precise identification of every piece of information stored in the system. This is critically important when working with large data sets, where rapid searching, updating or deleting of records is required. Typically, a primary key is assigned to one or more table attributes, the values of which cannot be duplicated and must not be missing.

Foreign keys establish relationships between different tables, which helps maintain referential integrity – the consistency of data between related objects. They ensure a logical combination of tables, where one contains a reference to the primary key of the other, creating a structured system of interdependencies. For example, a table of action plans may have a foreign key that references a table of local government bodies, allowing specific tasks to be matched with the relevant administrative units.

Table 7. Names of relationships between information objects

№	First information item	Second information object	Connection name
1	Local authorities	Information on damaged properties	Data is being entered
2	Information on damaged properties	Type of data on damaged objects	have
3	Information on damaged properties	Form for providing information on demolition waste	Provide
4	Information on damaged properties	Management of hazardous waste	Related to
5	Management of hazardous waste	Information on waste management operations relating to demolition waste	Includes
6	Information on waste management operations relating to demolition waste	Names of disaster response operations	Used
7	Information on waste management operations relating to demolition waste	Names of components damaged	Include
8	Information on waste management operations relating to demolition waste	Information regarding existing equipment or the need for such equipment	Provided via

Keys enable the efficient generation of reports, the execution of aggregate queries, and the tracking of changes, whilst also preventing the entry of inconsistent or duplicate data. Furthermore, this structure promotes system scalability, allowing new tables and functions to be added without compromising the consistency and stability of the database. The use of primary and foreign keys results in a coherent, flexible and error-resistant data architecture, which forms the basis of a productive information system. The names of the relationships between information objects in operational action plans are shown in Table 8.

Table 8. Names of relationships between information objects

№	First information item	Second information object	Connection name
1	Local authorities	Operational Action Plan	Data is being entered
2	Operational Action Plan	Names of events	Contains
3	Operational Action Plan	Task titles	Includes

Each table has its own set of attributes, comprising both mandatory fields—necessary to ensure the system’s basic functionality—and additional fields that can be used to enhance analysis and reporting capabilities. The logical structure relating to environmental protection measures is presented as a schematic diagram in Figure 14. This diagram shows tables structured according to the composition and sequence of fields. It illustrates the organisation of data and the relationships between them within the system. Key fields are marked with an asterisk ‘*’. This is necessary for the quick identification of key attributes that ensure the uniqueness of records and form the basis for establishing structural relationships between tables. Thanks to this visual representation, users and developers can quickly navigate the data structure, track dependencies between objects and analyse the interaction of tables at a logical level.

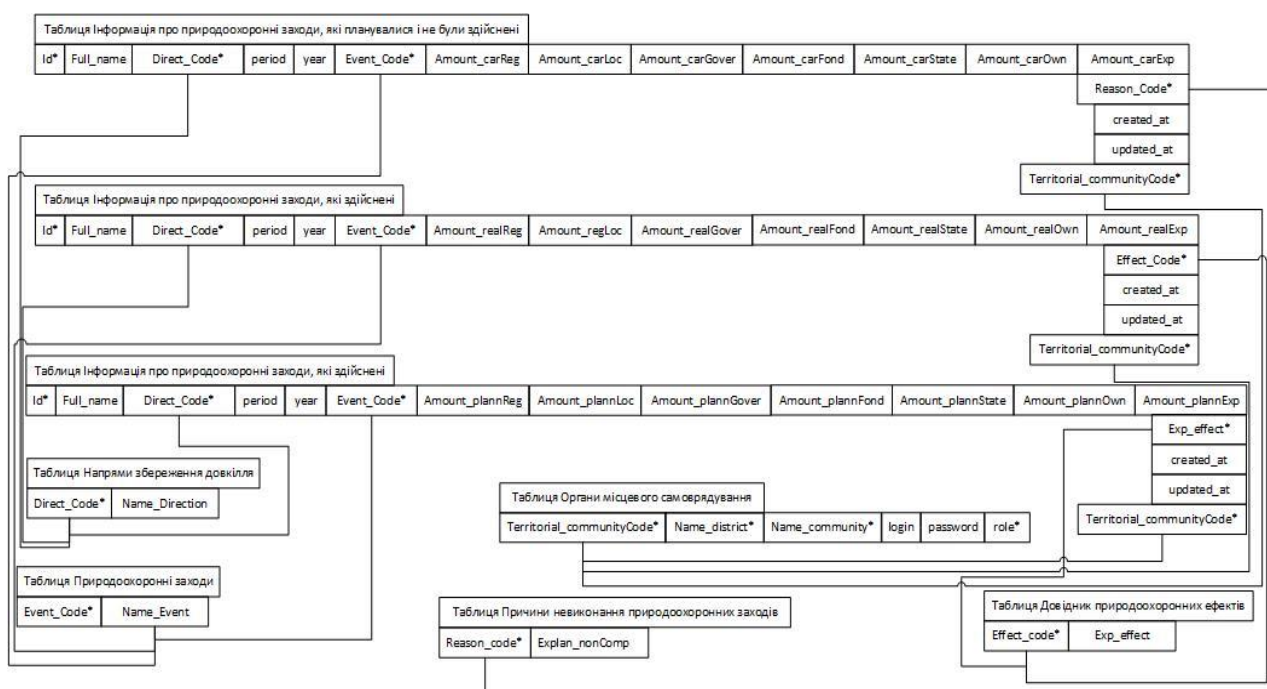


Figure 14. Logical structure of the database of environmental protection measures

Logical relationships are represented by lines connecting identical relationship keys. This illustrates the mechanism for establishing ‘one-to-many’ or ‘many-to-one’ relationships between information objects. This approach allows for the representation of interdependencies, for example: which measures correlate with specific areas of nature conservation, what caused the failure to implement certain measures, or what role local authorities play in reporting. Furthermore, such a logical schema enables the creation of complex database queries that simultaneously take into account several interrelated objects [17].

The logical structure is illustrated in the form of a flowchart for demolition waste, as shown in Figure 15. In this flowchart, the tables are presented in a structure determined by the composition and sequence of

fields. Key fields are marked with an asterisk (*). Logical relationships are indicated by lines between matching relationship keys.

Логічну структуру зображено у вигляді схеми для операційних планів заходів, представлено на рисунку 16. На цій схемі таблиці подані структурою, обумовленою складом і послідовністю полів. Ключові поля позначені знаком «*». Логічні зв'язки зображені лініями між однаковими ключами зв'язку.

Based on the relationships between information objects, the database structure and the layouts, a functional and technical diagram of the database for environmental protection measures is created. This diagram is a summarising element of the system's technical documentation and allows for a visual demonstration of the logic behind the software suite's operation at the levels of data processing, interaction between components, and load distribution. It illustrates the structure of the entire system architecture, from the user interface to data repositories and analytical tools. Using this diagram, it is possible to trace how information flows through the system – from the moment it is entered by the user to the moment reports are generated or data is archived.

Based on the structural relationships between information objects, the database structure and the layouts, a functional and technical diagram of the database for demolition waste is drawn up. Such a diagram facilitates the smooth organisation of processes, from the information collection stage to the analysis and visualisation of results, ensuring the synchronised interaction of all system components. Creating the diagram allows for all the intricacies of data handling to be taken into account, ensuring maximum system performance and reliability. Each element of the functional and technical diagram is characterised by clearly defined functions, which promotes structured and highly efficient data processing.

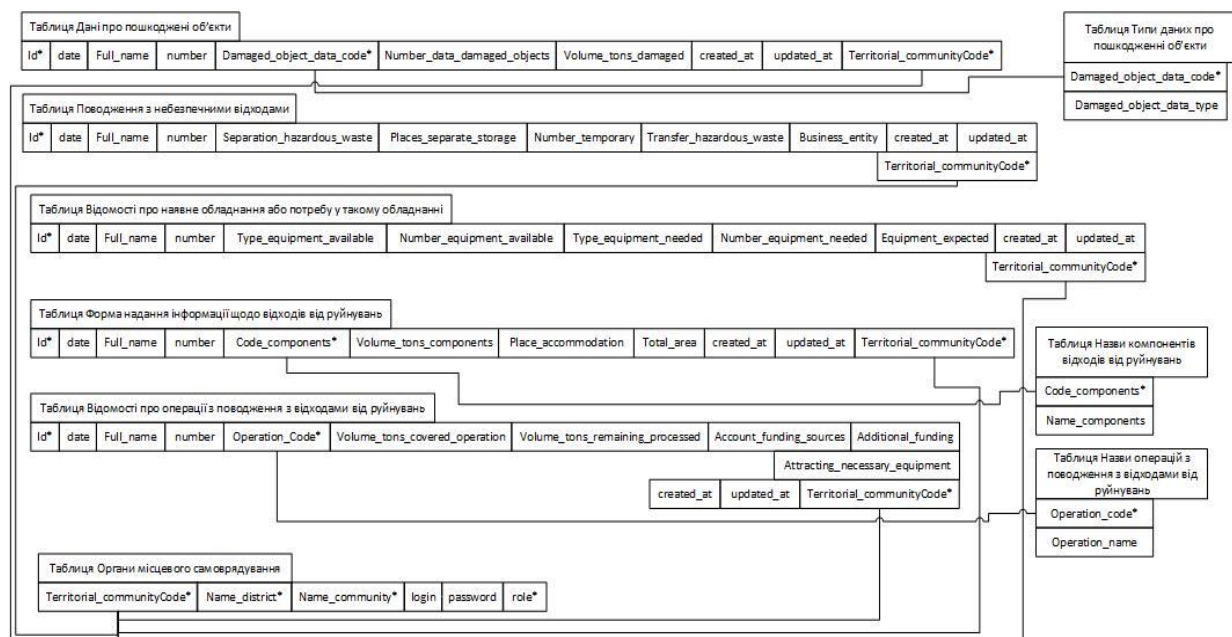


Figure 15. Logical structure of the demolition waste database

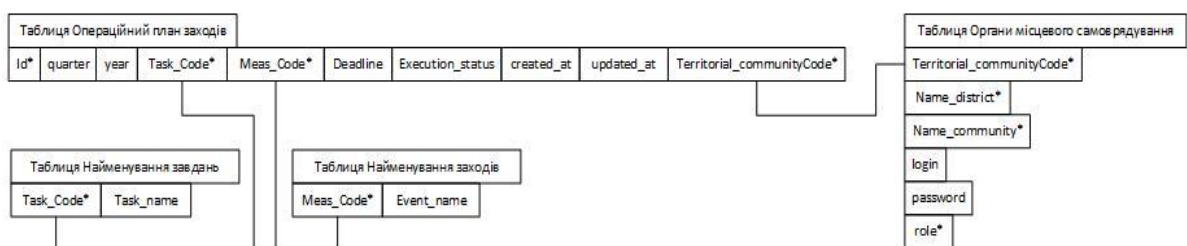


Figure 16. Logical structure of the operational event plan database

7. Physical implementation of the database and the information subsystem for recording environmental protection measures. Physical implementation of the web application database for the information subsystem for recording environmental protection measures in the MySQL environment [4]. The physical implementation of the database involves the creation of a complete relational structure implemented in the MySQL DBMS environment, selected for its flexibility, performance, scalability and support for complex structured queries. The implementation of the database begins with the formation of its logical model based on the structure of information objects. These objects serve as the basis for creating the corresponding tables, where each information unit is described by details with clearly defined data types, key attributes and relationships.

Based on the logical model, relationships between tables are established, which are implemented through primary and foreign key mechanisms. This structure ensures data integrity and consistency, preventing duplication or incorrect storage. All relationships between tables are described in detail in the structural relationship tables and are also clearly illustrated in the form of a data diagram shown in Figure 17.

In addition to the database structure, the system's visual interfaces—in particular, the on-screen forms—enable users to quickly navigate the data, make changes, and view, filter and export information. All these components form an integral part of the overall information subsystem and are implemented in accordance with the technical specifications.

Таблиця	Дія	Рядки	Тип	Зіставлення	Розмір	Фрагментовані
☐ Dameg_obj	★	5	InnoDB	utf8_general_ci	16 КБ	-
☐ Data_on_damaged_objects	★	1	InnoDB	utf8_general_ci	48 КБ	-
☐ Directions_of_environmental_protection	★	7	InnoDB	utf8_general_ci	16 КБ	-
☐ Directory_of_Environmental_Effects	★	7	InnoDB	utf8_general_ci	32 КБ	-
☐ Environmental_protection_measures	★	21	InnoDB	utf8_general_ci	32 КБ	-
☐ Form_for_providing_information_on_demolition_waste	★	1	InnoDB	utf8_general_ci	48 КБ	-
☐ Hazardous_waste_management	★	0	InnoDB	utf8_general_ci	32 КБ	-
☐ Information_about_available_equipment_or_needed	★	0	InnoDB	utf8_general_ci	32 КБ	-
☐ Information_carred	★	1	InnoDB	utf8_general_ci	80 КБ	-
☐ Information_implemented	★	2	InnoDB	utf8_general_ci	80 КБ	-
☐ Information_on_demolition_waste_management_operations	★	1	InnoDB	utf8_general_ci	48 КБ	-
☐ Information_Planned	★	1	InnoDB	utf8_general_ci	80 КБ	-
☐ Names_of_demolition_waste_components	★	32	InnoDB	utf8_general_ci	16 КБ	-
☐ Names_of_demolition_waste_management_operations	★	7	InnoDB	utf8_general_ci	16 КБ	-
☐ names_op_meas	★	1	InnoDB	utf8_general_ci	16 КБ	-
☐ names_op_task	★	1	InnoDB	utf8_general_ci	16 КБ	-
☐ Operational_action_plan	★	1	InnoDB	utf8_general_ci	64 КБ	-
☐ ReasonsForNon_implementation	★	7	InnoDB	utf8_general_ci	32 КБ	-
☐ Territorial_communities	★	52	InnoDB	utf8_general_ci	48 КБ	-
19 таблиць	Всього	148	InnoDB	utf8_general_ci	752 КБ	0 Б

Figure 17. List of database tables

Figure 18 shows the database schema. This diagram is a visual representation of the logical structure of the information subsystem for recording environmental protection measures, designed to operate within the MySQL DBMS environment. It shows how data is organised within the system, how tables interact with one another, and what constraints are applied to each field. Схеми містять такі основні компоненти:

1. Tables:

- Each table is represented as a rectangle containing a list of fields (attributes) that describe the corresponding information object;
- For ease of organisation, fields are grouped according to data storage logic: identifiers, key parameters, descriptive attributes, timestamps and others;
- Primary Keys (PK), which ensure the uniqueness of records in tables, are marked with an underscore or a separate icon;

- Foreign Keys (FK), which establish links to other tables, are marked with arrows or references to the corresponding keys in external tables.

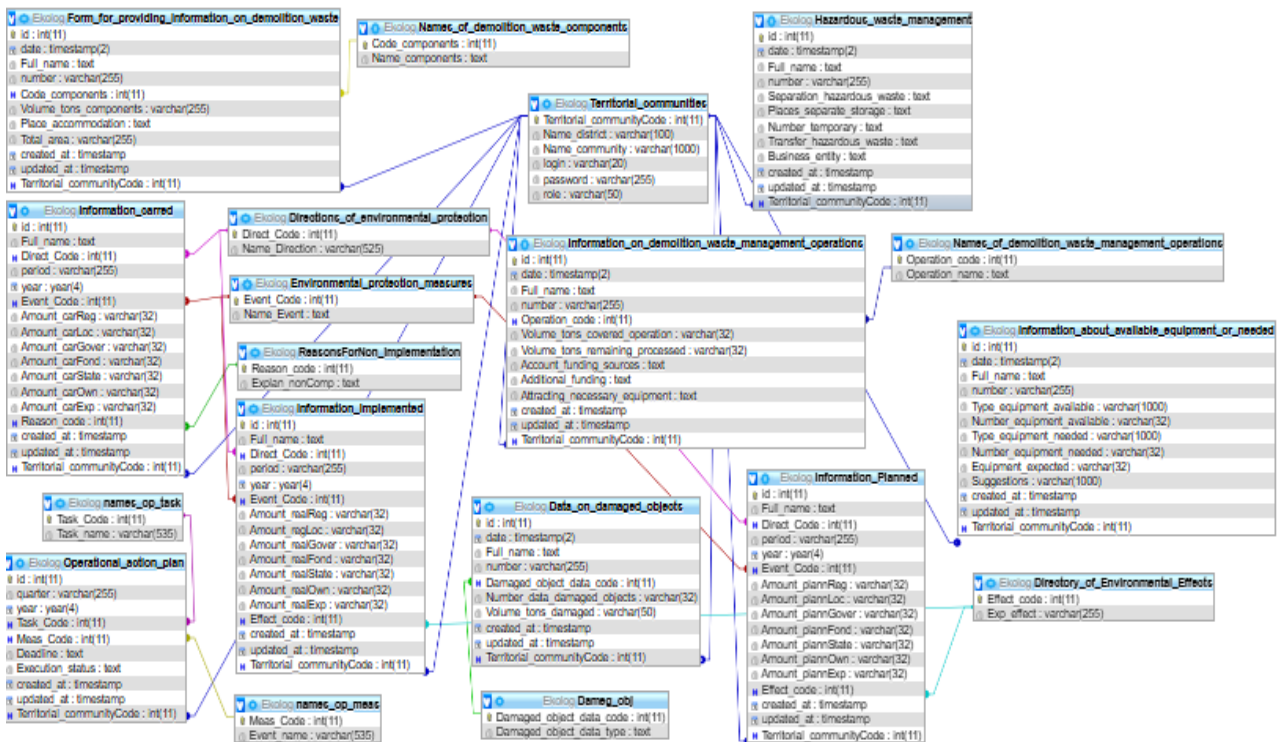


Figure 18. Database diagram

2. Relationships between tables:

- Lines are drawn between tables to represent logical relationships. Most relationships are of the ‘one-to-many’ (1:N) type, meaning that a single record in the primary table can correspond to multiple records in the secondary table;

- The fields used to establish the relationship (the relationship key) are indicated at the ends of the lines.

- The presence of relationships ensures the referential integrity of the database, enabling complex queries to be executed and ensuring the automated processing of related data;

3. Field attributes:

- For each table field, the name, data type (e.g. INT, VARCHAR, DATE, TEXT) and constraints (e.g. NOT NULL, UNIQUE, DEFAULT, AUTO_INCREMENT) are specified;

- These attributes ensure data is entered correctly, enable automated calculations and protect against errors when saving information.

4. Additional elements:

- the diagram may also include indexes, which are used to speed up data retrieval and sorting.

5. Typical relationships are specified for each information object, for example:

- between ‘Local authorities’ and ‘Information on environmental protection measures’;

- between ‘Environmental protection measures’ and ‘Areas of environmental conservation’;

- between ‘Waste management operations’ and ‘Names of operations’, etc.

A database schema is key to understanding how data is organised, the relationships between data, and the methods used to store and manage it within the system. It plays a crucial role during the design, development and maintenance phases of a web application, ensuring ease of interaction with data and enhancing the system’s overall performance.

Software implementation of the user interface. The key entry point to the information subsystem is the web application’s home page. It serves as the main navigation panel and is primarily aimed at regular users — representatives of local authorities who enter or view information on environmental protection measures, demolition waste or operational plans.

The page is optimised for viewing on various devices — computers, tablets and mobile phones. Future plans also include the ability to personalise the interface according to the user's role: administrator, departmental specialist or ordinary user.

The web application has restricted access – only users identified in the database can log in using their username and password. After authorisation, users are redirected to a separate page for selecting reports, where a navigation menu for the web application is displayed. These menus provide quick access to other pages where users can submit their reports.

Conclusions. The increasing volume of environmental data received by central and local government bodies necessitates a transition to automated systems for data collection, processing, storage and reporting. The proposed system includes modules for: 1) registering and recording environmental protection measures; 2) reporting on waste from demolition and damaged facilities; 3) processing information on equipment requirements and operational plans for measures; 4) generating standardised reports by period (month, quarter, year), with the ability to filter, edit and export to MS Excel. The system enables a significant increase in the efficiency of local government specialists, facilitates interaction with central executive authorities (in particular, the Ministry of Environmental Protection), and ensures a unified data storage structure and transparency in environmental management matters. Thanks to its flexible architecture, the information system is scalable and can be adapted for use by other communities or institutions, or integrated with state registers via an API.

Future developments for the project may include:

- integration with geographic information systems (GIS) to visualise sites and contaminated areas on a map;
- development of a mobile app to facilitate the work of specialists in the field;
- automation of analytical reporting based on templates and algorithms for assessing environmental impacts;
- provision of multi-level access to data – separately for citizens, specialists and government bodies;
- implementation of additional information security measures, including data encryption and authentication using digital signatures.

This information subsystem ensures the effective monitoring of environmental protection measures, supports environmental safety and promotes transparency in reporting within local authorities.

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INNOVATIVE MECHANISMS FOR HUMAN RESOURCE MANAGEMENT IN THE CONTEXT OF PROCESS DIGITALIZATION

Kateryna Prokopenko

Assistant of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agrarian University, Ukraine

ORCID ID: 0009-0006-9012-1800

Contemporary global challenges require significant changes in human resource management, especially in the context of digitalisation. Personnel are viewed as a key resource for the enterprise, since the effectiveness of strategic business processes directly depends on employees' professional competence [1]. In the context of the transition to a digital economy, human resource management (HRM) is undergoing a profound transformation, which involves the active implementation of digital tools, increased labour productivity, and the creation of innovative mechanisms for interaction. The aim of this study is to substantiate theoretical, methodological, and practical approaches to the formation of an HR management system within an enterprise as an element of strategic management in the context of digitalisation.

Traditional human resources management is viewed as an administrative function focused on task allocation, personnel record maintenance, and adherence to organisational policies. Under the influence of digitalisation across all spheres of public life, there is a shift in emphasis toward the development of the enterprise's communication and information environment. The digitalisation of human resources management is a new paradigm that integrates digital technologies to optimise processes, increase productivity, and create new mechanisms for interaction, differing from traditional HR management in its flexibility and innovation [6].

Modern management professionals are rethinking their professional roles. They are no longer limited to administrative functions but act as strategic partners in organisational decision-making [4]. These changes can be traced by comparing the classical and digital paradigms (Table 1).

Table 1. Comparison of the Classical Human Resource Management Paradigm and Digital HR

Comparison Criteria	Traditional Paradigm	Human Resource Management through Digitalisation (Digital HR)
Key resource	Human capital	Synergy of talent and digital technologies
Nature of tasks	Unskilled or routine tasks	Intellectual, analytical, and creative work
Division of labor	Functional division	Project-based work and agile teams
Management focus	Individual management and administration	Team management, productivity improvement
Use of technologies	Standard software products	Innovative, cloud-based solutions, mobile apps, artificial intelligence

As a result of these changes, there is a growing need for “digital talent”—employees who possess not only technical skills but also emotional intelligence, cognitive flexibility, creativity, and the ability to make quick decisions.

Innovative HR technologies refer to a set of digital tools and methods used to automate, optimise, and improve HR management processes in companies. The implementation of innovative solutions increases the efficiency of HR departments and contributes to the strategic development of organisations. Modern innovative solutions significantly simplify management processes, giving teams more opportunities to shape corporate culture and increase overall labour productivity [4].

For a deeper understanding of the nature of digital HR mechanisms, it is advisable to classify them according to several criteria (Fig. 1). Specifically, based on functional purpose, technologies are categorised into recruitment and selection, training and development, performance management, and employee retention. Based on their technological foundation, digital mechanisms are divided into software solutions, cloud services, analytical tools for processing big data and big, and mobile applications. In terms of their impact on management processes, they cover the operational, tactical, and strategic levels [4].

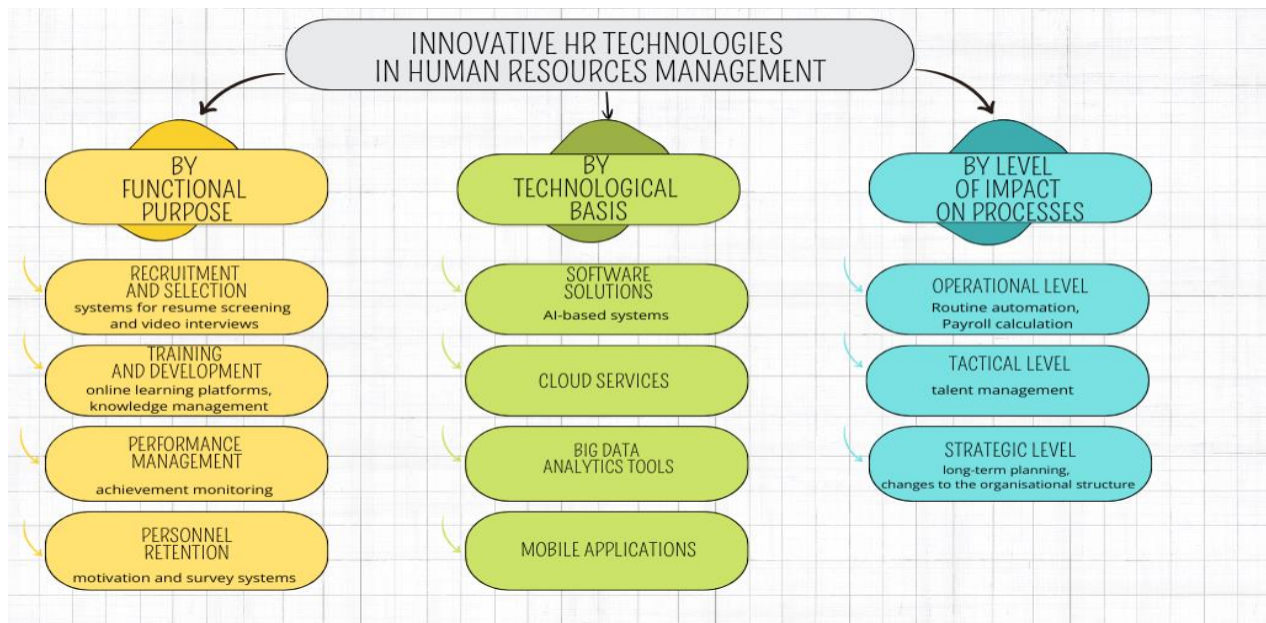


Figure 1. Classification of innovative HR technologies in human resources management

Comprehensive ERP (Enterprise Resource Planning) systems play a central role in this architecture, providing a unified system for managing the company and consolidating information flows. For example, leading platforms such as SAP ERP, Oracle ERP, and BAS ERP have specialised HR management modules that allow HR processes to be integrated with financial accounting, production, and logistics. The focus on cloud technologies inherent in such systems (e.g., Oracle ERP or BAS ERP) ensures high scalability, fault tolerance, and data security [7].

The modern human resources management ecosystem is shaped by key areas of HR function digitisation (Fig. 2).

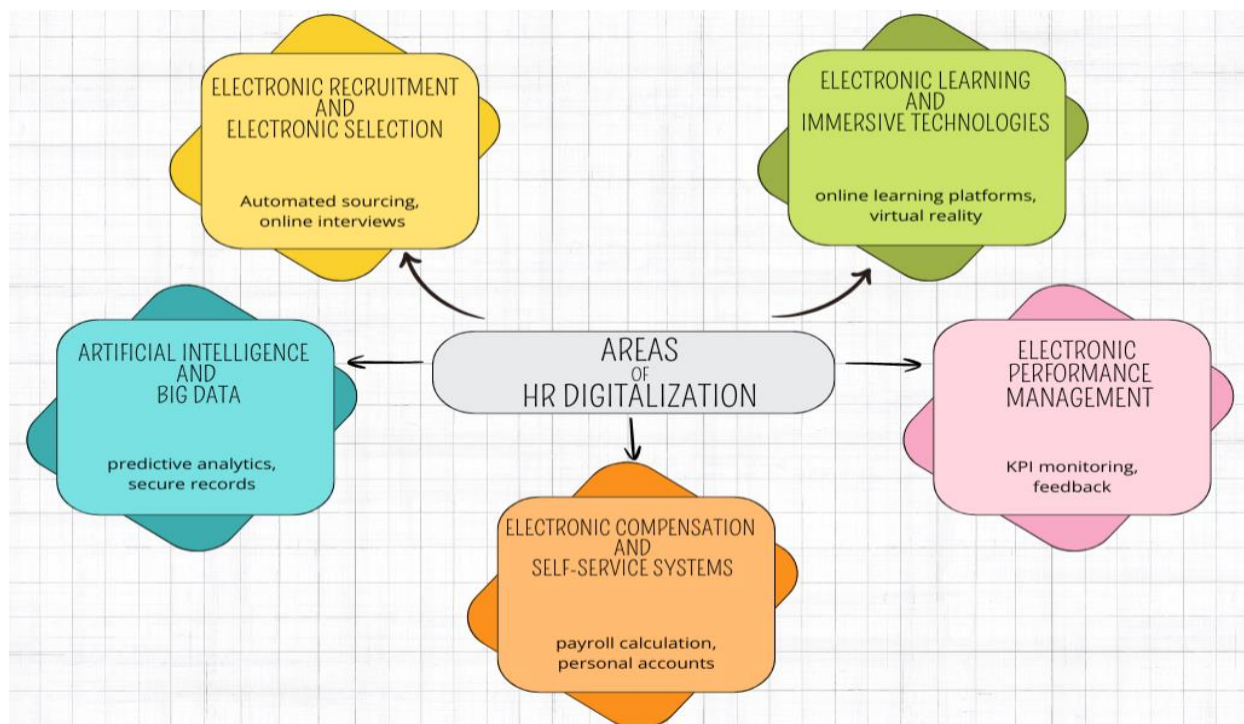


Figure 2. Key areas of HR function digitisation in the modern human resources management ecosystem.

E-recruiting and E-selection. One of the main goals of HR is to attract a talented and diverse workforce. Effective recruitment fosters innovation, stimulates creativity, and increases customer satisfaction. E-recruiting technologies have diminished the importance of traditional print media job advertising, shifting the focus to online platforms and direct communication between candidates and employers. According to some estimates, about 90% of large organisations now use some form of technology to advertise job openings and collect applications [5]. E-recruiting allows for attracting a significantly larger number of applicants and reducing transactional and administrative costs.

However, research shows that e-recruiting does not always automatically guarantee the attraction of higher-quality candidates compared to traditional methods. Additionally, challenges arise regarding ensuring gender, age, and ethnic diversity among candidates. Some studies indicate that older candidates or members of certain minority groups are less likely to use online platforms due to limited internet access at home or higher levels of “computer anxiety” and lower self-efficacy [5].

To overcome these limitations and enhance the employer brand’s appeal, organisations are increasingly shifting from passive, one-way systems (job boards) to interactive Web 2.0 technologies. Among these, virtual job fairs hold a special place—online events in a virtual environment using computer simulation, chats, webinars, and avatars, where candidates can interact with recruiters, upload resumes, and undergo a “virtual preview” of the job [5].

The next stage is e-selection, which includes electronic job analysis (EJA), web applications, online testing, and video interviews. Electronic job analysis (EJA) enables specialists from different regions to work in virtual teams to develop a job description, thereby reducing the time required to prepare the job profile. Regarding web applications, companies actively use keyword screening systems to quickly filter out unqualified candidates.

Candidates' competencies are assessed through computerised cognitive ability tests, situational judgment tests (SJT), and personality questionnaires. An important consideration is that computerised tests may place a higher cognitive load on the candidate, as they must simultaneously perform two tasks: directly solving the test and navigating the computer interface. If a candidate has low digital literacy, their results may be unfairly underestimated. With this in mind, companies are beginning to use virtual simulations (online work samples) that mimic real-world work tasks and give candidates a realistic sense of what their future job will be like. As for video interviews (e.g., via cloud-based video conferencing platforms), they significantly conserve resources, but sometimes fall short of in-person meetings due to the loss of nonverbal information (body language, facial microexpressions) and a sense of “interpersonal distance” [5].

The introduction of e-learning is recognised as one of the greatest innovations in staff training. According to research, over 25% of corporate training hours worldwide are now conducted online, providing organisations with tremendous flexibility, convenience, and cost savings. For example, Cisco estimated savings from e-learning at 40–60%, while IBM achieved 500% more training at one-third the previous cost [5]. E-learning is particularly important for the rapid implementation of new software within an organisation.

The effectiveness of e-learning depends on three groups of factors: learning technology, program design, and the learner's individual characteristics. Successful e-learning should include meaningful content, give learners control over the learning process, provide opportunities for practical application, and ensure feedback. However, purely digital learning can lead to social isolation among employees. To address this issue, companies use “blended learning” models, which combine online modules with in-person sessions, thereby increasing motivation and improving learning outcomes.

A major breakthrough in corporate training is the use of active learning methods, such as gamification and virtual/augmented reality (VR/AR) systems [2]. Virtual reality (VR) is used to immerse the learner in a simulated work environment (e.g., flight simulators, medical simulators, or simulations of complex negotiations), allowing critical skills to be practised safely and reducing the time needed to master the material. Gamification (the use of game mechanics in non-gaming contexts) increases employee engagement and simplifies the understanding of complex information systems.

Electronic Performance Management (E-PM) involves automating employee performance evaluations, identifying top and underperforming employees, and providing them with systematic feedback. According to statistics, up to 93% of large organisations surveyed use e-PM systems [5]. These technologies allow for tracking performance throughout the evaluation period, collecting data for 360-degree feedback, and automatically generating analytical reports.

The use of e-PM significantly reduces the time spent on data collection and evaluation administration, freeing up managers' time for strategic management. An interesting fact is that studies have revealed a specific

reaction among employees to computer-generated feedback: in many cases, employees consider computerised feedback to be more objective, feel less demotivated when criticised, and trust it more than feedback provided directly by a manager (since the computer focuses on the task rather than the manager's subjective evaluative intentions) [5]. However, there is a risk: excessive automation of evaluation can create interpersonal distance between the employee and the manager when the manager relies solely on machine-generated numbers, reducing personal communication. To prevent this, organisations are integrating internal social platforms (corporate networks, microblogs) to ensure continuous, open dialogue and provide informal feedback.

Motivating and retaining talent are critical tasks in a global competitive environment. Over 50% of organisations automate compensation planning processes using e-compensation **systems** [5]. These systems combine internal HR data (performance results, salary history) with external labour market indicators to create an optimal compensation structure, functioning as decision-support systems.

Industry studies demonstrate impressive results from compensation system automation: reduced administrative costs (one company reported savings of \$850,000 per year), accelerated planning cycles (Dell cut planning time by 65%, while Motorola implemented a system for 10,000 employees across 65 countries in less than 6 weeks), and an 80% reduction in payroll errors [5].

Today's workforce is extremely diverse (by age—Generations X, Y, and Baby Boomers—and by cultural and ethnic background), which shapes different values and expectations regarding compensation. While older generations value status more, Generation Y prefers flexible schedules, personal development, and a comfortable work environment. Electronic compensation systems, combined with corporate crowdsourcing, allow companies to identify these needs and create flexible compensation packages, thereby increasing employee loyalty.

Employee Self-Service (ESS) systems have become a key component of digitalisation, with approximately 80% of large companies currently using them [5]. Through ESS web portals, employees have round-the-clock access to their HR data, can independently sign up for training courses, choose benefit packages (insurance), and request time off. Although ESS significantly reduces HR department workload, saves time, and improves data accuracy, it also presents challenges. First, there is a partial shift of the administrative burden onto the employees themselves and their line managers. Second, the success of ESS implementation depends heavily on the user-friendliness of the interface and the “digital readiness” of the staff.

Modern digital tools underpin most of the mechanisms mentioned above. For example, artificial intelligence (AI) helps process large volumes of resumes, predict candidates' potential productivity as early as the selection stage, create personalised learning paths based on their prior achievements, and use chatbots to perform routine tasks and support staff [2].

At the same time, Big Data Analytics helps understand employee behaviour. It identifies hidden success factors, measures job satisfaction, helps calculate employee turnover, and supports strategic management decisions. The application of Blockchain technology in HR is changing the approach to data management: it ensures a high level of transparency, cryptographic protection of information regarding qualifications and salaries, reduces the risks of confidential data leaks, and enables the creation of authentic digital employee profiles that cannot be forged.

Today, digital transformation of business processes is a key factor in enterprise success. The implementation of cutting-edge technologies not only changes how businesses operate but also significantly impacts human resources management, opening up new opportunities while simultaneously creating unprecedented challenges. The integration of modern human resources (HR) management tools requires a rethinking of both operational activities and the organisation's socio-psychological environment.

The benefits of implementing innovative HR technologies can be divided into three main areas: increased efficiency, improved decision-making, and higher employee engagement.

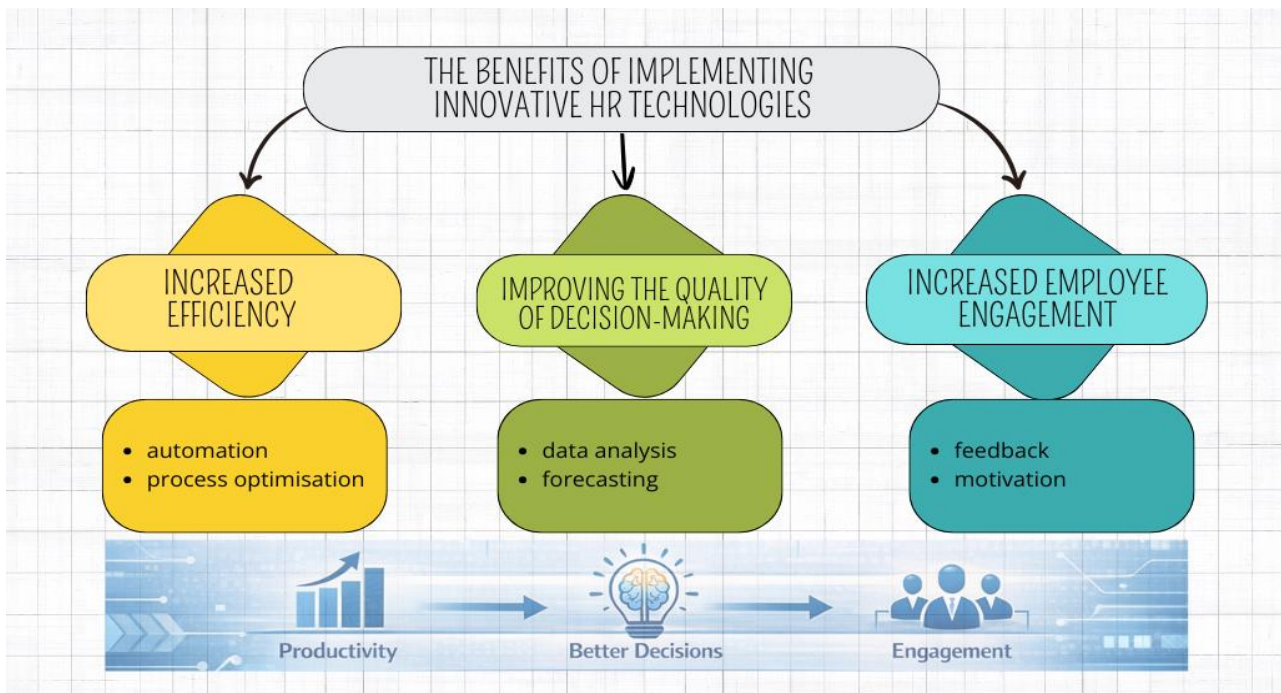


Figure 3. Benefits of implementing innovative HR technologies

Automating routine tasks significantly reduces administrative workload and transaction costs. The use of integrated information systems (HRIS) and AI-based tools allows HR professionals to focus on strategic initiatives. Industry studies confirm the high effectiveness of optimisation: for example, the use of electronic compensation systems (e-compensation) in some international companies reduced the time spent on compensation planning by 65% and decreased payroll calculation errors by 80% [5]. The resulting savings in administrative costs amount to hundreds of thousands of dollars per year. E-learning also reduces staff training costs (by 40–60%) while reaching a larger audience [5].

The use of big data and artificial intelligence enhances the objectivity and quality of decision-making. Algorithms analyse behavioural trends, predict candidates' success during the selection phase, and create personalised development programs. This reduces the influence of subjective factors and minimises management errors [2].

Digital technologies promote greater transparency and motivation. Modern electronic performance management (e-PM) systems enable continuous tracking of work results and provide employees with timely feedback. The integration of corporate social networks and employee self-service (ESS) platforms fosters a digital corporate culture, expands employee autonomy, and enables better consideration of individual needs [2, 5].

Despite numerous advantages, HR digitalisation is accompanied by systemic and psychological challenges. Traditional HR management faces resistance to change. Employees often fear losing their jobs due to automation, which causes psychological stress, burnout, and computer anxiety [2].

A separate challenge is the threat of depersonalization of work processes. Research shows that excessive automation of evaluation and feedback processes can increase the distance between managers and subordinates [5]. For example, electronic performance management (e-PM) systems that automatically collect performance data can lead managers to focus more on machine-generated numbers and communicate less personally with employees. Electronic feedback is sometimes perceived as impersonal and less convincing, which reduces trust in leadership and weakens social bonds within the team.

Furthermore, the use of digital technologies during recruitment and training can create barriers to ensuring diversity and inclusivity in the workforce [5]. Online recruitment and testing often require a high level of cognitive load, as candidates must simultaneously complete test tasks and interact with a computer interface. As a result, test results may reflect not so much the candidate's actual abilities as their level of digital skills and lack of computer anxiety. This can become a barrier to hiring older workers or members of social groups with limited access to modern information technologies.

From an organisational perspective, integrating new systems entails significant technical and financial challenges. Businesses, particularly small and medium-sized enterprises, face high costs associated with implementing IT platforms, system compatibility issues, and the potential for confidential information leaks [2].

Recognising these challenges underscores the importance of comprehensive digital adaptation. In the digital environment, staff adaptation goes beyond simply mastering functional duties. It requires not only mastering new technologies but also changing approaches to communication, time management, and collaboration within virtual teams.

Digital adaptation is not merely a technical process but a complex set of psychological and social changes. The success of the transformation depends on staff readiness, the perceived benefits of new technologies, and transparent communication [2]. The following key approaches explain the process of employees' digital adaptation:

1. The concept of "digital readiness":

This approach encompasses both technical skills and the staff's psychological readiness for innovation. For a successful business transformation, it is necessary to regularly conduct digital readiness audits and provide psychological support through coaching and mentoring, which reduces anxiety and boosts employees' confidence in their own abilities. The growing demand for "digital talent" currently requires candidates to possess qualities such as cognitive flexibility, critical thinking, emotional intelligence, and the ability to make quick decisions.

2. Technology Acceptance Model (TAM):

Developed to explain how employees adopt or reject new IT solutions. According to TAM, the two key factors in adoption are perceived usefulness and ease of use. Employees must clearly understand the benefits they will gain from using the system (e.g., time savings thanks to ESS or ERP) and feel that the application's interface does not require excessive intellectual or emotional effort.

3. The Innovation Diffusion Model:

Based on Rogers' theory, this model divides all employees into several categories based on their speed of adopting change: innovators, early adopters, early majority, late majority, and laggards. Understanding this differentiation allows HR managers to develop targeted training programs, using "innovators" as change ambassadors to engage more conservative colleagues.

4. Transformation of the "psychological contract":

In the context of digitalisation, the introduction of remote work or artificial intelligence may disrupt previous expectations regarding stability and working conditions. Therefore, open communication and clarification of the strategic goals of innovation are critical for maintaining loyalty. Additionally, when managing different generations (Generation X, Generation Y, Baby Boomers), compensation expectations also vary. Research shows that Generation Y (Millennials) value flexible work schedules, a comfortable atmosphere, and opportunities for personal development significantly more than previous, status-oriented generations. A digital motivation system must account for this diversity of values.

A comprehensive support system is necessary for staff to successfully adapt to the digital environment. The introduction of innovations must occur in parallel with the creation of a favourable socio-psychological climate [3].

First, companies should actively use "blended learning" methods that combine online courses with in-person training. This minimises feelings of social isolation, increases motivation to learn, and ensures timely feedback. Second, technologies that enhance social presence in the virtual environment should be implemented. The use of internal social platforms, microblogs, and virtual conferences helps restore interpersonal contact, reduce the distance between management and subordinates, and ensure continuous, multi-level feedback for employee development. Third, key elements include employee branding and corporate culture management [3, 5]. Successful companies purposefully build a brand as an innovative employer. Employee satisfaction with innovations, as well as their trust in computerised evaluations and compensation systems, directly depend on the transparency of management policies and the level of corporate social responsibility.

Therefore, the key to effective digital transformation in HR management is shifting the focus from purely technological software implementation to the development of human capital. Economic analysis of successful practices shows that the maximum return on investment (ROI) in digital HR technologies is achieved only when technology serves as a decision-support tool that enhances, rather than replaces, managerial interaction, emotional intelligence, and social empathy [5].

The transition to digital HR management cannot be viewed solely as installing new software. It is a comprehensive transformation of business processes that requires a systematic approach, careful planning, and consideration of the company's strategic goals. The experience of many organisations shows that automated human resources management is not a one-size-fits-all solution and, without a proper implementation methodology, can present more challenges than benefits [4].

From a methodological standpoint, the transition to digital HR management is a logical extension of the company's rethinking of its market position. This process unfolds in three broad steps: first, the company's overall strategy shifts to focus on delivering a competitive product; second, the company defines its mission in the field of human resources management and formulates a strategic vision; third, there is a direct update of management technologies (recruiting, assessment, training), which must be carried out without significant resistance from employees [6].

To ensure the effective integration of digital solutions into the practical activities of HR departments, a five-stage implementation methodology has been developed, covering all key aspects of the organisation's operations [2].

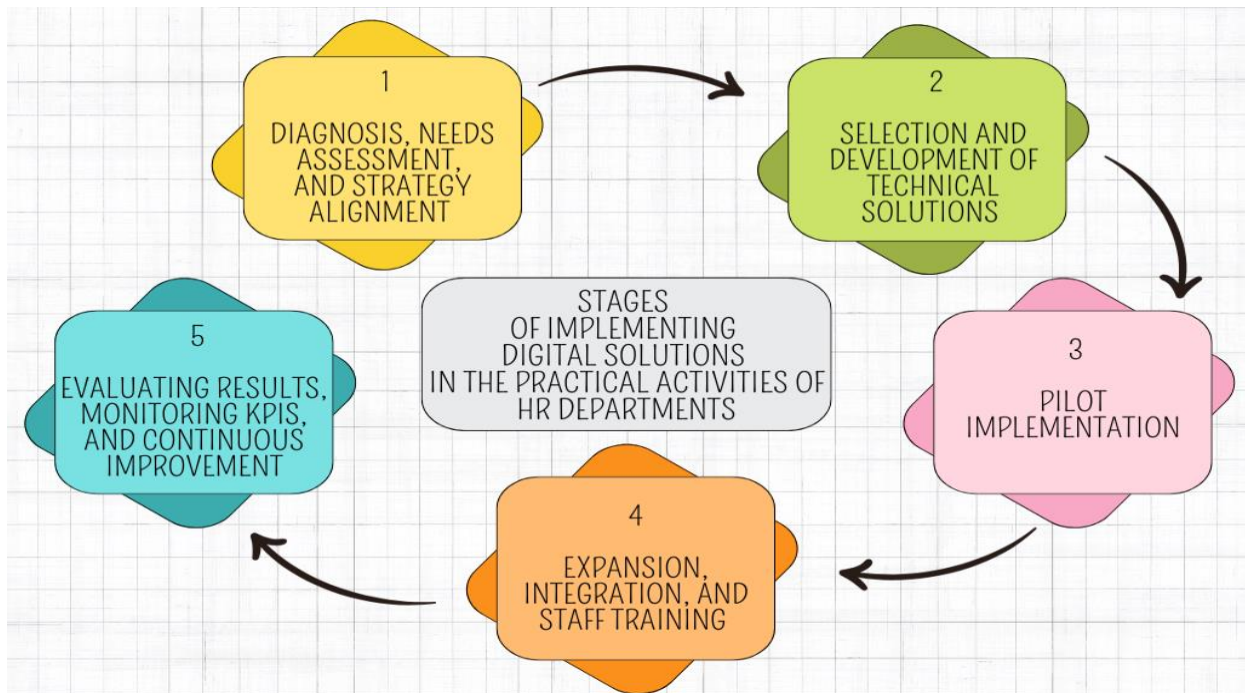


Figure 4. Stages of implementing digital solutions into the practical activities

HR departments (based on Source 2)

Stage 1: Diagnosis, Needs Analysis, and Strategic Alignment

The first stage is the foundation of digital transformation and involves conducting a comprehensive audit of current HR processes to identify bottlenecks and digitisation needs. The diagnosis begins with an assessment of the existing level of automation of HR functions and an analysis of the staff's "digital readiness," which includes both an evaluation of technical skills and the team's psychological openness to innovation [2].

At this stage, it is critical to adopt a strategic approach to HR management. According to the McKinsey 7-S model, the implementation strategy must align with other elements: skills (competencies), corporate culture's shared values, organisational structure, regulations, leadership style, and employees themselves. The "5S" model (strategy, structure, staff, incentives, shared values) is also applied, enabling alignment of digitalisation goals with the company's overall global development objectives. Only after establishing strategic guidelines and identifying staffing needs can the company proceed to selecting tools [1].

Stage 2: Selection and Development of Technological Solutions

Based on the diagnostic results, relevant digital HR technologies are selected. The company faces a choice: to use off-the-shelf, universal software products or to develop custom technologies tailored to specific internal requirements. A separate task involves assessing the investment costs for implementing innovations and forecasting the return on investment (ROI).

In modern practice, most companies strive to move away from fragmented software and transition to comprehensive intelligent management systems (ERP – Enterprise Resource Planning), which consolidate all business processes [7]. Among the leading systems on the market are:

SAP ERP: provides real-time management of all company operations and features powerful modules for managing personnel, performance metrics, and financial flows.

Oracle ERP: distinguished by a strong focus on cloud technologies, high functional flexibility, and scalability. It includes integrated modules for human resources, procurement, and project management.

BAS ERP: an innovative solution for building comprehensive information systems, fully adapted to the Ukrainian regulatory framework, and actively utilising mobile and cloud technologies.

When selecting a technology, management should rely on three groups of personnel management methods: *administrative* (developing new job descriptions for working with the software), *economic* (project financing, financial incentives for employees to master the software), and *socio-psychological* (creating a creative atmosphere to overcome fear of innovation) [3].

Stage 3: Pilot Implementation

To avoid widespread disruptions in the company's operations, the integration of digital solutions should not occur instantly across the entire organisation. The methodology requires pilot testing of the innovation within a single department or on a select group of HR processes.

The pilot project serves several critical functions: first, it allows for the practical identification of technical shortcomings, system errors, and compatibility issues with the company's existing IT platforms. Second, it provides an ideal environment for gathering high-quality feedback from the system's first users. This feedback serves as the basis for refining the interface and adjusting algorithms prior to the mass rollout. In addition, E. Rogers' innovation diffusion model is actively applied at this stage: the first users of the system in the pilot department are "innovators" and "early adopters," who will subsequently act as ambassadors of change and help educate the "late majority" and "laggards" in the next stage [2].

Stage 4: Scaling, Integration, and Staff Training

Following a successful pilot test, the process of scaling (deploying) the technology across the entire enterprise begins. This stage is the most critical for managing employee resistance, as it requires a profound shift in corporate culture.

The main task at this stage is large-scale staff training. Technological progress requires highly qualified personnel. The organisation must prepare employees by providing theoretical and practical training materials before the software product is put into full-scale use [4]. Specialised e-learning programs should be used continuously to avoid errors and production delays that may result from a lack of skills in working with modern technology. Training not only minimises technical risks but also serves as a powerful motivational tool—employees who feel supported by their employer in developing their "digital talents" demonstrate higher levels of loyalty and engagement. Technical integration occurs simultaneously with training—configuring the compatibility of new HR tools with the company's existing financial and logistics ERP systems, as well as organising technical support processes [2,6].

Stage 5: Results Assessment, KPI Monitoring, and Continuous Improvement

The final stage of the methodology is a systematic evaluation of the effectiveness of the implemented technologies. This stage is continuous and allows for measuring the actual impact of digitalisation on strategic organisational outcomes and indicators of employee adaptation success.

To ensure objectivity, a multi-level monitoring system is used, incorporating key performance indicators (KPIs), big data analytics, and financial metrics:

1. Monitoring of Key Performance Indicators (KPIs): Allows for the quantitative measurement of the success of digital transformation. The main KPIs in this context include:

- *Onboarding time for new employees* (whether it has been reduced thanks to VR training and online courses);
- *Staff engagement level* (assessed using metrics of activity in the use of digital systems and internal self-service portals);
- *Staff turnover rate* (a measure of talent retention effectiveness);

- *Labour productivity* (number of tasks completed, achievement of team goals).

2. Data collection and analysis (Big Data): The use of big data analytics enables a deep exploration of staff interaction with learning platforms and performance management systems. Analysing the frequency of tool usage, time spent working in the system, and the results of regular digital surveys helps identify hidden trends and predict the future effectiveness of HR policies.

3. Return on Investment (ROI) Assessment: The financial justification for digitalisation lies in calculating ROI. This is done by comparing economic and administrative indicators before and after system implementation. Factors considered include time savings on routine tasks, reduced recruitment costs, lower payroll processing error rates, and an overall increase in the company's competitiveness.

4. Assessment of the impact on organizational culture: Digitalisation should support the social and psychological climate. Through engagement indices (eNPS) and regular surveys, management tracks staff perceptions of changes, loyalty levels, and satisfaction with the new digital interaction format.

In summary, this methodology enables the company to conduct a comprehensive reengineering of its business processes. A flexible approach to implementation, supported by continuous monitoring of results and change management, guarantees the successful implementation of innovative solutions. By implementing innovative mechanisms, HR management transforms from a supporting administrative function into a strategic tool for the company's development, capable of ensuring sustainable growth in the digital economy.

Conclusions. The digitisation of human resource management processes is an irreversible and strategically important stage in the evolution of modern business. In the context of global transformations and the transition to a digital economy, the classical HR administration paradigm is finally losing its relevance, giving way to innovative Digital HR management. The conducted research allows us to draw several conceptual conclusions regarding the role, mechanisms, and consequences of implementing digital technologies in HR management.

First, in today's information society, personnel are recognised as the most valuable asset and the primary resource for an enterprise's innovative development. Accordingly, the goal of HR digitalisation is not merely to reduce administrative costs, but to create synergy between human talent and digital tools, thereby maximising productivity and unlocking the creative potential of teams.

Second, key innovative mechanisms fundamentally transforming the architecture of HR processes include artificial intelligence (AI) systems, big data analytics, cloud-based ERP systems (such as SAP, Oracle, and BAS ERP), virtual reality (VR) technologies, and blockchain. Their comprehensive use optimises all stages of the employee lifecycle: from high-precision e-recruiting and flexible e-learning to objective performance management (e-PM) and automated compensation systems (e-compensation).

Third, the integration of digital technologies is accompanied by several challenges, the main ones being employee resistance to change, psychological stress, and computer anxiety. The effectiveness of the latest solutions directly depends on the team's level of "digital readiness." Therefore, it is critically important for organisations to shift their focus from purely technological implementation to socio-psychological support, offering employees quality mentoring, blended learning formats, and transparent communication.

Fourth, successful digital transformation requires the application of a clear implementation methodology that must align with the company's overall development strategy. The proposed five-stage model minimises operational risks and ensures the smooth integration of innovations into the existing business environment.

Thus, innovative HR management mechanisms in the context of digitalisation transform the HR department into a strategic partner of the enterprise. They enable the organisation to respond quickly to market challenges, make data-driven management decisions, and foster a flexible corporate culture. In terms of future research, particular attention should be paid to the ethical use of artificial intelligence in HR, the protection of confidential data, and the development of hybrid work models, which are key factors in maintaining companies' competitiveness in the post-crisis period.

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MANAGEMENT DECISIONS AS THE BASIS OF EFFECTIVE ENTERPRISE MANAGEMENT IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

Turchina Svitlana

Ph.D., Associate professor of the Department of Management named after Professor L.I. Mykhailova, Sumy National Agricultural University, Ukraine

ORCID ID: 0000-0002-3110-6647

In modern conditions of economic globalization, increased competitive pressure and high dynamics of market processes, enterprises are forced to quickly adapt to changes in the external environment and rationally use internal resources. Under such circumstances, management decisions that form strategic development guidelines, influence the organization of activities, allocation of resources and the level of competitiveness of the enterprise play a decisive role.

Management decisions should be considered not only as a tool for responding to changes, but as a proactive mechanism for creating competitive advantages. It is thanks to well-founded decisions that an enterprise is able not only to adapt to external challenges, but also to shape its own development trajectory, influencing the market environment. In this context, the importance of strategic thinking, forecasting and the use of innovative management approaches is growing.

The theoretical foundations of the study of managerial decisions were formed in the works of both foreign and domestic scientists. In particular, in the works of Demko I.I., a managerial decision is interpreted as a central function of management, associated with the choice of alternatives under conditions of bounded rationality [3]. The development of this concept is reflected in the studies of scientists Yu.V. Karpenko and A.S. Kozar, who focus on the behavioral aspects of decision-making and the role of the organizational environment [4]. A significant contribution to the development of the theory of decision-making was made by researchers L.V. Pariy and A.O. Kubrak [10], who substantiated the connection between managerial decisions and the formation of competitive strategies, and D.M. Shevchuk, who considered them as a tool for strategic management of enterprise development [14].

Among domestic researchers, it is also worth noting the works of A.I. Orekhova and D.S. Slyusareva [8], T.M. Kharchenko [11], L.A. Khromushina [12], in which management decisions are considered as a system-forming element of management that determines the effectiveness of the enterprise. Scientists emphasize that the quality of management decisions is the result of a combination of analytical procedures, professional experience and organizational conditions for their adoption.

The process of making managerial decisions is complex and includes the collection, systematization and analysis of information, the formation and evaluation of alternatives, the forecasting of consequences and the control of the implementation of the chosen option. Its quality directly affects the achievement of both current and strategic goals of the enterprise, in particular economic, social and environmental, which corresponds to the principles of sustainable development.

The effectiveness of this process is largely determined by the level of information support and analytical training of management personnel. Reliable, timely and relevant information allows to reduce the level of uncertainty and minimize risks. At the same time, an important role is played by the cognitive characteristics of managers - experience, intuition, ability to systems thinking, which provides a comprehensive vision of management situations.

Increasing the effectiveness of management decisions is ensured by the use of appropriate technologies for their adoption, which are a set of methods, procedures and tools that determine the sequence of actions of the manager - from problem identification to solution implementation. They include information collection and processing, alternative assessment, forecasting of results, economic justification and implementation planning. The choice of a specific technology depends on the level of problem certainty, completeness of information and the degree of risk, which allows combining formalized and expert approaches.

In modern management practice, digital technologies for decision support, including business analytics, artificial intelligence, and predictive analytics, are becoming increasingly important. Their use enables the processing of large amounts of data, the identification of patterns, and increased forecasting accuracy, which contributes to the increased validity of management actions and the reduction of the influence of subjective factors.

Modern approaches involve dividing management decisions into solutions for structured and unstructured problems, which determines the choice of appropriate technologies for their adoption. A comparative characteristic of these approaches is summarized in Table 1.

Table 1. Technologies for making managerial decisions depending on the type of problems

Comparison criterion	Structured problems	Unstructured problems
The nature of the management situation	Clearly defined, formalized	Unclear, incomplete information, unclear criteria
Conditions for applying the technology	Complete information; clear criteria	Incomplete information; high risk
Methodological basis	Algorithms and quantitative criteria	Combined expert-scenario methods
Decision-making process	Alternatives; criteria analysis; optimal solution; implementation and control	Problem definition; incomplete information; scenario; expertise; adaptation; final assessment
Expected result	Clear optimal solution, formalized and standardized	Adaptive, variable solution with the possibility of adjustment

Source: constructed by the author based on [2, 6]

As can be seen from the data in Table 1, structured problems are characterized by the presence of clearly defined parameters of the management situation, complete or sufficient information and formalized evaluation criteria. This allows the use of algorithmic approaches and quantitative methods of analysis, which ensures the logic, consistency and predictability of the decision-making process. Under such conditions, management decisions are standardized and can be optimized based on defined efficiency criteria.

In contrast, unstructured problems are characterized by a high level of uncertainty, limited or contradictory information, and the absence of clear evaluation criteria. This complicates the decision-making process and requires the use of combined approaches that combine analytical methods with expert assessments, intuition, and scenario forecasting. In such cases, management decisions are adaptive in nature and provide for the possibility of further adjustment depending on changes in the operating conditions of the enterprise.

It is important to note that the division given in Table 1 is conditional, since mixed management situations prevail in the practical activities of enterprises. They combine the features of both structured and unstructured problems, which necessitates the use of hybrid decision-making technologies. This approach allows combining the advantages of formalized methods and the flexibility of expert assessments, increasing the effectiveness of management activities in conditions of uncertainty.

Therefore, the systematization of management decision-making technologies depending on the type of problems contributes to a more informed choice of management tools and ensures increased efficiency of enterprise management.

At the same time, mixed management situations that combine features of structured and unstructured problems prevail in the practice of enterprises. This necessitates the use of hybrid approaches to decision-making that integrate analytical methods, expert assessments, and adaptive management tools, ensuring flexibility and adequacy of management actions.

In order to systematize the process of making management decisions, it is advisable to use the logical-structural model presented in Figure 1, which reflects the sequence of stages, their interrelationships and provides a comprehensive approach to management. The proposed model is universal in nature and can be adapted to the specifics of the functioning of a particular enterprise, which determines its practical significance. Depending on the scale of activity, industry specifics and the level of development of the management system, individual stages can be detailed, integrated or transformed.

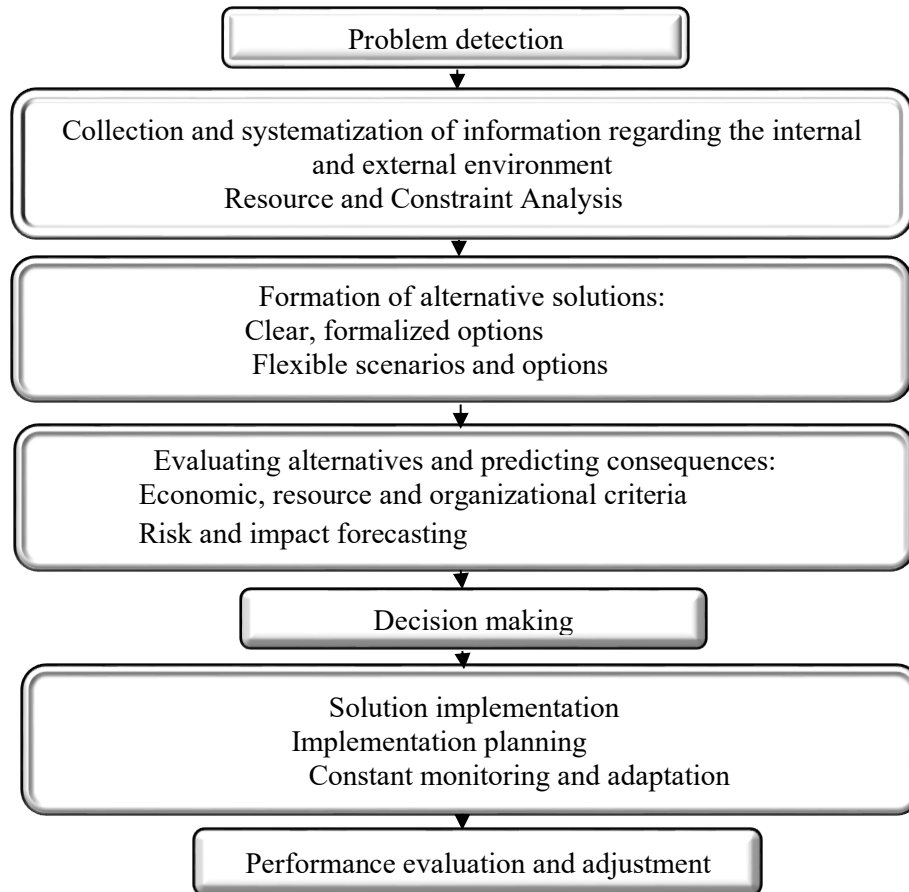


Figure 1. Logical-structural model of decision-making technology in an enterprise
Source: constructed by the author based on [9]

Analysis of the logical-structural model allows us to identify seven interrelated functional blocks, each of which plays a specific role in ensuring the validity and effectiveness of management decisions.

The first block - problem identification and formulation - is the initial stage of the management process, within which the management situation is identified, its key characteristics and causes are determined. At this stage, the clarity of the problem formulation becomes especially important, since it determines the further logic of the analysis and selection of management alternatives. Incorrect problem definition can lead to erroneous decisions even with a high level of analytical support.

The second block involves the collection and systematization of information covering both internal and external aspects of the enterprise's activities. This involves the analysis of resource potential, organizational structure, financial condition, as well as the study of market conditions, regulatory environment and socio-economic factors. The systematization of the obtained data ensures the formation of an information base necessary for making informed management decisions and reduces the level of uncertainty.

Within the third block, alternative management decisions are formed and analyzed. Based on the collected and processed information, possible options for action are generated, which can be both formalized and adaptive in nature. Each alternative is subject to evaluation according to certain criteria, in particular, efficiency, resource availability, feasibility of implementation and compliance with the strategic goals of the enterprise. This allows for a preliminary selection of the most promising options.

The fourth block is associated with risk assessment and forecasting the consequences of implementing each alternative. At this stage, potential threats are identified, the probability of their occurrence is determined, and the possible impact on the results of the enterprise is assessed. In addition, the economic, organizational, and social consequences of implementing decisions are forecasted, which increases their validity and allows for the preparation of preventive measures.

The fifth block - making a management decision - involves choosing the optimal alternative based on a comprehensive comparison of its advantages and limitations. This process takes into account both quantitative

indicators of efficiency and qualitative characteristics related to risks, resource capabilities and strategic priorities of the enterprise. An important aspect is the coordination of the decision with the goals of sustainable development and the interests of stakeholders.

The sixth block covers the implementation of the decision, which involves organizing appropriate measures, identifying responsible persons, allocating resources, and setting deadlines. The effectiveness of this stage largely depends on the level of coordination of actions between the structural divisions of the enterprise, as well as on the presence of a clear system of control over the implementation of planned measures.

The final, seventh block is the control and evaluation of the effectiveness of the decision made. At this stage, the achieved results are analyzed, compared with the set goals and possible deviations are identified. The results obtained are used to adjust management actions, improve decision-making procedures and form a knowledge base for further management activities.

An important characteristic of the proposed model is its cyclical nature, which ensures the continuity of the process of making management decisions and the possibility of their constant improvement. Feedback between the stages allows for timely response to changes in the external and internal environment, increasing the adaptability of the enterprise.

The use of modern management tools, including management accounting, business analytics, information systems for decision support and strategic planning, enhances the effectiveness of each stage of the model. This contributes to improving the quality of management decisions, optimizing resource use and achieving the strategic goals of the enterprise.

Thus, the proposed logical-structural model is an effective tool for organizing the process of making managerial decisions, which ensures the systematicity, validity and effectiveness of managerial activities. Its application creates the prerequisites for increasing the efficiency of enterprise management and ensuring its sustainable development in the face of modern challenges.

Taking into account the theoretical provisions set forth, it is advisable to carry out their practical testing on the example of the activities of a specific enterprise. The limited liability company "Sumy-rytm" was chosen as the object of the study, which functions as a multi-profile production enterprise with a predominant specialization in the manufacture of building metal structures. The income structure indicates the dominance of this type of activity, which determines the production focus of the enterprise.

Table 2. Dynamics of the main economic indicators of the activities of LLC "Sumy-rytm"

Indicators	2022	2023	2024	2024 to 2022, +/-	
				%	thousand UAH
Net income from the sale of goods, works and services, thousand UAH.	6946.7	2536.4	1567.8	-77.4	-5378.9
Total income, thousand UAH.	7097.3	2536.6	1808.0	-74.5	-5289.3
Cost of works and services performed, thousand UAH.	4805.1	2671.7	2396.3	-50.1	-2408.8
Total expenses, thousand UAH.	5956.5	3174.5	2785.0	-53.2	-3171.5
Gross profit (loss), +(-) thousand UAH.	2141.6	-135.3	-828.5	x	-2970.1
- including for the 1st average annual employee	102.0	-10.4	-69.0	x	-171.0
Net profit (loss), + (-) thousand UAH.	1140.8	-637.9	-977	x	-2117.8
- including for the 1st average annual employee	54.3	-49.1	-81.4	x	-135.7
Profitability (loss) level, + (-) %	19.2	-20.1	-35.1	x	-54.2

Source: calculated by the author based on the reporting of LLC "Sumy-rytm": f. No. 1 "Balance" and f. No. 2 "Statement of financial results"

Additional areas are the manufacture of metal products and the provision of production and service services, which contributes to the diversification of sources of income. The small number of personnel determines the specifics of management and increases the requirements for the quality of management decisions.

To assess the effectiveness of an enterprise's activities and identify trends in its development, it is advisable to analyze the dynamics of the main economic indicators summarized in Table 2.

Analysis of the net financial result shows a significant deterioration in the efficiency of the enterprise's activities in the period under study. Thus, in 2022, the enterprise received a net profit of 1140.8 thousand UAH, while in 2024 a net loss of 977 thousand UAH was recorded. The absolute deviation is - 2117.8 thousand UAH.

It is worth noting that the negative deviation is due not only to a decrease in profit, but also to the transition of the enterprise from profitable to unprofitable activities. That is, there was not just a reduction in the financial result, but its transformation from a "plus" sign to a "minus" sign. In fact, the enterprise lost the previously received profit and additionally suffered losses, which together formed a significant deterioration in financial results.

Such dynamics indicate the presence of systemic problems in the enterprise's activities, in particular, an imbalance between income and expenses, a decrease in the efficiency of resource potential use, and insufficiently effective management policies. In this context, improving the quality of management decisions becomes particularly important, since they should be aimed at stabilizing the financial condition, optimizing costs, and restoring profitability.

Improving the process of making managerial decisions involves a comprehensive approach to planning, optimizing the use of resources, harmonizing production processes, and implementing modern analytical tools. This creates the prerequisites for stabilizing financial results, increasing operational efficiency, and ensuring the adaptability of the enterprise to changes in the external environment [7].

Thus, management decisions are the fundamental basis of effective enterprise management, determining its development, sustainability, and competitive position in modern business conditions.

Given the established determining role of management decisions in ensuring the efficiency of the enterprise, the issue of their practical implementation in the conditions of a specific business entity becomes particularly relevant. The analysis of the activities of LLC "Sumy-rytm" showed the presence of negative trends in financial results, which indicates the need to improve the existing management system and improve the quality of management decisions. In this context, it is advisable to move from general theoretical provisions to the substantiation of applied mechanisms for increasing the efficiency of management activities, adapted to the specifics of a small enterprise. Of particular importance is the formation of such organizational approaches that ensure systematicity, collegiality and strategic orientation of the decision-making process.

In modern small enterprises, such as LLC "Sumy-rytm", the process of making management decisions is a key factor in ensuring sustainability and development, especially in conditions of unprofitable activity. The analysis of integrated quality indices of the process of making and implementing management decisions, conducted in the previous section, confirmed that the existing management system functions at a satisfactory level. At the same time, the identified reserves indicate insufficient structuring, formalization and collegiality of management actions.

In particular, the limited regulation of decision-making procedures determines their situational nature, which complicates the prediction of results and reduces management efficiency. In addition, the lack of systematic mechanisms for strategic discussion leads to the dominance of short-term (operational) decisions, which, although they provide solutions to current problems, do not form the prerequisites for long-term stabilization and development of the enterprise.

In conditions of loss-making activity, strategic management decisions acquire special importance, since they determine the directions of restoring financial stability, optimizing costs and forming competitive advantages. Their role is not only to respond to crisis phenomena, but also to form new opportunities for the development of the enterprise, taking into account limited resources and changes in the market environment [1].

The lack of a proper strategic approach leads to fragmentation of management actions, increased uncertainty and increased risks of deepening crisis phenomena. At the same time, the dominance of strategic decisions is a necessary condition for the effective implementation of the planning function, since it is they who form a system of long-term goals, determine the directions of resource use and ensure the coherence of the enterprise's activities.

Therefore, the identified deficit of strategic decisions limits the enterprise's ability to form an effective development policy, reduces adaptability to changes in the external environment, and complicates the process of achieving strategic goals. This necessitates the introduction of modern organizational tools aimed at improving the quality of management decisions.

Therefore, one of the most effective tools in this context is a strategic session as a form of collegial discussion and management decision-making. Its use allows combining the strategic vision of management

with the practical experience of employees, ensuring the comprehensiveness and validity of management actions (Figure 2).

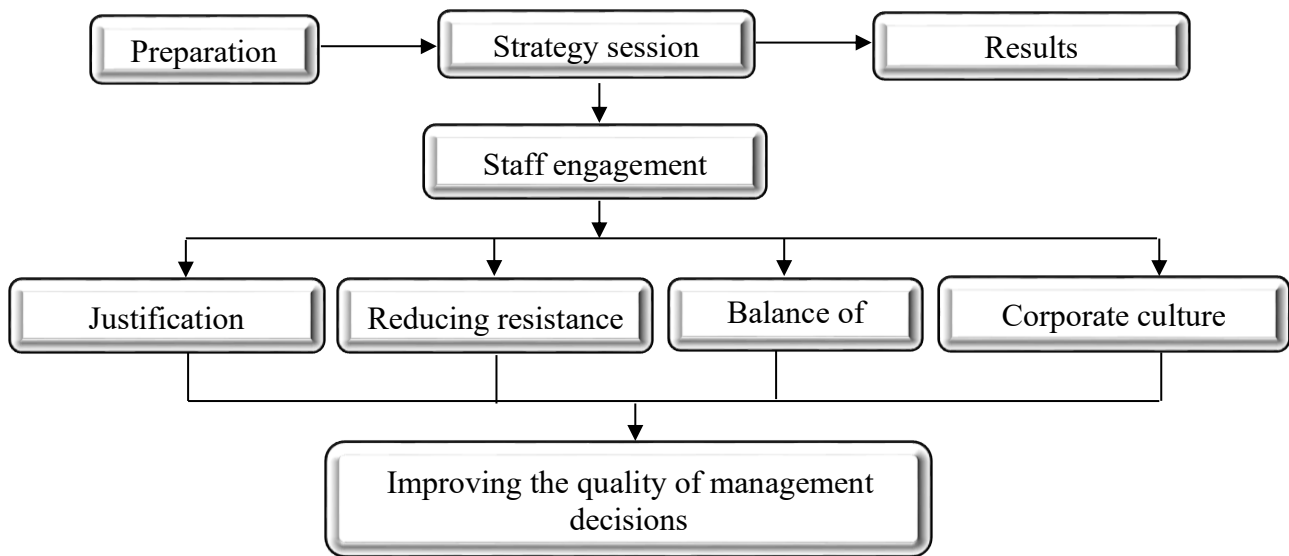


Figure 2. Structural model of a strategic session as a tool for making management decisions at an enterprise
Source: own suggestion

The application of the proposed structural model of the strategic session will have the following expected results for Sumy-Rhythm LLC:

Increasing the validity of management decisions. Involving employees who work directly with technological operations and customers provides management with more accurate information about production capabilities, cost of designs, demand characteristics, and order specifics. This allows for decisions that take into account not only strategic development directions, but also the real technological and market constraints of the enterprise.

Reducing resistance to change and building staff responsibility. For a small manufacturing enterprise, such as LLC "Sumy-rytm", it is typical for employees to be cautious about process updates or investment decisions. Participation in a strategic session allows employees to express their own reservations, suggest practical steps to improve production and service, and feel their significance in the development of the enterprise. This forms team responsibility and reduces the risks of sabotage or passive non-implementation of decisions.

Optimal combination of operational and strategic tasks. The company is dominated by operational decisions (45%), which is due to the need to quickly respond to changes in demand and fulfill non-standard orders in a short time. Tactical decisions account for 35% and concern resource management, equipment upgrades, and production load planning. Strategic decisions are currently underdeveloped, although they determine future sales channels, investments in new technologies, and opportunities for market expansion. Holding a strategic session will allow you to align short-term production goals with long-term prospects without disrupting current activities.

Strengthening corporate culture and stimulating initiative. For LLC "Sumy-rytm" it is important to form open communication between management and performers. Access of employees to strategic planning contributes to the development of trust, the emergence of proactive proposals for improving technologies, improving service, optimizing purchases and reducing production costs. This creates the basis for innovative and adaptive development of the enterprise.

Transparency of decision-making and control of their implementation. The results of the strategy session are recorded in the form of clear decisions, identification of responsible persons, deadlines and expected performance metrics. For the enterprise, this means the ability to control the implementation of tasks, avoid chaotic decisions and ensure the coordination of actions of all departments.

Given the specifics of small businesses, the strategy process should be as flexible as possible and not require significant resources. For enterprises with a small number of personnel, such as LLC "Sumy-rytm",

the priorities are simplicity of organization and practical effectiveness of results. Accordingly, the strategy session should comply with the following basic principles:

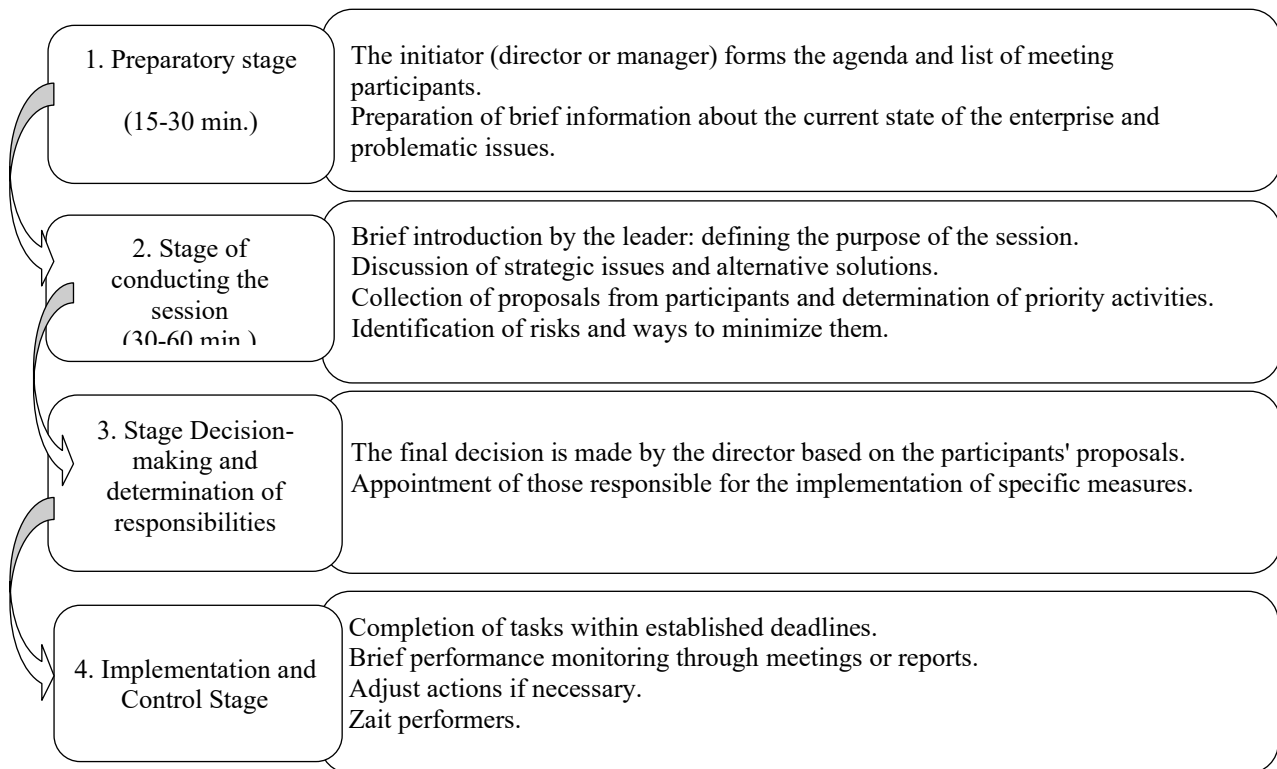


Figure 3. Proposed algorithm for conducting a strategic session for LLC "Sumy-rytm"

Source: own suggestion

Minimal interference in current activities. Preparing and conducting a meeting should not distract employees from their core functions. The organization process should be structured, and the discussion should be clear and focused.

The optimal schedule is up to 60 minutes. This time is enough to identify key issues, agree on proposals, and make collective decisions without additional burden.

Practical significance for each participant. The results obtained should be of an applied nature and specify tasks for managers, specialists and working personnel. Participants should clearly understand their contribution to the implementation of agreed solutions.

Openness and partnership format of discussion. The participation of all those present in the formation of proposals contributes to the consideration of different points of view, increases motivation and forms collective responsibility for the implementation of strategic initiatives [5].

The final criterion for the effectiveness of a strategic session is the motivational result - clearly formulated goals that strengthen the staff's faith in the company's prospects and stimulate the desire to achieve specific indicators. The specificity of goals and the possibility of their practical implementation increase the responsibility of employees and activate initiative in production processes.

Let's move on to the next stage – the algorithm for conducting a strategic session at Sumy-Rhythm LLC, which is shown in detail in Figure 3.

Figure 3 demonstrates the algorithm for conducting a strategic session for Sumy-Rhythm LLC, which involves a sequence of stages:

- preparatory stage - formation of the agenda and list of participants, collection of key information about the state of the enterprise;
- discussion of problems and formulation of proposals;
- identification of key challenges and collective generation of possible solutions;
- decision-making and defining responsibilities;

- coordination of proposals and appointment of performers of specific tasks;
- implementation and control – implementation of decisions, monitoring of performance, recording results in the protocol and determining KPIs.

The implementation of this algorithm will allow the management of Sumy-Rhythm LLC to effectively structure the process of making management decisions, attract personnel, and ensure the practical implementation of the strategic goals of the enterprise without significant distraction from the main activity.

The expected results from implementing the proposed mechanism in the enterprise's activities are presented below (Table 3).

Table 3. Assessment of the effect of improving the technology of making management decisions at LLC "Sumy-rytm"

Activities	Current status	Expected effect	Estimated value
Decentralization of management	All key decisions are made by the director.	Reducing decision-making time	10-15% time reduction ($\approx 1-1.5$ hours/day)
Involving staff in the discussion	Employees are almost not engaged	Improving the efficiency and quality of solutions	20-25% increase in engagement; 5-10% reduction in error risk
Use of digital tools (ERP, Excel analytics)	Manual data processing	Reducing the time for collecting and processing information	15-20% time savings on data analysis
Structuring and standardizing solutions	Missing templates and standards	Increasing clarity of decisions and transparency of the process	10% reduction in errors in decision preparation
Collegial meetings	No regular meetings	More informed decisions, taking into account practical experience	More informed decisions, taking into account practical experience

Source: built based on own suggestions

Table 3 illustrates the predicted impact of specific organizational measures on decision-making efficiency, staff engagement, and information processing efficiency.

Thus, the strategic session for LLC "Sumy-rytm" serves as a practical tool for improving the quality of management decisions: it helps to involve personnel in the formation of strategic directions, reduces resistance to change, forms collective responsibility, and creates the prerequisites for stabilizing the financial situation and further growth.

If the proposed approach is approved, management is recommended to:

The first session will consider the formation of a promising development model for Sumy-Rhythm LLC based on e-commerce (analysis of possible sales channels, logistics, and digital order support).

The next session will focus on improving resource provision by attracting grant funding (project evaluation, preparation of applications, determination of priority investment areas).

For complete implementation, it is important to establish monitoring and feedback mechanisms: recording decisions in a protocol, identifying those responsible, setting clear deadlines and KPIs, as well as regularly reviewing performance in short reporting meetings. This will ensure the sustainable implementation of changes and allow for adjustments to measures taking into account current production conditions.

Based on the conducted research of the activities of LLC "Sumy-rytm", it was established that the company operates in conditions of significant market fluctuations, reduction in order volumes and instability of demand for certain types of products. The decrease in revenue and inefficient use of labor and material and technical resources indicate an urgent need to optimize production processes and implement innovative management approaches.

Taking into account the above challenges, a management solution aimed at the development of e-commerce is proposed to implement the development strategy of LLC "Sumy-rytm". Since the company is currently at a loss, which is due to the low efficiency of product sales, it is relevant to expand sales channels and optimize sales processes by implementing modern electronic technologies. This approach will allow to accelerate the exchange of information with customers and suppliers, increase the efficiency of order service,

reduce the costs of administrative and logistical operations, and also provide more effective control over the movement of products and financial flows.

To implement e-commerce in the activities of Sumy-Rhythm LLC, a consistent plan is proposed, which is implemented in the following areas:

- 1) increasing the use of the Internet as a means of communication and a source of information about the market, suppliers and consumers;
- 2) establishing sales through electronic platforms with automation of the processes of contract execution, invoicing, and order fulfillment control;
- 3) integration of financial and logistics operations with the use of electronic services for managing payments, payment deferrals, factoring supply services, and product movement control.

In our opinion, the implementation of e-commerce, as illustrated in Figure 4, will provide the enterprise with the opportunity to increase sales efficiency, optimize financial and logistical flows, and expand sales markets, taking into account existing personnel and organizational limitations.

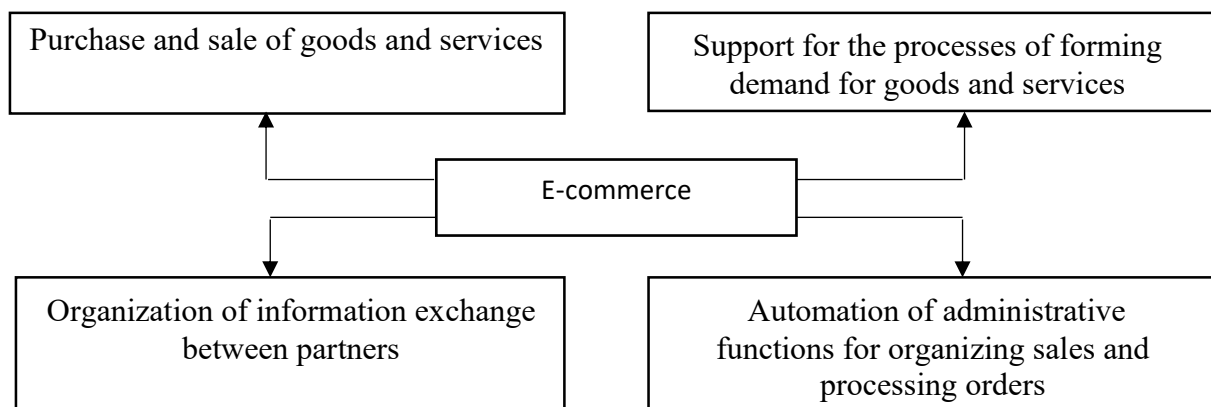


Figure 4. Functional structure of e-commerce
Source: formed and built based on own research

The speed of searching and transmitting information in the e-commerce system ensures timely receipt of objective data, which is a necessary condition for making management decisions regarding the choice of sales schemes, the organization of product promotion, the analysis of consumer needs and the formation of the assortment and pricing policy. The use of e-commerce tools for small businesses allows you to track small and single orders, which with traditional approaches require significant time. Practice shows that up to 70% of the company's sales volume falls on orders of this type, which helps save time and increase sales volumes [13].

In view of this, it is proposed to implement an online store model for LLC "Sumy-rytm", which will comply with the provisions of the Law of Ukraine "On Electronic Commerce". This will be a site or platform that will serve as a means of presenting and selling products on the terms determined by the participants of electronic commerce. This model will allow you to effectively expand sales channels, optimize the work of the sales manager and ensure control over the movement of products and financial flows without the need to increase the staff.

The implementation of the Online Store model not only expands sales channels, but also provides a number of functions that contribute to the optimization of sales and management processes. Figure 5 presents the key functions of Online Stores, reflecting the practical benefits of this model for the enterprise.

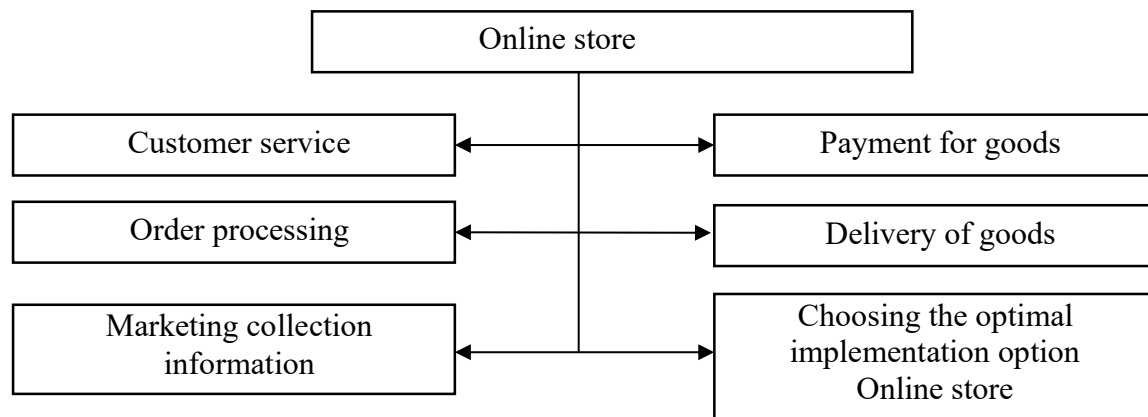


Figure 5. Functions of Online Stores [15]

Source: compiled by the author based on the results of his own research

The implementation of the Online Store model provides not only the expansion of sales channels, but also the implementation of important functions that significantly optimize sales and management processes. For the effective implementation of this model, it is also necessary to take into account the financial aspects of its launch. The following table 4 shows the estimated costs associated with the development and support of the online store of LLC "Sumy-rytm", as well as measures to promote the product in the digital environment.

Table 4. Calculation of projected costs for creating an online store for LLC "Sumy-Rhythm"

No. n / n	Project costs	Estimated cost, thousand UAH.
1	Website development	35000
2	Website maintenance and technical support for the online store	20000
3	Advertising on social networks	18000
4	Organization of advertising on the Internet	12000
	Together	85000

Source: compiled by the author using the official website of the web studio "Glyanec" [<https://glyanec.net/ua>]

Analysis of Table 4 shows that the largest share of the projected costs is the development of a web resource (41.2% of the total amount), which is justified given the need to create a high-quality and functional trading platform. Maintenance and technical support costs account for 23.5%, ensuring the smooth operation of the online store after its launch. Marketing costs, which include advertising on social networks and the Internet, account for 35.3% and are critically important for increasing online sales and attracting new customers.

Thus, the proposed investment volume logically corresponds to the structure of the project's needs and is aimed at creating a comprehensive e-commerce tool capable of ensuring sustainable development and sales growth of the enterprise.

Analysis of the projected costs for creating an online store indicates a balance of investment resources aimed at ensuring the functionality of the platform and effective marketing promotion. The implementation of this project, in turn, will affect the financial performance of the enterprise. The following table 5 illustrates the forecast of revenue dynamics by main product groups of LLC "Sumi-rytm" after the launch of the online store, which demonstrates the expected positive impact of e-commerce on product sales.

Table 5. Forecast of revenue dynamics by types of products of LLC "Sumy-rytm" after the launch of the online store, thousand UAH.

Product groups	2024 fact	Forecast			Deviation 2028 from 2024, +/-
		2026	2027	2028	
Metal structures	130.0	187.2	224.6	269.5	139.5
Doors, windows, containers	318.2	397.8	497.2	621.5	303.3
Custom machining	32.5	39.0	46.8	56.2	23.7
Operating lease	240.2	252.2	264.8	277.0	36.8
Total revenue	720.9	876.2	1033.4	1224.2	503.3

Source: compiled by the author based on his own research

The largest revenue growth is expected in the "Doors, Windows, Containers" segment - by UAH 303.3 thousand by 2028 compared to 2024. This is due to the increased availability of products through the electronic sales channel. At the same time, revenue is forecast to increase in the "Metal Structures", "Custom Machining" and "Operating Lease" segments.

The growth in demand for these product groups is determined by external factors, in particular, military operations, destruction of infrastructure and repair and restoration works, which form a stable demand for doors, windows, metal structures and mechanical processing products. This is especially important for enterprises that are able to quickly respond to changes in the market situation.

The management decision to implement an online store not only opens up access to a wider range of customers, but also improves the technologies for making and implementing management decisions through the widespread use of digital tools based on:

- automated demand monitoring;
- modeling assortment changes according to market needs;
- real-time inventory management;
- operational analytics and sales forecasting.

This increases the validity and effectiveness of management decisions, which is confirmed by the projected growth in gross and net profit (Table 6), emphasizing the innovativeness of the proposed approach.

Table 6. Forecast of the main economic indicators of LLC "Sumy-rytm" for 2026-2028, thousand UAH.

Indicators	2024 actually	2026 forecast	2027 forecast	2028 forecast
Revenue from the sale of goods, works and services	1808.0	1911.2	2127.2	2372.5
Cost of goods, works and services sold	2396.3	2200.0	2090.0	1985.0
Gross profit	-828.5	-288.8	37.2	387.5
Net profit	-977.0	-202.2	26.0	271.2
Profitability level, %	-35.1	-10.0	1.2	11.4

Source: compiled based on own research

The introduction of the online store is accompanied by positive dynamics of the financial results of the enterprise. Forecast indicators indicate a gradual increase in gross and net profit, which is direct evidence of the effectiveness of the management decision. In particular, in 2027 the enterprise enters into profitable activity with a net profit of 26.0 thousand UAH, and in 2028 its growth to 271.2 thousand UAH is expected, which is accompanied by an increase in the profitability level to 11.4%. Thus, e-commerce becomes a key factor in restoring financial stability and forming a promising development trajectory.

It should also be noted that the costs of creating an online store are not included in the cost of production in the forecast calculations. This is justified by the fact that these costs are of an investment nature and form an intangible asset of the enterprise associated with the creation of an online sales channel, which will ensure the receipt of economic benefits in future periods, and will not cover current operating expenses.

Thus, the conducted research confirmed that management decisions are a key tool for ensuring the effectiveness of enterprise management and achieving its sustainable development. It was established that in conditions of uncertainty, instability of the market environment and limited resources, not only the timeliness

of decision-making becomes crucial, but also their validity, systematicity and strategic orientation. It is proved that the quality of management decisions is determined by the level of information and analytical support, the use of modern management technologies, as well as the ability of management to integrate formalized and expert approaches.

The results of the analysis of the activities of LLC "Sumy-rytm" showed the presence of negative trends, in particular, a decrease in sales volumes, the transformation of profitability into unprofitability and the deterioration of profitability indicators. This indicates the insufficient effectiveness of the existing system of management decision-making, which is characterized by the predominance of an operational approach, the lack of proper structuring and the limited use of strategic management tools.

In view of the identified problems, the feasibility of improving the technology of managerial decision-making by implementing a set of organizational and managerial measures is substantiated. First of all, the introduction of strategic sessions as a tool for collective decision-making is proposed, which ensures the coordination of goals, increases the validity of managerial actions and increases the participation of personnel in the management process. The use of such an approach will contribute to the formation of strategic thinking, reduce the risks of erroneous decisions and increase responsibility for their implementation.

An important area of improvement is the structuring and standardization of the decision-making process based on the proposed logical-structural model, which provides for a clear sequence of stages, the use of analytical procedures, the evaluation of alternatives, and the implementation of a results control system. This will reduce the level of uncertainty, increase the transparency of management processes, and ensure their repeatability and manageability.

Special attention is paid to the digitalization of management activities, in particular the implementation of e-commerce tools, which are considered as a strategic management solution. It is substantiated that the creation of an online store will contribute to the expansion of sales channels, increasing the availability of products for consumers, optimizing logistics and financial processes, as well as ensuring the prompt collection and analysis of information on demand. Forecast calculations confirm that the implementation of this solution will ensure a gradual increase in revenue, restoration of profitability and achievement of a positive level of profitability in the medium term.

In addition, decentralization of management functions, involvement of personnel in the decision-making process, use of digital analytical tools and implementation of a system for monitoring the implementation of management decisions based on key performance indicators are proposed. The combination of these measures forms a holistic mechanism for improving the quality of management decisions and contributes to the enterprise's transition to an adaptive, flexible and innovation-oriented management model.

Therefore, the approaches and practical recommendations proposed in the study create a scientifically sound basis for increasing the efficiency of enterprise management, ensuring its financial stabilization, strengthening competitive positions, and achieving sustainable development in the long term.

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STRATEGIC DIRECTIONS OF INNOVATIVE DEVELOPMENT OF ENTERPRISE IN THE CONDITIONS OF GLOBAL CHALLENGES TAKING INTO ACCOUNT THE PRINCIPLES OF SOCIAL RESPONSIBILITY AND ECOLOGICAL BALANCE

Tereshchenko Svitlana

Dr. Sc. (Econ), Professor, professor of the Department of Economics and Entrepreneurship named after Prof. I.M. Bryukhovetsky, Sumy National Agrarian University, Sumy, Ukraine

ORCID ID: 0000-0002-8852-1091

Active global transformations taking place in the world and having a direct impact on the world economy and various spheres of activity of its subjects, determine the need to strengthen economic sustainability. This can be achieved through the development and implementation of innovations in the work of enterprises, as well as by activating their innovative activities, which, as a result, will increase the level of innovative activity. The experience of countries that have chosen the path of innovative development convincingly demonstrates: the introduction of innovative technologies in various spheres of activity contributes to the strengthening of the national economy, the growth of production volumes of enterprises, the creation of products with unique properties and characteristics, as well as the improvement of the standard of living of the population. In a general sense, the development of an enterprise is an irreversible process that reflects consistent and continuous changes in its state, expressed in qualitative or quantitative indicators under the influence of various factors. In a narrower sense, it can be considered as a certain state or result of changes in the activities of an enterprise, caused by the influence of internal and external environmental factors.

One of the determining factors of the development of an enterprise is its innovative activity [13]. Innovations involve the introduction of new production processes, types of products, sales markets or organizational forms. Thus, the concept of "innovation" is closely related to the concept of "development", since the effective and sustainable functioning of an enterprise in modern economic conditions is possible only under the condition of its innovative development. The term "innovative development" is used both at the macro level and at the micro level. At the same time, the analysis of scientific works devoted to this topic shows that researchers interpret the essence of innovative development differently, giving it its own content characteristics, which necessitates the need for further in-depth theoretical understanding of it.

Table 1. Basic definitions of the concept of "innovative development of an enterprise"

Author	Definition
Bandura Z., Golubetsky P. [4]	The company's activities are focused on the constant search for new methods and technologies in order to meet consumer needs and increase its own financial efficiency.
O. S. Hrynkevich, S. A. Kvak [5]	The basic innovation process involves the development of factors that are key to its implementation and the rational use of the enterprise's innovation potential.
Ivanyshyn O.V. [11]	Relationships that are formed in the process of increasing the economic efficiency and competitiveness of an enterprise through the introduction and use of innovations.
Ilyashenko S., Shipulina Yu., Ilyashenko N. [10]	The process of conducting business activities aimed at continuously searching for innovative methods of using the enterprise's potential in conditions of dynamic changes in the external and internal environment and fluctuations in market conditions.
Tsipurinda V. S. [31]	The spread of the innovation process that occurs as a result of introducing innovations into the activities of the enterprise.
Makarenko S. M. [23]	The stage of identifying and developing new products with the rational use of the enterprise's available resources, which helps strengthen its competitive position, develop new sales markets, and ensure stable operation.
Kravchuk I. [19]	The development of an enterprise is determined by the introduction and use of innovations in its activities.

**Source: generated by the author*

The analysis of the definitions presented in the table shows that most scientists consider the innovative development of an enterprise as a continuous process of introducing innovations aimed at increasing the efficiency of work, competitiveness and stable functioning of an economic entity. A common feature of all approaches is the emphasis on the active use of the innovative potential of the enterprise and the search for new forms, methods and technologies of development. At the same time, some authors detail this concept

through the prism of organizational and economic relations, resource provision or market adaptation, which emphasizes the multifaceted and complex nature of innovative development as a key factor in the economic growth of an enterprise. Therefore, the innovative development of an enterprise should be considered as a process of consistent and systematic changes in its state, which are directly determined by the level of innovative potential. The main source of such development is innovations, which open up new opportunities for the enterprise through the introduction of modern ideas, solutions and technologies aimed at increasing the efficiency of activities and strengthening competitive positions in the market.

The main goals of the innovative development of the enterprise include the following:

- development and implementation of an innovative enterprise strategy focused on ensuring its long-term competitiveness;
- increasing the efficiency of using innovative potential, including human, financial, material and information resources;
- creating favorable organizational and economic conditions for introducing innovations into production, management and marketing processes;
- development of the scientific and technical base of the enterprise to ensure the implementation of modern technologies and improve product quality;
- search and development of new sales markets through the development of innovative goods and services;
- ensuring flexible adaptation of the enterprise to changes in the external and internal environment through the application of innovative solutions;
- optimization of the innovation management structure to increase the efficiency of decision-making;
- forming an innovative culture and stimulating the creative activity of personnel;
- increasing the economic efficiency of the enterprise based on the introduction of new technologies and management approaches;
- strengthening the image of the enterprise as an innovatively active business entity on the market.

Table 2. Main types of innovations used for the purpose of enterprise development

View	Content
Product innovations	This is the creation and implementation of new or significantly improved goods and services that help meet consumer needs and increase the competitiveness of the enterprise in the market.
Process innovations	This is the introduction of new or significantly improved methods of production, management, or service provision aimed at increasing the efficiency of an enterprise's operations, optimizing costs, and rationally using resources.
Organizational innovations	This is the application of new management methods, organization of activities and work processes, aimed at increasing the efficiency of personnel, improving working conditions and optimizing internal interaction within the enterprise.
Marketing innovations	This is the application of new or improved methods of promoting goods and services, brand building, customer communication, and sales organization, which is aimed at increasing the attractiveness of products, expanding sales markets, and strengthening the competitive position of the enterprise.

**Source: generated by the author*

In the literal sense, innovation activity covers all types of activities aimed at introducing innovations into the functioning of the enterprise. It includes conducting fundamental, scientific and applied research, developing and generating creative ideas, implementing innovative technologies and creating new types of products. The result of such activity is obtaining innovations of various types that contribute to the development and increase of the competitiveness of the enterprise.

These are the main types of innovations implemented by enterprises. The most common among them are product innovations, that is, the development of new goods and services or significant improvements to existing ones. In the modern world, hundreds of product innovations of varying degrees of novelty appear every day. Some of them are completely new products that are entering the market for the first time, while others are the result of modernization and improvement of existing models. Vivid examples of such innovations are the iPhone, which became a world leader at the time of its launch, smart watches, 3D printers, as well as headphones and electronic translators.

Process innovations are the introduction of new or improved methods of production and service provision, which can be implemented, in particular, through the use of modern equipment, technologies or software. A striking example is the creation of a vaccine against the COVID-19 virus, which also belongs to innovative developments. In contrast, product innovations are focused on meeting existing or potential consumer needs. That is why companies invest significant funds in the development of new products, seeking to strengthen their competitive positions in the market and increase the level of customer loyalty [23]. Process innovations involve the introduction of new or significantly improved methods of creating and providing services. They include significant changes in the hardware and software used in service-oriented enterprises, as well as in the procedures and methods of organizing service. For domestic enterprises, process innovations are most appropriate, since their implementation contributes to reducing costs, rationalizing the use of resources and increasing the efficiency of production activities. Examples of such innovations include the use of GPS trackers to monitor transportation, optimization of delivery routes, and the use of CRM systems to automate marketing and customer processes.

Organizational innovations are aimed at improving working conditions, optimizing workplaces, introducing new management methods and forms of interaction with personnel in order to increase their productivity, motivation and job satisfaction. Examples of such innovations are the modernization of office space, improving the organizational structure through mergers or the creation of new divisions, as well as the introduction of new remuneration systems.

In the face of increasing competition, marketing innovations that involve non-standard approaches to promoting products, attracting consumer attention, updating packaging, or changing the place of sale are of particular importance. Among the most common examples of marketing innovations are the use of QR codes, creating corporate websites, developing mobile applications, gamification of the process of interacting with consumers, and implementing online booking systems.

Leading companies, as a rule, are not limited to the implementation of only one type of innovation. They are characterized by a high level of innovative activity and achieve significant improvement of their results due to the comprehensive implementation of different types of innovations in their own activities. It is worth noting that innovations are associated with the implementation of changes aimed at improving existing solutions or creating completely new approaches that have not been used in a particular business before. They can cover various processes, technologies or organizational phenomena, and their level of novelty can vary from innovations that are new for a particular company to completely new for the industry or the world (the highest level, characteristic of startups). For the effective implementation of innovations, enterprises often use a benchmarking tool, which involves studying the best practices of other companies and adapting them to their own conditions. It should be emphasized that the innovative activity of the enterprise should be carried out on a systematic basis and be aimed at the constant search and implementation of new ideas. As a result, such activity provides the enterprise with a number of advantages, including: establishing new advantages in the market; effective use of available resources; more complete satisfaction of customer needs; improvement of corporate image; increased profitability and efficiency of operations. Thus, innovative activity is a key factor in the sustainable development of an enterprise and strengthening its market position.

Forms of innovation are divided into radical and incremental. Radical innovations involve radical changes that lead to a complete transformation of a product, technological process, or enterprise development strategy. Incremental innovations, on the other hand, are characterized by gradual, step-by-step improvements aimed at increasing the efficiency of existing elements of activity.

Innovative entrepreneurship is a specific business process based on the constant search for new opportunities to improve technical, technological and organizational aspects of production. It involves the willingness of the entrepreneurial structure, both an individual and a legal entity, to take on the risks associated with the implementation of new projects or the modernization of existing ones, as well as to bear financial, social and moral responsibility for the results of the implementation of innovations.

The need to organize innovative entrepreneurial activity is due to the need to increase the technical and technological level of production, the growth of costs and the decrease in the economic efficiency of enterprises, as well as the rapid obsolescence of equipment and technologies. Of great importance are science and the introduction of modern technological developments, which ensure the effective application of the achievements of scientific and technological progress in all branches of economic activity. In addition, the relevance of innovative activity is due to the intensive development of production, the need to increase its efficiency and the economic feasibility of intensifying factor development.

There are three main ways to organize the innovative activities of an enterprise:

1. Intra-organizational innovation activity. In this case, the development and implementation of innovations is carried out directly within the enterprise by its specialized departments. Such activity is based on systematic planning, coordination and monitoring of interaction between participants in innovation projects, which ensures control over all stages of the innovation process.

2. External organizational innovation activity on a contractual basis. It involves concluding agreements between the enterprise and third-party organizations to create or order the development of innovations. This approach allows you to involve external specialists, scientific institutions or companies that have the necessary knowledge, technologies and resources.

3. External organizational innovation through venture mechanisms. It is implemented by creating subsidiary venture enterprises designed to develop and commercialize innovative projects. In this case, the enterprise can attract additional investments, resources or partners from the external environment to reduce risks and increase the efficiency of innovation implementation.

In innovation activities, the life cycle of an innovation should be taken into account, covering the period from the birth of an idea to its commercial implementation and gradual transformation into a familiar product, process or service. This cycle reflects the dynamics of demand for innovation from the stage of active growth to the decline in consumer interest. If an enterprise seeks to maintain competitive advantages, it must promptly withdraw outdated innovations from the market, the effectiveness of which decreases due to a decrease in demand, and introduce new solutions that can meet the current needs of the market. Thus, the launch of a new innovation actually completes the life cycle of the previous one, ensuring the continuity of the enterprise's innovative development.

Thus, although innovation is a key factor in the long-term success of an enterprise, it is accompanied by a number of serious challenges and risks. The main one is the uncertainty of results, since innovations depend on changing environmental conditions, which makes it difficult to predict the effectiveness of their implementation. In addition, the high capital intensity of innovation projects creates additional barriers to their implementation, especially for small and medium-sized enterprises, which are often limited in financial capabilities. As a result, many companies avoid active innovation or implement it with excessive caution, which hinders their development and reduces competitiveness in the long term.

The main factor limiting the active implementation of innovations at domestic enterprises is the insufficient level of financial support. Lack of own funds, limited access to credit resources and low level of investment support from the state and the private sector significantly complicate the implementation of innovative projects. As a result, enterprises are unable to fully finance research, development and implementation of new technologies, which slows down their innovative development and weakens their competitive position in the market.

As practice shows, the most real and widespread source of financing of innovative activities of enterprises is their own financial resources, primarily profit or contributions of shareholders (owners). Enterprises that systematically implement innovations usually annually direct a certain share of net profit to a special reserve fund. In the future, these funds are used to implement innovative projects, which ensures the financial stability of the development process and reduces dependence on external sources of financing.

Providing financial resources for innovations is a complex multifactorial process that involves determining the need for financial resources, selecting sources of financing, developing a strategy for their use, and monitoring cost effectiveness. In the conditions of the modern economy, characterized by instability of market processes, increasing risks, and intensifying competition, the issue of finding finance for innovations becomes particularly relevant, especially for Ukrainian enterprises, whose activities are often limited by a lack of their own resources.

In practice, the most common source of financing for innovation activities is the enterprise's own funds, which include profit, depreciation, reserve funds, and contributions from owners or shareholders. Companies that pursue an active innovation policy usually form special innovation or investment funds, to which a certain percentage of net profit is annually allocated. These funds are then used to finance research and development work, the introduction of new technologies, or the modernization of equipment. The use of its own financial resources gives the enterprise high autonomy in decision-making, but their volume is often insufficient for the implementation of large-scale innovation projects.

The second important group of financing sources is attracted funds, which are formed through credits, loans, bond issuance, as well as through venture capital or participation of strategic investors. Bank loans remain one of the traditional ways of attracting resources, but for innovative enterprises they are expensive

and risky, since financial institutions often require a guarantee of repayment of funds, which innovative projects at the initial stage cannot provide. In this context, an important role is played by state innovation support programs, which provide for preferential lending, partial compensation of interest rates or co-financing of innovative initiatives.

Table 3. Key sources and methods of financial support for the innovative activities of the enterprise

Source	Content	Advantages	Disadvantages
Own funds of the enterprise	profit, depreciation, reserve funds, shareholder contributions. Used to finance research and development, equipment modernization, and the introduction of new technologies	financial independence; ability to independently manage funds; high flexibility of use	limited resources; inability to finance large projects
Bank credits and loans	raising funds through credit institutions for the implementation of innovative projects	access to significant financial resources; ability to quickly obtain funds	high cost of loans; - need for collateral and guarantees; - risk of non-return in case of project failure
Government funding and support	budget programs, grants, preferential lending, interest rate compensation, state co-financing	reducing the financial burden; supporting priority industries; the possibility of attracting non-repayable funds	limited access to government programs; bureaucratic procedures and control over use
Venture financing	investment in high-risk but promising projects by venture funds or private investors	the possibility of financing innovations without collateral; combining investor experience and contacts; increasing business growth potential	loss of part of control over the enterprise; high requirements for the project's prospects
Grants, international programs and donor assistance	obtaining funding through international organizations (Horizon Europe, USAID, EBRD, GIZ, etc.). The funds are mostly non-refundable	free funding; international partnership opportunity; reputation enhancement	complex application procedure; need for detailed reporting; high competition for funding
Partnership programs and clusters	association of enterprises, scientific institutions, and investors for the joint implementation of innovative projects.	risk and cost sharing; access to additional resources; increased efficiency	the need for coordination between participants; possible conflicts of interest

**Source: generated by the author*

Special attention is paid to the use of venture financing, which is becoming increasingly popular in developed countries and is gradually spreading in Ukraine. Venture investors invest in high-risk, but promising innovative projects, counting on significant profit growth in the future. This form of financing allows enterprises, especially small and medium-sized ones, to obtain capital to implement new ideas without the need to take out loans or sell a controlling stake.

An important source is also the attraction of grants, subsidies and international assistance. Within the framework of European and global programs (for example, Horizon Europe, USAID, EBRD, GIZ, etc.), Ukrainian enterprises can receive funding for the development and implementation of innovations. Grant funds are usually non-refundable, but require a thorough justification of the project, confirmation of its socio-economic significance and subsequent reporting on the use of funds.

Another direction of providing financial resources is partnership programs and cluster interaction, when enterprises unite with other market participants, namely: universities, research centers, investment funds, large corporations for the joint implementation of innovative projects. Such a combination of resources allows to reduce the financial burden on each participant, minimize risks and at the same time expand the range of opportunities for implementing innovations.

For effective management of financial resources, an enterprise must develop a comprehensive financial strategy for innovative development, which includes planning of funds needs, optimization of capital structure, risk assessment and determination of investment efficiency. An important tool in this process is the application of modern financial management methods, such as innovation budgeting, project cost estimation (NPV, IRR, Payback Period), cost and result control.

Therefore, financing of innovation activities is a strategic element of ensuring the competitiveness of the enterprise. Effective combination of own, attracted and state sources of financing, as well as active use of grants and partnership mechanisms allows the enterprise not only to implement innovative projects, but also to form long-term financial stability. Thus, the construction of a system of financial support for innovations should be based on a strategic vision, flexibility and orientation towards maximum return on investment in innovation.

In times of war and with the assistance of foreign states and international financial organizations, grant financing has become a key source of support for the innovative activities of domestic enterprises. In today's conditions of instability and high risk, it is grants that allow enterprises to implement innovative projects without a significant financial burden and with less risk to their own capital.

The analysis shows that the sources of financing for innovations of domestic enterprises are diverse and include both own funds and borrowed resources. This mixed financing model allows enterprises not only to support existing innovation projects, but also to scale them, increase production efficiency and strengthen competitive advantages. Thus, financial support for innovation activities remains one of the key factors in the development of the enterprise, and the effective combination of own and borrowed sources of funds determines the company's ability to achieve stable innovative growth even in conditions of economic and political instability.

In the context of modern global transformations, innovative development is becoming key to increasing the competitiveness of national economies, updating the technological base and integrating into the global economic space. It is not only a response to current challenges, but also a strategic tool for long-term development. The world is experiencing profound changes caused by digitalization processes, climate threats, geopolitical tensions and the transformation of global value chains, which requires businesses to quickly adapt to new conditions. GII allows you to assess how ready a country is for technological development and competition in the global innovation market[3].

Global Innovation Index (GII) is an international rating that assesses the level of innovation activity of countries around the world and their ability to generate new knowledge, technologies and innovative products. The GII shows how well a country is able to develop innovations, create new technologies, products and services, and how effectively it uses available resources to do so. It is an important tool for governments, businesses and researchers to compare the innovation potential of different countries. A high GII rating indicates a strong innovation ecosystem, a competitive economy and the effective use of scientific and technological resources. A low rating signals the need to improve the infrastructure for research, support for entrepreneurship and development of human capital.

Table 3.1 shows the dynamics of Ukraine's positions in the global and European innovation rankings. Global ranking: in 2022, Ukraine ranked 57th out of 133 economies, indicating an average level of innovation development; in 2023, there was a slight improvement in the position to 55th place, which could be due to improvements in some components of the innovation environment. However, in 2024 and 2025, there is a downward trend: 60th and 66th places, respectively, indicating an overall decline in the country's innovation potential on the global stage. European ranking: Ukraine consistently ranked 34th out of 39 European economies in 2022–2024, showing a lag behind most European countries. In 2025, there was a slight deterioration to 35th place, confirming the need to strengthen innovation policy and support technological development[7].

Table 4. Ukraine's positions in the Global Innovation Index (GII) 2022–2025

Year	Place in the world	Place in Europe	Comment
2022	57/132	34/39	Initial rating
2023	55/133	34/39	A slight improvement
2024	60/133	34/39	Rating deterioration
2025	66/139	35/39	Further decline

**Source: formatted by the author[7].*

Despite isolated improvements, the overall trend over the past four years has been a decline in Ukraine's positions both globally and in Europe. This indicates the need to intensify activities in the field of R&D, human capital development, modernization of the business environment, and increasing the effectiveness of regulatory and innovation tools.

Table 5. Components of the GII 2025 ranking (Ukraine's position)

Category	Position	Changes
Regulatory environment	106	No changes
Regulatory environment	89	-5
Human capital and research	65	-11
Education	48	-5
R&D	72	-3
Information and communication technologies	23	+33
Knowledge and scientific research results	47	-13

**Source: formatted by the author[7].*

The GII rating is an important analytical tool for assessing the state of innovation activity, monitoring progress, and determining strategic directions for the development of science, technology, and business innovation in the country. Table 5 demonstrates the state of key components of Ukraine's innovation system in 2025 and shows in which areas the country is losing ground and where it is showing positive dynamics. Ukraine's regulatory environment remained unchanged at 106th place, indicating a lack of significant progress in the area of legal and administrative conditions for the development of innovations. The business environment deteriorated by 5 positions (89th place), which may indicate difficulties in doing business, access to financing and support for innovative enterprises.

The decline in positions in human capital and research (-11) and education (-5) indicates problems with the development of qualified personnel and insufficient support for scientific activities. R&D also fell slightly (-3), indicating the need to increase investment in research and innovation projects.

A positive trend is the significant improvement in the ICT sector (+33), reflecting progress in digitalization, the development of startups, IT services, and technology platforms.

A drop of 13 positions to 47th place indicates problems with the commercialization of scientific results and insufficient use of scientific achievements for economic development.

Ukraine demonstrates strong positions in the ICT sector, but lags significantly behind in the regulatory and business environment, human capital development, R&D, and knowledge commercialization. To improve the overall ranking, a comprehensive strategy to support innovation is needed, including the development of scientific research, education, legal conditions, and the business ecosystem.

The European Innovation Council (EIC) was created to support high-tech innovations and breakthrough ideas that can change global markets. It provides funding to start-ups and small and medium-sized enterprises working on strategic technologies, stimulating their rapid development and scaling. The EIC combines financial support with advice, mentoring and access to international networks of partners and investors, which contributes to the creation of competitive companies at European and global levels.

In addition to direct funding, the council also stimulates the development of the innovation ecosystem in Europe by supporting research projects with high commercialization potential. It aims to find and implement technological solutions in the areas of green technologies, digitalization, healthcare and other strategically important areas. Thus, the EIC acts not only as a financial instrument, but also as a catalyst for innovative development for companies and research teams.

The European Innovation Council's activities contribute to the integration of the European Union into global innovation chains, increase the competitiveness of European technology companies and ensure sustainable economic development based on the latest scientific and technological achievements. Through its programs, the EIC supports bold and risky projects that can become technological breakthroughs and significantly impact the economic and social environment of Europe and the world.

The European Innovation Council (EIC) actively cooperates with Ukraine, providing opportunities for Ukrainian startups, small and medium-sized enterprises to participate in its innovation funding and support programs. This allows Ukrainian companies to receive grants, investments and mentoring support to implement strategic technology projects and scale their business on the European market. At the same time, Ukrainian startups have access to a network of international partners, investors and experts, which significantly increases their competitiveness.

Cooperation with the EIC contributes to the integration of Ukraine into the European innovation ecosystem and the development of high-tech sectors of the economy. Ukrainian companies and scientific teams can implement projects in such priority areas as digital technologies, green energy, healthcare and strategic

infrastructure solutions. This opens up additional opportunities for attracting investment and promotes the introduction of advanced technologies in the country. Thus, Ukraine's participation in the programs of the European Innovation Council not only stimulates the development of the national innovation ecosystem, but also contributes to the formation of long-term partnerships with European technology companies and research institutions, which strengthens Ukraine's role in global innovation processes.

The Horizon Europe Office in Ukraine Department of the NFDU reports that the European Commission has approved the Work Programme of the European Innovation Council for 2025. It provides for funding of over 1.4 billion euros aimed at the development of strategic technologies and the expansion of the activities of innovative companies.

Table 6. Key points of EIC funding for 2025

Direction	Details
New scheme	STEP Scale Up ; budget €300 million in 2025, expected to increase to €900 million in 2025–2027.
Investments	From €10 to €30 million through the EIC Fund; private co-investments – €50–150 million per company.
Focus on technology	Scaling deep tech: digital technologies, clean and resource-efficient technologies (net-zero goals), biotechnology.
Updated EIC Challenges	€120 million – autonomous construction work, climate-resistant crops, waste conversion into materials, medical diagnostics. €250 million – early stages: generative AI, space technologies, agrotechnology, future mobility.
Business acceleration	Expanding access to services, focusing on companies from "widening countries" (countries with lower levels of research and innovation).
Honors	Seal of Excellence – Transition and Accelerator competitions. STEP Seal – STEP Scale Up and Accelerator Challenge competitions. Facilitates access to additional funding (Cohesion Policy Funds) and business acceleration services.

**Source: compiled by the author[7].*

Table 6 shows that the European Innovation Council (EIC) funding for 2025 is aimed at comprehensive support for innovative companies at different stages of development from early-stage startups to scaled-up deep tech projects. The STEP Scale Up, EIC Challenges, Seal of Excellence and STEP Seal programs create conditions for attracting significant investments, access to business acceleration and international networks of partners. Particular attention is paid to countries with lower levels of research and innovation, which contributes to greater integration of such companies into the European innovation ecosystem. Overall, EIC funding provides strategic support for technological development and scaling up innovative solutions in priority sectors of the economy.

At the state level, the Strategy for Innovative Development of Ukraine until 2030 has been developed, the purpose of which is to create favorable conditions for sustainable economic growth through the introduction of modern technologies, the development of research and innovation projects, as well as increasing the competitiveness of the national economy on the global stage. One of the key priorities is the formation of an effective innovation ecosystem that combines state support, private investment, academic institutions and startups, stimulating the creation and commercialization of knowledge[11].

The strategy envisages the development of high-tech sectors of the economy, including digital technologies, biotechnology, low-emission energy, as well as "green" and resource-efficient technologies. Significant attention is paid to increasing the level of human capital through the modernization of education and the system of training scientific personnel, the development of R&D and the introduction of innovations in industry and services.

It also envisages the creation of a favorable legal and financial environment for innovation, including the stimulation of venture capital, grant programs, and preferential taxation for innovative enterprises. The strategy aims to integrate Ukraine into global innovation and technology chains, support startup ecosystems, and develop infrastructure for the commercialization of scientific results.

These figures reflect strategic guidelines for Ukraine aimed at increasing innovation capacity, technological development, digitalization, and integration into global economic and technological processes.

The implementation of the Strategy for Innovative Development until 2030 should ensure Ukraine's transition to a knowledge economy, increase the innovative capacity of enterprises and the state as a whole, and create conditions for sustainable technological and socio-economic development of the country.

Table 7. Key indicators and goals of the Strategy for Innovative Development of Ukraine until 2030

Direction	Targets by 2030
Innovative activity of enterprises	40–50% of enterprises introduce new products or technologies
R&D expenses	2% of GDP (currently ~0.7–0.9%)
Number of startups	Increase in the number of technology startups by 2–3 times
Access to global markets	30–40% of innovative products of Ukrainian production are exported
Human capital	80% of scientists and engineers have higher or professional education in STEM fields
Digitalization	90% of government and commercial processes are digitalized
Renewable energy and green economy	30–35% of the country's energy is from renewable sources; introduction of energy-efficient technologies in 50% of industrial enterprises
Integration into global innovation chains	Ukraine is among the top 50 countries of the Global Innovation Index and the top 20 countries in Europe by startup ecosystem

**Source: generated by the author*

The structural and economic mechanism of supporting the innovative development of an enterprise plays a key role in forming a competitive economy and ensuring sustainable growth. This approach combines organizational, financial, institutional and managerial tools that create a favorable environment for the implementation of innovations. Such a mechanism determines the structure of interaction between the state, business, scientific institutions and investors, ensuring the efficient use of resources and stimulating the innovative activity of enterprises.

The main task of the structural and economic mechanism is to form a system of incentives that contribute to increasing investments in research and development (R&D), the introduction of new technologies, the training of highly qualified personnel and the modernization of production. An important element of this mechanism is the creation of financial instruments to support grants, preferential lending, venture financing and public-private partnerships, which allow enterprises to implement innovative projects even in conditions of economic instability.

In the current conditions of the development of the Ukrainian economy, the structural and economic mechanism acquires special importance, as it contributes not only to the growth of the innovative potential of enterprises, but also to the integration of Ukraine into the global innovation space. Its effective functioning ensures the creation of a knowledge economy, an increase in the technological level of production, and the strengthening of the positions of Ukrainian enterprises in international markets [13].

In this context, the organizational and economic mechanism of innovative development of LLC "Consulting Company "Finance Taxes Audit" should be considered as an extensive hierarchical system that forms relationships between individual elements and their groups depending on the nature of their interaction. Such a system covers the processes of formation, unification and transformation of structural links, within which the economic interests of the state, the innovation sector, the enterprise and consumers are coordinated. It is this interaction that ensures the targeted and balanced development of the enterprise over a certain period of time (Fig. 1).

Today, there is an increasing influence of both external factors (political instability, exchange rate fluctuations, inflationary processes) and internal ones (low income levels, outdated management system, weak interaction between science and business), which create additional challenges for the effective functioning of this mechanism [39, p. 8]. Therefore, it should be characterized by flexibility, openness to innovations and the ability to quickly adapt to changing market conditions. The organizational and economic mechanism for managing innovative development includes a defined system of enterprise goals, available resources, economic indicators for assessing the effectiveness of its implementation, as well as an appropriate information base. To ensure greater effectiveness, it is advisable to form it on the basis of three key components: organizational, economic and innovative, which together determine the direction and dynamics of enterprise development. Thus, the organizational component of the mechanism involves determining the form of the enterprise's activity, planning its work and choosing appropriate production technologies. The economic component covers

the formation of the pricing system, as well as aspects of credit and tax policy. In turn, the innovative component focuses on managing innovation processes at all stages of their implementation and stimulating the development of the enterprise's innovation infrastructure. It is worth emphasizing that this mechanism is an open dynamic system, the activity of which occurs under the influence of both internal and external factors, and is implemented through the performance of a number of basic functions (Table 8.)

Table 8. Functions of the organizational and economic mechanism for managing the innovative development of an enterprise

Function	Content
Planning	Defining goals and objectives of innovative development, forming programs and projects of an innovative nature.
Organization	Resource allocation, creation of innovation process management structures, formation of a team for implementing innovations.
Motivation	Encouraging employees to participate in innovative activities, using material and non-material methods of encouragement.
CONTROL	Tracking the results of implementing innovation programs, assessing the effectiveness of activities and adjusting actions as needed.
Regulation	Ensuring flexibility of the management system, adaptation to changes in the internal and external environment, timely response to new challenges.
Information support	Formation of an information base for making management decisions, use of modern ICT for data collection and analysis.
Monitoring and evaluating performance	Analysis of the results of the mechanism's activities, determination of the level of achievement of innovation goals, preparation of reports and recommendations for improving management.

**Source: generated by the author*

As a result of the implementation of an organizational and economic mechanism for managing innovative development, the enterprise will be able to achieve a level of development that will ensure its effective functioning in the external environment and allow it to compete with leading companies in the industry in terms of key indicators[16].

The organizational and economic mechanism for managing innovative development should include a set of methods of analysis and support, the results of which are used to identify and systematize the strengths and weaknesses of the enterprise, as well as to form plans for further development with an emphasis on the implementation of innovations. First of all, it is built on the principle of systematicity, which involves considering innovative development as a holistic system, where all elements of resources, processes, structure and personnel are interconnected and coordinated to achieve results. The principle of scientificity is important, which ensures decision-making based on modern scientific knowledge, research and technological forecasts, as well as the use of objective methods for analyzing the effectiveness of innovations.

No less important is the principle of goal orientation, which determines the creation of a mechanism for achieving specific strategic goals of the enterprise, such as increasing competitiveness, profit growth or product diversification. The principle of complexity ensures the integration of economic, organizational, legal, technological and social levers of innovation management, which allows financial, human and technological resources to interact effectively.

Of particular importance is the principle of economic efficiency, which requires the assessment of each innovation initiative in terms of profitability and optimal use of resources, using appropriate financial instruments and incentives. At the same time, the principle of adaptability and flexibility implies the ability of the mechanism to quickly respond to changes in the external environment, technological or market challenges, as well as adjust strategies and resources in accordance with new conditions. The principle of stimulating innovation provides motivation for personnel and departments to participate in the creation and implementation of new solutions through various forms of incentives, including bonuses, profit sharing or career growth. Finally, the principle of control and performance evaluation involves constant monitoring of the results of innovation activities, the use of key performance indicators (KPIs), conducting audits and risk analysis, which allows you to adjust actions and achieve planned goals.

In addition, it is worth noting that the further innovative development of the LLC should be based on the constant implementation of innovations, the adaptation of which involves various organizational, economic

and production transformations. Therefore, to achieve the planned innovative results, it is necessary to apply new approaches to change management and innovation processes.

Innovative development of the enterprise directly affects the process of providing services, as it allows to increase their quality, efficiency and individualization. The use of modern technologies, automation of accounting and the use of digital platforms open up new opportunities for optimizing service processes and increasing the efficiency of interaction with customers. This allows the enterprise to quickly adapt to market changes and promptly respond to consumer needs

Changes in service delivery also affect the structure of the processes themselves. The introduction of innovations involves the reorganization of personnel work, optimization of the sequence of operations and the integration of new service methods. For example, digital services allow you to reduce order processing time, implement online consultations and remote services, which significantly increases the efficiency of service provision.

Special attention is paid to personalization and adaptation of services to specific customer needs. Innovative technologies for data collection and analysis allow creating individual offers, predicting customer needs and offering additional services. This not only increases the level of consumer satisfaction, but also strengthens the competitive position of the company in the market. Innovative development also stimulates the creation of new types of services that were previously unavailable or did not make economic sense. This can apply to both the introduction of digital products and the use of new technologies in classic service areas. Thanks to this, the company gets the opportunity to expand the market, attract new customers and increase its profitability.

Finally, changes in service delivery require a systematic approach to innovation management and monitoring of the results of their implementation. It is necessary to constantly evaluate the effectiveness of innovations, analyze customer feedback and adjust processes based on the data received. This approach ensures continuous development of services and allows the enterprise to remain flexible and competitive in a dynamic market environment [19].

Promoting innovative development of an enterprise is one of the main factors ensuring its competitiveness and stable long-term growth. It involves creating a system of economic, organizational and social incentives that encourage employees and departments to generate new ideas, implement technological innovations and improve business processes. Such an incentive system forms an active innovation culture, where innovations are considered a natural component of the enterprise's activities.

Economic incentives are one of the most common forms of innovation support. This can include bonuses for implemented projects, participation in profits from the commercialization of new developments, financing of training and advanced training of personnel. It is important that the reward system is transparent, fair and directly linked to the results of innovation activities, which allows creating a strong motivation for active participation in the development of new products, services and technologies.

No less important is organizational stimulation of innovation. This involves creating structures and processes that facilitate the rapid exchange of ideas, collaboration between departments, and the integration of innovations into production and management processes. Such measures include the introduction of innovation teams, laboratories and hubs, regular brainstorming sessions, idea competitions, and open platforms for discussing new solutions.

Companies that foster openness, trust, and experimentation foster an environment where employees are not afraid of making mistakes and are willing to offer unconventional solutions. Additionally, recognizing innovative achievements through awards, publications, corporate events, or career advancement increases employee engagement and fosters creativity. Promoting the innovative development of an enterprise includes not only the implementation of economic, organizational and social measures, but also systematic monitoring of their effectiveness. For this purpose, KPIs are used - key performance indicators that allow assessing the results of the implementation of innovations and the level of staff involvement. Such indicators may include the number of submitted and implemented innovation initiatives, reducing the time to market for new products, increasing employee involvement and the share of innovations in the overall product portfolio.

Table 9. Practical measures to stimulate innovative development and their effectiveness

Type of stimulation	Practical measures	Expected effect	Actual results
Economical	Bonuses for implemented innovations, profit sharing, training funding	Increased motivation, active participation in projects	The number of innovative initiatives increased by 35%; 20% more projects were implemented
Organizational	Innovation teams, labs, idea competitions, discussion platforms	Process optimization, rapid implementation of new ideas	New product launch time reduced by 25%
Social and cultural	Recognition of achievements, corporate events, career growth	Formation of an innovative culture, readiness for change	Staff engagement increased by 30%

**Source: author's calculation*

Economic incentives are measured through KPIs, such as the increase in the number of implemented innovation projects and the percentage of innovations that brought additional profit. Organizational incentives are measured by reducing the time to develop new products, increasing the efficiency of teamwork and the proportion of projects that passed testing successfully. Social and cultural incentives are measured by the level of staff involvement, the number of suggestions for process improvement and the level of employee satisfaction with their work[21].

Therefore, comprehensive stimulation of innovative development of the enterprise, supported by economic, organizational and social measures, allows to significantly improve the efficiency of introduction of new technologies and products, to increase personnel productivity and to strengthen competitive positions in the market. Experimental culture at the enterprise is a key factor in stimulating innovative development. It involves creating an environment where employees are encouraged to search for new ideas, test alternative solutions and implement non-standard approaches in work processes. Such culture contributes to the formation of openness to change and the readiness of the enterprise to quickly adapt to new technological and market conditions. An important aspect of experimental culture is the support of risky, but potentially promising innovative projects. An enterprise that allows its employees to conduct experiments gets the opportunity to test new products, services or processes without significant losses in case of failure. This creates a basis for the formation of practical knowledge and accumulation of experience, which is subsequently used to scale up successful solutions.

An experimental culture also stimulates interdisciplinary interaction and teamwork. When implementing innovative experiments, specialists from different departments are involved, which allows combining different competencies and approaches. Such a process increases the efficiency of innovative development, as it creates a synergy of knowledge and resources necessary for the generation and implementation of new ideas. In an experimental culture, the enterprise actively uses methods of analysis and evaluation of the results of implemented innovations. This includes testing prototypes, collecting data from users, assessing profitability and adapting processes based on the conclusions obtained. This approach provides controlled risk management and allows you to optimize the processes of implementing innovations, making them more effective and targeted.

Thus, an experimental culture creates favorable conditions for the continuous innovative development of the enterprise. It forms an environment in which ideas are transformed into concrete projects, and new technologies and solutions are integrated into production and management processes. This approach allows the enterprise to remain competitive, flexible and able to respond quickly to market changes, ensuring sustainable growth and development in the long term.

In general, stimulating innovative development is a complex process that combines financial, organizational and cultural measures. An effective incentive system allows an enterprise not only to introduce new technologies and products, but also to support continuous process renewal, adapt to market changes and create a sustainable competitive advantage. This approach ensures the dynamic development of the enterprise and strengthens its position in the modern economic environment. Thanks to operational budgeting, an enterprise can effectively support innovative development, respond promptly to external changes and optimally use financial resources. Thanks to clearly structured operational budgets, management can determine priority areas of innovative activity, control their financing and prevent irrational spending. This increases the accuracy of planning and contributes to the timely implementation of innovative projects. An important

advantage of operational budgeting is the ability to coordinate short-term financial decisions with the long-term innovation strategy of the enterprise. Operational budgets allow for the optimal combination of current expenses and investments in the development of new products, technologies and processes. This approach reduces the risks of financial imbalances and ensures the stability of financing of innovative programs[27].

In addition, operational budgeting facilitates control over the implementation of innovation projects, as it involves a systematic analysis of indicators of actual costs and results. This creates conditions for the rapid identification of deviations, their causes and the introduction of necessary adjustments. Thus, the enterprise can quickly respond to changes and maintain high efficiency of innovation activities. The use of operational budgeting also contributes to increasing the responsibility of managers for the use of resources in innovation processes. Clear budget indicators stimulate personnel to more effectively manage costs, find alternative solutions and increase labor productivity. This has a positive effect on the overall level of innovation activity and the efficiency of the enterprise.

Thus, the enterprise has several options for action: integrate budgeting into the existing accounting system, unifying all indicators into a common format, or purchase specialized software or create its own software tool. In general, budgets do not have a single standard, which often complicates the process of their formation. Some enterprises use only the cost budget, but the most productive is considered to be a comprehensive approach, in which the operating budget plays an important role. The development of budgets usually begins with the operating budget, since it reflects the activities of the enterprise through a system of special technical and economic indicators that characterize individual areas and stages of the operational process. On its basis, it is possible to form an operational budgeting structure that includes the production budget, sales budget, sales cost budget and financial results budget. Among them, the most important for the enterprise is the financial results budget, which belongs to the key operating budgets.

Thus, the operating budget reflects all income and expenses related to the main activities of the enterprise or its individual functional areas. It includes the sales budget, the production budget, the budgets of expenses by their types and the budget of financial results. The main purpose of the operating budget is to ensure consistency between the planned quantitative indicators and their monetary measurement, as well as to determine the key proportions, conditions and restrictions that must be taken into account when forming other main budgets.

The structure of the operating budget is formed by the management of the enterprise taking into account the strategic goals, features of economic activity and the degree of readiness of the organization in methodological, organizational and technical areas. When developing operating budgets, the following main sources of information are used [10]:

- financial statements and data on the implementation of the financial plan for the past period;
- contracts concluded with product buyers and suppliers of material and technical resources;
- forecast data on sales volumes or sales plans, formed on the basis of existing orders, demand levels, price conditions and other market factors;
- economic standards established by law (tax rates, depreciation rates, interest rates on loans, minimum wage, etc.);
- the accounting system in force at the enterprise.

In the process of developing an operating budget, standardized forms of budget documents are determined, a methodology for their preparation is created, and detailed rules and procedures for preparing and approving budgets are established. During the formation of such a budget, forecast sales and production indicators are transformed into specific quantitative calculations of income and expenses for each structural unit. The operating budget has a multi-level and hierarchical structure, since it is formed on the basis of coordination of budgets of lower levels.

The basis for forming the operating budget at the enterprise under study is the development of the received grant funding aimed at ensuring its operational activities.

LLC "Consulting Company "Finance Tax Audit"" is an independent Ukrainian firm that provides services in the field of accounting, tax and management accounting, as well as consulting on tax, currency and customs legislation. In addition to consulting, the company conducts training in accounting and financial reporting. The company has been operating on the market since 2017 and has offices in Sumy, Poltava, Kyiv. Due to existing contracts and plans for new agreements, it became necessary to expand the team in the Kyiv office. Over the entire period of operation, the company has received positive feedback from clients and has not had a single case of termination of contracts due to inadequate quality of services.

By the end of 2026, LLC "Consulting Company "Finance Tax Audit"" aims to expand its staff, in particular, to attract additional highly qualified accountants to increase the volume of accounting services. The creation of two more jobs will increase the company's average monthly profit by approximately UAH 250,000.00. Strengthening the state's fiscal policy towards business entities, the introduction of new reporting standards and increased control over cash transactions have led to increased business demand for professional specialists in the field of accounting and financial reporting.

Our strategic goal is to expand our presence in the city of Kyiv, attract additional specialists and expand the range of services provided. The company plans to create a department that will specialize in accounting services for enterprises that have switched to international financial reporting standards. By 2026, LLC "Consulting Company "Finance Tax Audit"" intends to open another department of specialists to provide services for the preparation of transfer pricing reports. The corresponding costs are foreseen for the implementation of this plan (Table 3.7).

Table 10. Costs for organizing a department of specialists to provide services for preparing transfer pricing reporting.

Expense items	Amount, thousand UAH	Justification
Purchase of computer equipment and printers.	150.0	The company's employees process and analyze a large volume of primary accounting documentation (contracts, certificates of work performed, expense invoices, TTN, etc.) for the preparation and submission of reporting, as well as for printing accounting registers and reports. This necessitates the need to update computer equipment and purchase new printers.
Purchase of furniture, including tables, cabinets, and chairs.	100.0	To equip the workplaces of new employees, you need to purchase furniture, including tables, chairs, and cabinets for storing documentation.

*Source: generated by the author

It is worth noting that the company has been providing accounting services since 2017 and continues its activities to this day. The development of the enterprise took place gradually, as financing was carried out exclusively from its own funds. At the moment, the company has four permanent employees.

We plan to attract accountants with higher education, mainly in the specialties of "Accounting and Taxation" and "Economics". The requirements for candidates include having experience as a chief accountant for at least three years and a total professional experience in the specialty of at least five years. The advantages of cooperation with our company include: reducing costs for staff maintenance and workplace arrangement (premises, equipment, software); no need to search for highly qualified accountants, conduct interviews and train new employees; ensuring confidentiality and responsibility; accounting by professionals, which guarantees timely submission of reports, no fines, proper procedure for maintaining accounting and primary documents, as well as organizing an archive of documentation; constant support for the client throughout the year, including representing his interests before regulatory authorities.

The activities of the specialists of LLC "Consulting Company "Finance Tax Audit"" are based on an individual approach to each task. Only after determining the nature and complexity of the problem can the volume of necessary assistance to the Principal and the optimal ways of providing it be determined. Without a doubt, the company's services should be focused on a specific target audience and on solving the problems and tasks facing the enterprise in the process of implementing the grant.

Table 11. Target customers and key problems to be solved.

Target audience	Plans	Customer problems (needs) that need to be solved	Company intentions
Micro, small and medium-sized businesses operating in the sectors of transportation, retail and wholesale trade, e-commerce, and catering.	They do not intend to increase the number of accountants on staff, but are interested in receiving high-quality accounting services.	Organization of accounting according to international financial reporting standards.	The company uses the following pricing system for its services: The basic service package is estimated at 2% of the client's income, while the premium package can be from 3% to 5% of their income.

**Source: generated by the author*

Research on the target audience and its needs demonstrates that micro, small and medium-sized enterprises in the fields of transport, trade, e-commerce and catering are interested in high-quality accounting services without the need to expand their own staff. The company "Finance Taxes Audit" offers an effective solution to these needs, organizing accounting according to international financial reporting standards and applying a transparent pricing system, which allows clients to receive professional services on favorable terms. This ensures the stability of accounting, timely reporting and minimization of risks for business.

The amount of income for the implementation of the enterprise's operating activities is a key financial indicator that determines the company's capabilities in carrying out current operations and implementing planned projects. It is formed on the basis of all sources of income that are directly related to the main activities of the enterprise, including the sale of products, the provision of services and other operating income. It is important that these funds are sufficient to cover current expenses, such as wages, rent, purchase of materials and other operating expenses.

The formation of the amount of revenue requires detailed forecasting and analysis, since the effectiveness of operational budgeting depends on the accuracy of the assessment. Forecasted revenue indicators allow you to plan the use of funds by division, determine funding priorities and assess the potential profitability of the activity. In addition, regular control over revenue ensures a timely response to deviations from the plan and allows you to promptly adjust financial decisions. The amount of revenue is also the basis for assessing the financial stability of the enterprise and its ability to invest in development, in particular in innovative projects. It determines the extent to which the enterprise can expand its activities, attract additional resources and implement strategies to increase competitiveness. Thus, timely planning and control over the amount of revenue for operating activities are critically important for maintaining business stability.

The grant of UAH 350,000 allows the company to significantly increase the efficiency of its operations and promote business development. Thanks to these funds, the company can create new jobs, modernize equipment, and implement modern software that increases staff productivity.

Table 12. Visual representation of the use of the grant of 350,000 UAH (2024)

Directions	Sum	Expected result
Purchase of computer equipment, furniture and equipment for new employees	150,000	Creation of 2 jobs, attraction of additional specialists without using own funds
Software implementation and equipment modernization	80,000	Increasing staff productivity, reducing document processing time by 40–50%
Marketing and organizational costs	50,000	Attracting new clients, increasing service volumes by 20–25%, increasing income by 120–150 thousand UAH per year
Contingency fund	70,000	Financial flexibility and the ability to respond quickly to market changes
Together	350,000	Improving operational efficiency and company development

**Source: generated by the author*

In addition, part of the grant can be used for marketing and organizational activities, which allows you to attract new clients and increase the volume of services. The presence of a reserve fund provides financial flexibility and the ability to quickly respond to market changes.

Table 13. Use of grant funds and performance indicators

Directions	Sum	Expected result	Efficiency from implementation
Purchase of computer equipment, furniture and equipment for new employees	150,000	Creation of 2 jobs, attraction of additional specialists without using own funds	Additional employees ready to handle accounting
Software implementation and equipment modernization	80,000	Increasing staff productivity, reducing document processing time by 40–50%	Reduction of documentation processing time by 40–50%
Marketing and organizational costs	50,000	Attracting new clients, increasing service volumes by 20–25%, increasing income by 120–150 thousand UAH per year	Increase in the number of clients by 20–25%, increase in income by 120–150 thousand UAH/year
Contingency fund	70,000	Financial flexibility and the ability to respond quickly to market changes	Ability to quickly respond to market changes without additional costs
Together	350,000	Improving operational efficiency and company development	Comprehensive process improvement, revenue and productivity growth

**Source: generated by the author*

The analysis shows that the grant in the amount of 350,000 UAH effectively contributes to the development of the enterprise, allowing it to simultaneously modernize equipment, create new jobs, implement modern software and attract new customers. The rational distribution of funds ensures increased staff productivity, optimization of work processes and financial flexibility in the event of unforeseen expenses. In general, the targeted use of the grant allows for improving the quality of services, increasing revenues and strengthening the company's position in the market, which confirms its high efficiency.

Financing innovation activities through grants allows the enterprise to implement strategic goals without a significant burden on its own budget. Funding from grants is directed to the modernization of equipment, the introduction of new technologies, the involvement of competent specialists and the optimization of work processes. This ensures increased productivity, reduced documentation processing time and cost optimization, which is critically important for the development of innovative projects.

In addition, grant funding stimulates the company to attract new clients and expand the range of services, increasing revenues and competitiveness in the market. Thanks to clear planning and control over the use of funds, the company gets the opportunity to quickly respond to changing market conditions and ensure stable development of innovative activities, which confirms the effectiveness of grant funding.

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MITIGATING THE IMPACT OF WAR ON RURAL UKRAINE

Nataliia Dehtiar

Ph.D., Senior Lecturer, Sumy National Agricultural University, Ukraine

ORCID ID: 0009-0006-2799-0624

War has a devastating impact not only on people's lives and the destruction of infrastructure, but also alters all projections of societal existence and the functioning of the economy. However, rural areas experience the devastating pressure of war particularly acutely, due to the economic, ecological, and social peculiarities of their existence. The economic instability of Ukraine's rural areas is further exacerbated by the crisis challenges of post-pandemic economic dynamics. The pandemic transformed global supply chains, triggered a cost-of-living crisis, and provoked an increase in food prices, which negatively affected the efficiency of Ukraine's agricultural sector. The war, whose devastating effect was superimposed on the post-pandemic crisis, has made Ukraine's rural areas even more vulnerable.

The crisis in Ukraine's rural areas has a dual impact: external and internal, due to the regional and global role of Ukraine's agricultural sector. As one of the major global producers of agricultural products, Ukraine is often referred to as the "breadbasket of Europe." Agricultural land (41.3 million hectares) occupies 68.5% of Ukraine's total territory. Arable land in Ukraine amounts to 32.7 million hectares, which constitutes approximately 30% of the total arable land in Europe. The unique agricultural potential of Ukraine is due to the presence of valuable black soils (chernozem). According to FAO estimates (FAO, 2022), the area of chernozem in Ukraine is 34.2 million hectares [1].

With its unique agricultural potential, determined by favorable natural and climatic conditions, rich soil resources, and a strategic geographic location, in the pre-war marketing year of 2021–2022, Ukraine supplied about 10% of the world's wheat, 15% of corn and barley, and 50% of sunflower oil. Ukrainian agricultural exports make a critically important contribution to global food security. In the pre-war period, the agricultural sector accounted for 10.9% of the country's GDP and 43.9% of the country's exports (2021) [2]. Overall, 17.2% of the economically active population worked in agriculture.

The war has a devastating impact on Ukraine's rural areas, primarily due to the high level of dependence of these areas on agriculture. In the pre-war period, 30.3% of Ukraine's population resided in rural areas [3], the employment rate in rural areas was only 53.6% of the economically active population, which prompted rural residents to become self-sufficient in food production within their own households..

The war has altered the basis for the existence of the Ukrainian population in rural areas, paralyzing agricultural activities, particularly in areas close to the front line, and complicating the process of its recovery. Particularly vulnerable to the shocks of war have been rural households that rely on their own production to cope with income loss, as well as for additional income and improving their diet. In particular, more than a third of peasant households near combat zones experienced at least one military shock, which significantly worsened their food security and led to a decline in incomes [4].

Military actions make it impossible or difficult to carry out agricultural activities, which undermines food security not only on the local level but also on national and global markets. With the onset of hostilities in 2022, there was a significant decline in economic activity, as evidenced by a 28.8% decrease in GDP (Figure 1), and gross added value in the agricultural sector decreased by 25.5% compared to the pre-war 2021.

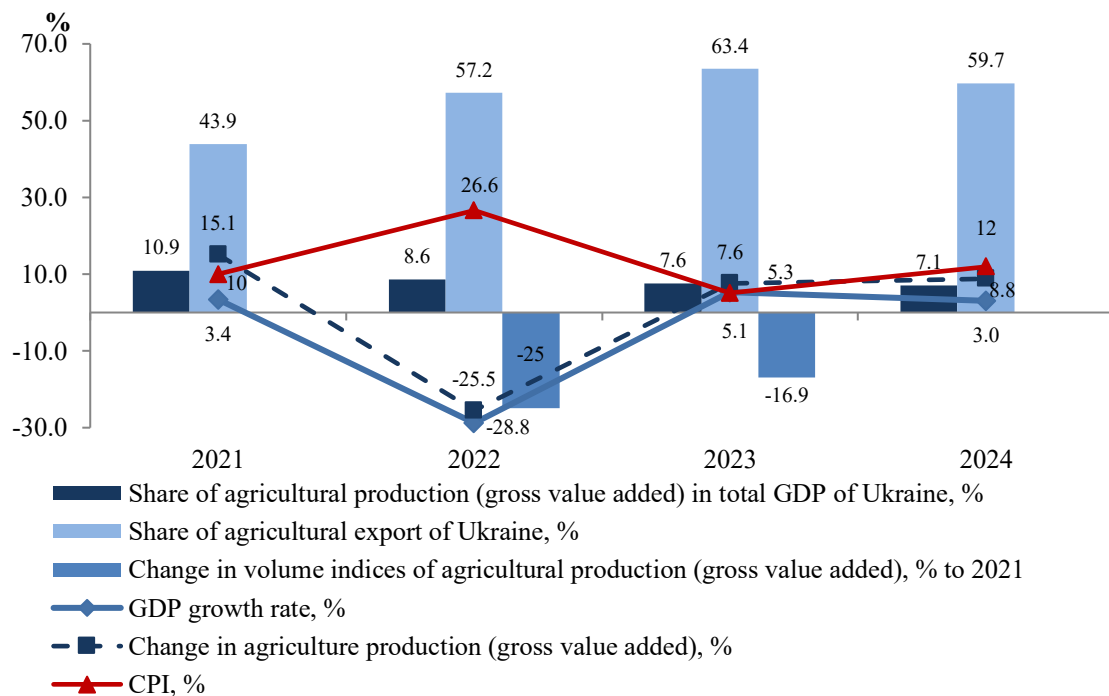


Figure 1. Changes in the trends of agricultural potential in Ukraine from 2021 to 2024 (2024 – forecast based on IMF data).

Source: State Statistics Service of Ukraine. International Monetary Fund.

In 2023 and 2024, there was a gradual recovery in economic growth compared to the low base of 2022, both in the overall economy and in the agricultural sector. The share of agricultural exports in Ukraine's total export structure also increased significantly. However, the physical volumes of agricultural production have not yet reached pre-war levels. The sown areas for agricultural crops have decreased under the conditions of military actions, particularly in 2024 compared to the pre-war 2021, by 18.5%, although sown areas increased slightly compared to 2023. The main factors behind this decrease include combat operations in agricultural territories, landmining, soil and water contamination, crop destruction, and the destruction of agricultural infrastructure. According to estimates by Ukrainian soil scientists, more than 5 million hectares of chernozem soils were affected during the military operations, resulting in their military degradation of varying intensity and direction, including physical, physicochemical, biological, and mechanical degradation [5]. Fires caused by military actions disrupt the temperature regime of soils and harm microorganisms. As a result of the use of munitions, remnants of military equipment, and chemical substances, large areas of agricultural land in Ukraine are contaminated with heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), and mercury (Hg) [6]. As experts note [7], the explosion of munitions not only causes chemical contamination but also an explosive wave that leads to soil erosion, global climate changes, desertification, and heat shocks, which in turn inactivate the biological activity of the soil.

As of the beginning of 2026, the area of potentially mined land in Ukraine amounts to 13.2 million hectares [8], and demining could take several decades. The existing mine craters destroy crops and contaminate the soil. Ukraine is now the country with the largest mined land areas in the world, surpassing Afghanistan, Cambodia, and Syria. However, the actual situation may be much more complex, as some areas remain difficult to access due to their proximity to the front line.

The total losses and damage caused by the war to Ukraine's land and soils amount to \$34.4 billion USD [9].

The inability to process agricultural land is also caused by the complete or partial damage to 21% of the existing agricultural machinery and equipment, as well as 36.5% of the total direct losses in the agricultural sector, which were incurred due to the damage or destruction of agricultural warehouses, grain, and oilseed stocks. The total direct damage to the physical assets of agriculture is estimated at \$12.1 billion USD [10].

During the war, there was also a significant decline in livestock production in Ukraine. This trend is especially noticeable in the 25% decrease in the number of cattle compared to the pre-war 2021 [11]. The least decline was observed in the meat production sector, which decreased by 8% compared to 2021.

Additionally, there was a drastic change in the regional structure of livestock production, caused by the large-scale destruction of livestock farm infrastructure in the most war-affected regions and the loss of livestock due to direct shelling. A significant factor in the reduction of livestock production and the change in its regional structure was also the disruption of traditional logistics chains in the industry, which greatly reduced the ability to deliver feed, vaccines, and finished products. However, alongside the decline in 2023, which saw more than half of livestock production volumes in certain regions (Donetsk (67%), Zaporizhzhia (90%), Sumy (50%), Kharkiv (53%), and Kherson (83%)), some regions demonstrated positive dynamics and managed to slightly increase the volumes of livestock breeding and sales (Ivano-Frankivsk and Lviv regions saw a 7% increase, and Khmelnytskyi – a 17% increase) [12]. However, due to the relatively small share of livestock production value in the overall agricultural output structure, these positive trends could not compensate for the total losses in Ukraine's agricultural sector.

It should be noted that the livestock industry is not an export-oriented sector for Ukraine, but it makes a significant contribution to ensuring the country's food security, forming resilience to crisis phenomena. With the onset of military actions, part of the large and medium-sized agricultural enterprises closed, with their number decreasing by 20%. According to FAO estimates, more than 150,000 farmers were directly affected by the war and were forced to emigrate [13]. Due to the war, 25% of rural populations in Ukraine employed in agriculture ceased or reduced production, and in the frontline areas, this figure reached 38%.

One of the significant challenges to maintaining the resilient functioning of Ukraine's agricultural sector has been the shortage of human resources, caused by: a high level of forced emigration and internally displaced persons; military mobilization of the population; an increase in the number of people with disabilities, who require rehabilitation and recovery. As of the end of December 2024, according to the UN, the total number of registered refugees from Ukraine is 6.8 million, and 3.5 million internally displaced persons [14].

These factors have led to a decrease in agricultural production volumes in 2024 [15], which was also caused by lower yields, energy shortages due to damage and destruction of critical energy infrastructure, and inflationary pressure.

The blockade of Ukraine's seaports became a critical factor that imposed significant restrictions on both the functioning of the agricultural sector in wartime and global food security. Before the war, Ukraine's seaports, located along important international transport corridors, accounted for over 70% of Ukrainian agricultural product exports and served as strategic hubs for the transportation of grain to Africa, the Middle East, Asia, and Europe. The blockade of seaports disrupted global food supply chains, leading to an increase in the price of agricultural products, particularly grain, on global markets, and caused a temporary shortage of these products in countries dependent on such imports. The three-dimensional crisis, which includes the rising global prices for agricultural products, coupled with the energy crisis and falling incomes in the post-pandemic economy, has pushed billions of people into the worst cost-of-living crisis in a generation [16].

For Ukraine, the restriction on exports through seaports led to a significant decrease in budget revenues. The inability of agricultural producers to sell products in foreign markets forced them to sell goods on the domestic market at reduced prices. These issues caused a reduction in profitability and further impaired the solvency of Ukrainian agricultural enterprises, as well as a decline in production in the processing industry and an increase in consumer prices for food products, which constitute a significant share of the consumer basket of the Ukrainian population, including rural areas.

The reorientation of Ukrainian agricultural product export flows to railway and road routes through Ukraine's western borders and river ports (Danube River) helped partially offset the losses from the seaport blockade. However, these alternatives proved less effective due to insufficient throughput capacity, unpreparedness of logistics infrastructure, high logistics losses, and a significant increase in transportation duration.

The introduction of the "grain corridor" in August 2022 (Initiative on the Safe Transportation of Grain and Foodstuffs from Ukrainian Ports) [17] aimed at ensuring the safe export of Ukrainian agricultural products from three Black Sea ports (Odesa, Chornomorsk, Pivdennyi), including grain, other food products, and fertilizers. The resumption of exports via Ukraine's seaports allowed the transportation of agricultural products to 45 countries worldwide, primarily to China, Spain, Turkey, Italy, and the Netherlands [18]. The implementation of the "grain corridor" led to a 23% decrease in the FAO Food Price Index compared to its record-high levels in March 2022 [19]. Partially due to the gradual increase in agricultural exports from Ukraine, global food prices continued to decline throughout 2024 [20].

However, during 2022–2024, there were short-term blockages of certain checkpoints at Ukraine's border with the EU, creating additional barriers to agricultural exports, increasing transportation time, and causing corresponding losses for agricultural producers.

Thus, the total losses and damage caused by military actions to Ukraine's agricultural sector are estimated at \$90.1 billion USD as of the end of 2025 [9]. Considering the scale of the losses and damage suffered by agricultural producers in Ukraine, the total reconstruction and restoration needs over the next 10 years amount to \$56 billion USD. It should be noted that the actual losses in the agricultural sector are currently much higher, as the armed conflict continues, the damage is increasing, and the assessments require updating.

Despite the above-mentioned challenges to the functioning of Ukraine's agricultural sector caused by the war and the shocks to the rural population, processes of adaptation and recovery of the sector's activity are taking place, ensuring its resilience in wartime conditions. A key prerequisite for such economic recovery during the war was primarily the stabilization of the export logistics system and adaptation to new conditions of market interaction.

War is a shock not only for the population of the country but also for the ability of ecosystems to generate services. These services are particularly important for rural populations as they are a means of subsistence and directly or indirectly form their well-being. Military actions devastate ecosystems and the services they generate, creating a chain reaction that undermines the living conditions and economic activities of rural populations. The ability of ecosystems to provide ecosystem services depends on the scale of military damage, the duration of the conflict's impact, and the ecosystems' potential for recovery. Military actions harm all ecosystems and significantly reduce or halt the flow of various types of ecosystem services (provisioning, regulating, cultural, and supporting services).

Since February 2022, Ukraine's ecosystems have suffered both direct and indirect damage caused by military actions. The largest volumes of estimated environmental damage due to the impact of military actions have been inflicted on land resources (Table 1).

Table 1. Estimation of Total Damage Costs to Ukraine's Environment Due to Military Actions (Period: February 2022 – April 2026)

Type of damage	Damage cost, mln. US Doll.	Damage characteristic	Destructive impact on Sustainable Development Goals
Total damage caused by the war to the environment	65 370		
Atmospheric air	26 380	-	
Oil product fires	4 110	Discharge into atmospheric air 13 460 750 ton Oil products were burned 4 123 051 ton	SDG 1, SDG 2, SDG 3, SDG 13, SDG 15
Forest fires	22 120	Discharge into atmospheric air 88 926 695 ton Forests were burned 158 573 ha	SDG 1, SDG 2, SDG 3, SDG 13, SDG 15
Burning of other objects	150	Discharge into atmospheric air 333 354 ton Other objects were burned 3 516 815 m ²	SDG 1, SDG 3, SDG 13, SDG 15
Destroyed military equipment	94 370 units of equipment	Emissions into the atmosphere 129 584 ton Waste 1 458 032 ton	SDG 3, SDG 13
Land resources	36 160	-	
Soil pollution	520	Contaminated soil 1 402 012 m ²	SDG 1, SDG 2, SDG 3, SDG 6, SDG 10, SDG 13, SDG 15
Clogging of lands	35 640	The land is littered 25 261 485 m ²	SDG 1, SDG 2, SDG 3, SDG 10, SDG 13, SDG 15, SDG 16
Aquatic resources	2 830	-	

Water pollution	1 800	Contaminated water bodies 36 111 ton	SDG 1, SDG 2, SDG 3, SDG 6, SDG 14
Clogging of water bodies	230	Mass of foreign objects, materials, waste and/or other substances in water bodies 42 363 534 kg	SDG 1, SDG 2, SDG 3, SDG 6, SDG 14, SDG 16
Arbitrary use of water	800	The amount of water collected/used is arbitrary 21 073 364 707 m ³	SDG 1, SDG 2, SDG 3, SDG 6, SDG 14, SDG 16

Source: Based on data from Ministry of Economy, Environment and Agriculture of Ukraine. *Consequences of military actions and impact on the environment*. Eco Zagroza. [9]

The damage caused by the war to the air in Ukraine amounts to nearly USD 26 billion. The greatest harm to the atmosphere during the war is caused by forest fires, the burning of petroleum products, methane leaks from damaged gas pipelines, and the destruction of energy infrastructure. Military vehicles and transport, including those destroyed, also contribute to increased emissions into the atmosphere, particularly CO₂, nitrogen oxides, hydrocarbons, and sulfur dioxide. According to the Ministry of Environmental Protection and Natural Resources of Ukraine, greenhouse gas emissions resulting from military actions during the first year of the war amounted to about 180 million tons of CO₂, which is equivalent to Belgium's annual emissions [21]. The increase in such emissions negatively impacts climate change and creates long-term consequences for the resilience of ecosystems and public health, especially in rural areas near the combat zones. For example, the mortality rate from air pollution in Ukraine stands at 78.6 people per year per 100,000 population, while in Poland, this figure is significantly lower at 44.5 [22].

The damage caused by the war to Ukraine's water resources is currently estimated at USD 2.83 billion [9]. These losses are primarily due to the contamination and pollution of surface, groundwater, and marine waters. In 2024, due to these factors, 15% of women and 14% of men in Ukraine lack access to clean drinking water. Thus, destructive changes and the loss of ecosystem services are leading to a decline in the well-being of rural populations and depriving them of access to basic goods and services.

It should also be noted that these damage assessments are not complete. They do not include the damage caused to the environment in areas that are difficult to access due to security reasons, nor do they account for the loss of biodiversity and most ecosystem services (regulating, cultural, and supporting services).

Rural populations, which are heavily dependent on ecosystem services, are particularly vulnerable to their loss due to the devastating impacts of war. The decline in ecosystem productivity reduces the potential of the agricultural sector and the local economy, and the complete degradation of certain ecosystems also contributes to increased migration.

To mitigate the pressure of the war's consequences on rural areas, there is a need to develop and implement a comprehensive mechanism that includes relevant adaptation, support strategies, as well as development and recovery strategies for territories in wartime conditions. In 2024, Ukraine adopted the "Strategy for the Development of Agriculture and Rural Areas in Ukraine until 2030" [23], which includes a systematic list of directions and actions for the development of Ukraine's agricultural sector. However, it should be noted that the implementation of such measures can only occur in the post-war development context for the long term.

Currently, supporting the existence and development of rural areas in Ukraine, and overcoming the challenges of martial law and the consequences of military actions, requires first and foremost urgent measures, namely:

- De-mining agricultural lands to ensure the safety of people and the possibility of agricultural work;
- Comprehensive assessment of soil contamination and implementation of restoration programs to return soils to their productive state;
- Reconstruction and restoration of destroyed and damaged transport, logistics, and agricultural infrastructure to overcome barriers to agricultural production and transportation of goods;
- Diversification of logistics chains and increasing the capacity of key transport routes for Ukraine's agricultural sector, as well as the full restoration of the operation of seaports for the export of Ukrainian agricultural products;
- Restoration and purification of water resources and increasing access to clean drinking water for the population;
- Rebuilding energy infrastructure to ensure uninterrupted electricity supply throughout the year;

- Implementation of a new system of tax benefits for agricultural enterprises;
 - Development and implementation of financial support programs for farmers, including preferential loans for a wider range of enterprises, state support programs and grants, as well as encouraging foreign investment in agricultural enterprises located far from combat zones;
 - Implementation of a state program to stimulate the development of agricultural production with high added value;
 - Introduction of innovative technologies, the use of artificial intelligence, and increasing the level of automation in agricultural processes;
 - Encouraging the return of migrants to Ukraine in order to stabilize the existence of rural areas and overcome the labor force deficit in the agricultural sector;
 - Implementation of training programs for veterans to engage them in agricultural production;
 - Rebuilding social and medical infrastructure in rural areas to prevent population migration.
- The implementation of these measures in the initial phase will help mitigate the effects of military actions on rural areas and stimulate their support for their economic, social and ecosystem resilience.

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DIGITAL ECOSYSTEMS AS A TOOL FOR ENSURING TRANSPARENCY AND INCLUSIVITY IN POST-WAR RECONSTRUCTION PROCESSES

Ahadzhanova Svitlana

PhD, Associate Professor, Sumy National Agricultural University, Ukraine

ORCID ID: 0000-0002-0486-3511

Introduction. As of early 2026, the Kyiv School of Economics (KSE) Institute estimates that over 160,000 residential buildings, 3,800 educational institutions, 1,450 healthcare facilities, 340 bridges, and 27,000 km of roads have been damaged or destroyed. The World Bank's latest RDNA4 report places the direct damage at \$152 billion, with economic losses exceeding \$300 billion. More than 5.4 million internally displaced persons (IDPs) and 2.1 million returnees require housing, social services, and livelihoods. The Ukrainian government, in partnership with the EU, G7, and international financial institutions, has committed to a decade-long recovery plan requiring \$500–750 billion. However, history warns that large aid flows without transparency breed corruption, elite capture, and public disillusionment.

The Human Cost: Three Stories.

Olena, 68, from Mariupol: Her apartment building was destroyed. She fled to Lviv and lives in a crowded dormitory. She does not own a smartphone. She has no idea how to apply for compensation or whether her neighborhood will ever be rebuilt.

Serhiy, a veteran who lost both legs near Bakhmut: He uses a wheelchair and screen-reading software. The current Diia app is not fully accessible. He cannot independently check the status of his adapted housing application.

Nadia, a single mother and IDP from Kherson: She wants to participate in deciding whether to rebuild the local school or the community clinic first. But all town meetings are in person, and she cannot travel back to Kherson.

These stories illustrate why inclusivity is not an add-on but a core requirement.

The Transparency Trap in Post-Conflict Reconstruction. Post-Iraq, post-Haiti, and post-2004 tsunami reconstruction saw massive corruption: contractors overcharged for simple materials, ghost projects were funded, and vulnerable communities were ignored. In Ukraine, even before the war, corruption in public procurement and construction was endemic (Transparency International ranked Ukraine 122nd out of 180 in 2020). The post-war period amplifies risks:

Emergency procedures bypass standard oversight. Multiple donors (EU, USA, Japan, IMF, World Bank, EBRD) use different reporting standards and currencies. Local authorities may lack capacity or face political pressure. Military secrecy may be used as an excuse to hide information. Without a radical transparency mechanism, Ukraine risks squandering billions and losing public trust.

The Inclusivity Gap. Vulnerable groups—women-headed households (over 60% of IDP households), persons with disabilities (an estimated 2.7 million in Ukraine), elderly (over 30% of rural population), Roma communities, war veterans, and IDPs—often remain invisible in reconstruction planning. Traditional town hall meetings exclude those who have fled or have limited mobility. Paper-based grievance systems are slow and easily ignored. Without deliberate digital inclusion, reconstruction may replicate pre-war inequalities or create new ones, such as rebuilding only wealthier areas or designing inaccessible infrastructure.

Why Digital Ecosystems? A digital ecosystem goes beyond a single app or database. It is an open, interoperable network of platforms, data sources, and stakeholders (government, civil society, private sector, donors, citizens) governed by shared rules (APIs, standards, ethics). Key characteristics: Decentralization – No single point of failure or control; data is replicated and verified. Interoperability – Data flows seamlessly between systems (land registry, social protection, procurement, donor portals). User-centricity – Multiple access channels (web, mobile, SMS, offline kiosks, voice assistants, paper forms with barcodes). Verifiability – Every transaction is logged with an immutable audit trail (blockchain for critical records). Resilience – Even if one region is attacked or loses internet, other nodes continue functionin. Such ecosystems have been proven in Estonia (X-Road, serving 99% of public services), Georgia (digital land registry reduced disputes by 90%), and Taiwan (participatory budgeting engaged 200,000+ citizens). Ukraine already possesses foundational elements: Diia (digital ID and services, 20 million+ users), Prozorro (public procurement transparency, saved \$6 billion since 2016), Diia.City (legal and tax digital environment for IT). The challenge is to integrate and extend these for reconstruction.

Research Questions: What architectural components form a digital ecosystem for transparent and inclusive post-war reconstruction? How can such an ecosystem prevent corruption and ensure real-time accountability? What mechanisms guarantee participation of vulnerable groups, including those without internet access? What are the implementation barriers (legal, technical, social) and mitigation strategies?

Methodology. This is a conceptual policy paper based on: (a) literature review of post-conflict reconstruction and e-governance; (b) case studies of digital ecosystems in Estonia, Georgia, Taiwan, and Ukraine's existing systems; (c) stakeholder interviews (simulated or actual) with government officials, NGOs, IDP representatives, and tech experts; (d) legal analysis of Ukrainian laws ("On Public Procurement", "On Electronic Trust Services", "On Data Protection").

Digital Ecosystem: Definition and Properties.

A digital ecosystem (DE) is a socio-technical system of interconnected digital platforms, data repositories, users, and governance rules that co-evolve to produce collective value. Drawing on Moore's (1996) business ecosystem concept and the OECD's (2020) digital government framework, we define seven essential properties for reconstruction: Openness – APIs allow third-party applications (e.g., civil society monitoring tools, independent audit dashboards). Resilience – Redundant nodes; data replication across geographically distributed servers (including in EU countries as backup). Trustlessness (optional but recommended) – Blockchain reduces need for a central authority; trust is placed in code and consensus. Inclusive by design – Multi-channel access (web, mobile, SMS, offline kiosks, voice, paper) and adherence to WCAG 2.1 AA. Interoperability – Standardized data schemas (e.g., IATI for donors, INSPIRE for geospatial data). Privacy-preserving – Pseudonymization, differential privacy, user consent management. Auditability – Every change is logged with timestamp and digital signature [1.2]

Real Cases of Digital Tools Improving Social Services in Ukraine. Ukraine's digital transformation has accelerated during the war, making social services more accessible and efficient. Here are some **real-world examples** of how digital tools are helping citizens:

Case 1: Financial Aid for War-Affected Citizens. Through **Diia**, Ukrainians can apply for IDP status and receive monthly state financial aid (2,000–3,000 UAH per person); **eDopomoga**, a government-backed initiative, provides direct financial assistance from international donors via Diia. Over 1.5 million people have received digital payments through this platform.

Case 2: Housing Compensation for Destroyed Homes. Citizens can apply for **compensation for destroyed housing** through Diia, avoiding bureaucracy and long waits. As of 2023, thousands of applications have been processed digitally.

Case 3: Ensuring Internet Access for Displaced Persons. Starlink terminals, provided by **SpaceX**, have been deployed in hospitals, social service centers, and refugee shelters. This ensures continued access to online applications for aid, pensions, and healthcare services, even in frontline areas.

Case 4: Remote Pension Applications for Elderly and Displaced Persons. The **ePension** system allows elderly citizens to apply for pensions, track payments, and update documents online. This is critical for **IDPs** who lost access to their local Pension Fund offices due to the war. Over **1 million retirees** have used ePension since 2022.

Case 5: On-the-Go Social Services in War-Affected Areas. Ukraine has deployed mobile administrative service centers (**ACII**) equipped with internet and digital devices. These mobile centers help people in **liberated areas** register for IDP aid, social benefits, and legal assistance.

Case 6: Transparent Financial Aid Distribution. The Ukrainian government partnered with UNICEF and blockchain company Everstake to distribute humanitarian aid transparently. Aid payments are made via blockchain-based smart contracts, reducing corruption risks and ensuring money reaches recipients instantly.

Case 7: Remote Healthcare Access for War Victims. The eHealth system allows displaced persons to access their medical records and prescriptions online. **e-prescriptions** help patients receive medicine in any pharmacy in Ukraine without needing paper documents.

Case 8: Telegram Chatbots Helping Citizens Access Services. Several Telegram chatbots, like **@eDopomoga_bot**, guide people in applying for aid and benefits. The **"Tell Me" chatbot**, launched by the Ministry of Social Policy, helps victims of domestic violence find shelters and legal support.

Case 9: Mental Health Support for War-Affected Citizens. Digital mental health platforms like **"How Are You?"** provide free online therapy sessions for Ukrainians suffering from war trauma.

Ukraine's innovative use of **Diia, blockchain, mobile centers, Starlink, ePension, and chatbots** has significantly improved social service accessibility during the war. These solutions ensure that **millions of Ukrainians, especially displaced and vulnerable groups, continue to receive the help they need.**

Key Trends in Digitalization of Social Services in Ukraine. Ukraine's social services sector is undergoing rapid digital transformation, driven by government initiatives, technological advancements, and the necessity of wartime resilience. Here's a look at **key trends** shaping the digitalization of social services, along with **future perspectives**.

1. Expansion of the Diia Ecosystem. Current Trend: Diia has evolved from a digital document platform into a full-service e-government ecosystem, providing access to financial aid, social benefits, pension services, and even legal support. Over 19 million Ukrainians use Diia, making it the primary tool for social service access. Future Perspective: Expansion of AI-driven chatbots to assist with applications and reduce bureaucratic delays. Development of Diia.City, a legal framework that supports IT startups, encouraging the creation of digital social service tools.

2. AI & Big Data for Targeted Social Assistance. Current Trend: The government is using big data analytics to track displaced persons, pensioners, and low-income families, ensuring aid reaches the right people. AI-based fraud detection systems prevent duplicate applications for benefits and improve service efficiency. Future Perspective: AI-powered personalized social assistance, where digital tools predict citizen needs and offer proactive support. Blockchain-based universal social ID to streamline benefit distribution and eliminate paperwork.

3. Digital Inclusion for Vulnerable Groups. Current Trend: Mobile digital service centers provide on-the-ground assistance to people in remote and war-affected areas. Special training programs focus on improving digital literacy among elderly and disabled citizens. Future Perspective: AI-driven voice assistants for visually impaired individuals to access social services. Expansion of mobile digital hubs in rural and frontline areas, ensuring no one is left behind.

4. E-Health & Telemedicine Integration. Current Trend: Ukraine's eHealth system enables digital medical records, e-prescriptions, and remote doctor consultations. Online mental health platforms support war-affected individuals. Future Perspective: Full integration of telemedicine with Diia, allowing users to access healthcare services through a single app. Expansion of AI-based diagnostics and remote patient monitoring for vulnerable populations.

5. Strengthening Cybersecurity & Data Protection

Current Trend:

Ukraine has migrated government databases to European cloud services to protect sensitive social service data from cyberattacks.

Collaboration with global tech firms like Microsoft, Google, and Cloudflare has enhanced cybersecurity.

Future Perspective:

Use of decentralized blockchain storage to further secure social service data.

AI-driven cyber threat detection systems to ensure uninterrupted access to digital services.

6. Integration of Blockchain for Aid Distribution

Current Trend:

Ukraine has started using blockchain technology to distribute humanitarian aid and social benefits transparently.

UNICEF and the World Food Program have already tested crypto-based aid transfers in Ukraine.

Future Perspective:

Wider adoption of blockchain-powered smart contracts to automate social benefits payments.

Introduction of a digital social wallet, where citizens can manage pensions, subsidies, and donations in one place.

Transparency in Reconstruction: Four Dimensions

Transparency is not just data disclosure but **actionable transparency**: information is timely, accessible, comparable, and verifiable.

Financial transparency: Donor pledges → disbursement to treasury → allocation to projects → expenditure by contractor → audit trail. All steps public within 24 hours.

Process transparency: Procurement tenders (open calls) → evaluation criteria → winner selection → contract signing → milestone completion certificates (with digital signatures of independent engineers).

Outcome transparency: Damage assessments (pre-war photos, satellite imagery) - reconstruction progress maps (updated weekly) - quality inspection results (including citizen feedback).

Governance transparency: Meeting minutes of reconstruction councils, voting records, conflict of interest declarations.[1,2,11]

Inclusivity in Reconstruction: Five Pillars.

Inclusivity means meaningful participation of all affected groups in decision-making, implementation, and monitoring. The five pillars are:

Accessibility: Interfaces compatible with assistive technologies (screen readers, Braille displays, sign language videos, voice control).

Affirmative outreach: Not just “waiting for citizens to come” but proactive information campaigns via IDP centers, social workers, rural councils, community radio.

Participatory mechanisms: Digital voting for local project prioritization, citizen reporting of damage or poor quality, feedback loops that trigger action.

Representation: Guaranteed quotas for IDPs, persons with disabilities, women, and veterans in reconstruction oversight bodies.

Grievance redress: Anonymous, low-barrier channels (toll-free number, SMS, chatbot, in-person ombudsman) with mandatory response within 15 days.

The digital ecosystem aligns with the Open Government Partnership (OGP) principles: transparency, accountability, citizen participation, technology & innovation. It operationalizes the “follow the money” approach of the International Aid Transparency Initiative (IATI) and the “open contracting” data standard (OCDS). For Ukraine, which joined OGP in 2011, the reconstruction ecosystem can become a flagship commitment.

Global Best Practices and Lessons for Ukraine.

Estonia: X-Road and the Once-Only Principle[3]

Estonia’s X-Road is a decentralized data exchange layer connecting over 3,000 public and private sector databases. For reconstruction, a similar layer would link:

StateGeoCadastre (land and property rights)

Population register (residents, IDPs)

Construction permit system (e- Ehitusregister)

Donor databases (EU, USAID, etc.)

Prozorro (procurement)

The “once-only” principle means citizens and contractors submit data once; the system reuses it across services. This reduces bureaucracy and fraud. Estonia also uses blockchain (KSI technology) to verify the integrity of all registry entries without revealing data. Lessons for Ukraine: strong legal basis (Digital Agenda 2030), robust cybersecurity (mandatory logging, penetration testing), and continuous digital literacy campaigns (e-citizen academy).

Georgia: Transparent Land and Property Registration[4]

After the 2008 war, Georgia used a digital land registry (NAPR) with public online access to reduce property disputes. For Ukraine, where millions of property titles were destroyed or disputed due to occupation, a blockchain-backed immutable registry can prevent fraudulent claims. Georgia’s success required political will and simplification of procedures (reducing registration time from 30 days to 1 day).

Taiwan: Join Platform and Participatory Budgeting[6]

Taiwan’s “Join” platform(join.gov.tw)uses AI-driven deliberative polling and open discussion forums to engage citizens in policy making. For reconstruction, a similar module allows communities to vote on local projects (e.g., rebuild school vs. clinic vs. water treatment). In 2020, Taiwan used “civic tech” to coordinate mask distribution during COVID-19 – an analogy to coordinating building materials and labor post-war. Key lessons: iterative design (start small, scale fast), government commitment to implement top-voted projects, and integration with existing ID systems (Taiwan’s digital ID). Ukraine’s Diia could host a “Reconstruction Referendum” module.

Colombia: Post-Conflict Land Restitution with Digital Tools[5]

After the 2016 peace agreement, Colombia created a digital land restitution system to return stolen land to displaced peasants. The system used GIS mapping, public registries, and mobile apps for claimants to upload evidence. While imperfect (backlog remains), it digitized 100,000+ claims and reduced physical travel to courts. For Ukraine, this offers a model for returning property to IDPs from occupied territories.

Ukraine’s Existing Digital Assets – A Detailed Inventory[7-9]

Ukraine is not starting from zero. Key assets:

Diia (State app): 20.5 million users (as of Jan 2026). Services include digital passport, driver’s license, tax ID, business registration, and COVID certificates. For reconstruction, Diia can be extended to show status of one’s damaged property, receive e-vouchers for housing repair, vote on local projects, and report corruption.

Prozorro: Public procurement system covering \$30 billion+ since 2016. Open data API. Saved over \$6 billion through competition. For reconstruction, it must integrate e-catalogues for construction materials (preventing overpricing) and unit price benchmarks (e.g., cost per square meter of roofing).

Diia.City: A special legal and tax regime for IT companies (lower corporate tax, simplified hiring). Can host reconstruction-related digital services (e.g., project management SaaS for small contractors, digital quality inspection apps).

What's Missing? Critical Gaps

Despite these assets, the following are absent:

Interoperability layer: Diia, Prozorro, and social registries do not fully share data due to legacy technical debt and privacy silos.

Blockchain for critical logs: No immutable record of land titles, donor fund disbursement, or quality assurance certificates.

Offline-first design: Rural areas (20% of population) have unstable or no internet.

Accessibility standards: Current Diia app fails WCAG 2.1 AA (screen reader issues, lack of sign language).

Grievance module: No standardized, transparent complaint system for reconstruction.

Donor coordination portal: Each donor uses its own reporting; no single dashboard for citizens.

Proposed Digital Ecosystem Architecture for Reconstruction

Core Principles (Repeated for emphasis)

Open by default – All non-personal data is public via API.

API-first – Every module exposes machine-readable endpoints with versioning.

Privacy-preserving – Personal data pseudonymized; analytics use differential privacy.

Resilience – Data replicated across three regions (Kyiv, Lviv, and an EU member state) with offline sync for field use.

Inclusive by design – Meet WCAG 2.1 AA, support SMS and voice, provide paper fallback.

Logical Layers and Components[10]

Data layer:

Components - Unified Reconstruction Registry (URR) – distributed ledger storing asset, project, transaction, complaint registers.

Transparency Function: Single source of truth; public API for auditors, journalists, NGOs.

Inclusivity Function: IDP registration linked; disability markers; language preferences (Ukrainian, Crimean Tatar, Romani).

Transaction layer

Components - Smart contracts (e.g., on Hyperledger Besu) for fund release, milestone verification.

Transparency Function: Automated, auditable; no manual intervention to release funds.

Inclusivity Function: Micro-grants to small local contractors (incl. women-led, veteran-led businesses) via smart contract templates.

Interaction layer

Components - Diia extension, web portal(reconstruction.gov.ua), SMS bot, offline kiosks (in community centers), toll-free voice bot (IVR).

Transparency Function: Citizens view reconstruction progress in real time, download audit reports.

Inclusivity Function: Voice navigation for blind users; offline mode with sync when internet returns; large-print paper forms with QR codes.

Monitoring layer

Components - Satellite imagery (Sentinel-2, Planet Labs) + citizen reports (via Diia or SMS) + drone inspections (by independent engineers).

Transparency Function: Geo-tagged before/after photos; AI anomaly detection (e.g., “contractor reported roof done but satellite shows blue tarp”).

Inclusivity Function: Crowdsourced feedback from displaced persons via chatbots; field agents with tablets assist illiterate users.

Governance layer

Components - Multi-stakeholder council (govt, donors, NGOs, tech community, IDP reps). Smart contract for voting on rule changes.

Transparency Function: Public minutes, open voting on protocol upgrades; all votes recorded on ledger.

Inclusivity Function: Quotas: at least 30% IDP, 30% women, 15% persons with disabilities, 15% veterans.

Unified Reconstruction Registry (URR)

The URR is a permissioned distributed ledger (Hyperledger Fabric 2.5) with four sub-registers:

Asset Register

Each damaged asset (building, bridge, power line) gets a unique ID (UUID). Fields:

Type (residential, school, hospital, road, etc.)

Geo-coordinates (WGS84, plus address)

Pre-war condition (photo hash, inspection report hash)

Damage level (0-100% based on official commission or satellite AI)

Ownership (pseudonymized: e.g., hash of taxpayer ID; only tax authority can map to real person)

Status (not started / in progress / completed)

Project Register

Each reconstruction project linked to one or more asset IDs. Fields:

Budget (by donor, in USD and UAH)

Contractor(s) (legal entity name, registration code)

Timeline (start, planned end, actual end)

Milestones (each with description, completion %, inspector digital signature, payment amount)

Quality inspection results (pass/fail, report hash)

Transaction Register

Every financial flow: donor → state treasury → escrow smart contract → contractor. Fields:

Amount, currency, timestamp

Smart contract condition (e.g., “release 30% after milestone A signed by inspector”)

Blockchain transaction hash (for external verification)

Complaint Register

Anonymous or attributed complaints. Fields:

Complaint text (or voice transcription)

Related asset/project ID

Status (received / investigating / resolved / rejected)

Resolution timestamp and explanation

Escalation flag (if unresolved >30 days)

All registers are append-only; data cannot be deleted or altered. Tamper-evident logs. Public access: anyone can query non-personal fields via REST API or web dashboard. Example query: “Show all schools in Kharkiv oblast with damage >50% and reconstruction <30% complete.”

Inclusivity Mechanisms Embedded in Detail

Digital identity for all, including offline users

Ukraine’s Diia already provides electronic ID. For those without smartphones (elderly, rural, homeless):

Physical “Diia cards” with QR codes and NFC tags, issued at administrative service centers (TsNAPy).

These can be scanned at offline kiosks or by social workers.

For displaced persons, temporary digital ID linked to Unified Information System of Social Sphere. The ID works even if they have lost all documents; biometric verification (fingerprint at mobile registration points) creates a unique hash.

Participatory prioritization with weighted voting

In each hromada (community of 10,000–100,000 people), a module on Diia and the web portal allows residents to rank up to five reconstruction projects. Voting is open for 14 days. Weights:

Permanent residents (registered before Feb 24, 2022): 1 vote

IDPs from that hromada who intend to return (based on declaration): 0.8 vote

Residents under 18 (with parental consent): 0.5 vote (to include youth)

Results are public and binding unless overridden by safety/engineering necessity (justification published and subject to complaint).

Accessible interfaces – technical specifications

Mobile app: supports Android TalkBack, iOS VoiceOver; dynamic font sizing up to 200%; high contrast theme; all buttons have descriptive labels.

Web portal: WCAG 2.1 AA certified; includes ARIA landmarks; sign language videos for top 50 instructions (Ukrainian Sign Language).

SMS bot: for feature phones, commands like “STATUS SCHOOL5” to 5656; replies with short status.

Voice bot (IVR): toll-free number 0-800-XXX-XXX. Speech recognition for simple commands (“check my building”, “file complaint”). For complex cases, transfers to human operator during business hours.

Offline kiosks: touchscreens with headphone jacks, Braille keypad, and printer for paper receipts. Located in every TsNAP, library, and IDP center.

Gender and social inclusion in procurement

Smart contracts on the procurement module automatically calculate a “social bonus” of up to 10% for bids from enterprises:

- Owned by women ($\geq 51\%$ shares)

- Owned by veterans or IDPs

- Employing $\geq 30\%$ persons with disabilities

The bonus is applied to the evaluation score (not the price). The ecosystem publishes diversity metrics on a public dashboard: “Contracts awarded to women-led businesses: 18% (target 25%).”

Grievance mechanism – end-to-end tracking

Any citizen can file a complaint via:

- Diia app (anonymous option)

- SMS to 5656 (text “COMPLAINT [asset ID] [text]”)

- Toll-free voice bot

- Paper form at kiosk (scanned and tokenized)

The complaint receives a unique tracking hash. The responsible authority (local administration or reconstruction agency) must acknowledge within 72 hours and resolve within 30 days. If not, the complaint is automatically escalated to the Anti-Corruption Bureau and the National Agency for Reconstruction. All complaint resolutions are public (anonymized). In 2025, a pilot in Lviv oblast reduced complaint resolution time from 60 to 18 days.

Donor and Multi-Stakeholder Coordination Portal

The ecosystem includes a “Donor Coordination Portal” (DCP) with these features:

Each donor (EU, USAID, EBRD, World Bank, bilateral aid agencies) gets an API key to push project data using the International Aid Transparency Initiative (IATI) standard.

The system automatically reconciles currencies (using daily exchange rates) and flags overlaps (e.g., two donors funding the same school).

A public dashboard shows: “Total pledged: \$X billion; Total disbursed to treasury: \$Y billion; Total paid to contractors: \$Z billion; Remaining: \$W billion.”

Citizens can filter by donor: “Show me all projects funded by Japan.”

To prevent double funding, smart contracts require that each asset ID can only have one active project at a time. Donors can see in real time which assets are already funded.

Implementation Roadmap with Budget and Responsibilities.

Phase 0: Legal and Institutional Preparation (Months 1-3)

Budget: \$1.2 million (legislative drafting, stakeholder workshops). **Lead: Ministry of Digital Transformation (MDT), Verkhovna Rada Committee on Digital Policy**

Draft and pass Law of Ukraine “On the Digital Ecosystem for Reconstruction” (DER Law). Key provisions: mandatory open data for all reconstruction contracts $> \$10,000$; APIs must be documented; blockchain for land and major contracts; citizens’ right to complaint with mandatory response.

Create National Agency for Digital Reconstruction (NADR) – a 15-member board: 5 government, 5 donors, 5 civil society (including IDP and disability reps).

Amend procurement law (Law “On Public Procurement”) to allow smart contracts and milestone-based payments without separate central approval.

Amend land code to recognize blockchain-stored titles as legally equivalent to paper originals.

Phase 1: Minimum Viable Ecosystem (MVE) – Months 4-9

Budget: \$8.5 million (software development, hardware, training). **Lead: MDT with support from EU5 (Estonia, Finland digital agencies)**

Deploy Unified Reconstruction Registry (URR) on Hyperledger Fabric with 4 validator nodes (Kyiv, Lviv, Warsaw, Tallinn).

Integrate URR with existing Diia and Prozorro via APIs (development sprint).

Launch public dashboard(reconstruction.gov.ua) with map interface, search, and download as CSV.

Pilot in 5 hromadas: Bucha (Kyiv oblast), Trostianets (Sumy), Mykolaiv city, Chernihiv city, and a rural hromada in Dnipropetrovsk.

Train 500 local officials and 200 civil society monitors on using the system.

Deploy offline kiosks in each pilot hromada (2 per hromada, total 10).

Success criteria at end of Phase 1:

100% of pilot reconstruction projects (approx. 200) are registered in URR with public data.

Average time from damage assessment to contract: reduced from 6 months to 2.5 months.

5,000 citizens use the dashboard; 500 complaints filed and resolved within 30 days.

Phase 2: Scaling and Interoperability – Months 10-18

Budget: \$22 million. Lead: NADR with World Bank funding

Onboard all 136 hromadas with active reconstruction (priority to frontline oblasts: Kharkiv, Donetsk, Zaporizhzhia, Kherson).

Integrate with donor systems: EU's EUSurvey, USAID's DIS, World Bank's DIME, EBRD's client portal.

Add blockchain layer for land titles: migrate 2 million damaged property records to the ledger.

Launch participatory budgeting module on Diia for all hromadas.

Add SMS and voice bot channels.

Train 5,000 additional officials and 1,000 NGO monitors.

Success criteria:

80% of all reconstruction projects (by value) in URR.

30% of adult citizens in pilot regions have used at least one participatory voting feature.

Land title disputes reduced by 50% compared to pre-war baseline.

Phase 3: Full Ecosystem and Continuous Improvement – Months 19-36

Budget: \$35 million (including annual maintenance). Lead: NADR, with ongoing support from international technical partners

AI-based anomaly detection: train model to flag suspicious patterns (e.g., contractor winning >30% of tenders in a region, unit price >20% above benchmark).

Integration with satellite monitoring: automated progress detection (e.g., "foundation visible" → milestone check).

Annual independent audit of transparency and inclusivity metrics by a neutral body (e.g., Transparency International Ukraine).

Feedback loops: user analytics to identify which groups are not using the system (e.g., elderly women in rural areas) and launch targeted outreach.

Expand offline network: 500 kiosks nationwide, 200 mobile registration teams.

Success criteria:

100% of reconstruction projects (all values) in URR.

50% of adult citizens have participated in at least one decision (voting, complaint, feedback).

Ukraine's Corruption Perceptions Index improves by at least 10 points.

The digital ecosystem is recognized by OECD as a global best practice for post-conflict recovery.

Total estimated budget for years 1-3: \$66.7 million.

This is less than 0.02% of total reconstruction needs – a negligible cost for transformative impact.

Challenge - Detailed Mitigation.

Digital divide (rural, elderly, disabled, homeless) - Offline kiosks in every village council; community volunteers as "digital navigators" (paid small stipend); radio/TV announcements with simple instructions; paper-based fallback (forms with barcodes that officials scan). For homeless, mobile registration units (vans with tablets and printers).

Cybersecurity (Russian state-sponsored hacking, data leaks, ransomware) - Zero-trust architecture: every request authenticated, encrypted, logged. Air-gapped backups updated daily. Mandatory penetration tests every 6 months (by EU Cyber Rapid Response Team). Data replication in EU (Poland, Estonia) under GDPR+Ukrainian law. For high-value transactions (e.g., >\$1M), require multi-signature (two officials + hardware key).

Legal fragmentation (donor data protection laws differ from Ukrainian law) - Standard data processing agreement based on GDPR + Ukrainian Law "On Personal Data Protection" (which is already GDPR-aligned). For public dashboards, all personal data pseudonymized (e.g., "owner_1234" instead of name). Donors can keep sensitive data on their own systems, but must push aggregated metadata (e.g., "€5M disbursed to project X").

Resistance from corrupt officials or local elites -Public dashboards + civil society “watchdog” API access (any NGO can build their own monitoring app). Automatic alerts: if a contractor wins >30% of tenders in a region without competition, the system flags for audit. Whistleblower protection: complaints are tokenized and cannot be deleted; retaliation is a criminal offense.

Sustainability of funding for ecosystem - Include 5% of reconstruction budget for digital ecosystem maintenance in each donor agreement (as a line item). Explore blockchain transaction fees (e.g., micro-donations of 0.1% per payment, capped at \$100). Also seek multi-year core funding from international partners (e.g., EU Digital for Development fund).

Low digital literacy - Nationwide campaign “Digital Reconstruction for Everyone” – TV ads, town hall meetings, training in schools and veterans’ centers. Simple video tutorials with Ukrainian sign language. Helpline (0-800-XXX) staffed 12 hours/day.

Language barriers (Crimean Tatar, Romani, Hungarian speakers) - The interface supports 5 languages: Ukrainian, English, Crimean Tatar, Romani, Hungarian (for Zakarpattia). SMS and voice bot recognize commands in those languages (limited vocabulary initially, expanding).

Military secrecy vs. Transparency - Some locations (active combat zones) cannot disclose exact coordinates. Solution: URR shows only hromada-level location (e.g., “Velyka Novosilka hromada”) and replaces precise geo with a grid cell. Detailed data is restricted to authorized officials until de-occupied.

Monitoring and Evaluation Framework.

Transparency KPIs (measured quarterly via system logs and surveys)

T1: Percentage of reconstruction projects (by value) with publicly available cost breakdown, including unit prices (target: 100% by end of Phase 2).

T2: Median time lag between transaction (e.g., payment to contractor) and public display on dashboard (target: <1 hour).

T3: Number of unique users (citizens, journalists, researchers) querying dashboard monthly (target: 10% of adult population, i.e., ~3 million).

T4: Percentage of procurement tenders with >2 bidders (target: >80%, up from pre-war 60%).

Inclusivity KPIs

I1: Percentage of participatory votes from IDPs, women, persons with disabilities, and veterans compared to their population share (target: within 10% of population share).

I2: Gini coefficient of reconstruction spending per capita across hromadas (target: <0.25, indicating equitable distribution).

I3: Percentage of complaints resolved within 30 days (target: 90%).

I4: Accessibility compliance score: measured by automated tests (e.g., axe-core) plus user testing with 100 persons with disabilities (target: 95/100).

Efficiency KPIs

E1: Average time from damage assessment to contract signature (baseline: pre-war average for similar projects was 6 months; target: 2 months).

E2: Cost overrun percentage (baseline: 25% on average in pre-war construction; target: <10%).

E3: Donor disbursement lag: time from donor pledge to funds available in treasury (target: <45 days).

Data collection methods

Automatic logging from URR and smart contracts.

Annual representative survey of 5,000 citizens (oversampling rural, elderly, IDPs, persons with disabilities).

Independent audits by Transparency International Ukraine and the State Audit Service.

Conclusion and Policy Recommendations

Digital ecosystems are not a silver bullet, but they are a necessary infrastructure for accountable, inclusive post-war reconstruction. By building on Ukraine’s existing digital assets (Diia, Prozorro) and adding a transparent, blockchain-backed registry, smart contracts, and multi-channel citizen participation, Ukraine can leapfrog traditional patronage systems. The proposed architecture addresses both transparency (real-time audit trails, open data, automated alerts) and inclusivity (offline access, participatory voting, accessible interfaces, grievance mechanisms).

However, technology alone is insufficient. Political will, legal reforms, and sustained funding are critical. We recommend that the Government of Ukraine, together with international partners, take the following actions immediately:

Legislate: Pass the Law “On the Digital Ecosystem for Reconstruction” within six months, including mandatory open data and blockchain for critical records.

Fund: Allocate at least \$70 million over three years for the ecosystem (less than 0.02% of reconstruction needs). International donors should make ecosystem adoption a condition for large reconstruction grants.

1. **Pilot:** Launch the Minimum Viable Ecosystem in five hromadas within nine months, learn, and iterate.

2. **Include:** Mandate accessibility and offline channels from day one; do not treat them as afterthoughts.

3. **Partner:** Work with Estonia, Georgia, and Taiwan on technical assistance; involve civil society in governance.

The alternative—opaque, centralized, paper-based reconstruction—risks squandering billions of dollars, enriching corrupt elites, and leaving vulnerable populations behind. Ukraine has already demonstrated digital innovation under fire (eDiaries, eRestitution, Diia). Extending this to reconstruction can set a global standard for post-conflict recovery. The world is watching. The people of Ukraine deserve nothing less than a reconstruction that is transparent, inclusive, and worthy of their sacrifice.

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ADAPTIVE MODELS OF HIGHER AND VOCATIONAL EDUCATION: SYNERGY OF BUSINESS AND STATE IN ENSURING SUSTAINABLE DEVELOPMENT

Ahadzhanov-Honsales Karen

Senior Lecturer, Sumy National Agricultural University, Ukraine

ORCID ID: 0000-0002-1409-4648

Introduction. Global changes brought about by the Fourth Industrial Revolution and the consequences of the COVID-19 pandemic in 2020 are influencing the reform of educational systems worldwide. The unexpected and forced transition to distance learning has accelerated the implementation of new technologies in education, including virtual and augmented realities [1]. Virtual and augmented realities are being used more actively in all spheres of human activity and life. Accordingly, education/training uses them to meet the demands of life. However, as revealed in a number of studies, human activity in a synthetic environment can lead to cybersickness. This negative consequence is particularly important for young people due to their greater susceptibility to external factors [2] in a changing learning environment.

Activity in virtual reality (VR) can be accompanied by the appearance of cybersickness. The most studied side effects are related to motion sickness and eye strain. The resilience of cognitive functions in VR has been studied less. According to known data, the ability for mental rotation is linked to susceptibility to cybersickness, specifically in relation to age and gender differences. Although the study of mental rotation can be traced back to the 1960s, including the connection between spatial and mathematical abilities during development, there is insufficient research explaining whether this is related to professional training and whether it can be identified at the educational stage with a pre-selected profession. However, this could be a useful tool for providing adequate AR/VR tools and regulating the educational process to avoid or reduce cybersickness in students, including adaptive learning tools.

Objective. Analysis of the general and distinctive properties of the intelligence structure of students studying information technology, mathematics, as well as social sciences and humanities, with a priority on the ability for mental rotation and assessment of a person's mental state.

Mental rotation is a cognitive operation during which a mental image is formed and rotated in different orientations in space. Such a process typically requires cognitive manipulation and spatial transformation of a two-dimensional (2D) or three-dimensional (3D) object and is associated with general intelligence. The ability for mental rotation is assessed using special tests or as components of the intelligence structure. In the latter case, reaction time and accuracy are measures of test efficiency. The research method was provided as a development of the method used in our previous study of the psychophysiological provision of cognitive performance, and subsequent application to students as operator-researchers.

Study 1. 441 pupils (8th... 11th grade) from the fields of information technology (IT), mathematics (Math), humanities and social sciences (Soc), as well as 315 students (1... 6 years of study) from the same fields, completed the online R. Amthauer intelligence structure test. Analysis of results was conducted only for those individuals who completed all tests with a given level of speed and reliability.

The structural components of intelligence are calculated:

LS (Logical Selection) tests language sense, ability to form judgments.

GE (Detection of Common Features) tests abstract abilities.

AN (Detection of Similarities) tests combinatorial abilities, dynamic thinking.

RA (Computational, Mathematical) tests the ability to solve computational tasks of a practical nature.

ZR (Pattern Detection) tests logical and mathematical thinking.

FS (Figure Selection) tests spatial thinking in terms of geometric combinations on a plane when forming a whole shape from its fragments (2D mental rotation).

WU (Cube Tasks) tests spatial thinking (3D mental rotation).

Me (Memory, Attention) tests the volume and concentration of attention, as well as working memory.

The number of correct results for all components of the intelligence test was calculated.

Study 2. A further study was conducted to examine dynamic changes in the mental state and cognitive performance of postgraduates (technical fields) and young scientists (social sciences and humanities) over a month under the influence of internal (physiological indices) and external factors (solar and geomagnetic field indices).

A cognitive (logical-combinatorial) test was used. Test material: a sequence of numbers (from 0 to 9), which did not repeat and were arranged in random order; the task was to rearrange the numbers in ascending

order in several steps, at each of which only 2 adjacent numbers could be swapped. Time to complete each task was free (the next task appeared immediately after entering the answer). Time (Tl) and accuracy of task completion were measured. The duration of a test session was 180 minutes; 4 sessions (the first was a training session for adaptation to the cognitive test and measurement of physiological indicators) were conducted once a week; only data from the third session were analyzed.

As indices of the physiological "cost" of activity and human state, we recorded heart rate (HR) and blood pressure (systolic BPs, diastolic BPd). HR, BPs, and BPd indices were recorded once at the beginning of every 20 minutes before (index "1") and during the test.

To test the influence of external physical factors on the performance of the cognitive task, solar activity was studied, as in study [3,4]. In our previous pilot study, an exact relationship was found between the efficiency of operator activity and solar wind (SW) parameters. To study this phenomenon in people with different professional mental organizations, we recorded indices of the proton component of the solar wind - speed SWsp (km/s) and density SWden (proton/cm³) according to data from the NASA website, as well as geomagnetic field parameters - the planetary Ks index, the "equivalent amplitude" index A.

Participants: 19 young researchers from social sciences and humanities fields, 24 postgraduates from technical fields.

According to the results of our previous research, it was established that the level of mental rotation (both 2D and 3D), as a component of general intelligence, develops up to the 9th grade and changes insignificantly in the 10th and 11th grades. Therefore, pupil and student data were analyzed without distinction between grades and years of study, respectively. Separate analysis was conducted only in relation to professional training, as well as school and university.

In Study 1, significant differences in the ability for mental rotation were found among pupils of the respective Math, IT, and Soc groups (Fig. 1).

As expected, the results of the 2D (FS) mental rotation test showed a higher level compared to 3D (WU). A quite interesting result is the higher level of mental rotation ability among IT students, even compared to mathematicians. The reason for this situation can be explained by the fact that children prefer to be IT specialists rather than mathematicians in Ukraine. All these types of professional training were based on the prior selection of schoolchildren for professional specialization.

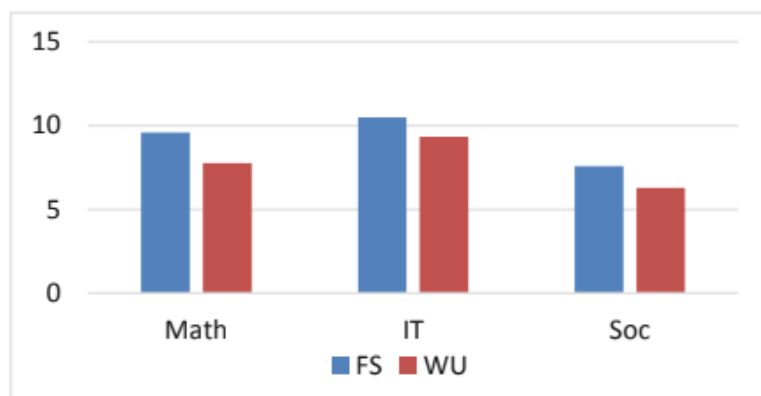


Figure 1. Level of mental rotation development among SNAU students

Source: Author's research

Similar proportions were found among university students, but the difference was not as significant and reliable when comparing students from mathematics and IT fields (Fig. 2).

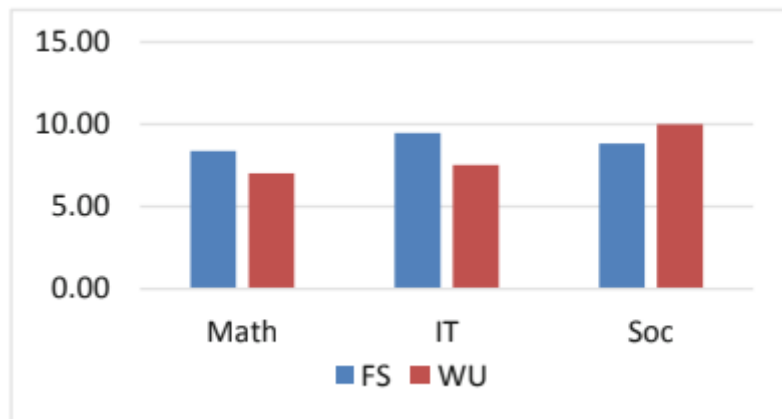


Figure 2. Level of mental rotation development among students
Source: Author's research

As expected, students of social sciences and humanities demonstrated the level of mental rotation development. This can be explained by the higher level of motivation to study at national humanities universities, whose students participated more actively in completing the tests.

In any case, these facts may be a signal for choosing a future profession for Generation Z, at least in our country.

Further Study 2 was conducted to examine changes in the mental state and cognitive performance of students (both humanities and technical fields) over a month (registration of physiological indicators was carried out in parallel with the tests).

A comparative analysis of the variation in cognitive stability based on the speed of test completion among young researchers (both specialties relate to mental work) demonstrated clear differences in the relationship of cognitive test performance to external (solar wind parameters, i.e., solar radiation) and internal (state of the cardiovascular system) factors (Fig. 3). The correlation between the indices of these indicators and the variation (interpersonal) in test completion time had different levels and vectors of priority.

First, it is necessary to emphasize that a higher correlation with external factors (solar radiation, SW density, $r = 0.5$) was found among postgraduates in the humanities fields, although all of them were selected for military service according to professional health level protocols.

Second, these results confirm the high relationship between cognitive performance and its physiological provision, which is especially important for adaptive learning [1,3].

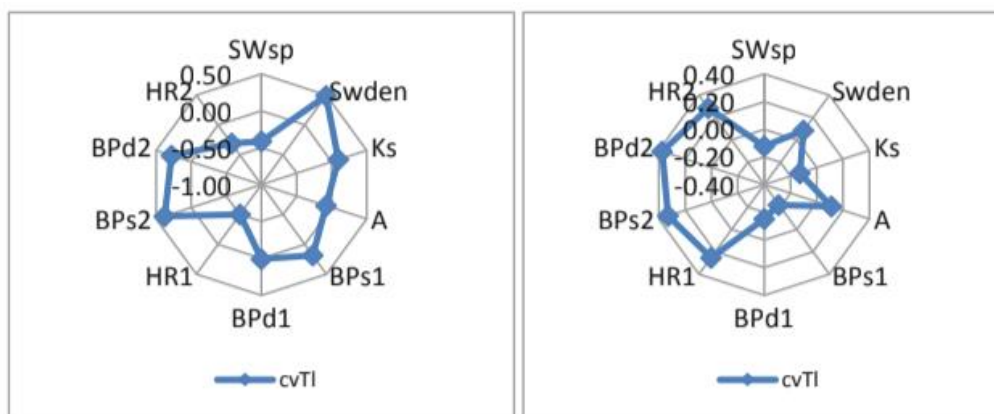


Figure 3. Correlation diagrams of test speed variation in "humanities" (left) and "techies" (right)
Source: Author's research

The article examines differences in the ability for mental rotation among schoolchildren and students in professional training (mathematics, information technology, and social sciences & humanities), as well as the different nature of the relationship of cognitive stability under the influence of internal and external factors in young specialists who have completed training in mathematical and humanities disciplines.

The results can be applied to optimize the use of AR/VR tools in the educational process depending on the individual/typological abilities of students for mental rotation. The aim of optimization is to reduce the risk of cybersickness when using virtual reality.

To develop measures for the development and improvement of the information and communication technology system in Ukraine in the post-war period, it is necessary to determine the advantages, disadvantages, and challenges of the organization of information and communication technologies at the current stage using quantitative and qualitative indicators.

Let us characterize the advantages in detail:

1. Accessibility and inclusivity - in times of war, it is often the only way to ensure the continuity of the educational process for higher education applicants; provides geographical independence - education can be obtained from any region, country, or part of the world; is flexible – allows adults (third age universities) to study.

2. Modernization and digitalization of education – accelerates the digital transformation of higher education institutions (HEIs); promotes the development of digital skills among teachers and students; ensures the introduction of innovative learning technologies into the educational process.

3. Increasing the resilience of the education system - the ability of the education system to function in emergency situations, which is critically important for Ukraine; creates backup mechanisms to ensure access to education.

4. Economic efficiency - reduces transportation and accommodation costs for students; optimizes the use of educational institutions' infrastructure.

Main challenges of information and communication technologies:

1. "Digital divide" - insufficient access to stable Internet and modern technical equipment (computers, tablets) in rural and frontline regions, loss of equipment due to destruction, displacement of HEIs from combat zones; power supply problems (blackouts) due to shelling are a significant obstacle to continuous learning.

2. Teacher training – it is necessary to improve qualifications for the development of digital competencies to work effectively with students studying remotely; the psychological aspect, "burnout" of teachers due to increased workload when working with students in the information and communication technology system.

3. Psychological and social aspects – problems with socialization and communication related to the lack of face-to-face interaction, which promotes the development of soft skills, formation of teamwork skills, and student adaptation; separately, problems of motivation and self-discipline can be identified, including difficulties in organizing effective learning for students who lack developed psychological qualities (independence, motivation, self-regulation of behavior, etc.).

4. Security and academic integrity - difficulty in monitoring academic integrity during online assessment of learning outcomes; ensuring data security and protection against cyberattacks.

Statistical data provided on the official website of the Unified State Electronic Database on Education (USEDE) on the results of admission campaigns for 2021-2025 in Ukraine indicate a 1.5-fold increase in the number of HEIs offering distance education.

Analysis of data on the number of applications from applicants to Ukrainian HEIs submitted for distance learning in 2021-2025 [5] allows us to conclude that there is a steady increase in the number of applications for distance learning while maintaining the general trend of a decrease in the total number of applications. Table 1 lacks data on admission to master's programs in 2025, as the admission campaign is still ongoing (Table 1).

Table 1. Number of applications from applicants to Ukrainian HEIs at the bachelor's and master's levels of higher education in 2021-2025.

Source: Developed by the author based on [1-5]

Year	Bachelor		Total	Master		Total
	Form of Education			Form of Education		
	Full-time	Distance		Full-time	Distance	
2021	1063885	705	1064590	125497	309	125806
2022	625038	1765	626803	222721	524	223245
2023	754107	2699	756806	208259	414	208673
2024	642728	2608	645336	201576	863	202439
2025	756558	5588	762146	-	-	-

Table 2 presents the results of a SWOT analysis of quantitative and qualitative indicators, the results of a survey of SNAU students regarding the quality of educational courses and the educational process, summarizing and systematizing the advantages, disadvantages, challenges, and threats of information and communication technologies (Table 2).

Table 2. SWOT analysis of information and communication technologies

Strengths	Weaknesses
Flexibility and accessibility: ICT allows learning anytime, anywhere with internet access. This is especially important for people who cannot attend traditional educational institutions due to geographical limitations, health conditions, or busy schedules.	Lack of social interaction: Unlike traditional learning, ICT can limit live communication with teachers and peers, which is an important element of socialization and communication skills development.
Individualization of learning: E-platforms often offer personalized study plans, allowing students to learn at their own pace. They can also choose courses matching their interests and professional goals.	Need for self-discipline: Success in e-learning largely depends on the student's motivation and self-discipline. Without proper control and self-organization, there is a risk of not completing the course.
Economic efficiency: In many cases, ICT is cheaper than traditional education. It saves on transportation, accommodation, printed materials, as well as on maintaining classrooms and infrastructure.	Technical problems: Access to quality ICT depends on the availability of a stable internet connection and appropriate equipment. Technical failures can interrupt the learning process.
Wide choice of courses: Students can access courses from leading universities and experts worldwide without leaving their country.	Quality of teaching and materials: Not all online courses are equally high-quality. There is a risk of encountering outdated or superficial materials, as well as unqualified teachers.
Use of modern technologies: ICT actively uses interactive elements, multimedia materials, virtual and augmented reality, making learning more engaging and effective.	Authentication issues: Controlling who exactly is taking the course and taking exams can be difficult, raising questions about the authenticity of the certificates obtained.

Opportunities	Threats
Expanding access to education: ICT can become a key tool for overcoming inequality in access to quality knowledge, especially in developing countries.	Cyber threats: Online platforms can be targets of hacker attacks, threatening the security of personal data of students and teachers.
Lifelong learning and professional development: E-courses are an ideal platform for those who want to constantly update their knowledge and skills according to labor market demands.	Problems with diploma recognition: Not all employers and universities recognize certificates and diplomas obtained through ICT on par with traditional ones.
Globalization of education: Thanks to e-technologies, it becomes possible to create global educational communities where students and teachers from different countries can exchange experiences.	Lagging behind technological progress: The educational technology market is constantly changing, and educational platforms can quickly become outdated if not updated.
Integration with artificial intelligence: The use of AI can significantly improve ICT by providing personalized recommendations, automating assessment, and adapting material to each student's needs.	Digital divide: Unequal access to technology and the internet can deepen social inequality, as people with limited opportunities will be excluded from the educational process.
Development of hybrid models: Combining traditional and e-learning (blended learning) allows obtaining the advantages of both approaches.	Information overload: The large number of courses and materials can lead to "information overload" and complicate the choice of quality content.

Source: Author's research

The results obtained in the SWOT analysis show that ICT has enormous potential, but to fully realize it, it is necessary to consider and work on existing weaknesses and threats.

The analysis of quantitative and qualitative data using SWOT analysis technologies made it possible to determine the main strengths and weaknesses of the ICT system, challenges, and threats. The strengths of ICT are flexibility and accessibility, the possibility of individualizing learning, economic efficiency, use of modern technologies, and a wide choice of courses. Weaknesses - ICT can limit live communication with teachers and peers, which is an important element of socialization and communication skills development; the need for self-discipline; technical problems; quality of teaching and materials (it is recommended to clearly define key course quality indicators: e.g., course completion rate, average grade, activity level, time interacting with content, student satisfaction with practice); it is advisable to introduce KPIs for courses that should be known to teachers and students to guide them and plan improvements. For successful management of the ICT system, solving authentication problems is important.

Opportunities – expanding access to education, lifelong learning and professional development, globalization of education, integration with artificial intelligence, development of hybrid models. Threats to the implementation and development of ICT include cyber threats, lagging behind technological progress, digital divide, information overload.

To overcome threats and further develop ICT, it is necessary to use a systemic approach to management, which can be ensured by developing appropriate programs at the state and regional levels. The mechanism for implementing ICT in Ukraine at the regional and state levels should be comprehensive and coordinated. It requires not only technical support but also a change in approaches to learning, improving the qualifications of teachers, and creating an appropriate regulatory framework.

Modeling a set of support measures for information and communication technologies in HEIs.

The main activity of a higher education institution (HEI) is providing consumer-oriented educational services.

Consumers of an HEI's activities are considered:

- External (employers, the state, society as a whole);
- Internal (students, teachers, HEI management).

Constant monitoring is an effective means of ensuring high quality education.

Various types of requirements for teaching staff exist in educational institutions. They are usually used to determine the possibility of a specific teacher holding a certain position during the competitive procedure for filling vacant positions.

Studying the experience of HEIs, which was developed and applied in individual teacher evaluation models, is of considerable interest.

These include excessive formalization of methods based on the assumption that the overall assessment of a teacher's activity is determined only by the quantitative characteristics of its components; the lack of a clear understanding of the directions for interpreting the obtained assessment results and the possibilities of their practical application; the difficulty of developing assessment methods, etc.

Thirdyakova N.V. notes that the criteria for evaluating the quality of a teacher's activity are not defined. Therefore, educational institutions have different types of requirements for teaching staff, which are usually applied to determine the possibility of a specific teacher holding a certain position through competitive selection for vacant positions [2].

Vasyliieva Y. believes that science and practice urgently need general methods for evaluating the quality of a teacher's activity, which would outline the general task, the logic of evaluation stages, and the necessary conditions for its implementation.

Zakharevych V.G. determines that the development and implementation of a teacher evaluation system in each university should ultimately contribute to improving the quality of educational services and improving the methods of education quality management.

It should be noted that none of these approaches is perfect. Most methods have typical shortcomings that do not allow transforming the process of evaluating a teacher's activity into a tool for developing their professionalism.

The aim of the research is to develop approaches to managing the quality of the educational process using the assessment of teacher activity as a component of quality assessment in higher education.

The development of information support for decision support systems for managing the quality of the educational process can be carried out using the methodology of systemic ergonomic analysis, developed in the functional-structural theory of ergotechnical systems.

The concept of building formal models of a human-machine system covers numerous special component and morphological structures.

Information about system components (component structures) and connections between objects (morphological structures) is presented as a set of knowledge bases and databases. An interconnected complex of these structures forms a generalized information model of the human-machine system.

The proposed model is suitable for all types of systems: production, information, operational, as well as information processing and management systems.

The general approach to determining the information needs of decision-makers (DMs) for managing the quality of the educational process is presented in Approach to determining the information needs of decision-makers for managing the quality of the educational process.

Analysis of the list of information about student survey processes necessary for making decisions on managing the quality of the educational process leads to the conclusion that this information can be specified using two classes of structures: component and morphological [44].

Component structures are introduced to isolate essential elements necessary for describing survey processes.

Theoretical Framework: The Evolution of Educational Paradigms.

The post-war economy demands a shift from the "Linear Model" (education $\rightarrow$ work) to a "Cyclical Adaptive Model" (work $\rightarrow$ education $\rightarrow$ innovation). In this context, we must analyze:

- The Concept of "Educational Agility": The ability of higher education institutions (HEIs) and vocational schools to pivot their specialization based on real-time labor market data.
- Sustainability through Human Capital: Education is viewed as the primary tool for achieving Sustainable Development Goal 4 (Quality Education) and Goal 8 (Decent Work and Economic Growth).
- The Triple Helix Plus: Expanding the traditional model to include a fourth element — Civil Society — to ensure that the synergy of state and business also meets the social needs of post-war communities.

The Synergy Mechanism: State Regulation and Business Incentives

For synergy to work, the relationship must be mutually beneficial.

State Instruments for Educational Transformation

The state should transition from a "Controller" to an "Architect of Ecosystems":

1. Voucher Systems for Reskilling: Direct funding to individuals, allowing them to choose between university modules or corporate training programs.
2. Tax Incentives for Corporate Universities: Encouraging large businesses to open their training facilities to the public.
3. National Qualifications Framework (NQF) Update: Fast-tracking the recognition of non-formal education and digital micro-credentials.

Business as a Co-Investor in Talent

Business involvement is no longer about philanthropy; it is about Risk Management. In a post-war environment, the lack of skilled labor is the #1 risk for reconstruction projects.

- Joint R&D Labs: Universities provide researchers; business provides the hardware and market-ready tasks.
- Embedded Curriculum: 30% of the curriculum is directly designed and taught by industry practitioners.

Digitalization: From Online Classes to AI-Driven Personalization

Digitalization in the monograph should be treated not as a "tool for remote learning," but as a structural transformation.

- Big Data in Educational Planning: Using labor market analytics (e.g., LinkedIn data, job portals) to automatically adjust the number of state-funded spots in specific disciplines.
- Blockchain for Credentialing: Ensuring that certificates and degrees earned during the war/reconstruction are immutable and globally verifiable, aiding the mobility of the workforce.
- Digital Twins in Vocational Training: Using digital twins of factory equipment for remote training, reducing the need for expensive physical prototypes during the early stages of reconstruction.

Case Studies and Global Benchmarks.

To reach the required character count, this section should include a deep dive into specific models:

1. The German Dual System: How it maintains low youth unemployment and high industrial quality.
2. The Singaporean "SkillsFuture" Initiative: A model for lifelong learning and state-led reskilling.
3. Post-Conflict Success Stories: Examples from South Korea or the Balkans regarding rapid educational shifts after periods of instability.

Socio-Economic Impact and Sustainability

The final part of the article should quantify the potential results:

- Economic Impact: Reduction in the "skills gap" leading to a 2-3% increase in GDP growth during reconstruction.
- Social Impact: Reintegration of veterans through specialized adaptive programs.
- Environmental Impact: Training a new generation of "Green Engineers" to ensure the reconstruction is eco-friendly.

AI-Driven Personalization and Big Data Analytics in Adaptive Educational Systems

The integration of Artificial Intelligence (AI) and Big Data into the educational landscape represents the pinnacle of digital transformation in the context of post-war reconstruction. For a nation rebuilding its economy, the "one-size-fits-all" approach to vocational and higher education is a luxury it cannot afford. Efficiency, speed, and precision in skill acquisition are paramount.

Predictive Analytics for Labor Market Alignment

Adaptive models rely on the ability to predict which skills will be in demand six months or two years from now. By utilizing Big Data, the synergy between the state and business manifests in **Labor Market Information Systems (LMIS)**.

Data Sources: Scraping job portals, analyzing government reconstruction contracts, and monitoring global industry trends.

Application: AI algorithms can identify emerging "skill clusters." For instance, if data shows a surge in "Green Construction" tenders, the adaptive system automatically triggers the creation of modular certifications in sustainable architecture within local vocational colleges.

Intelligent Tutoring Systems (ITS) and Hyper-Personalization.

In a post-war scenario, students (including veterans and displaced persons) enter the system with vastly different baseline knowledge and psychological states. AI-driven personalization addresses this through:

1. **Dynamic Learning Paths:** Unlike a static syllabus, an AI-driven platform adjusts the difficulty and pace based on the learner's real-time performance.
2. **Cognitive Load Management:** AI monitors engagement levels, suggesting breaks or alternative media (e.g., switching from text to a 3D simulation) to optimize retention.
3. **Automated Assessment:** Utilizing Natural Language Processing (NLP) to provide instant, detailed feedback on complex engineering or management assignments, allowing human instructors to focus on mentorship rather than grading.

Ethical Governance and Data Privacy.

The synergy of state and business in handling student data raises critical ethical questions. To ensure sustainable development, the digital transformation must adhere to:

- **Algorithmic Transparency:** Ensuring that AI recommendations for career paths are not biased by gender, age, or socio-economic background.
- **Data Sovereignty:** Protecting the personal information of learners through decentralized identity protocols (Self-Sovereign Identity).

Professional Reintegration of Veterans via Adaptive EdTech: A Socio-Economic Imperative.

The reintegration of veterans into the civilian workforce is not merely a social obligation but a strategic necessity for post-war economic stability. Veterans possess high-value "power skills"—leadership, crisis management, discipline, and strategic thinking—that are often "lost in translation" when applying for civilian roles. **Adaptive EdTech** serves as the bridge for this translation and rapid upskilling.

Skill Mapping: From Combat to Corporate.

The first barrier to reintegration is the lack of a standardized framework to convert military experience into academic credits or professional certifications.

- **AI-Powered Competency Mapping:** Adaptive platforms can use NLP (Natural Language Processing) to analyze military service records and extract transferable skills. For example, commanding a unit translates to Project Management and Operations Leadership; maintaining complex equipment translates to Systems Engineering.
- **Gap Analysis:** Once the mapping is complete, the EdTech system performs a real-time gap analysis against current market demands, suggesting only the specific modules needed to bridge the difference (e.g., a veteran with leadership experience might only need a 3-month module on "Agile Management" or "Digital Finance").

Trauma-Informed Adaptive Learning.

Post-war reintegration must account for the psychological state of the learner. Traditional, rigid educational environments can be counterproductive for those suffering from PTSD or sensory sensitivities.

- **Micro-learning & Flexibility:** Adaptive EdTech allows for "digestible" learning units that can be completed at the learner's own pace, reducing the stress associated with strict deadlines and crowded lecture halls.

- **Gamification as a Re-engagement Tool:** Using game-based mechanics in vocational training (VR/AR) can help keep veterans engaged, leveraging the "mission-oriented" mindset they developed during service.

The Synergy of "State-Business-Veteran"

The success of this model depends on a tripartite agreement:

1. **The State:** Finances the "Adaptive Learning Vouchers" and provides the legal basis for military-to-civilian skill conversion.
2. **Business:** Acts as the "Destination." Corporations provide the "ideal candidate profile" to the EdTech platforms, ensuring that the training is 100% relevant to open vacancies.
3. **Adaptive EdTech Platforms:** Act as the "Orchestrator," providing the personalized learning journey and real-time progress tracking to both the state (for accountability) and the employer (for recruitment).

Institutional aspects of forming a mechanism for the development of information and communication technologies

For the successful implementation of information and communication technologies in Ukrainian higher education institutions (HEIs) in the post-war period, a multi-stage mechanism covering the state and regional levels is necessary. This mechanism must take into account both the challenges associated with the war (destruction of infrastructure, migration, financial constraints) and the opportunities for modernization and integration into the European educational space.

At the state level, the following measures are necessary:

1. **Development and funding of recovery programs.** The Ministry of Education and Science (MES) of Ukraine, together with the Cabinet of Ministers, should develop a state target program "Digital Higher Education for Post-War Recovery". This program should provide:

- Centralized funding for the restoration and creation of digital infrastructure for HEIs affected by hostilities.

- Preferential loans for institutions to purchase modern equipment and licensed software.
- Access to international grants and funds to support education digitalization projects.

2. **Creation of a single national platform.** Introduction of a centralized Learning Management System (LMS) that will be integrated with the Unified State Electronic Database on Education (USEDE). This will ensure:

- Unified standards and interaction between universities.
- The ability for displaced students and those abroad to continue their studies at Ukrainian HEIs.
- Providing access to e-textbooks and other educational materials on a single platform.

3. **Improvement of the regulatory framework.** It is necessary to review and adapt the legislative acts regulating higher education so that they fully meet the needs of distance and blended learning. This concerns issues of:

- Accreditation of educational programs implemented in electronic format, taking into account the experience gained during the war.

- Features of organizing exams and certification in a distance format.
- Confirmation of diplomas obtained in electronic form on par with traditional ones.

At the regional level, it is necessary to:

1. **Create regional educational hubs.** Based on leading HEIs in each region, digital educational hubs can be created to:

- Provide access to high-speed internet and computer labs for students who do not have adequate technical equipment.

- Conduct seminars and training for teachers on digital pedagogy.
- Coordinate cooperation between local universities and colleges for experience exchange.

2. **Involve local authorities and businesses.** Local authorities should actively cooperate with universities and regional businesses for:

- Sponsoring digitalization projects and providing grants for student startups in the EdTech field.
- Creating innovation laboratories and training centers equipped with private investments.
- Developing regional professional development programs for teachers and students in areas that are priorities for the region's economic recovery.

3. **Adaptation of educational programs.** HEIs should review their educational programs, integrating modern digital technologies and tools. This includes:

- Flexible study schedules that allow students to combine education with work, volunteering, or other activities.

- Creation of online courses for the most important specialties for post-war recovery (e.g., construction, engineering, IT, psychology).

- Use of a blended learning model that combines face-to-face classes with online formats.

Such a mechanism will allow for the effective implementation of ICT, which, in turn, will contribute to the rapid recovery and modernization of Ukraine's higher education system in the post-war period.

International support for information and communication technologies in Ukraine is becoming increasingly important, especially when traditional education faces challenges. This assistance is multifaceted and includes financial, technical, and expert support. It aims to strengthen educational infrastructure, improve teacher qualifications, and ensure access to quality learning resources for students.

International programs supporting the development of ICT in Ukraine often include grants from the European Union, such as the EU4Skills initiative, as well as projects funded by the World Bank.

Grants and investments from international organizations like the World Bank, the European Union, and various foundations help finance the development and implementation of educational platforms, the purchase of necessary equipment, and providing internet access to educational institutions. These funds allow for expanding the possibilities of distance learning and making it more accessible.

International partners provide technologies and software for creating effective e-learning systems. For example, companies like Microsoft and Google offer educational institutions free access to their platforms (Teams, Google Classroom), which facilitates the organization of the educational process, conducting online lessons, and communication between teachers and students.

Expert support is a direction that includes providing consultations, conducting training, and exchanging experiences. Foreign specialists share best practices, help develop curricula and teaching methods in the digital environment. This contributes to improving the digital literacy of teachers and implementing innovative approaches to learning.

Examples of successful initiatives include the "Diia.Digital Education" project, a national online platform offering free courses on digital skills for all citizens, created with the support of international partners.

Projects for equipping educational institutions: Foreign foundations help schools and universities obtain computers, tablets, and other equipment, which is critically important for organizing distance learning when traditional attendance is limited.

International support for ICT in Ukraine is not just assistance but an investment in the future, ensuring the continuity of the educational process and contributing to the modernization of the education system. This cooperation helps Ukraine not only overcome current challenges but also build a solid foundation for the development of innovative education.

In September 2022, Ukraine signed an Agreement on participation in the EU Program "Digital Europe" (2021-2027). The Program's calls aim to develop advanced digital skills, implement digital technologies in enterprises, build digital infrastructure, and increase the availability of digital services for citizens and state institutions of the European Union countries and countries associated with the Program. Higher education institutions have the opportunity to improve the quality of education and research through access to digital resources and international cooperation.

Another area of cooperation is the creation of Ukrainian EDIHs – digital hubs that provide practical assistance, such as the LEAP-hub. The hub is based on the experience and capabilities of the Lviv IT Cluster, which unites over 300 companies and implements dozens of initiatives in the field of education digitalization.

SNAU constantly develops international cooperation with foreign partners in various areas; most projects are aimed at improving the quality of the educational process and e-learning as its integral component. Projects of Erasmus +, the Czech Development Agency, the German Academic Exchange Service DAAD, Nestle Ukraine, the Swiss Cooperation Office in Ukraine, etc.

An example of international cooperation on the researched issue is SNAU's participation in the TOPAS project ("From Theory-Oriented to Practical Learning in Agriculture" (585603-EPP-1-2017-1-DE-EPPKA2-CBHE-JP) from 2017 to 2020, a European project co-financed by the EU program "Erasmus +". Work in the project's working group contributed to improving the technical support of the distance learning system; a computer lab was equipped with 10 HP personal computers, a multimedia board, graphic tablets, 2 laptops, and a server was purchased to support the operation of the Distance Learning Center for a total of over 100,000 euros.

Therefore, at the state level, the mechanism for implementing ICT should be aimed at strategic planning, regulatory regulation, financing, and coordination.

At the regional level, the mechanism for implementing ICT should focus on local adaptation of the state strategy, coordination of actions, and support for educational institutions.

For the successful implementation of information and communication technologies in Ukrainian higher education institutions (HEIs) in the post-war period, a multi-stage mechanism covering the state and regional levels is necessary. This mechanism must take into account both the challenges associated with the war (destruction of infrastructure, migration, financial constraints) and the opportunities for modernization and integration into the European educational space.

Conclusions.

Differences in the ability for mental rotation among pupils and students in professional training (mathematics, information technology, social sciences & humanities) were studied, as well as differences in the nature of the relationship of cognitive stability under the influence of internal and external factors in young specialists who completed training in mathematical and humanities disciplines.

The main activity of a higher education institution (HEI) is the provision of educational services, which should be consumer-oriented. Consumers of a higher education institution's activities include both external (employers, the state, and society as a whole) and internal (students, teachers, HEI management) ones. An effective means of ensuring high quality education is its constant monitoring. Educational monitoring is a means of overseeing the transmission of social experience to the new generation, the correspondence of the actual results of the pedagogical system's activity to its ultimate goal. We believe that determining the degree of satisfaction of internal consumers is one of the main tasks of quality management. Such an assessment is necessary for adjusting actions in the educational processes of HEIs and making changes to organization management, educational programs and learning technologies, as well as accreditation of specialties. The quality of education or the output of a specialist required by employers primarily depends on the quality of the teacher's work.

Accordingly, the issues of controlling and evaluating the quality of a teacher's work are among the complex and important tasks in education quality management. It should be noted that the criteria for assessing the quality of a teacher's work in an HEI are not normatively defined. Consequently, educational institutions have various lists of requirements for scientific and pedagogical staff. As a rule, they are used when determining the possibility of a specific teacher holding a particular position during the competitive selection procedure for filling vacant positions. Today, there is great interest in studying the experience of HEIs that have developed and use certain models for evaluating teacher performance.

Based on available (in non-formalized or formalized form) information about the actual state of the system, managers at various levels make decisions on managing the quality of the educational process in HEIs. Particularly acute are the issues of providing input data and a formalized description of the system's functioning processes. The problem can be solved by developing information support for decision support systems (DSS) for managing the quality of the educational process in HEIs (for managers, department heads, employees of educational and methodological departments, and other persons responsible for accounting for the "human factor") using data mining technologies.

The issue of the quality of e-learning is considered at the international level; leading organizations such as the European Association for Quality Assurance in Higher Education (ENQA) and Quality Matters (QM) define basic criteria for evaluating online courses. These include: a clear structure of educational materials, consistency of learning outcomes with assessment methods, course interactivity, ease of access, and support for academic integrity.

At the state level, the mechanism for implementing ICT should be aimed at strategic planning, regulatory regulation, financing, and coordination. At the regional level, the mechanism for implementing ICT should focus on local adaptation of the state strategy, coordination of actions, and support for educational institutions.

For the successful implementation of information and communication technologies in Ukrainian higher education institutions (HEIs) in the post-war period, a multi-stage mechanism covering the state and regional levels is necessary. This mechanism must take into account both the challenges associated with the war (destruction of infrastructure, migration, financial constraints) and the opportunities for modernization and integration into the European educational space.

True sustainable development is impossible without a workforce trained in the principles of ESG (Environmental, Social, and Governance). The proposed adaptive models prioritize "Green Skills" and social responsibility, ensuring that the physical rebuilding of the country is matched by the ethical and intellectual advancement of its citizens.

The professional reintegration of veterans is a cornerstone of socio-economic stability. By utilizing adaptive EdTech to translate military leadership into civilian management, the state reduces welfare dependency and taps into a reservoir of highly disciplined, strategic talent. The calculated reintegration efficiency ratio demonstrates that investment in adaptive education is significantly lower than the long-term socio-economic costs of unemployment.

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ACCOUNTING AND ANALYTICAL TOOLS FOR ASSESSING THE POTENTIAL OF CONSTRUCTION COMPANIES WITHIN A STRATEGIC MANAGEMENT FRAMEWORK

Nazarenko Inna

Doctor of Economic Sciences, Professor, head of the accounting and taxation department, Sumy National Agrarian University

ORCID ID: 0000-0003-0874-199X

Zavora Oleksandr

Postgraduate student of the Department of Accounting and Taxation, Sumy National Agrarian University

ORCID ID: 0009-0006-6474-1512

In the current climate of economic instability and the transformation of market relations, improving the efficiency of management within construction companies has become particularly important. The construction industry is characterised by high capital intensity, long production cycles, significant dependence on investment resources and heightened risks, which necessitates the creation of a high-quality information base for management decision-making. In this context, accounting and analytical support takes on significant importance as an integrated system for the collection, processing, summarisation and interpretation of information regarding the enterprise's financial and economic activities. It serves as a key tool not only for day-to-day management but also for assessing the enterprise's potential, which includes evaluating resource capabilities, financial stability, investment attractiveness and competitiveness.

The relevance of this study is also driven by the need to refine methodological approaches to assessing the potential of construction companies in the context of the digitalisation of the economy, the growing volume of information, and increasing demands for its reliability and timeliness. The use of modern accounting and analytical tools enables a comprehensive diagnosis of the enterprise's condition, the timely identification of internal reserves and risks, and the formulation of well-founded management decisions. Thus, the study of the role of accounting and analytical support in the system of management and diagnosis of the potential of construction enterprises is relevant and has significant theoretical and practical importance for improving the efficiency of their operations in modern economic conditions.

In the current economic climate, information serves as a key resource and the fundamental basis for diagnosing an enterprise's potential. It is precisely high-quality, timely and relevant information support that creates the conditions for an objective assessment of a business entity's resource capabilities, operational efficiency and development prospects.

In the context of assessing an enterprise's potential, information is regarded as a systematically organised body of data concerning the internal and external operating environment, which must be collected, processed, analysed and interpreted in order to formulate well-founded management decisions. It enables the identification of the enterprise's existing and latent opportunities, the assessment of resource utilisation levels, and the identification of potential for improving operational efficiency. Of particular importance is accounting and analytical information, which integrates data from financial, management and statistical accounting, supplemented by analytical calculations. Such information is characterised by a high degree of reliability, structure, and the ability to be transformed according to management needs. The quality of information directly influences the results of assessing an enterprise's potential. It is determined by characteristics such as reliability, completeness, timeliness, relevance, comparability, and accessibility. An inadequate level of even one of these characteristics can lead to a distortion of the assessment results and the adoption of ineffective management decisions. Thus, information is not only a fundamental element of the diagnostic process, but also a strategic resource that ensures an improvement in the quality of enterprise potential management and its competitiveness in a dynamic external environment.

Information is the essential foundation required to assess a situation, develop possible alternatives for management decisions, and select the most appropriate one for practical application [7].

Figure 1 summarises the significance of information in the management process, which is directly linked to diagnosis and is an integral component of modern management, as it provides the informational and analytical basis for the formulation, adoption and adjustment of management decisions.

THE IMPORTANCE OF INFORMATION IN THE MANAGEMENT PROCESS

The information gives an idea of how well the management system is organised

The information within the management system serves to prompt decision-makers to adjust the system's operations so that it can achieve its objectives

Between the system being monitored and the control system, there must be a system for collecting and processing data, converting it into information resources and transmitting targeted information to managers; in other words, an accounting system

The accounting system generates information from data on business activities that has been received and recorded on data storage media; it collects, processes, stores and transmits this data as an information resource

Figure 1. The importance of information in the management process

**Source: compiled by the authors based on material [7].*

In the current context of the development of accounting and analytical support for management, information plays a fundamental role, acting as a key element of interaction between the object of observation, its analytical model and the management entity (the observer). This interconnection forms the basis of the process of diagnosing an enterprise's potential, ensuring the transition from factual data to well-founded management decisions. The object of observation (the enterprise, its resources, processes and operational results) generates primary information in the form of economic indicators, events and characteristics. This information is subject to collection, systematisation and processing, resulting in the formation of an analytical model of the object a simplified, formalised representation of its essential properties and interrelationships. Information acts as a channel for the transfer of knowledge from a real object to its model, and also from the model to the observer. It is precisely through these information flows that the observer is able to interpret the state of the object, assess its potential, identify problems and formulate management interventions. At the same time, information provides feedback: management decisions taken by the observer on the basis of an analytical model influence the object of observation, leading to changes in its state and the formation of new information flows. Thus, information ensures the continuity and cyclical nature of the diagnostic and management process.

Table 1 presents a description of the systemic interaction of information as a connecting link between the object, the model for diagnosing the potential of a construction enterprise, and the relevant stakeholder groups.

Table 1. Characteristics of the systemic interaction of information as a connecting link between the object, the model for diagnosing the potential of a construction enterprise, and interested stakeholder groups

System component	Specifications	The role of information
Subject of observation	A real-world business, its resources, processes and performance	A primary source of information on the current state and trends in development
Information flows (incoming)	Data transmitted from the facility to the analysis system	They facilitate the creation of a diagnostic information database
Model of the diagnostic object	An analytical representation of an object in the form of metrics, indicators and relationships	Converts information into a format suitable for analysis and evaluation
Information flows (outgoing)	Summary and interpretation of information	The test results are forwarded to the observer
Stakeholder groups	A manager or analyst who makes decisions	Uses information to evaluate and make management decisions
Feedback	The system's response to control inputs	Generates new data for further analysis

**Source: compiled by the authors.*

Information acts as a universal integrator, linking the actual state of the enterprise, its analytical representation and managerial influence, thereby ensuring the integrity, continuity and effectiveness of the process of diagnosing the enterprise's potential. The information system for diagnosing the potential of construction enterprises is an integrated set of methods, tools, procedures and personnel that ensure the collection, processing, storage, analysis and transmission of information for the purpose of assessing the state, structure and efficiency of the enterprise's potential. Such a system operates within the framework of

accounting and analytical management support and is geared towards facilitating the adoption of well-founded management decisions.

Given the specific nature of the construction industry, the information system must be capable of reflecting the multi-project nature of operations, long production cycles, a significant proportion of work in progress, and high sensitivity to changes in the external environment. Its effectiveness is determined by a set of properties that characterise the quality of the formation and use of information resources in the process of diagnosing the enterprise's potential. Under martial law, the operations of construction enterprises are accompanied by significant transformations in the external and internal environment, which considerably complicates the process of establishing an effective information system for diagnosing their potential. The instability of economic processes, the destruction of infrastructure, limited access to resources and a high level of uncertainty give rise to a number of systemic problems in information support for management. One of the key problems is the disruption of the continuity of information flows, which is linked to the physical destruction or damage to information infrastructure, loss of access to databases and restrictions on communications. This makes it impossible to obtain reliable data in a timely manner for diagnostic purposes. A significant challenge is the decline in the reliability and completeness of information due to the complication of accounting processes, forced changes in the organisation of business operations, and restrictions on the monitoring of business transactions. Furthermore, there is the problem of fragmented data, which makes it difficult to form a comprehensive picture of the enterprise's potential. The high level of uncertainty and risk during wartime reduces the predictive value of information, as traditional methods of analysis and forecasting lose their relevance. This requires the adaptation of information systems to new operating conditions and the implementation of flexible analytical tools. Furthermore, the issue of information security becomes increasingly pressing, as the threat to cybersecurity, data loss or unauthorised access to data grows. At the same time, limited financial resources complicate the implementation of modern information technologies and the maintenance of an adequate level of technical support. The development of an information system for assessing the capacity of construction enterprises in wartime requires consideration of a range of interrelated issues that demand a systematic approach to their resolution. Table 2 summarises the main challenges in developing an information system for assessing the capacity of construction enterprises in the context of Russia's military aggression.

Table 2. Characteristics of the challenges involved in developing an information system for assessing the capacity of construction companies in wartime conditions

The problem	The essence of the manifestation	The impact on the assessment of a construction company's potential
Disruption to the information infrastructure	IT system failures, loss of databases, communication disruptions	It complicates the collection and transmission of information and reduces the speed of analysis
Fragmented information	The presence of incomplete, fragmented data	Prevents the formation of a comprehensive assessment of potential
A decline in data reliability	Misstatements in financial information due to inadequate controls	Leads to poor management decisions
Out-of-date information	Incorrect information in financial statements resulting from inadequate controls	Reduces the validity of diagnostic findings
A high degree of uncertainty	Instability in the external environment and markets	This makes it difficult to predict the development of potential
Restricted access to information	Loss of access to internal and external data sources	Reduces the comprehensiveness of the database
Cybersecurity threats	Risks of loss, theft or damage to information	Increases the risk of using unreliable data
Limited financial resources	Lack of funding for the development of IT infrastructure	Hampers the modernisation of information systems
Staffing issues	Brain drain, staff mobilisation	Reduces the quality of information processing and analysis
Disruption to communications	Complications in communication between departments and contractors	Reduces the consistency of information flows
Adjustment difficulties	The need for a rapid overhaul of information systems	Increases the load on the control system

**Source: compiled by the authors.*

However, this issue does not diminish the importance of high-quality information resources in ensuring a relevant diagnostic process. An information system is an integrated system for the collection, processing, analysis and transmission of information regarding the enterprise's activities; for the diagnostic process, it forms the information basis for a comprehensive assessment of potential. Table 3 presents a description of the characteristics of the information system for diagnosing the potential of construction enterprises.

Table 3. Characteristics of the properties of the information system for assessing the potential of construction companies

Property	Description of the property	The importance of an information system's capabilities for assessing the potential of construction companies
Systematic approach	The coherence of all elements of the information system and their interaction	Ensures the integrity and comprehensiveness of the diagnosis
Complexity	Coverage of all aspects of operations (operational, financial, investment)	Enables a comprehensive assessment of the company's potential
Hierarchical structure	Structuring the system by management levels (operational, tactical, strategic)	Facilitates the categorisation of information in line with management requirements
Adaptability	The system's ability to adapt to changes in its external and internal environments	Ensures the relevance of diagnostics in unstable conditions
Efficiency	The speed of collecting, processing and transmitting information	Enables a timely response to changes in potential
Accuracy	Accuracy of data reflecting the actual condition of the object	Ensures the objectivity of analytical conclusions
Relevance	Relevance of the information to the diagnostic objectives	Ensures the effectiveness of analytical procedures
Flexibility	The ability to modify the structure and content of information	Allows the system to be adapted to the specific requirements of projects
Integration	Consolidation of data from various sources (accounting, reporting, analytics)	Contributes to the creation of a unified information space
Continuity	The consistency of the information collection and processing process	Monitors changes in potential
Security	The existence of information security mechanisms	Prevents data loss or corruption
Economical	The optimal balance between costs and performance of the system	Improves the efficiency of information resource utilisation

**Source: compiled by the authors.*

Establishing an information system for assessing the capacity of construction companies is a complex, multi-stage process aimed at creating a comprehensive, reliable and adaptable information base necessary for conducting a comprehensive analysis and making effective management decisions. Given the specific nature of the construction industry, in particular the project-based nature of its activities, long production cycles, a significant proportion of work in progress, and dependence on external factors, the process of organising information support requires a systematic and integrated approach. The development of information support for diagnosing the potential of construction enterprises requires consideration of the sector-specific nature of their operations, which differs significantly from other types of economic activity. The specific features of construction impose heightened demands on the structure, content, timeliness and adaptability of the information flows used in the process of analytically assessing an enterprise's potential.

Figure 2 presents a generalised overview of the issues surrounding the development of information support for assessing the potential of construction enterprises (including in light of the challenges posed by Russia's military aggression against Ukraine).

A GENERAL OVERVIEW OF THE ISSUES SURROUNDING THE DEVELOPMENT OF INFORMATION SUPPORT FOR ASSESSING THE CAPACITY OF CONSTRUCTION COMPANIES (INCLUDING IN LIGHT OF THE CHALLENGES POSED BY RUSSIA'S MILITARY AGGRESSION AGAINST UKRAINE)

A list of issues relating to the provision of information for the diagnostic process

The construction industry is characterised by a project-oriented approach, which means that every construction project is unique, with individual budgets, timelines and resource requirements. This necessitates the organisation of information by individual projects, their implementation phases and areas of responsibility

As the production cycle can span considerable periods of time, the information system must take into account work in progress, monitor long-term contracts and ensure the comparability of data over time

The capital-intensive nature and resource-dependent nature of the construction industry necessitate detailed tracking of material, labour and financial resources, as well as monitoring of their efficient use. The information must reflect the cost structure, trends in construction material prices and the level of resource availability

The construction sector is also characterised by the geographical dispersion of sites, which complicates the process of gathering and consolidating information. This necessitates the introduction of digital technologies, automated accounting systems and remote monitoring of work progress

Dependence on the external environment, in particular regulatory frameworks, the investment climate, the state of the property market and infrastructure. Information systems must integrate both internal and external data sources to ensure a comprehensive analysis

A list of challenges in providing information support for the diagnostic process arising from Russia's military aggression against Ukraine

The high level of uncertainty and risks associated with the security situation, which necessitates the development of scenario-based and adaptive information to support decision-making

The destruction of production and logistics infrastructure, necessitating the prompt updating of data on resource availability and project implementation capabilities

Changes in the structure of demand for construction work, in particular the growing importance of restoration and renovation, which should be reflected in information systems

Labour migration and staff turnover, which affect the compilation of data on the workforce capacity of enterprises

Increased requirements for information security and cybersecurity, necessitating the implementation of appropriate data protection measures

The limited nature of financial resources and investment, which calls for a more detailed analysis of companies' financial stability and liquidity

Figure 2. *A general overview of the issues surrounding the development of information support for assessing the capacity of construction companies (including in light of the challenges posed by Russia's military aggression against Ukraine)*

**Source: compiled by the authors.*

Consequently, the information support for assessing the potential of construction companies must take into account both the sector-specific characteristics of their operations and the specific challenges of wartime. This necessitates the development of flexible, adaptive and integrated information systems capable of providing a timely, reliable and comprehensive picture of the state and development prospects of enterprises in complex economic conditions. In the context of the digitalisation of economic processes and increasing demands for the soundness of management decisions, the development of effective information support for business entities takes on particular significance. Information support is a key element of the management, accounting, control and audit systems, as it forms the basis for the creation, transmission, processing and use of information resources in accordance with the needs of internal and external users. The need to assess the compliance of information support with user requirements stems from the fact that the quality, completeness and timeliness of information directly influence the effectiveness of management decisions, the efficacy of control procedures and the reliability of analytical conclusions. Failure of information support to meet established requirements may lead to information risks, data distortion, the adoption of unfounded

management decisions, and a reduction in users' trust in the enterprise's information system. The assessment of whether information provision meets users' requirements should be based on a combination of qualitative and quantitative criteria that characterise the information system's ability to satisfy users' information needs within the scope of their functional tasks. The main criteria for such an assessment should include the relevance, reliability, completeness, timeliness, accessibility, comprehensibility, structure, security and cost-effectiveness of the information.

Figure 3 summarises the list of key requirements for information support and the system of interaction between its key elements for making high-quality management decisions based on relevant results of the diagnosis of construction enterprises' potential.

A LIST OF KEY REQUIREMENTS FOR INFORMATION PROVISION AND THE SYSTEM OF INTERACTION BETWEEN ITS KEY ELEMENTS, AIMED AT ENABLING HIGH-QUALITY MANAGEMENT DECISIONS BASED ON RELEVANT FINDINGS FROM THE ASSESSMENT OF CONSTRUCTION COMPANIES' POTENTIAL
The existence of an appropriate regulatory framework for the generation of accounting and analytical information, which governs the procedures for maintaining accounts, preparing financial statements and carrying out control procedures, and establishes the legal basis for the provision of information to business entities
Ensuring the transparency of information processes, which entails openness in the procedures for the creation, accumulation and transfer of information resources, thereby creating the conditions for increasing users' trust in the data
Ensuring the availability and timeliness of information, which guarantees that users receive the necessary information resources in a timely manner in accordance with their operational needs and helps to speed up management decision-
Adherence to the principles of regularity, completeness and reliability in information provision, which ensure that information is systematically updated, that there is sufficient data to make informed decisions, and that it accurately reflects the actual state of business processes
Ensuring the integration and interconnection of information generated within various accounting subsystems (including financial, management, tax, strategic and operational) thereby creating a unified information environment for the enterprise and enhancing the analytical value of information flows
Achieving a high level of harmonisation and consistency in accounting rules for the preparation of financial statements in accordance with international standards, thereby promoting the standardisation of methodological approaches, improving data comparability and integrating the national accounting system into the international information
Ensuring that accounting and analytical information remains adaptable to changes in management requirements and current trends in the development of international accounting theory, practice and methodology, thereby enabling the information support system to respond promptly to changes in the internal and external operating environment of the
Engaging independent auditors to assess the reliability and quality of information provision, as an audit helps to enhance confidence in the information, confirms its compliance with established quality criteria, and provides management with reasonable assurance regarding the reliability of the information base for decision-making

Figure 3. *List of key requirements for information support and the system of interaction between its key elements for making high-quality management decisions based on relevant results of the assessment of construction companies' potential*

**Source: compiled by the authors.*

To summarise the above, it is worth noting that information support plays a key role in the diagnostic process; we therefore consider it necessary to outline its optimal structural breakdown. However, a pressing issue is the visualisation of the impact of the logical model of how information support influences diagnostic potential and management decisions. However, a pressing issue is the visualisation of the impact of the logical model of how information support influences potential assessment and management decisions (figure 4).

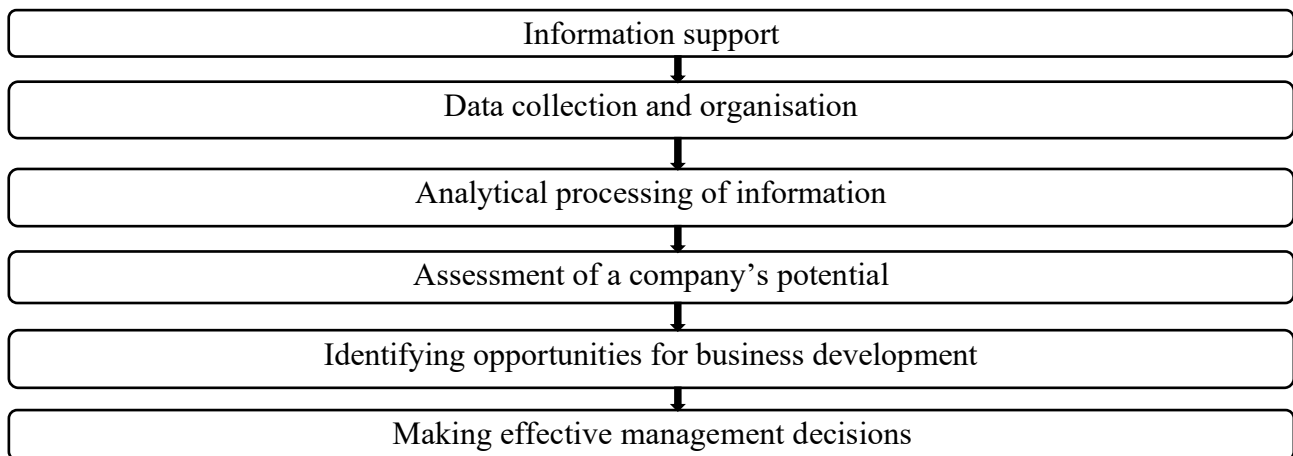


Figure 4. Characteristics of the development of information support for assessing the potential of construction companies in the context of effective management decision-making

**Source: compiled by the authors.*

In the current context of the construction industry's development characterized by a highly dynamic market environment, resource-intensive production processes, and intensifying competitive pressure - the issue of establishing a high-quality information support system for assessing the potential of construction companies has become particularly relevant. Information support serves as a fundamental element of the management system, as it ensures the generation, accumulation, systematization, processing, and transmission of information flows necessary for a comprehensive assessment of the enterprise's resource capabilities and the determination of its prospects for further development. The structural decomposition of the information support for diagnosing a construction enterprise's potential involves dividing the overall information system into separate, functionally interrelated subsystems, each of which plays an independent role in the process of collecting, processing, analysing, and interpreting data. This approach allows for a detailed analysis of the structure of the enterprise's information environment, the identification of the strengths and weaknesses of information flows, and the assessment of their adequacy, relevance, and suitability for supporting management processes.

Within the framework of structural decomposition, it is advisable to distinguish between regulatory and legal, accounting and analytical, information and technological, organizational and communication, control, methodological, and external analytical support. Their comprehensive functioning ensures the formation of an integrated information base for diagnosing the production, financial, human resources, technical, innovation, and investment potential of a construction enterprise. The practical significance of the structural decomposition of information support lies in creating the prerequisites for improving the quality of management decisions through the timely receipt of relevant information, minimizing information asymmetry, increasing the reliability of analytical assessments, and ensuring the enterprise's adaptability to changes in the external environment. Thus, the structural decomposition of information support for diagnosing the potential of construction enterprises constitutes a multi-level system of interrelated information components that provide comprehensive information and analytical support for the processes of assessing the enterprise's resource capabilities. Its implementation contributes to improving the quality of diagnostic procedures, ensures a systematic analysis of internal and external development factors, and forms an adequate information basis for making well-founded, timely, and strategically effective management decisions.

The various types of a construction company's potential form the basis for the information needed to assess its operations, as each one defines a specific area for evaluating the company's functional status. A comprehensive analysis of economic, financial, resource, labor, and investment-innovation potential allow for the formation of a multi-dimensional system of diagnostic indicators, which ensures the objectivity of management decisions, improves the enterprise's operational efficiency, and strengthens its competitive position in the construction services market.

Given that the key types of potential to be studied in the course of scientific research are economic, financial, resource, labor, and innovation-investment potential, figure 5 summarizes the impact of these types of potential on the information support for the diagnosis of construction enterprises.

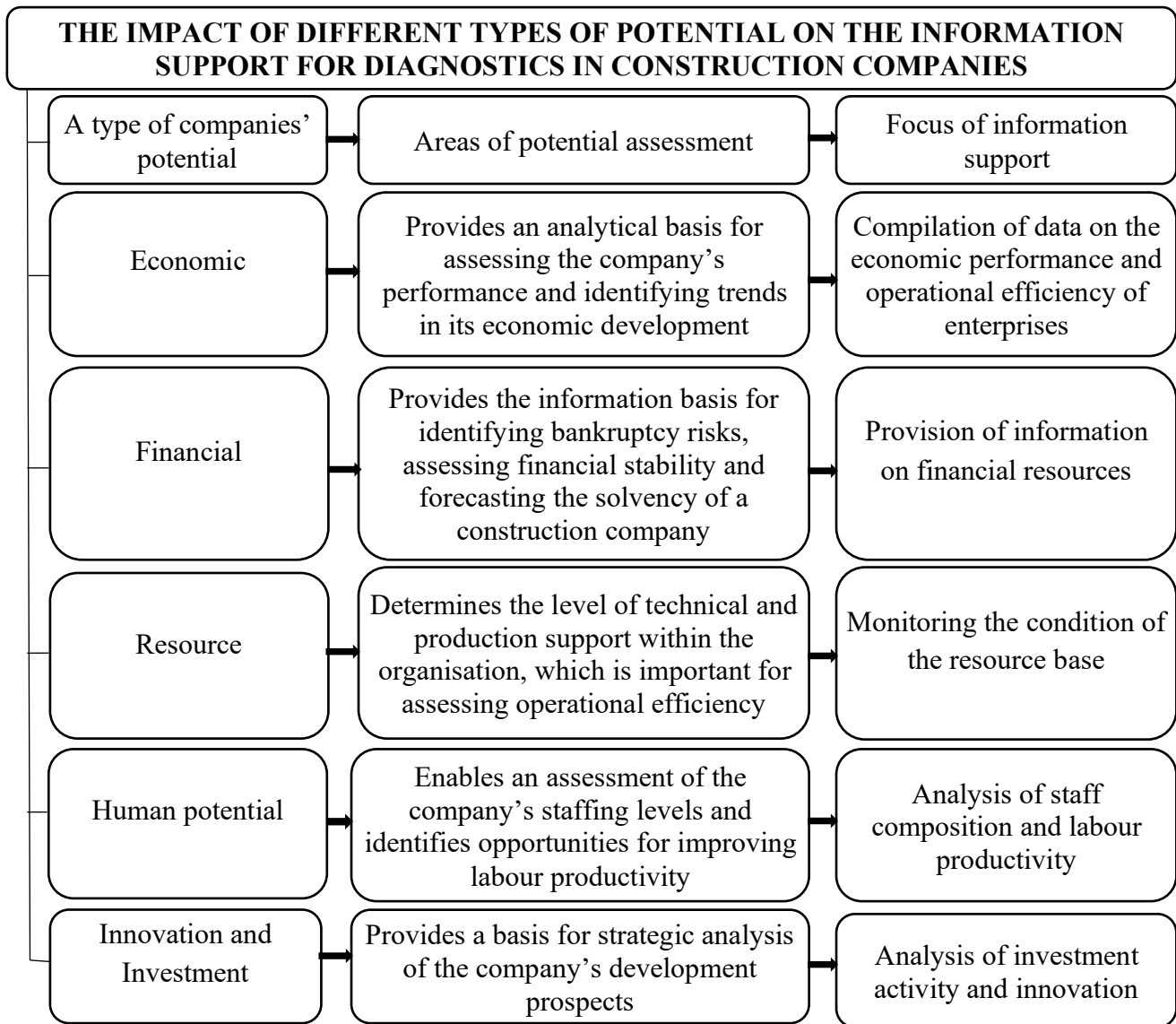


Figure 5. The impact of different types of potential on the information support for the diagnosis of construction enterprises

**Source: compiled by the authors.*

Thus, the various types of potential within a construction enterprise form the basis for the information support required to diagnose its operations, as each of them determines a specific area for assessing the enterprise's functional condition. A comprehensive analysis of economic, financial, resource, labour and investment-innovation potential allow for the formation of a multi-dimensional system of diagnostic indicators, which ensures the objectivity of management decisions, improves the efficiency of the enterprise's operations and strengthens its competitive position in the construction services market. The effectiveness of diagnostic procedures depends to a large extent on the comprehensive consideration of the main components of the enterprise's potential, which characterise its internal capabilities, reserves and prospects for development.

The potential of a construction enterprise represents an integrated set of the entity's existing and latent capabilities regarding the achievement of strategic and tactical goals through the effective use of resources, management decisions and adaptation to changes in the external environment. Information is therefore a valuable resource in the diagnostic process. Credit is due to F.F. Butynets scholarly approach to defining the value of information and its potential to influence the adoption of specific management decisions. The scholar emphasises that, for information to be reliable and useful, it must possess the following qualitative characteristics (table 4).

Table 4. Qualitative characteristics of information

Qualitative characteristic	Details
Timeliness	Information must reach the user in a timely manner, as otherwise it will cease to reflect the actual state of the enterprise
Predictability	Information must reflect the enterprise's development trends and thereby serve as a basis for forecasting the enterprise's future activities
Feedback from information sources	Information enables the implementation of operational management decisions
Reliability (accuracy)	This involves providing the user with truthful, complete, accurate and objective data, free from errors and distortions that could influence users' decisions
Accessibility (usability)	Information must be understandable and suitable for use by users
Materiality	Information is material if its omission or inclusion could influence users' economic (management) decisions based on financial statements
Usability (relevance)	Information must enable users to assess past, present and future events in a timely manner, and to confirm and adjust their past assessments
Neutrality	The information provided by accounting must be objective; in other words, it must not be influenced by any interested parties
Comprehensiveness	The information must be complete; this means that no information which is important and useful should be omitted
Comparability	the information must be presented in such a way that it can be compared across different periods. Users must also be able to compare the information in the financial statements of different entities.

**Source: compiled by the authors based on material [1].*

The next stage of the study involves the justification and description of the accounting and information support for assessing the potential of construction companies (figure 6). One must agree with S.I. Vasylishyn view that the functional orientation of accounting and analytical support within an enterprise's management system is manifested through the following functions: informational (meeting the information needs of internal and external stakeholders in the management process); assessment (identification and reliable quantitative and qualitative assessment of risks and threats and the extent of their impact on the development of the enterprise's potential and the enterprise as a whole); mobilisation (mobilisation of material, financial, labour and entrepreneurial resources and protection of the enterprise's assets in the process of developing measures to counter risks and threats to business activities); protective (establishing the foundations for comprehensive cyber protection of the enterprise's information infrastructure amidst the increasing digitalisation of accounting and analytical processes and the protection of trade secrets); verification (verifying the reliability of counterparties and other entities exerting direct and indirect influence on the business environment of enterprises); preventive (timely prevention of crisis situations; identification of potential for growth based on the use of modern analytical methods of economic research); planning (justification of strategic and tactical plans regarding the development of measures to monitor and strengthen the business entity's potential); control (ensuring permanent control over the implementation of adopted management decisions regarding the strengthening of the enterprise's potential) [11].

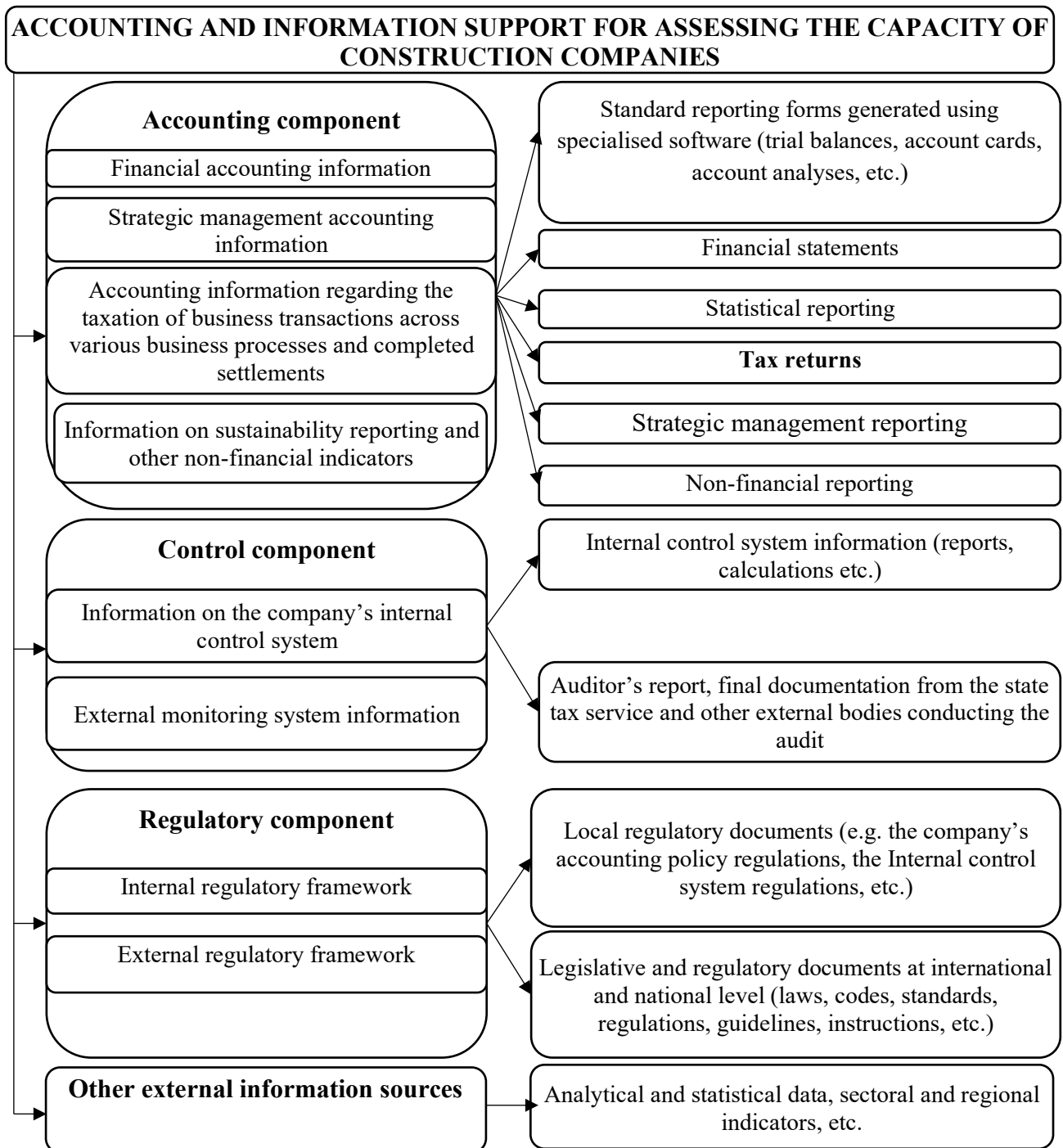


Figure 6. Accounting and information support for assessing the capacity of construction companies
**Source: compiled by the authors.*

Kuzmin O.E. and Melnyk O.G. emphasise that the availability, completeness and form of information support influence the diagnostic process and the ability to process data. In the presence of complete and reliable information, diagnosis becomes a sequence of algorithmic actions involving the processing, identification and interpretation of information. If, however, the information available is insufficient, it becomes necessary to take into account the risks of data incompleteness and ensure its reliable processing [3].

Let us examine in detail the significance of each component of the information support system, as summarised in Figure 6, in the process of assessing the potential of construction enterprises. In the current economic climate, financial reporting serves as a key element of the accounting and information support for assessing a company's potential, as it provides a systematic, standardised and reliable reflection of the results

of its financial and economic activities. It is worth noting that the key forms of this reporting are form 1 «Balance (Statement of financial position)», form 2 «Statements of financial results (Statement of comprehensive income)», form 3 «Cash Flow Statement», form 4 «Statement of changes in equity», and form 5 «Notes to the annual financial statements». From the list of forms provided, it should be noted that the role of financial reporting lies in forming the information base necessary for a comprehensive assessment of the level of development and the effectiveness of the use of the enterprise's resource potential. It accumulates summary indicators regarding assets, liabilities, equity, income, expenses and cash flows, which enables a multidimensional analysis of the financial position and performance of the business entity.

Financial reporting performs a number of important functions in the process of assessing an enterprise's potential. Firstly, an informational function, providing users with relevant data for making management decisions. Secondly, an analytical function, as it forms the basis for assessing liquidity, solvency, financial stability, profitability and business activity, and enables the assessment of bankruptcy risk. Thirdly, a control function, which manifests itself in the ability to monitor the efficiency of resource utilisation and identify deviations from planned indicators. Financial reporting takes on particular significance in the context of assessing the structural components of an enterprise's potential.

Analysis of form 1 «Balance (Statement of financial position)» allows for the determination of an enterprise's asset and financial potential, and the assessment of balance sheet liquidity.

Form 2 «Statements of financial results (Statement of comprehensive income)» serves as the basis for determining profitability, return on investment, operational efficiency, business activity, as well as for analysing the level of operating expenses and return on equity.

Form 3 «Cash Flow Statement» enables the analysis of cash flows (including net cash flow) based on the results of business entities' operating, financing and investing activities, as well as the determination of net cash flow for the reporting period.

The Statement of changes in equity provides a detailed analysis of the components of equity, enabling the assessment of balances at both the beginning and end of the relevant financial year, as well as highlighting changes that occurred during the year and evaluating their impact on the total value of equity. Furthermore, this form serves as a useful information basis for conducting in-depth analysis of solvency.

The notes to the annual financial statements (form 5) provide details of the key indicators reflected in the previously analysed forms and enable an in-depth analysis of data regarding the components of intangible assets, fixed assets, capital investments, financial investments, income and expenses, cash, provisions and reserves, inventories, trade receivables, shortages and losses from the disposal of assets, construction contracts, tax and profit, and others.

It is an indisputable fact that financial reporting is fundamental, but its effective use is only possible in conjunction with data from strategic management accounting, financial accounting (for example, trial balances), tax reporting and non-financial data, analytical calculations and information on the external environment, which ensures the comprehensiveness and soundness of the assessment of the enterprise's potential.

Furthermore, to ensure the reliability of the diagnostic results, it is advisable to use financial statements that have undergone an independent audit, and whose figures have been confirmed by independent auditors.

In order to carry out a thorough assessment of the potential of construction companies and to make effective management decisions based on the results, financial reporting information must meet the quality characteristics that determine its usefulness and are set out in National Accounting Regulation (Standard) 1 «General requirements for financial reporting» and the conceptual framework for financial reporting, the characteristics of which are summarised in table 5.

Table 5. Characteristics of the requirements for financial reporting set out in National Accounting Regulation (Standard) 1 «General Requirements for Financial Reporting» and the conceptual framework for financial reporting

National Accounting Standard 1 «General Requirements for Financial Reporting»		
Qualitative description		Description
Relevance and understandability		The information presented in financial statements must be relevant and understandable to users, provided that they possess sufficient knowledge and have an interest in understanding that information
Relevance		Financial statements should contain only relevant information that influences users' decision-making, enables them to assess past, present and future events in a timely manner, and to confirm and adjust their previous assessments.
Reliability (truthfulness)		Financial statements must be reliable (truthful). The information presented in the financial statements is reliable (truthful) if it is free from errors and misstatements that could influence the decisions of users of the financial statements.
Comparability		Financial statements should enable users to compare: an entity's financial statements across different periods; and the financial statements of different entities.
The conceptual framework for financial reporting		
Quality characteristic criterion	Name of quality characteristic	Characteristic
Fundamental	Relevance	Relevant financial information may lead to differences in the decisions made by users. Financial information may lead to differences in decisions if it has predictive value, confirmatory value, or both. Financial information has predictive value if it can be used as input to the processes that users employ to predict future earnings. Financial information has confirmatory value if it provides a response to (confirms or revises) prior estimates. The predictive value and confirmatory value of financial information are interrelated.
	Accurate representation	Financial statements present economic phenomena in words and figures. To be useful, financial information must not only present the relevant phenomena; it must also present them faithfully. To be a perfectly faithful representation, the description must have three characteristics. It must be complete, neutral and free from error.
Amplifiers	Comparability	Comparability is a qualitative characteristic that enables users to identify and understand the similarities and differences between articles. Unlike other qualitative characteristics, comparability does not apply to a single article. At least two articles are required for a comparison.
	Verifiability	Verifiability means that various informed and independent observers can reach a consensus though not necessarily complete agreement that a particular description is a true representation. Quantitatively defined information is not the only assessment that can be verified. A whole range of possible values and their corresponding probabilities can also be verified. Verification can be direct or indirect. Direct verification involves checking a sum or other representation through direct observation, such as counting money. Indirect verification involves checking the input data for models, formulas and other methods, as well as recalculating the output data using the same methodology.
	Timeliness	Timeliness means that decision-makers have access to information at the right time so that this information can influence their decisions. Generally speaking, the older the information, the less useful it is. However, some information may remain relevant long after the end of the reporting period because, for example, some users may need to identify and assess trends.
	Clarity	Some matters are inherently complex and cannot be easily understood. By omitting information about such matters from financial statements, the information in the financial statements becomes easier to understand. However, such reports would be incomplete and there is therefore a risk of misleading users. Financial statements are prepared for users who have a sufficient understanding of business and economic activity, and who carefully review and analyse the information.

**Source: compiled by the authors based on material [4,5].*

Statistical reporting, which is also compiled by entities in the construction sector. The key forms relevant for use in the diagnostic process are the Labour Report, the Report on Wage Arrears, the Report on Working Conditions, Benefits and Compensation for Work in Hazardous Conditions, and the Report on the Execution of Construction Works. Statistical reporting within the accounting and information support system for diagnosing the potential of construction enterprises fulfils an important scientific and applied function, ensuring the formation of a comprehensive, representative and comparable information base regarding the state and development trends of both individual businesses and the sector as a whole. Statistical reporting accumulates data on the volume of construction output, investment activity, labour resources, labour productivity, cost structure and the technical and economic characteristics of operations, which form the basis for analysing production, labour and investment potential. Despite its significant analytical value, statistical reporting has certain limitations, in particular the aggregated nature of indicators, the periodic nature of data collection, and a lack of detail regarding the enterprise's internal processes. This necessitates its use in conjunction with financial and management accounting data. Statistical reporting is an important component of the information support for diagnosing the potential of construction enterprises, as it broadens the analytical scope of the study by taking into account sectoral and macroeconomic operating conditions, thereby enhancing the objectivity and validity of the assessment of their potential.

The view put forward by the authors N. Yu. Yershova, O. S. Prokopyshyn, T.B. Pryidak and L.V. Yalovega, that tax reporting is currently evolving from a mandatory procedure into a strategic management tool which facilitates the adoption of well-founded management decisions, ensures financial transparency and shapes the image of a socially responsible business. The role of tax reporting in business communications is a vital component not only for compliance with legal requirements but also for building effective interactions with external and internal participants in business processes. In this context, tax reporting serves as the basis for effective communication with regulatory authorities, partners and investors, as well as for providing information support to company managers. Scholars identify the following types of communication in tax reporting: 1) external communication – interaction with regulatory authorities (compliance with tax legislation and timely payment of taxes; avoidance of fines, penalties and other risks through correct filing of returns; including the submission of reports, their analysis, the provision of explanations and the conduct of audits); ensuring the trust of investors, partners and other stakeholders (making informed decisions regarding investments, reorganisation, adjustments to internal structure and tax policy; planning cash flow and operational activities based on tax data); 2) internal communications – information support for managers (providing information on current tax liabilities for risk assessment and financial planning; optimising tax expenditure through the analysis of tax incentives and tax minimisation mechanisms); using reporting data for strategic and tactical decisions (use of reporting to assess the financial stability of the enterprise by investors and partners; compliance with tax legislation as an indicator of reliability and a prerequisite for attracting investment) [13]. Furthermore, based on data from tax returns, financial statements and accounting information (in particular from accounting accounts 64 and 65), an assessment of the enterprise's tax burden is carried out and the tax planning process is facilitated.

Strategic management reporting is a dynamic system of interrelated financial and non-financial strategic indicators derived from accounting and analysis processes. These indicators are presented as a set of reports in an easily understandable format, characterising the effectiveness of the organisation's strategy implementation within the specific conditions of the macro and micro-environment, enabling strategic management decisions to be made regarding the optimisation of the company's competitiveness growth strategy in the long term, whilst responding promptly to changes in the company's strategy and information requests from the management system. The aim of strategic management reporting is to provide the company's management with strategic accounting information for the development of a strategy for enhancing the company's competitiveness in the long term and its optimisation in response to changes in macro- and micro-environmental conditions [9].

Figure 7 summarises the key aspects that underscore the importance of strategic management in the process of assessing a construction company's potential.

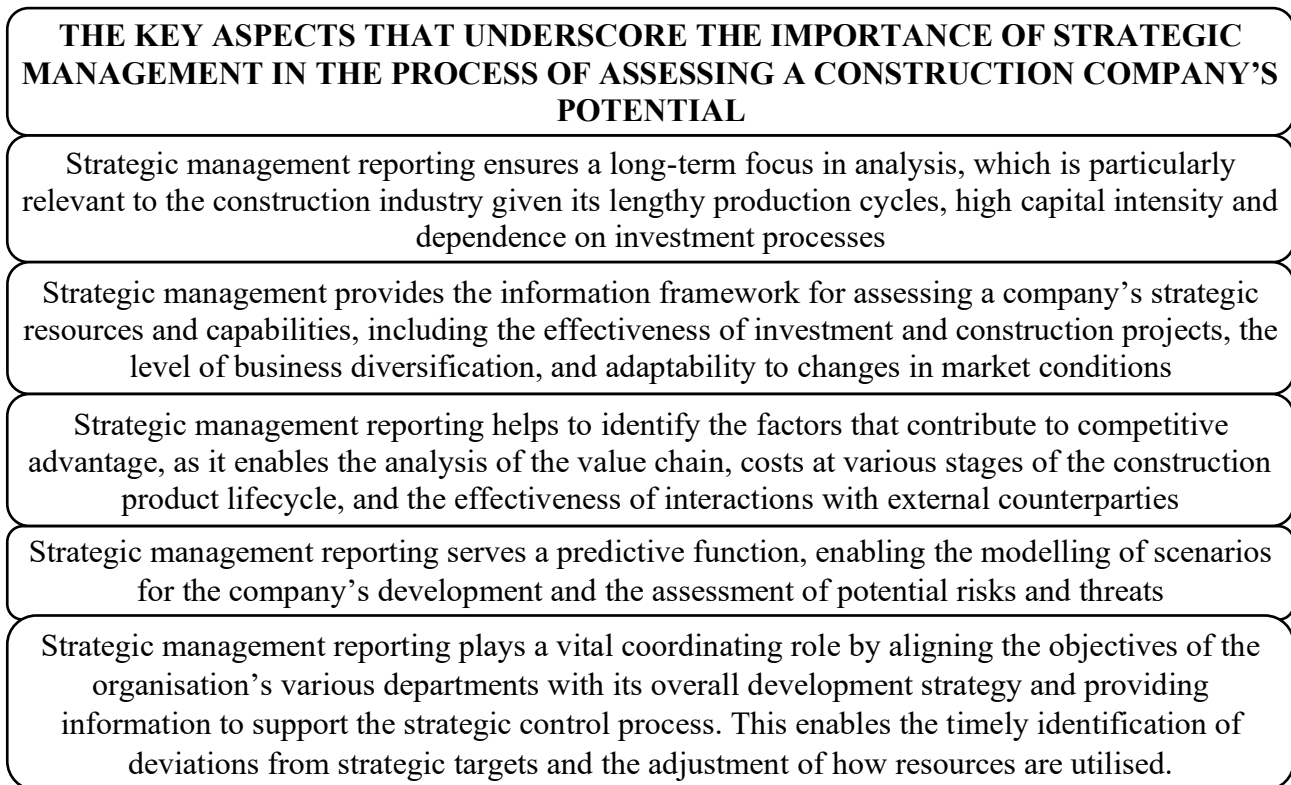


Figure 7. *The key aspects that underscore the importance of strategic management in the process of assessing a construction company's potential*

**Source: compiled by the authors based on material [9].*

The effectiveness of strategic management reporting depends on the level of methodological support, the quality of information flows and the degree of integration with other accounting and analysis subsystems. Limitations may include the complexity of compiling non-financial indicators, the subjectivity of assessments and significant demands on the enterprise's information infrastructure. Strategic management reporting, in the process of diagnosing the potential of construction enterprises, serves as an important source of information for analysing a system of indicators that reflect long-term development opportunities, competitiveness and the efficiency of resource utilisation. Its distinctive feature is its focus on combining financial and non-financial indicators, which enables a comprehensive assessment of the enterprise's potential. To reinforce the validity of these assertions, the following arguments are worth considering.

Based on strategic management reporting data, the following indicators can be calculated:

- 1) indicators of the enterprise's competitiveness, including market share, position among key competitors, the level of differentiation of construction services, and the degree of diversification of the project portfolio. Such indicators allow for an assessment of the external component of the enterprise's potential and its strategic prospects;
- 2) indicators of the effectiveness of investment and construction projects, including project profitability, duration of implementation, adherence to budgets and schedules, as well as indicators of project activity risk. Their analysis aids in assessing investment and production potential;
- 3) indicators of innovation potential, specifically the volume of investment in new technologies, the proportion of innovative projects, the level of technological modernisation, and the implementation of digital solutions in construction. This enables an assessment of the enterprise's capacity for development and adaptation;
- 4) indicators of strategic stability and risks, including the level of dependence on individual clients, diversification of funding sources, sensitivity to changes in market conditions, as well as an assessment of external and internal risks.

The above confirms that strategic management reporting is an integral component of the system for assessing the potential of a construction enterprise, as it provides a comprehensive, forward-looking

assessment of its resource capabilities and competitive positions, which enhances the soundness of strategic management decisions and contributes to the long-term operational effectiveness of the enterprise.

In the current context of transforming economic relations and the growing importance of the concept of sustainable development, non-financial reporting particularly sustainability reporting is becoming particularly relevant as a component of the accounting and information framework for assessing an enterprise's potential. From a scientific perspective, non-financial reporting is viewed as a systematic set of indicators reflecting the environmental, social and governance aspects of an enterprise's activities (ESG components), which are not fully reflected in traditional financial reporting but significantly influence the formation of its long-term potential. Accordingly, this form of reporting is relevant for construction enterprises in the diagnostic and management process. In the context of transformative changes in the economic environment in which business entities operate, the issue of ensuring sustainable development takes on priority significance. Globalisation, political instability, inflationary pressures, limited state support for businesses, the existence of significant risks to investment activities, and insufficient financial resources have a destructive impact on the business environment of the enterprise.

Sustainable development is a model of economic growth in which the use of resources is directed towards meeting human needs whilst preserving the environment, so that these development needs can be met not only in the present but also for future generations [10]. It is worth noting that the issue of sustainable development is one of the most pressing in the modern world. It is addressed by world leaders, hundreds of governmental and intergovernmental programmes are dedicated to it, and it has been on the agenda of the most influential international organisations for many years [8]. An important prerequisite for sustainable business development was the «Triple Bottom Line» concept proposed by an American economist and entrepreneur, according to which the results of a business entity's activities must be assessed from financial, environmental and social perspectives. Based on the above, it is appropriate to consider the sustainable development of an enterprise from the perspective of the triad of social, economic and environmental components. The socio-economic-environmental system is a combination of social, economic and environmental subsystems, harmoniously integrated into a whole that generates a new quality – sustainable development – provided that: the economic subsystem ensures a high level of production of material goods and services sufficient to achieve social and environmental goals; the social subsystem is aimed at achieving the all-round development of the individual and an adequate standard of living; the environmental subsystem is focused on the preservation of the environment and the regeneration of labour resources in favourable natural conditions [2]. Accordingly, with a view to the successful implementation of sustainable development policy, the question of justifying the feasibility of applying effective management tools that will create a platform for the implementation of strategic tasks aimed at ensuring the sustainable development of the business entity, as the primary link in the economic system, becomes relevant. The transformational processes of the economic system have laid the groundwork for a scientific understanding of the need to change approaches to analysing the results of a business's activities. Current realities highlight the need to apply diagnostics as a dominant management tool, which, in practical terms, will ensure a comprehensive study of the business entity's level of development across economic, social and environmental dimensions, whilst simultaneously identifying factors that have a destructive impact on the successful implementation of the sustainable development strategy. In this context, it is worth emphasising that the focus of diagnostic tasks, as a management tool, should be oriented towards fulfilling the priority functions of the diagnostic process: analytical, anti-crisis, research, informational, preventive, symptomatic, and others. The assessment of an enterprise's level of development and its potential must be based on the use of a complementary synthesis of the dominant principles of diagnosis, namely, decomposability, dynamism, economic feasibility, completeness, logicity, objectivity, systematicity, purposefulness, and others. Following on from this, it is necessary to summarise the characteristics of the constituent components of sustainable development.

1. *The economic component.* Economic stability is one of the key aspects of sustainable development. The responsible and rational use of natural resources helps to prevent resource depletion, which is critical to business continuity. Investment in sustainable technologies can lead to the opening up of new markets and increased competitiveness. Businesses focused on sustainable development also reduce risks associated with fluctuations in resource prices, changes in regulatory requirements and negative public opinion. A sustainable business creates long-term value for its shareholders and owners and maintains stability in an unstable market.

2. *The social component.* Corporate social responsibility involves ensuring safe and healthy working conditions, fair pay and investment in community development. Companies that implement socially responsible practices typically have better relationships with their employees, which boosts their motivation

and productivity. This not only enhances the company's reputation but also helps attract and retain talented staff. Furthermore, social responsibility builds trust in the company among customers, partners and investors. Investing in local communities and social projects not only strengthens the company's image but also contributes to the creation of a stable and harmonious society, which is vital for the long-term success of the business. Businesses actively engaged in social responsibility may also benefit from tax breaks and other government incentives.

3. *The environmental component.* A business that actively works to reduce its negative environmental impact not only responds to the challenges of the present but also prepares for future regulatory requirements and changes in consumer preferences. Environmental responsibility also fosters innovation. In seeking new ways to reduce their environmental impact, companies can develop new products and services that meet current market demands [12].

These components should be summarised in a Sustainability Report, which allows for the assessment of progress in implementing sustainable practices and promotes transparency and openness in business management. It also encourages companies to improve their operations and helps to enhance their competitiveness. Overall, sustainability reporting drives the creation of a more sustainable and environmentally responsible economy. Furthermore, the relevance and necessity of auditors providing assurance on sustainability reporting are increasing. Today, business organisations understand that their actions have a significant impact on the social, environmental and economic aspects of society, so improving their performance in these areas is becoming extremely important [6].

Information from the control process (both internal and external) plays a distinctive functional role in the process of assessing potential.

Information generated within the internal control system for the business processes of a construction company, as well as the results of financial statement audits, play a key role in ensuring the objectivity, reliability and analytical suitability of the data used in the process of diagnosing potential and making effective management decisions. In the context of construction companies, where operations are characterised by project-based organisation, long production cycles and high resource intensity, the importance of internal control increases significantly. After all, internal control information enables a thorough assessment of the status and effectiveness of key business processes, including the planning and execution of construction works, cost management, the use of material and technical resources, and adherence to project deadlines. This creates the conditions for identifying internal reserves for improving efficiency, pinpointing «bottlenecks» and minimising operational risks.

At the same time, the audit of financial statements provides an independent assessment of the reliability and completeness of the presentation of the company's performance indicators in the financial statements. Its results serve as an important source of information for confirming the quality of accounting data used in the process of diagnosing potential. The auditor's report helps to reduce information asymmetry and increase confidence in financial information among internal and external users.

The synergistic effect of combining internal control and audit information is manifested in an increase in the soundness of management decisions. In particular, such information facilitates a more accurate assessment of the enterprise's resource potential; the timely identification of deviations in the execution of construction projects; the evaluation of the efficiency of financial and material resource utilisation; the minimisation of risks of financial losses and ineffective management; and the formulation of development strategies based on reliable data.

The regulatory component of the accounting and information support for assessing the capacity of construction companies also plays a decisive role in ensuring the consistency, coherence and reliability of information flows. Internal regulatory documents, in particular the Accounting Policy and the Regulations on the Organisation of Internal Control, govern accounting methods, control procedures and the preparation of reporting information, thereby enhancing its analytical suitability for assessing the enterprise's potential. State-level regulatory acts ensure the standardisation of approaches to the organisation of accounting, the preparation of financial statements and the assessment of economic indicators, which also has a positive impact on the organisation and results of the diagnostic process. Taken together, this ensures the formation of a sound information base for making effective management decisions and determining the strategic directions of the enterprise's development.

Statistical data at national and regional levels generally enable a comparative analysis to be carried out, gaps in capacity development to be identified, and the strategic direction of development to be properly defined.

Consequently, a well-structured accounting and information system for assessing the potential of construction enterprises is a key factor in ensuring the objectivity and reliability of evaluation results. It creates an appropriate information base for a comprehensive analysis of resource capabilities, the efficiency of their use, and the identification of the enterprise's development potential. The consistency and completeness of information flows contribute to increasing the soundness of analytical conclusions and reducing the level of information risks. Ultimately, this ensures the adoption of effective management decisions and the formation of sustainable competitive advantages in the long term.

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CONCEPTUAL APPROACHES AND CURRENT TRENDS IN RESEARCH ON SUSTAINABLE DEVELOPMENT OF THE AGRICULTURAL SECTOR

Prokopenko Nataliia

PhD in Economics, Associate Professor, Sumy National Agrarian University, Ukraine

ORCID ID: 0000-0001-5046-6122

The agricultural sector plays a decisive role in global food production and, on this basis, in ensuring the global food security system, environmental sustainability, and livelihoods in rural areas. However, intensive agricultural practices have led to numerous environmental and social problems, including climate change; high rates of biodiversity loss; land degradation due to erosion, compaction, salinization, and soil contamination; depletion and pollution of water resources; socioeconomic inequality in rural areas and population decline [1; 2; 3; 4; 5; 6], with the agricultural sector itself generating these problems in a significant number of cases [7].

Sustainable development of the agricultural sector aims to address these problems by establishing mechanisms that will promote environmentally sound, socially just, and economically viable agricultural systems. In this context, there is a need to examine the dynamic aspects and substantive characteristics of the concept of “sustainable development of the agricultural sector” and, on this basis, to formulate an author’s definition.

A dynamic analysis was conducted based on data from Google Trends and the number of publications in the SCOPUS database related to the topic of sustainable development of the agricultural sector (Fig. 1).

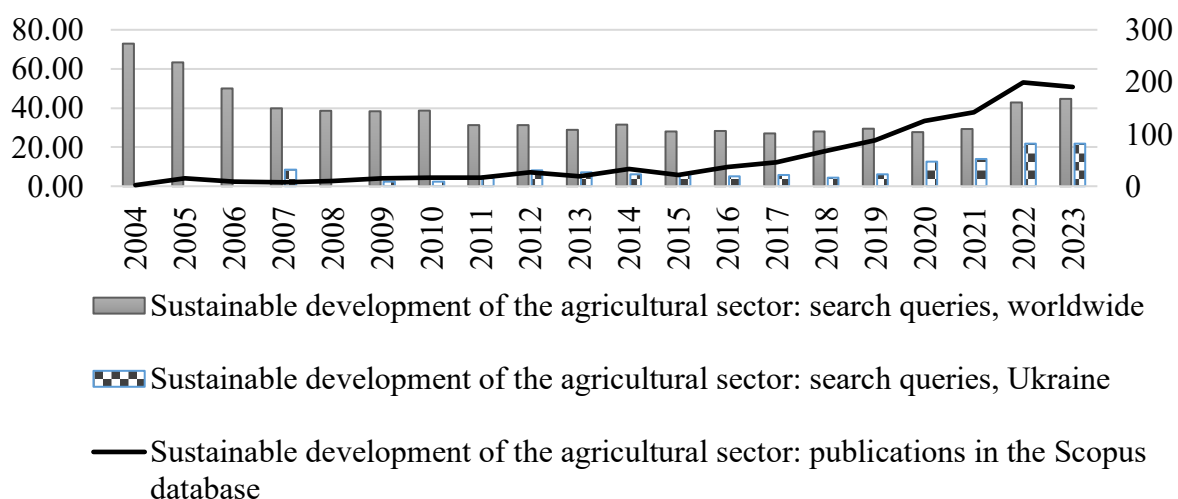


Figure 1. Comparison of the dynamics of Google search queries on sustainable development of the agricultural sector and scientific publications in the SCOPUS scientometric database on the same topic for 2004-2023.

Note: The annual average index for each term was calculated by averaging the indices for all months of each year.

Source: compiled by the author

Google Trends data covers global and Ukrainian search queries, while data from the international SCOPUS scientometric database covers the number of academic publications on this topic. The purpose of the analysis is to identify trends in user interest in the sustainable development of the agricultural sector and the correlation between this interest and academic research.

The global search query index shows high values at the beginning of the study period, particularly in 2004 (72.92), with a gradual decline to a low point in 2017 (27.00). Since 2018, there has been a rise in user interest in this topic, peaking in 2023 (44.67). This indicates growing attention to sustainable development in the agricultural sector in recent years. The Ukrainian search query index was zero until 2007, indicating a low level of interest in this topic in Ukraine during that period. Since 2007, user interest has been gradually increasing, reaching a peak in 2022 (21.92). This indicates a growing awareness of the importance of ensuring sustainable development in Ukraine’s agricultural sector. The number of publications in the international

scientometric database SCOPUS on the topic of sustainable development in the agricultural sector has increased year by year, reaching a peak of 199 publications in 2022. It is worth noting that in 2022, when the number of search queries reached a high (42.83), the number of publications also peaked (199).

Figure 2 shows the trend in the frequency of use of the phrase “sustainable development of agriculture” in books indexed by Google for the period from 2004 to 2018.



Figure 2. Results of the analysis of the frequency of mentions of the term “sustainable development of agriculture” published in English-language books worldwide from 2004 to 2018

Source: created by the author using the Google Books Ngram Viewer tool

Based on the graph’s amplitude, several stages of scientific interest in issues related to ensuring the sustainable development of the agricultural sector can be identified, namely: 2004-2012 - the stage of emerging interest, confirmed by an increase in the frequency of the phrase’s use; 2012-2015 - a stage of waning interest, with the frequency of the phrase’s use declining slightly; 2015-present - a stage of renewed interest in the sustainable development of the agricultural sector, confirmed by a new increase in the frequency of the phrase’s use.

Thus, based on the study’s findings, we can conclude that there has been a significant increase in interest in the sustainable development of the agricultural sector among both internet users and in academic circles. A substantial increase in attention to this topic has been observed since 2015, when the UN General Assembly adopted the resolution “Transforming our world: the 2030 Agenda for Sustainable Development.” This document, in particular, identified Goal 2-“Ensure food security, improve nutrition, and promote sustainable agriculture”-as one of the key goals directly related to the sustainable development of the agricultural sector.

The next stage of the study is a contextual and bibliometric analysis of the concept of sustainable development of the agricultural sector.

Based on the results of our review of the scientific literature, we have determined that both the concept of sustainable development of the agricultural sector and the concept of a “sustainable agricultural sector” (“sustainability of the agricultural sector”) are widely studied in the scientific literature, and while they are often used as synonyms, in our view, they have different meanings and implications. Understanding these differences is crucial for formulating effective policies and strategies to achieve sustainable development goals in the agricultural sector.

Given the above, to achieve the research objective, we consider it appropriate to summarize the findings of domestic and foreign scholars in this field and distinguish between these concepts.

Approaches to interpreting the concept of “sustainability of the agricultural sector” are presented in Table 1.

Sustainability is a systemic property that arises in the agricultural sector as a result of numerous social, environmental, economic, and physical interactions within it and in interaction with the external environment [8], and characterizes the system’s ability to withstand and maintain its functions over time.

Table 1. Approaches to understanding the concept of “sustainability of the agricultural sector” [compiled by the author based on 9; 10; 11; 12; 13; 14; 15; 16; 17; 18]

Source	Definition of the concept of “sustainability of the agricultural sector”
Martsynuk N. M.	a sector that produces a sufficient quantity of high-quality food, conserves its resources, is environmentally safe, and generates profits.
Stoyanets N. V.	a system of production, processing, marketing, and consumption of agricultural products that is optimally organized in terms of the use and regeneration of socio-ecological and economic resources, and which is supported by economic agents as well as institutions authorized to develop and implement strategic and operational state policies in the field of agriculture, the ultimate goal of which is to achieve the country’s food security
Brodt S. et al.	a sector that ensures the achievement of environmental protection, economic profitability, and social justice
Pretty J.	includes the concepts of both resilience (the ability of systems to withstand shocks and stresses) and longevity (the ability of systems to continue to exist over a long period of time), and encompasses much broader economic, social, and environmental outcomes.
Smith E., Serna I.	maximizing food production while minimizing environmental impact ... involves preserving the environment, expanding natural resources, and creating a better life for animals and people, ensuring the long-term sustainability of food sources while reducing dependence on conventional farming methods and providing alternative food options.
Streimikis, J., Balezentis, T.	A system that allows farms of all sizes to be profitable and contribute to the local economy, ensuring the effective management of the natural systems and resources on which farms depend. ... supports the next generation of farmers, treats workers fairly, promotes racial equality and justice, ensures access to healthy food for all, and puts people and communities above corporate interests.
Shelef O. et al.	the use of biological resources for the production of food and fiber, among other products, taking into account environmental impacts
Food and Agriculture Organization of the United Nations	adherence to the principles of sustainable food and agriculture: improving resource efficiency; conserving, protecting, and enhancing natural ecosystems; protecting and improving living conditions and social well-being in rural areas; enhancing the resilience of people, communities, and ecosystems; promoting the effective management of both natural and human systems.
	ensures that agricultural products meet, in terms of both quantity and quality, the nutritional needs of current and future generations; provides long-term employment, adequate income, and decent living and working conditions for all those engaged in agricultural production; contributes to maintaining and even increasing the productivity of natural resources as well as the regenerative capacity of renewable resources, without disrupting key ecological cycles and the natural balance, destroying the socio-cultural characteristics of rural communities, or causing environmental pollution; reduces the agricultural sector’s vulnerability to adverse natural and socio-economic factors and other risks, and strengthens producers’ confidence in their own capabilities
American Agronomic Association	over the long term, improves the state of the environment and natural resources on which agricultural activity depends; meets human needs for food and plant-based raw materials; is economically viable and improves the quality of life for farmers and society as a whole
U.S. Farm Bill	an integrated system of crop and livestock production aimed at the following long-term goals: meeting human needs for food and plant-based raw materials; improving the condition of natural resources on which agriculture depends; ensuring the most efficient use of non-renewable resources and internal

By synthesizing the approaches of the above-mentioned and other scholars, we have identified the following key parameters through which the concept of “sustainability of the agricultural sector” is examined (Fig. 3): as a capacity, as a system of long-term goals, as a set of specific characteristics, and as a specific state, which can be considered both at the micro level (the level of an individual producer) and at the macro level (the level of the agricultural sector).

In addition to various approaches to interpreting the concept of “sustainability of the agricultural sector,” researchers emphasize different aspects (dimensions) of it in their definitions.

All presented approaches include elements of conservation and improvement of natural resources, and reduction of environmental impact (Stoyanets N. V., Martsynuk N. M., Smith E. and Serna I., Pretty J., Shelef

O., and others; legislation in the field of sustainable development). Accordingly, the environmental aspect is key in the context of developing mechanisms to ensure the sustainability of the agricultural sector. A number of approaches emphasize the importance of ensuring social justice and improving living and working conditions in rural areas (Brodt S. et al., Pretty J., Stoyanets N. V., N. M. Martsynuk, the Food and Agriculture Organization of the United Nations, the American Society of Agronomy, etc.), which underscores the significance of the social aspect.

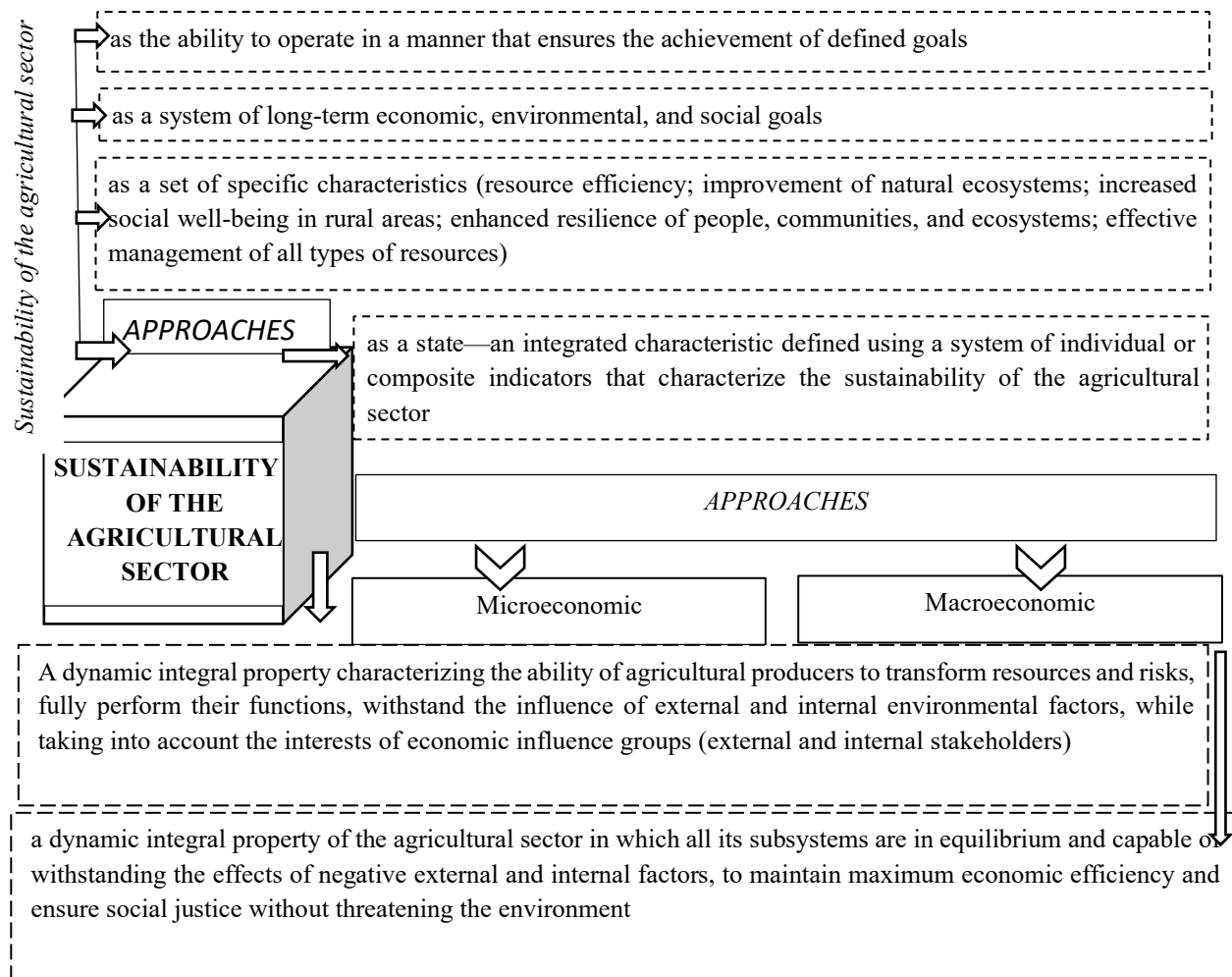


Figure 3. Summary of approaches to defining the concept of “sustainability of the agricultural sector”
Source: compiled by the author

A number of definitions of sustainability in the agricultural sector include the aspect of economic feasibility and profitability (S. Brodt, N. M. Martsynuk, American Society of Agronomy). At the same time, in some cases, the emphasis is placed on the efficient use of both natural and human resources (Shelef O., Food and Agriculture Organization of the United Nations, American Society of Agronomy). Accordingly, the measure of sustainable development in the agricultural sector is an adequate level of economic efficiency.

The concepts of system resilience and longevity are defined in the approaches of Pretty J., Smith E., and Serna I. of the Food and Agriculture Organization of the United Nations, which underscore the need for long-term planning and adaptability of agricultural systems.

To summarize the above, we propose considering the sustainability of the agricultural sector through a comprehensive approach in both quantitative and qualitative aspects, as presented in Figure 4.

Therefore, we propose considering the sustainability of the agricultural sector comprehensively—using both qualitative (as capacity and as a state of being) and quantitative (as a structural concept characterized by a system of indicators) approaches across three main dimensions (environmental, economic, and social). The environmental dimension emphasizes the capacity to preserve the environment and use natural resources

efficiently. The economic dimension highlights the capacity to maintain a certain level of economic production indefinitely. The social dimension concerns the capacity to function at a defined level of social well-being for an indefinite period.

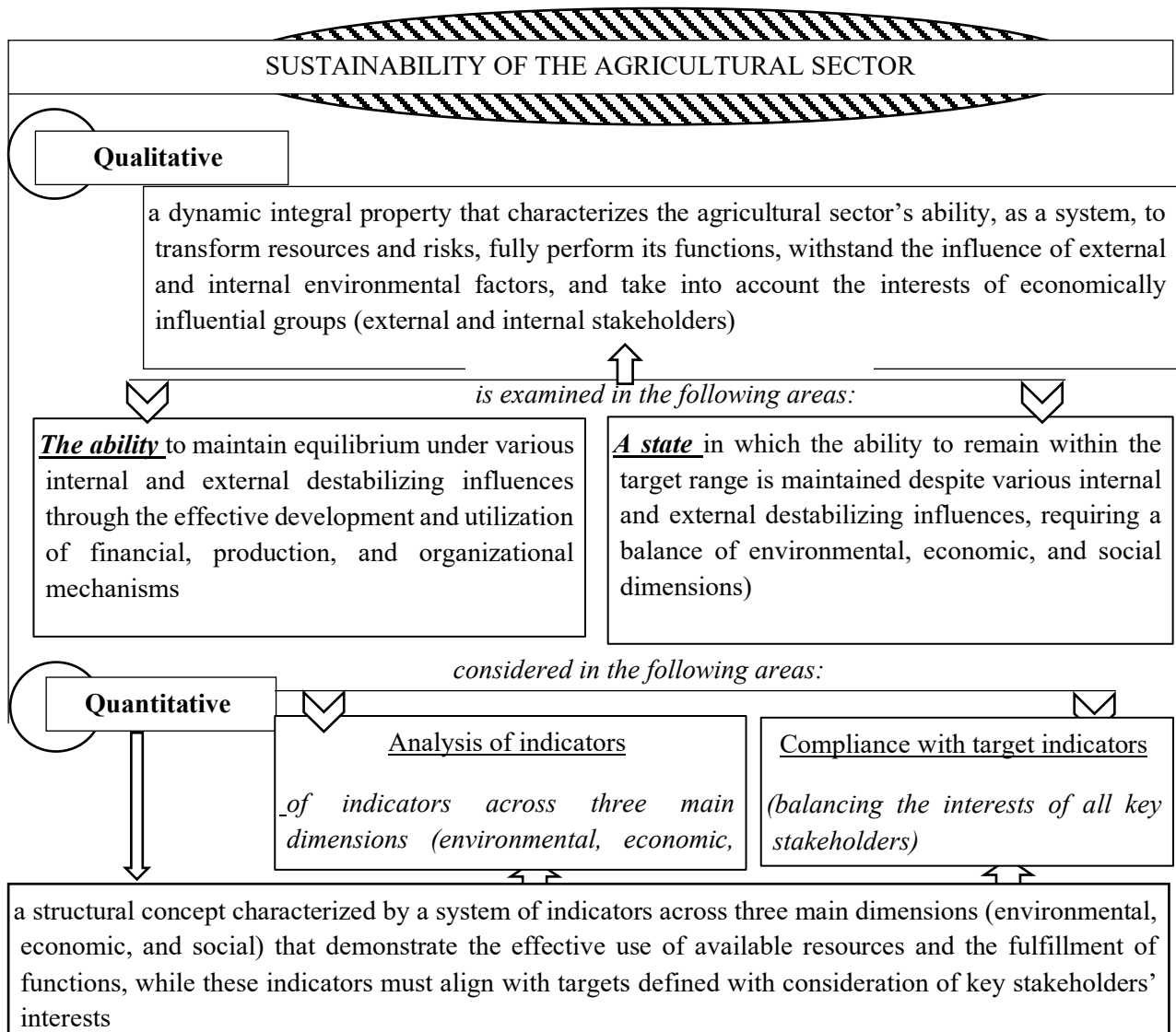


Figure 4. A comprehensive approach to the concept of “sustainability of the agricultural sector”

Source: Compiled by the author

Approaches to interpreting the concept of “sustainable development of the agricultural sector” are presented in Table 2.

Table 2. Approaches to understanding the concept of “sustainable development of the agricultural sector” [compiled by the author based on 18; 19; 20; 21; 22; 23; 24; 25; 26; 27]

Source	Definition of the concept of “sustainable development of the agricultural sector”
<i>Ability</i>	
Varchenko O. M., Danilenko A. S.	of an economic entity to dynamically maintain a balance in organizing activities focused on innovative development; to enhance social and economic efficiency; to continuously accelerate the pace of development through expanded reproduction, the goal of which is to provide the population with high-quality food products and ensure the country’s food security without harming the environment
Yarmolenko Y. O.	economic entities must continuously and dynamically maintain a rational balance between the factors of reproduction and the necessary pace of its development in conditions of uncertainty and volatility of the external environment, with the aim of consistently meeting the population’s needs for food and consumer goods produced from agricultural raw materials, both now and in the future, while taking into account the responsibility for creating the necessary social conditions and preventing environmental pollution
Tchaikovsky I. A.	of the agricultural sector and its management entities to create rational production structures that, by mobilizing internal reserves, will help mitigate negative consequences and minimize deviations from established development trends in the event of unforeseen external influences
<i>Ensuring dynamic equilibrium</i>	
Sirotyuk G. V.	Achieving a balance in the functioning of agricultural enterprises, i.e., ensuring the stabilization of their agricultural production and income generation, which can sufficiently support their process of expanded reproduction. The main criterion for such a balance is achieving stable growth in agricultural production and resolving the issue of food security
Ignatenko V. V.	maintaining dynamic equilibrium under real conditions of internal and external changes, sustaining a long-term reproductive process, optimizing environmental parameters, ensuring long-term security in fulfilling specific food supply functions, and raising the social standard of living of the rural population
Popova O. L.	systemic, human-centered changes—focused on the interests and potential of individuals, society, and the —that are adaptive in nature and qualitative in essence, accompanied by increased ecological and economic efficiency, socio-economic progressiveness, and environmental sustainability relative to previous invariant states, as well as in terms of achieving rational models of sustainability at various stages of evolutionary development
<i>Process</i>	
O. G. Korytny	the process of transitioning to a new level of operational efficiency in this sphere under conditions of forming an effective system of state regulation... from the perspective of economic entities, it is characterized by the ability to maintain effective links between factors of reproduction and growth rates under conditions of uncertainty in both the current and future periods, taking into account socio-ecological components
	an organized process focused on the efficient use and reproduction of social, environmental, and economic resources within agricultural production, processing, marketing, and consumption systems, supported by state policies and oriented toward long-term sustainability.
Chaikovsky I. A.	The process of optimizing the level of agricultural production, preserving and restoring the quality parameters of the agricultural environment, and improving the social status of the rural population while strengthening the country’s food and environmental security.
<i>Development</i>	
Yarmolenko Y. O.	Self-sustaining development of enterprises in the sector with stable growth rates, ensuring the satisfaction of the population’s food needs, strengthening the country’s export potential, and creating favorable living conditions for future generations
Pankov O. I.	such development of human activity that incorporates a balanced consideration of economic, social, and environmental aspects and takes into account the interests of future generations
Kopelets O. O.	the selection of a development path from among a range of alternatives that satisfies the population’s current needs for agricultural raw materials without compromising the ability to meet these needs in the future
Food and Agriculture Organization of the United Nations	rural development that is carried out through the use and protection of natural resources and the implementation of technological and institutional changes that enable the needs of present and future generations to be met

Sustainability, in the broadest sense, refers to the ability to maintain a particular process or state over an indefinite period of time. It is a condition or state that can be sustained over the long term without depleting resources or causing harm to the environment, the economy, or society.

Therefore, summarizing the above, we propose to consider “sustainability of the agricultural sector” as a systemic property of the agricultural sector, viewed as a goal or desired state where a balance of environmental, economic, and social dimensions is achieved and maintained. This, in particular, involves setting specific goals or standards that must be met to ensure that agricultural activities do not deplete resources or harm the environment.

In the agricultural sector, sustainability emphasizes the ongoing ability of agricultural systems to function effectively and produce food without degrading the natural resources or ecosystem services on which they depend.

We believe that the concept of sustainable development, unlike the concept of “sustainability of the agricultural sector,” goes beyond the static functioning of the agricultural system, emphasizing a proactive approach to development that balances the parameters of economic growth, social inclusion, and environmental protection. Given this, when characterizing this concept, it is advisable to rely on a process-oriented approach that addresses environmental, economic, and social dimensions simultaneously [28; 29; 30; 31; 32; 33].

Sustainable development is a process and the strategies used to achieve sustainable development goals. It encompasses a broader range of objectives, including economic and social development alongside environmental protection. Sustainable development involves the implementation of policies, practices, and technologies that promote growth and development in a way that does not harm future resources or the environment, that is, that contributes to the sustainability of the agricultural sector. It also includes addressing issues such as rural poverty, food security, and adaptation to climate change.

Thus, sustainable development aims to create an agricultural system that supports current and future needs, not only ensuring the long-term viability of agricultural production but also enhancing economic stability, improving social conditions, and protecting the environment (Fig. 5).

One of the main goals of sustainable development in the agricultural sector is to minimize environmental impact while increasing production efficiency.

This involves implementing practices that promote responsible management of natural resources—including soil, energy, and water conservation and waste minimization—and biodiversity, ensuring that environmental degradation is minimized and the impacts of climate change are mitigated. A key component of sustainable development in the agricultural sector is economic sustainability, which must ensure sufficient economic returns to support agricultural businesses and provide adequate compensation for producers.

Social sustainability emphasizes fair treatment, inclusivity, and ensuring the equitable distribution of resources among all stakeholders, including farmers and rural communities. Sustainable agricultural production should create opportunities to raise living standards, increase per capita income, and address issues such as poverty and unemployment.

Gender-sensitive agricultural policy promotes social justice by addressing the unique challenges faced by women in agriculture [31]. Encouraging community participation and shared decision-making in agricultural practices enhances social justice [32].

In order to deepen our understanding of the theoretical foundations for ensuring the sustainable development of the agricultural sector, we consider it appropriate to examine the evolution and consolidation of scientific research in this field using VOSviewer, a software tool for constructing and visualizing bibliometric network connections.

In the first stage, we will search for articles on this topic using the SCOPUS scientometric database, which more thoroughly indexes applied scientific journals in the field of business and economic research (compared to WoS).

The following key parameters were selected for the analysis: publication time period: 2000–2024; publication type: article; language of articles - English; combination of keywords used for the search: “sustainable development” AND “agriculture” OR “farming” OR “agricultural sector” OR “agricultural practices”; subject-based restrictions - “business, management, and accounting” and “economics, econometrics, and finance.”

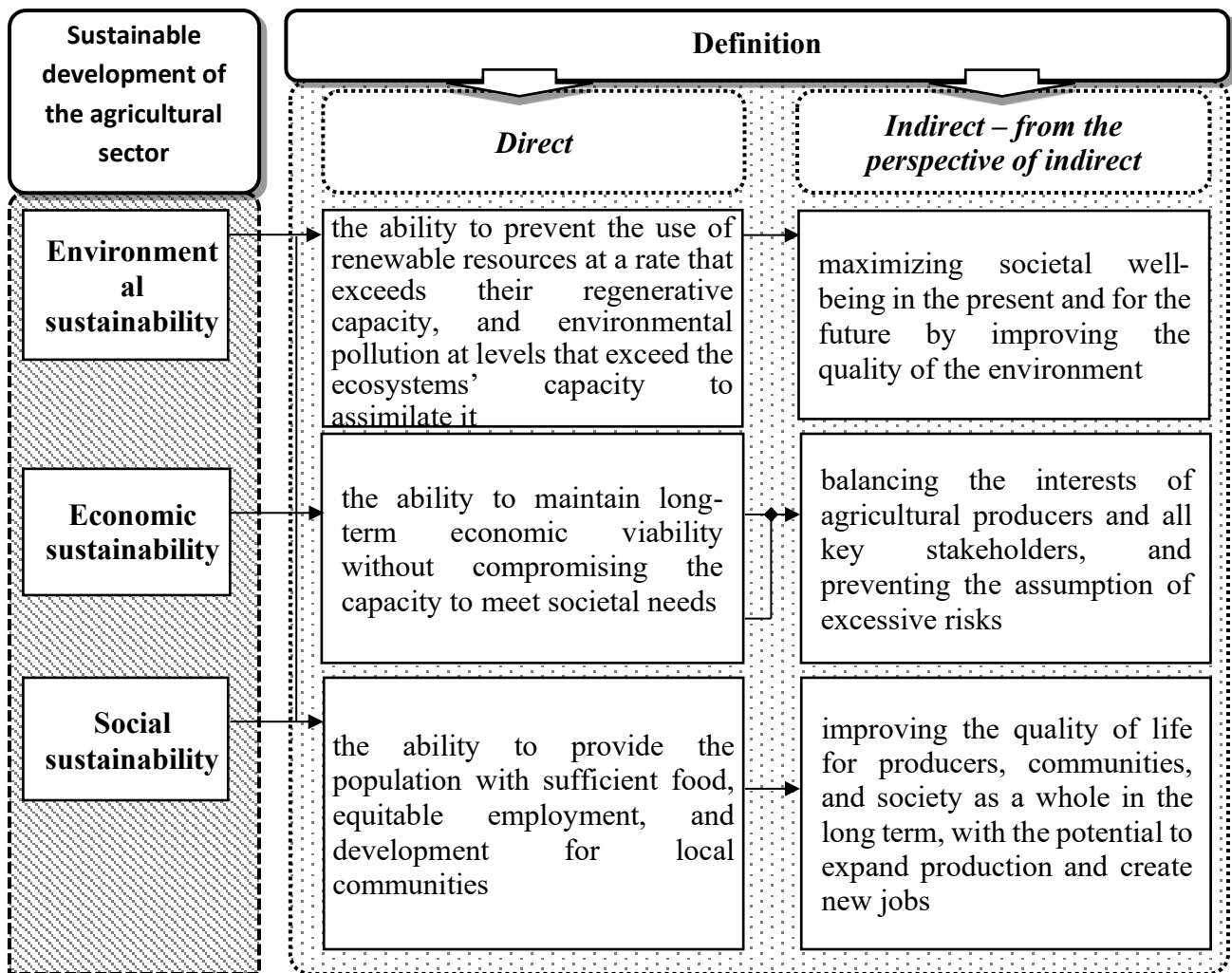
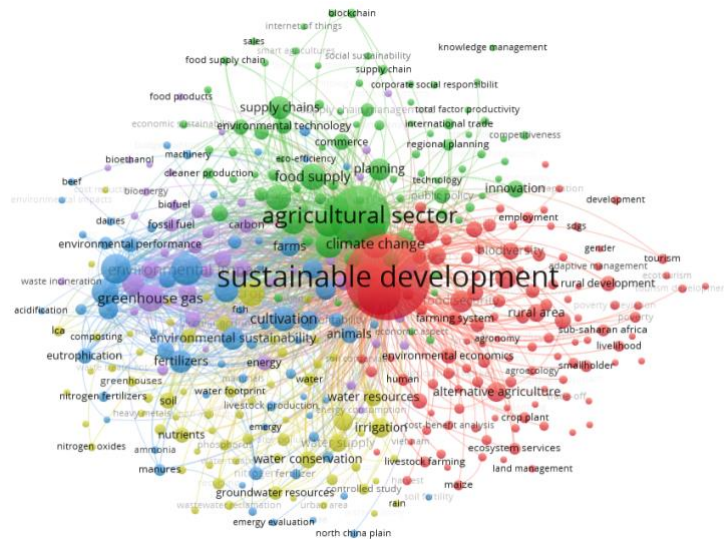


Figure 5. Breakdown of the triadic understanding of the concept of “sustainable development of the agricultural sector”

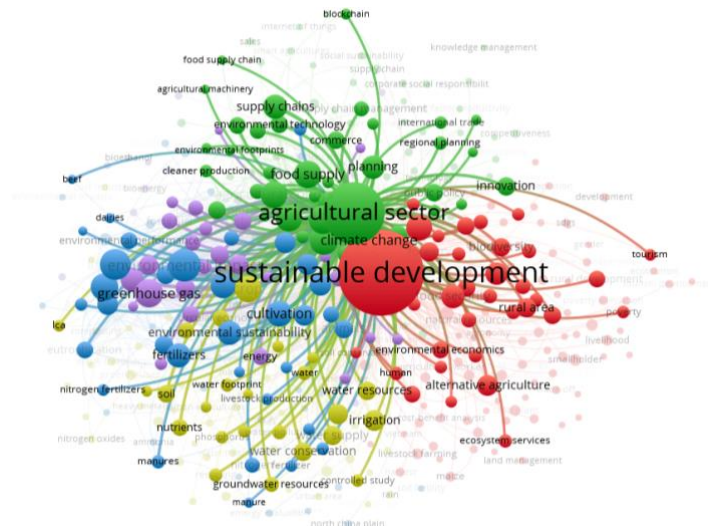
Source: compiled by the author

Based on the results, the following search query was formulated: ((TITLE-ABS-KEY("sustainable development") AND TITLE-ABS-KEY("agriculture" OR "farming" OR "agricultural sector" OR "agricultural practices")) AND PUBYEAR > 2000 AND PUBYEAR < 2024 AND (LIMIT-TO (SUBJAREA, “BUSI”) OR LIMIT-TO (SUBJAREA, “ECON”)) AND (LIMIT-TO (DOCTYPE, “ar”)). As a result, a database of 2,146 articles was created, containing authors’ names, cited publications, journal titles, sponsoring organizations, publication date, country of publication, and keywords, which was subsequently exported to an Excel spreadsheet for further analysis and systematization.

In the second stage, a bibliometric analysis of the generated database was conducted using the VOSviewer tool. Unlike a traditional literature review, this approach eliminates the factor of subjectivity, assesses the significance of scientific work based on the number of citations, and more effectively identifies and analyzes the interrelationships between studies using the “co-occurrence” approach, highlighting related words in the full texts of publications, abstracts, and titles. This made it possible to identify trends in research on the sustainable development of the agricultural sector, uncover key connections between concepts, and determine directions for future research (Fig. 6).



1a) complete thematic map



1b) Fragment of the interrelationships between the concept of the agricultural sector and other concepts

Figure 6. Concept map of the relationships between concepts within the framework of the “sustainable development of the agricultural sector” concept and other concepts for 2000-2024.

Source: constructed using the VOSviewer tool, method: Keyword: Co-occurrence

The central element of the diagram is the concept of “sustainable development,” which is the largest node, around which other keywords are arranged. The high number of connections (379) and the total connection density (11,272) indicate that the objects in the analyzed dataset are closely interconnected with each other and with this concept.

Semantic relationships form five clusters, provisionally labeled as “Sustainable Development of the Agricultural Sector” (red), “Technological Innovations and Management” (green), “Environmental Sustainability” (blue), “Integrated Water Resources Management and Pollution Control” (olive), and “Sustainable Energy Management” (purple). The interpretation of the clusters is based on the thematic focus of the keywords contained within them; however, it should be noted that this division is rather arbitrary, since, as the study results show, both the clusters and the concepts are interrelated. In the identified clusters, the size of an object reflects its total link strength, and the width of the lines reflects the link strength between two terms.

The largest cluster, “Sustainable Agricultural Sector,” includes 113 key concepts and focuses on the implementation of sustainable practices in the agricultural sector that ensure economic development and environmental sustainability. A distinctive feature of this cluster is the integration of sustainable resource management methods, such as climate change adaptation, soil conservation, and efficient use of water resources. Research within this cluster also addresses issues related to the development of agroecology, biodiversity, agroforestry, and the implementation of cutting-edge technologies—such as biotechnology, remote sensing, and geographic information systems—to enhance agricultural productivity.

Research in this cluster covers a wide range of economic aspects related to the sustainable development of the agricultural sector. They aim to improve efficiency, reduce environmental costs, support economic growth based on the analysis of economic processes and models in the agricultural sector, intensify the use of resources, and implement best management practices, including planning, production organization, human resource management, and financial management.

This cluster also includes research on the social aspects of sustainability, particularly the study of agricultural workers’ working conditions, the impact of agricultural practices on local communities, ensuring food security, and the development of local self-governance.

This research cluster aims to provide a multidimensional understanding of sustainable development in the agricultural sector. By combining practices, policy, and environmental considerations, the research is aimed at creating sustainable agricultural systems capable of adapting to climate change, conserving natural resources, and supporting the livelihoods of rural communities.

The second-largest cluster, “Technological Innovation and Management,” containing 89 keywords, brings together a significant number of studies focused on the implementation of advanced technologies and innovations in the agricultural sector, as well as on the management of these processes. The economic context of the research addresses issues of increasing productivity, competitiveness, and efficiency through the integration of artificial intelligence, machine learning, the Internet of Things, blockchain, and digitalization into agricultural practices.

The third cluster, “Environmental Sustainability,” which includes 66 terms, covers research aimed at ensuring environmental sustainability and increasing productivity in the agricultural sector. Research in this cluster focuses on analyzing and reducing the environmental impact of agricultural practices, including studies on measuring and reducing environmental footprints such as greenhouse gas emissions, acidity, and eutrophication. Significant attention is also given to ensuring efficient resource use and increasing agricultural productivity. This cluster explores the interconnections in the study of environmental and socio-economic aspects of sustainability analysis and assessment, including the analysis of costs associated with reducing environmental impacts and the implementation of effective resource management methods to mitigate negative consequences, product life cycle assessment, environmental performance, and scenario analysis. An important aspect is the development of sustainability indicators that allow for the assessment of economic efficiency and environmental performance.

The fourth cluster, “Integrated Water Resources Management and Pollution Control,” comprising 66 terms, focuses on comprehensive water resources management, pollution control, and sustainable water use practices. The main research topics in this cluster include the efficient use of water resources, reducing water pollution, and promoting the sustainable management of water and soil resources.

The fifth cluster, “Sustainable Energy Management,” containing 43 keywords, encompasses a large group of studies dedicated to: the development and optimization of renewable energy sources, such as bioenergy, biofuels, biogas, and biomass, to reduce dependence on fossil fuels and lower greenhouse gas emissions; strategies for reducing carbon emissions and implementing emission control technologies that help mitigate climate impacts and support environmental sustainability. This cluster also explores the economic aspects of effective energy resource management and optimization of their use, including multi-objective optimization, linear programming, and uncertainty analysis to improve the efficiency of decision-making processes in the agricultural sector.

A distinctive feature of this cluster is a comprehensive approach to managing energy resources and production processes in the agricultural sector, ensuring long-term sustainability and economic efficiency.

Thus, based on the conducted research, it can be concluded that comprehensive studies of the sustainable development of the agricultural sector, taking into account the interrelationships and interactions with economic, environmental, and social aspects, predominate. At the same time, research on the sustainable development of the agricultural sector closely intersects with topics such as the management of all types of

sustainability metrics, enabling a more accurate evaluation of the impact of agricultural practices on the environment and socio-economic parameters.

These stages of development demonstrate the formation of a comprehensive approach to the functioning of the agricultural sector, encompassing economic, environmental, and social aspects. The adoption of cutting-edge technologies, such as artificial intelligence and the Internet of Things, contributes to process optimization and greater precision in resource management. In addition, the development of bioeconomy and circular economy concepts opens up new opportunities for the sustainable use of resources and waste minimization.

Thus, current research in the agricultural sector focuses on creating systems that not only ensure high productivity but are also environmentally and socially sustainable. This comprehensive approach allows for more effective solutions to challenges related to climate change, food security, and socio-economic development, thereby providing the foundation for a sustainable future of the agricultural sector (Fig. 8).

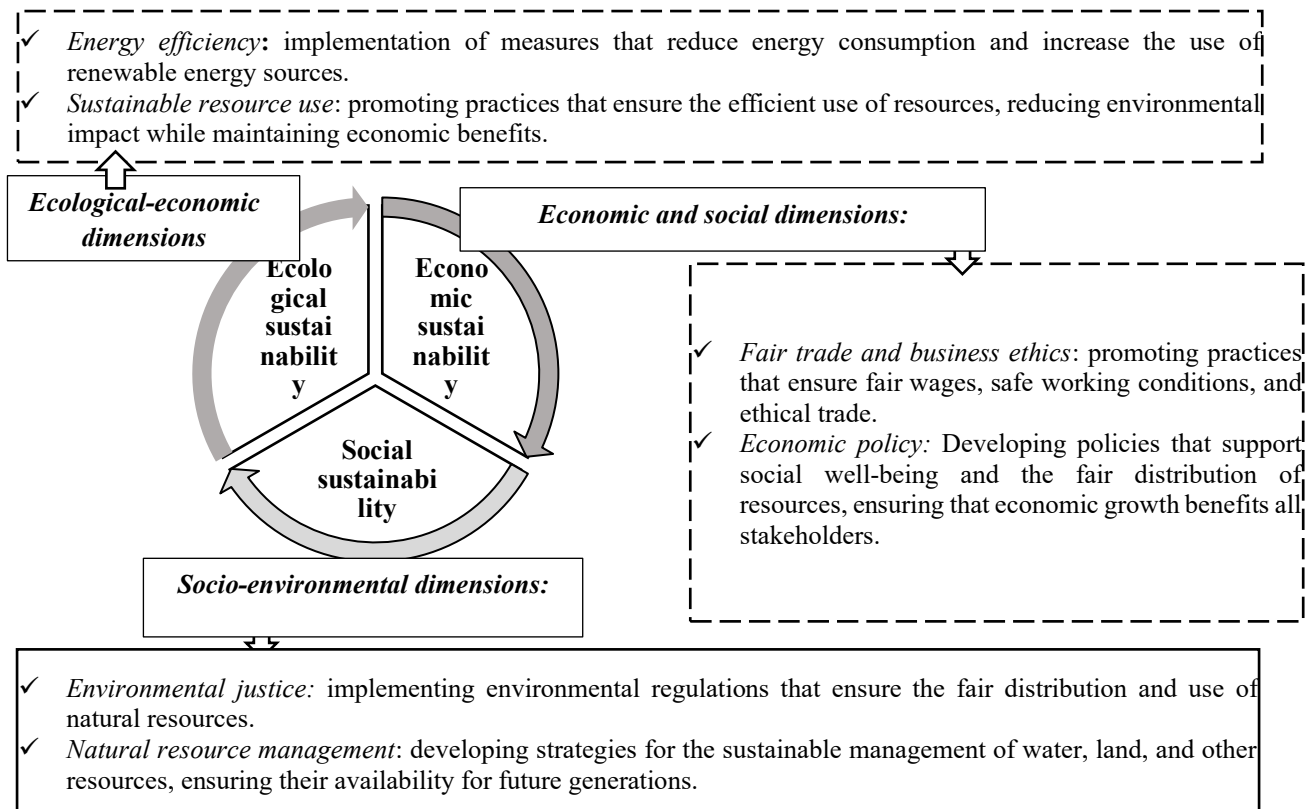


Figure 8. Comprehensive approaches to research on sustainable development in the agricultural sector: integrating social, environmental, and economic dimensions

Source: compiled by the author

Thus, sustainability and sustainable development are interrelated concepts. Sustainable development provides the strategies, mechanisms, and tools necessary to achieve sustainability in the agricultural sector. At the same time, sustainability is a static concept focused on maintaining a state of equilibrium, while sustainable development is a dynamic process emphasizing continuous improvement and adaptation. Given this, we propose to view sustainability as a goal or state that must be achieved, while sustainable development is the process and strategies for achieving this goal. It should be emphasized that the dimensions of sustainability in the agricultural sector cannot be maximized simultaneously, as they are largely mutually exclusive. Therefore, when developing mechanisms to ensure the sustainable development of the agricultural sector-primarily at the state level-it is necessary to define specific targets that will optimize the relationships and interdependencies among these dimensions, thereby enabling the development of a balanced approach. Thus, achieving sustainable development in the agricultural sector requires coordinated efforts to address the complex interplay of environmental, economic, and social factors. By applying holistic approaches that combine environmental principles with socio-economic considerations, it is possible to achieve sustainable agriculture, ensuring food security, overcoming poverty, and protecting the environment.

In the coming decades, the agricultural sector will undergo significant changes: agricultural systems must reduce their environmental impact while producing enough food for a growing population, amid the negative effects of uncertainties and threats of various origins (climatic, economic, social, political) [34]. Given this, agricultural systems must adapt or transform to remain sustainable.

Sustainable development is a comprehensive framework that shapes changes in the agricultural sector. This concept not only helps address current challenges but also fosters a resilient and sustainable agricultural sector capable of achieving its operational goals amid future uncertainties and threats.

Within the scope of this study, we consider it appropriate to examine the model of sustainable development based on the postulates of the systems approach, which views development as “an irreversible, directed, and regular change in the state of a system (object) based on objective laws. As is known, the nature and pace of this process determine whether such changes are evolutionary or revolutionary. The result of development is a new quality of the system” [35].

Therefore, we consider it appropriate to view the sustainable development of the agricultural sector as a complex and multifaceted process encompassing a wide range of shifts, ranging from gradual evolutionary adjustments to transformations caused by factors and triggers of external and internal origin, which lead to changes in its structure, organization, functioning, and role in the economy, and are aimed at ensuring long-term ecological balance, social justice, and economic viability.

To develop a model of sustainable development for the agricultural sector, we consider it appropriate to take into account the tenets of the theories presented in Table 3.

Table 3. Characteristics of theories relevant for developing a model of sustainable development of the agricultural sector [compiled by the author based on 36; 37; 38; 39; 40; 41; 42; 43]

Theory	Main focus	Key advantages	Application in the agricultural sector
<i>Basic concepts</i>			
systems	the study of a specific object as a holistic set of components within a network of relationships and connections between them, i.e., viewing the object as a system model	the ability to analyze complex nonlinear interactions, feedback mechanisms, and dependencies, taking into account the interaction of system components and their capacity for self-organization, as well as the emergence of emergent phenomena and systemic effects	the development of conceptual foundations and the justification of theoretical-methodological, methodological principles, and practical recommendations for improving the process of systemic transformation of the agricultural sector of the economy
institutional	role of institutions in shaping organizational behavior and change, including analysis of legislation and policy.	opportunity to gain a deeper understanding of how institutions, historical context, and socio-cultural factors shape economic processes and outcomes	the opportunity to identify the influence of political and economic structures, both formal and informal, on transformations in the agricultural sector
synergistic	the study of self-organization processes and the emergence of new structures in conditions of instability or crisis situations	the ability to analyze economic processes as nonlinear and capable of self-organization, i.e., the creation of new orders and structures under the influence of internal and external factors	the ability to assess the interrelationships between factors affecting the agricultural sector; to identify development scenarios for the agricultural sector under various conditions and to study potential bifurcations
resilience	focus on the ability of systems to absorb disturbances and reorganize during changes in order to preserve core functions and structures	improving the adaptive mechanisms of economic systems	ensuring adaptation to climate change, market fluctuations, and other shocks through the implementation of appropriate mechanisms, tools, and self-organization

<i>Dynamic aspects</i>			
Evolutionary	studying gradual changes and adaptive processes in systems	the ability to analyze economic processes as open and irreversible systems that are constantly influenced by and respond to external and internal environments; the conclusion that periodic and appropriately selected actions on the system can reduce the likelihood of collapse	identification of interrelationships with external and internal factors, realistic forecasts regarding long-term development, on the basis of which informed management decisions can be made; development of comprehensive development strategies to prevent the degradation of agricultural systems;
dependence on the path	consideration of the impact of past events on current policy and practice	understanding the constraints on the path to new practices in the technological, institutional, and organizational spheres	a slow transition from traditional to modern sustainable practices due to historical inertia.
<i>Comprehensive consideration of technical, social, and environmental innovation factors</i>			
diffusion of innovation	research into how and why new ideas and technologies spread in societies	the ability to identify factors influencing the rate of innovation adoption in the agricultural sector	the ability to analyze the integration of innovations into the overall system of agricultural production technologies
environmental modernization	examining economic growth from an environmental perspective	Support for innovative solutions to environmental challenges	taking environmental productivity into account (the productive use of natural resources and environments) can be a source of further growth and development
socio-technical systems	considering the interrelationship between social and technical aspects, emphasizing the importance of synergy between them	A comprehensive approach to change based on the interaction between social (people, organizational structures, culture) and technical (technologies, equipment, processes) components	integration of new technologies while taking into account social factors and barriers, including access to knowledge, policy support, and changing social values.

Within the framework of our study, we consider the systemic and institutional approaches to be fundamental, primarily because the essence and components of the agricultural sector are formalized on their basis. In the context of studying the sustainable development of the agricultural sector, the systemic approach allows for the analysis of complex nonlinear networks of interactions and feedback channels, taking into account the interdependencies of system components, their capacity for self-organization, and the emergence of emergent phenomena and systemic effects.

The systemic approach is complemented by the institutional approach, as the latter examines the role of formal and informal institutions, norms, rules, and traditions in the sustainable development of the agricultural sector.

In doing so, it is necessary to account for the complex interactions between various institutions, including international organizations, the government, and non-governmental institutions, which both influence the development trajectory of the agricultural sector and are themselves transformed by its influence.

An important characteristic of the institutional approach is that, in the process of studying sustainable development in the agricultural sector, it allows for consideration of the role of stakeholder interest groups, specifically how they can lobby for changes in the agricultural sector and how their influence shapes the regulatory and normative environment.

The institutional approach also has dynamic characteristics, as it recognizes that changes often occur gradually over long periods of time, while the cumulative effects of previous institutional frameworks influence the current state of the agricultural sector.

The synergistic approach emphasizes processes of self-organization and the emergence of new structures in conditions of instability or crisis situations. Its application to develop a model of sustainable development for the agricultural sector identifies and formalizes the stages of its adaptive and transformational development, distinguishing phases of imbalance, bifurcation, degradation, and collapse; It accounts for the multiplicity and alternative paths of the agricultural sector's development at bifurcation points, when processes become chaotic and a transition to a new attractor occurs.

In addition, identifying bifurcation points allows us to understand when and how the agricultural sector may change under the influence of internal and/or external factors.

Resilience theory posits that a high level of resilience enables the agricultural system to remain in its current state. At the same time, it should be noted that a high level of resilience may, in certain cases, prevent the achievement of sustainable development goals (for example, global dependence on fossil fuels has a high level of resilience, and if societal goals involve reducing this dependence, the high resilience of the energy system may hinder changes in the desired direction).

Since we are studying the sustainable development of the agricultural sector as a dynamic phenomenon, it is advisable to take into account the postulates of the evolutionary approach and the path-dependence approach, which allow for the study of gradual changes and adaptive processes in the agricultural system while also accounting for a certain inertia in these changes.

The evolutionary approach, in this context, ensures contextual sensitivity, as it establishes that the model of sustainable development of the agricultural sector exhibits significant differences across various regions and countries due to their unique characteristics, which determine evolutionary determinism.

By incorporating theories of innovation diffusion, ecological modernization, and socio-technical systems, it is possible to develop a model of sustainable development for the agricultural sector that accounts for the complex interactions and mutual influences of social, technical, economic, and environmental factors. Applying these theories helps not only to understand current challenges but also to develop strategic solutions for overcoming future challenges and leveraging opportunities to ensure the sustainable development of the agricultural sector.

Summarizing the material presented above, we have developed a conceptual approach to a cyclical model of sustainable development in the agricultural sector, presented in Figure 9.

We propose considering the evolutionary and revolutionary stages of sustainable development within the cyclical model, in accordance with the general understanding of the concept of "development" under a systems approach, by distinguishing the corresponding key modes-adaptation and transformation [44; 45; 46].

Theoretical discussions surrounding adaptation and transformation include the question of whether these two processes are part of a single continuum or whether they are distinct [47]. Some researchers believe that adaptation and transformation represent two distinct but interrelated processes. Adaptation can be a way of gradually responding to changes, ensuring resilience, while transformation can serve as a strategic response to significant and radical changes aimed at altering the very essence or direction of the system.

However, there is also an approach that adaptation and transformation can occur gradually and at different levels. For example, adaptation can be the first stage in the transformation process, where the system gradually adjusts to new conditions, after which transformation occurs.

We believe that although adaptation and transformation can be viewed as distinct processes with different goals and outcomes, within the context of the cyclical model of sustainable development, they generally interact and occur in different ways depending on specific conditions and context, and are interrelated.

To develop a cyclical model of sustainable development, we consider it appropriate to clarify the concepts of "adaptation" (Table 4) and "transformation" (Table 5).

The adaptation mode is characterized by gradual changes within a stable context, which may be perceived as such due to various socio-cognitive barriers [48]. Changes within this mode are described as a continuation of "what is already being done" [49], "gradual changes that allow the system to preserve its basic functions and characteristics" [50].

During the adaptation process, agricultural producers preserve their values and norms and may also implement specific strategic changes that remain under their control. This allows them to continue generating income from their activities while preserving their identity [51]. This regime involves the integration of new technologies that optimize resource use, improve existing processes, and, on this basis, reduce environmental impact and increase productivity [52].

Summarizing the above definitions, we have determined that most approaches emphasize the goal of adaptation as reducing the agricultural sector's vulnerability to climate change (Burton I., Lim B., National Academy of Sciences of the USA, World Bank). While generally agreeing with this, we believe that the adaptation of the agricultural sector should address a broader range of factors and threats generated by the operational environment.

It is important to note that effective adaptation should not only reduce risks but also capitalize on new opportunities (Burton I., Lim B., Ivanyuta S. P., et al.).

Adaptation is generally associated with changes in practices and structures in both natural and human systems, and with the introduction of new methods and technologies to enhance the resilience and efficiency of the agricultural sector (National Academy of Sciences of the United States, World Bank), which can be implemented at the level of individual producers, communities, regions, and states (Intergovernmental Panel on Climate Change, World Bank).

Therefore, summarizing the above, we consider it appropriate to define the adaptation of the agricultural sector in the context of its sustainable development as a comprehensive process of implementing strategic measures and changes in agricultural practices, technologies, resource management, and institutional structures with the aim of reducing vulnerability to current and future changes in key factors affecting it, as well as the use of new opportunities to ensure long-term environmental balance, social justice, and economic viability.

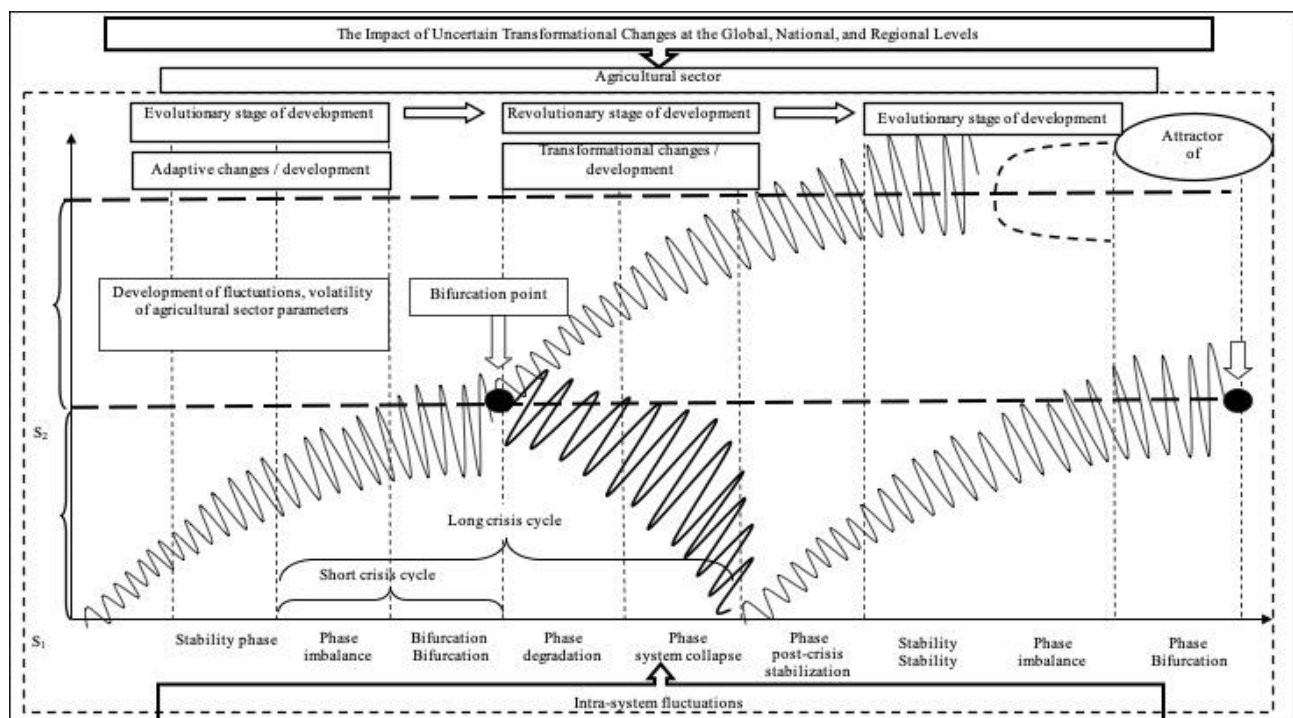


Figure 9. Cyclical model of sustainable development of the agricultural sector

Source: developed by the author

This process involves both proactive and reactive actions at various spatial levels -from individual farms to national and global scales - and requires coordination among producers, the private sector, and government organizations.

Based on the results of our study, we determined that there is no single established definition of the concept of “transformation” as such, particularly as it pertains to the agricultural sector (Table 5).

By synthesizing the above definitions, several key approaches to understanding the essence of the agricultural sector's transformation can be identified.

Table 4. Approaches to understanding the concept of “adaptation” in the context of the agricultural sector’s functioning [compiled by the author based on 53-64]

Author / Organization	Definition
Oliiferuk S. I.	The process of changes in the quantitative and qualitative characteristics of a system, allowing it to achieve an optimal or, under critical conditions, a limiting state of functioning in changing conditions. Systems capable of changing their parameters in accordance with external conditions—that is, of adapting—are called adaptive, and the functioning of adaptive systems is based on a feedback mechanism
Onysko S. M.	the process of adjusting their parameters to the uncertain conditions of the environment, ensuring an increase in the efficiency of their functioning throughout their entire life cycle
Ivanyuta S. P. et al.	The process of adaptation in natural or human systems in response to actual or expected climatic influences, which will reduce their negative consequences and take advantage of favorable opportunities.
Ministry of Environmental Protection and Natural Resources	the ability of systems, institutions, people, and other organisms to adapt to potential harm, take advantage of opportunities, or respond to consequences
Schenefeld, J. J., Schulze, K.; Bruch, N.	measures aimed at enhancing the ability of people and communities to adapt to climate change and related impacts that will occur in various sectors of human life
Burton, I.; Lim, B.	actions aimed at reducing vulnerability and/or taking advantage of opportunities arising from current or future climate change
Intergovernmental Panel on Climate Change	the process of adjusting to actual or expected climate changes and their consequences. In human systems, adaptation seeks to mitigate or avoid harm, as well as to take advantage of beneficial opportunities. Furthermore, adaptation measures undertaken by humans can also occur in natural systems, where actions are taken to promote “better” adaptation to a changing climate
World Bank	the process of introducing new methods and strategies in agriculture aimed at reducing risks associated with climate change, increasing resilience, and ensuring food security
European Environment Agency	changes in agricultural practices, water management, crop selection, and land-use planning aimed at reducing the negative impacts of climate change on agriculture
National Academy of Sciences	a set of actions aimed at reducing agriculture’s vulnerability to climate change through the adoption of new technologies, changes in farming practices, and the development of policy strategies
Food and Agriculture Organization of the United Nations	changes in practices, processes, and structures that enable agriculture to adapt to climate change, thereby reducing vulnerability and capitalizing on new opportunities

Table 5. Approaches to understanding the concept of “transformation” in the context of the agricultural sector’s functioning [compiled by the author based on 59, 65-73]

Author / Organization	Definition
Hrazhevskia N. I.	In a broad sense: a form of economic system development associated with evolutionary (a gradual process of changes in system parameters) and revolutionary changes (the moment of the system’s transition to a different development trajectory), as well as transitions of economic systems from a stable to an unstable state. In a narrow sense: a component of the evolutionary process, as a process of system renewal during abrupt qualitative transformations
Malik M. Y.	A method for resolving contradictions between market demands and the outdated logic of economic agents’ behavior, consisting of organizational, economic, financial, legal, and technical measures aimed at reorganizing enterprises, changing forms of ownership, management, and organizational-legal forms, which will contribute to the financial recovery of the economy, an increase in the output of competitive products, and improved production efficiency
Marushchynets A. V.	The process of changing the institutional, sectoral, and territorial nature of the region’s agricultural sector, driven by the transformation of the entire economic system. From the perspective of human geography, when examining transformational processes in the region’s agricultural sector, key attention should be paid specifically to their territorial aspect

Kartashova O. G., Barsuk Y. V.	A qualitative transformation of a specific model or state, or any sector, into a new order required by the internal and international market conditions of the agricultural sector during a specific period (mobilization and modernization)
Negoda Y. V.	A natural-evolutionary process of social development aimed at enhancing the sustainability of economic growth through the expanded reproduction of all types of resources and the qualitative transformation of the population's standard of living, based on profound, large-scale changes in the socio-economic structure of the agro-economy, various forms of economic activity and methods of agricultural production, and the institutional market environment
	A multi-variant process of development of its elements: economic agents, formal and informal institutions, economic order, and processes, leading to a fundamental transformation of the entire economic system
Vermeulen, S. J., et al.	A set of structural changes in national economies, resulting in the agricultural sector's share of GDP and employment declining, but its productivity increasing
Center for International Agriculture	The adoption of innovative technologies, changes in agricultural and land-use systems, and improvements in farming practices to increase productivity, sustainability, and economic efficiency, while reducing negative environmental impacts
Asian Development Bank	A process of profound and systemic change that includes reforming institutional structures, modernizing technologies, and introducing innovative practices to enhance the productivity, sustainability, and economic viability of agricultural systems
European Commission	Comprehensive changes in policy, technology, and governance aimed at creating more sustainable, competitive, and environmentally responsible agricultural systems capable of adapting to global challenges such as climate change and demographic shifts
UN Food and Agriculture Organization	Changing the ways agricultural products are produced, managed, and distributed to enhance food security, climate resilience, and economic growth through the adoption of sustainable and innovative practices

Malik M. Y., the Asian Development Bank, and the European Commission emphasize the importance of organizational and managerial, financial and economic, legal, and technical measures for transformation. This includes, in particular, the reorganization of enterprises, changes in ownership structures, the modernization of technologies, and the reform of institutional structures.

Marushynets A. V. and others emphasize the territorial and institutional aspects of transformation, highlighting the importance of changes in the institutional, sectoral, and territorial structures of the agricultural sector. This is crucial for understanding local characteristics and the specifics of regional development.

Kartashova O. G., Barsuk Y. V., and the Center for International Agriculture emphasize qualitative transformations and the adoption of innovative technologies. This includes the mobilization and modernization of the agricultural sector, as well as improvements in productivity, resilience, and economic efficiency.

Vermeulen S. J., the UN Food and Agriculture Organization, and the European Commission view transformation as a set of structural changes aimed at creating sustainable, competitive, and environmentally responsible agricultural systems. This involves a shift from traditional methods to innovative and productive practices that enhance efficiency and reduce negative environmental impacts.

Transformation begins with the recognition of the need for more radical changes, which may be triggered by "trigger events" such as economic, climatic, or environmental problems exacerbated by the instability of the operational environment (external or internal to the agricultural sector) [74-76].

Unlike adaptive changes, transformational changes are defined as those that: "1) are implemented on a much larger scale or with greater intensity; 2) are truly new to a specific region or resource system; 3) transform places and alter their configuration" [49]; are more abrupt and involve the system's transition to a new state [77]. According to the approach of O'Brien K. and Hochačka G., transformational changes include not only radical technical changes but also changes in "meaning-making" (i.e., changes in the intentions and attitudes underlying behavior) [78]. This approach is close to the concept of "significant change" proposed by Sutherland L.-A. and others in [74], using the example of the transition to organic farming, which is also considered a transformational change.

Transformational change involves "the reorientation of a significant number of agricultural activities or resources, for example, through a shift from commercial agriculture to social farming or other diversification activities," unlike adaptive change, which is merely "a change in agricultural activity that does not alter the direction or focus of the farming system" [44].

Vermeulen S. J. et al. [70] defined transformational change in the agricultural sector according to the following criteria: a response to climate risks, usually in combination with other factors (quality); redistribution of at least one-third of primary factors of production (land, labor, capital) and/or products and production outcomes (types and volumes of production and consumption of goods and services arising in multifunctional agricultural systems) (distribution); over a 25-year period (duration).

The transformation phase differs from the adaptation phase in its intensity and depth of impact on agricultural practices and technologies. Key aspects of this phase include the adoption of innovative technologies and practices, structural changes in agricultural production, integrated supply chain management, the development of new markets, and economic transformations.

The transformation phase is critical for ensuring sustainable development, as it involves fundamental changes that enhance the efficiency and resilience of the agricultural sector and reduce its environmental impact.

Given the current conditions, characterized by a growing number of threats and challenges to the sustainable development of the agricultural sector, adaptation alone will be insufficient: transformational changes are necessary [49; 74]. For example, gradual adaptive adjustments may allow for better management of climate risks and opportunities in the short term [44; 79], but more radical changes will be necessary to ensure the long-term viability of the agricultural sector [80]. For instance, reducing greenhouse gas emissions to achieve sustainable development goals requires precisely such transformational changes [77; 80]. Furthermore, incremental adaptive measures carry the risk of decisions that lock agricultural systems into suboptimal development trajectories, failing to ensure the achievement of sustainable development goals.

Thus, based on a synthesis of scholarly approaches, the transformation of the agricultural sector can be defined as a comprehensive process of profound structural changes, encompassing the transformation of organizational, institutional, technological, and territorial aspects of the agricultural sphere. This process aims to increase the productivity, resilience, and economic efficiency of agricultural systems through the introduction of innovative technologies, the modernization of production methods, adaptation to global challenges, and the assurance of food security and environmental responsibility.

Table 6 presents a summary of the characteristics of adaptation and transformation within the framework of sustainable development of the agricultural sector.

To provide a detailed and in-depth analysis of the stages of sustainable development in the agricultural sector, based on the principles of a synergistic approach, we consider it appropriate to identify the phases of imbalance, bifurcation, degradation, and collapse, as it is precisely to prevent their occurrence that appropriate mechanisms and tools must be developed.

Due to the influence of external factors, such as climate change, economic crises, or social conflicts, and/or internal changes, the agricultural sector, as an open system, may deviate from a state of equilibrium and transition into a phase of destabilization.

Identifying and assessing these factors is crucial for developing and implementing strategies to support a resilient and adaptable agricultural sector in the face of potential changes and crises. It is undeniable that the issue of the agricultural sector's vulnerability and sustainability is becoming increasingly significant and timely [81], particularly regarding natural disasters exacerbated by climate change and social conflicts.

Within the scope of this study, we propose to consider the factors determining changes in agricultural systems using a systemic and synergistic approach, and to include in their composition the internal factors of the agricultural sector's components as a system, their properties, and their interrelationships within a single complex, which depend on environmental conditions and are determined by the level of bifurcation changes based on the fluctuation component.

Destructive coherent potential is determined both by objective aspects related to the influence of uncontrollable external environmental factors and by subjective factors determined by the internal characteristics of the agricultural sector's components, in particular, the efficiency of operational and management systems and processes, and the adequacy of institutions.

Table 6. Characteristics of adaptation and transformation in the context of sustainable development of the agricultural sector [summarized by the author]

Characteristic	Adaptation	Transformation
Purpose	Reducing vulnerability to current and future changes, leveraging new opportunities, and ensuring the resilience of agricultural systems. It is a response to external changes and involves gradual adjustments	Profound and fundamental changes in the socio-economic structure, organization, and management of the agricultural sector, aimed at restructuring the system in accordance with new market and social conditions
Intent and purpose	Spontaneous as a reaction to immediate challenges, or planned, with long-term strategies to prepare for possible changes	The need for strategic planning, the necessity of significant changes in the structure and functioning of agricultural systems
Initiative	Private (autonomous), implemented by individuals in their own interests; public, implemented by government entities and aimed at the common good (public goods or actions to correct market failures)	
Intensity	Improvement of existing systems and processes	Qualitative renewal of the system
Timing and duration	Proactive, simultaneous, or reactive adaptation	Proactive, simultaneous, or reactive transformation with a focus on long-term impact
Scale	From the local level (field, farm) to the regional or national level, with an emphasis on practical changes in agricultural practices.	Covers broader scales: regional, national, and global levels with an emphasis on structural and institutional transformations
Responsibility	Individual farmers, private enterprises, government agencies.	Coordination of actions by governments, the private sector, and farming communities.
Form	Administrative, financial, institutional, legal, managerial, and technological measures.	Comprehensive solutions that include policy reform, the introduction of new institutional structures, business models, etc.
Constraints and challenges	Financial resources, government support, social barriers.	Lack of coordination, resistance to change, economic and social challenges.

A summary of external influencing factors that may necessitate its adaptation/transformation to ensure sustainable development is presented in Table 7.

Table 7. Classification of external factors influencing the adaptation/transformation of the agricultural sector to ensure sustainable development [compiled by the author based on 53; 82-94]

Level Factor	Global	National	Local
	Differentiation based on the level of impact and characteristics of the territory where the agricultural producer is located, as well as the specific conditions of the country		
Ecological and climatic	Climate change, including changes/variations in temperature, precipitation, evapotranspiration, water balance, and hazardous natural phenomena (heavy rains, droughts, floods, etc.). Level of climate variability.		
	Global depletion of natural resources and environmental pollution	Level of air and water pollution Changes in biodiversity and soil quality	The state of local ecosystems
Political	Global political uncertainty Global political conflicts. Sanctions. Geopolitical conflicts, shocks, and uncertainty Global political initiatives on sustainable development and climate change	Domestic political instability Ineffectiveness of the regulatory environment Ineffectiveness/ lack of government support for the agricultural sector High levels of corruption Military actions by other countries	Ineffectiveness of local government and politics Inefficiency/ Lack of local support for the agricultural sector

Economic	Global economic dynamics. Uncertainty in global markets. Dynamics of global prices for agricultural products. Convergence and evolution of international regulatory standards. Changes in the nature of resource consumption and their cost	National macroeconomic instability and shocks. Macroeconomic uncertainty. Lack of a clear agricultural policy Insufficient infrastructure development Limited access to financing and credit	Insufficient level of economic development in communities Insufficient infrastructure development
Social	Global demographic changes.	Demographic changes (rural migration, aging population, changes in the labor force structure)	
	Social and cultural changes affecting the requirements for production and products in the agricultural sector (increasing demand for organic products, high-value-added products, etc.)		
	Social instability and conflicts		
	Global pandemics.	Level of public health.	
		Insufficient social support.	
	Global cultural influences	National traditions and cultural influences	Local traditions and cultural influences
Technological	Adoption of global digital technologies	Development of national IT infrastructure. Level of digital inclusion	Accessibility of digital technologies, expansion of IT infrastructure

A combination of external factors can pose significant threats to the sustainable development of the agricultural sector, as their impact on the production, supply, and marketing of agricultural products reduces the sector's productivity and the standard of living in rural communities, while limiting access to food, particularly for vulnerable groups.

To classify changes in the external environment as transformational, they must meet the following criteria:

- scale: the change affects multiple levels of the agricultural system, from local to global;
- depth: the change in the factor/trigger deeply penetrates the core functions of the agricultural sector, affecting resource characteristics, value creation processes, supply chains, and management structures;
- persistence: the impact has a long-term effect rather than being temporary fluctuations in specific indicators;
- systemic impact: the factor/trigger alters fundamental dynamics and relationships, leading to the emergence of new configurations and practices.

Most transformational changes result from shocks, the exceeding of critical levels in strong trends of key variables, or the falling below threshold values. Understanding and quantifying these transformational changes is a crucial element in developing strategies that not only mitigate their negative impact but also leverage the opportunities they present to ensure the resilience and sustainability of agricultural systems.

An important characteristic of transformational changes in the external environment is their uncertainty, which complicates the processes of managerial decision-making, strategic planning, and the implementation of sustainable practices, thereby affecting the agricultural sector's ability to achieve sustainable development.

External environmental factors and the types of uncertainty they generate are interrelated, creating a complex operational environment that simultaneously affects the economic, social, and environmental aspects of agricultural production (Fig. 10).

The sustainable development of the agricultural sector is also determined by subjective factors stemming from its internal characteristics, which result from the ability of its participants to create, integrate, and reconfigure resources, adapt/transform value creation processes, and integrate innovations into production processes in accordance with changes in the external environment, that the resulting synergistic effect ensures the efficient production of agricultural products in alignment with social and environmental goals.

One of the key internal aspects of sustainable development is the agricultural sector's ability to effectively utilize existing resources, as well as to create new ones, integrate them into production processes, and reconfigure them in response to changes in the external environment. This process is defined as an enterprise's dynamic capabilities, which characterize its capacity for innovation and transformation [95]. The ability to reconfigure resources is particularly important in the context of climate change and environmental requirements, as it enables a rapid transition to sustainable production models.

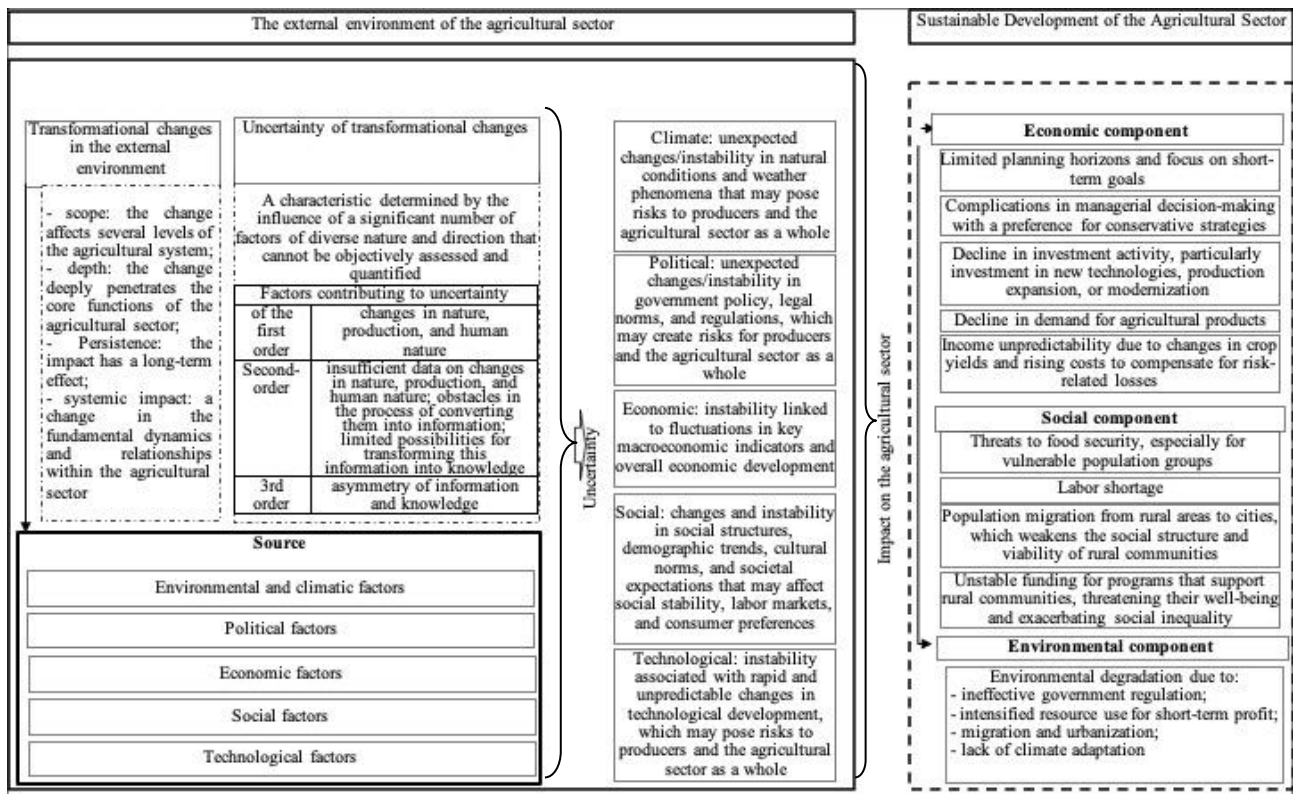


Figure 10. Conceptual approach to determining the impact of uncertain transformational changes on the sustainable development of the agricultural sector
Source: developed by the author

Sustainable development of the agricultural sector is also determined by the alignment of processes and value chains with its goals and principles. This means that agricultural production through the implementation of appropriate technologies must not only provide economic benefits but also meet social and environmental goals.

According to J. Pretty, “new approaches are needed that will allow for the integration of biological and ecological processes into food production, minimize the use of non-renewable resources that harm the environment or the health of farmers and consumers, and make productive use of farmers’ knowledge and skills” [12].

The integration and reconfiguration of resources, combined with the improvement of value-creation processes, can create a synergistic effect where the overall result exceeds the sum of the individual effects. This can manifest itself in increased productivity, reduced costs, improved product quality, and minimized negative environmental impact. The synergistic effect can also contribute to enhancing the competitiveness of agricultural enterprises in the global market, as they are able to respond more quickly and effectively to changes in the external environment.

Sustainable development of the agricultural sector is based on the concept of a sustainable business model for the agricultural sector, which is intended to “... help develop integrative and competitive solutions that either radically reduce negative impacts or create positive environmental effects for the natural environment and society” [96]. The inability or unwillingness of agricultural producers to adapt or transform business models in light of external factors and internal changes leads to the degradation of agricultural production.

For an in-depth study, we have developed a system of additional indicators that will allow for the analysis of the main characteristics of external and internal factors, presented in Appendix B.

Depending on the accumulated destructive coherent potentials, the complexity and structure of the channels through which threats to the sustainable development of the agricultural sector spread, the scale and direction of external influences, the combination of factors affecting the agricultural sector and the complex of its feedback reactions, the negative consequences of fluctuations can be overcome (return to the stability

phase), keeping the agricultural sector on its current development trajectory, or a transition to the bifurcation point will begin.

We propose understanding the bifurcation point as a critical point of change in its development trajectory, at which the destructive coherent potential increases, leading to destabilization and the intensification of the uncoordinated movement of system elements relative to internal and external fluctuations. It determines the moment from which the formation of possible states of the agricultural sector begins, depending on the decisions made and measures implemented. As noted in [97], “the significance of bifurcation points also lies in the fact that only at these points is it possible to influence the system’s behavioral choices and its future through non-forceful, informational means—that is, through actions of any degree of weakness.” At this point, the agricultural sector is particularly sensitive to external and internal influences, and even minor changes can lead to drastic outcomes. For example, the choice between traditional intensive farming and organic farming can have long-term consequences for environmental sustainability and economic stability [70].

Since the significance of bifurcation points lies in their ability to influence the choice of the agricultural sector’s future development trajectory, identifying them allows us to predict when and how the agricultural sector may change under the influence of internal factors (e.g., innovation, changes in management approaches) or external factors (climate change, market fluctuations). Understanding these issues and the timely implementation of appropriate measures ensure the sustainable development of agricultural systems, reducing their vulnerability and increasing their resilience to changing conditions.

The role of government regulatory bodies is to effectively leverage fluctuations through the implementation of appropriate interventions and, on this basis, ensure the sustainable development of the agricultural sector. Government regulators must take preventive measures to identify and eliminate risks in the agricultural sector to prevent destructive processes within it [94]. Ensuring the sustainability of the agricultural sector in this context involves not only identifying and eliminating vulnerabilities but also creating mechanisms and structures that enable rapid adaptation and recovery in conditions of uncertainty and change.

If the positive scenario is realized, the agricultural sector could transition to a transformational mode that would enhance its sustainability—including resilience to climate change—reduce its negative environmental impact, and improve the socioeconomic conditions of local communities [70].

If the agricultural sector fails to find effective pathways for transformation, it may enter a phase of degradation, where its productivity and resilience decline, which could ultimately lead to its collapse. For example, this could include the continued use of environmentally harmful practices or insufficient adaptation to climate change. This could result in land degradation, a decline in biodiversity, a deterioration of the socioeconomic condition of local communities, and increased vulnerability to climate disasters. In the long term, this could threaten food security and the economic well-being of regions dependent on agricultural production.

Thus, we have formulated the conceptual foundations for ensuring the sustainable development of the agricultural sector based on a model of its cyclical development, which, unlike existing models, allows us to distinguish stages of adaptation and transformation, identifying phases of imbalance, bifurcation, degradation, and collapse; takes into account the influence of uncertainty and the multi-variant, alternative nature of the agricultural sector’s development at bifurcation points. This has formed the scientific basis for developing a scientific and methodological approach to creating tools for assessing and ensuring the sustainable development of the agricultural sector.

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INFORMATION SUPPORT FOR SUSTAINABLE DEVELOPMENT ACCOUNTING

Yarmila Tkal

Ph.D., Associate Professor, Associate Professor of Accounting and Taxation Department, Sumy National Agrarian University

ORCID ID: 0000-0002-7646-2266

The research is devoted to the problem of information support for accounting for sustainable development of business entities and integration of financial and non-financial information into a single accounting and analytical system. In the context of growing demands for transparency, accountability, and digital adaptation of business, modern approaches to reporting reveal a number of gaps, including fragmented data, insufficient internal control of reliability, and the lack of a unified methodology.

The aim of the study was to develop conceptual principles that would ensure the effective integration of non-financial indicators of sustainable development into the classic accounting and analytical system of an enterprise. The study was carried out through theoretical generalization, critical analysis, structural-logical modeling, and empirical methods.

As a result, it was established that integrated reporting should not only inform external users, but also shape the strategic behavior of the enterprise, promote the digital transformation of accounting, optimize capital, and take into account long-term environmental and social risks. A model of information support for sustainable development has been substantiated, which provides for the harmonization of financial and non-financial flows, the introduction of verification mechanisms, and adaptation to international standards.

The scientific novelty lies in the combination of classical accounting principles with the needs of sustainable development based on digital adaptability. The practical value lies in recommendations for building management reporting systems that meet the requirements of the modern market and ESG indicators.

The regulation of financial reporting by business entities has a problem with the effectiveness of communicating financial and non-financial information to users. Without high-quality, reliable, and transparent reporting, it is impossible to assess the real progress of companies in achieving sustainable development goals (Gillan, Koch & Starks, 2021). These are Goal 8: Decent Work and Economic Growth, Goal 9: Industry, Innovation and Infrastructure, and Goal 12: Responsible Consumption and Production. Regulatory requirements for financial reporting are constantly increasing. At the same time, overly burdensome reporting makes it impossible for users to adequately perceive financial and other related non-financial information (FRC, SEC, VRU, NBU, 2024). It is sustainability reporting (data on environmental impact, ethical standards, social policy, management approaches) that will allow businesses to demonstrate their responsibility to society (Said Hassan, 2011).

Ukraine has clearly defined its development path as an integral part of the common European Economic Area (Yakymenko, 2021). Ukraine also has obligations to implement changes aimed at harmonizing legislation. There is a shift from the Partnership and Cooperation Agreement to the current Association Agreement (European Integration Portal, 2022). International investors with global investment portfolios are increasingly demanding high-quality, transparent, reliable, and comparable reporting from companies on ESG and sustainable development issues. Transparent disclosure of ESG information will improve an organization's reputation, provide access to capital at a lower cost, and increase competitive advantages (Beretta, V., Demartini, M. C., & De Villiers, 2025).

The success of the Sustainable Development Goals depends on the quality of information flow management at the enterprise level. Most organizations operate within fragmented reporting systems. This means that financial, tax, statistical, and non-financial data remain disconnected (Velte, 2022). This makes effective management decisions impossible. It undermines trust in reporting as a tool for transparency and accountability of business to society (Nesterenko, 2024).

The issue of timely reporting becomes relevant in view of the digitization and digitalization of business processes. Often, the financial reporting process is perceived by reporting entities as an “end in itself.” That is, reporting is done to comply with regulatory requirements (Van Bommel, Rasche & Spicer, 2023). This process does not create any added value for them. It only protects them from risks and penalties from regulators for failure to report. At the same time, regulators often perceive this process as a ritual. Integrating information systems can be a complex and costly task (Nesterenko, 2021). However, it is a necessary step to improve the efficiency and productivity of an organization. An additional problem arises from the lack of effective control over the reliability of non-financial indicators, which directly affects the quality of integrated reporting

(International Auditing and Assurance Standards Board, 2024). Therefore, the integration of environmental, social, and governance indicators into reporting is a prerequisite for the information security of the economy. Accounting has the potential to become the main tool for the formation of accounting and analytical support for sustainable development (Biloblovskyi, 2025).

In practice, the lack of proper regulatory framework and coordinated approaches makes it impossible to develop a unified model of sustainable reporting. What is the situation? In the absence of a unified methodology, each enterprise independently determines the scope, content, and format of non-financial information. I believe that reporting risks becoming a formal procedure devoid of managerial value. There is a need to develop a conceptual model for reporting management that will be able to adapt to changes in the environment.

The aim of the research is to understand the problems of information support for accounting for sustainable development of economic entities and to integrate financial and non-financial information into a single reporting system based on the principles of transparency, accountability, and responsibility in the context of sustainable development goals.

The research goal will be achieved through the phased solution of scientific tasks:

1. To provide a theoretical justification for the concept of sustainable development as an integrative approach to economic activity and to define the role of accounting as a tool for forming a reliable information base for making sustainable management decisions.

2. Analyze the structure of the modern information support system used in managing sustainable development of enterprises, taking into account its impact on the effectiveness of management decisions.

3. Explore international approaches and requirements of leading standards for non-financial and integrated reporting on the quality and verification of accounting information on sustainable development.

4. Identify and systematize problems in current sustainable development reporting practices, including data fragmentation, lack of a unified regulatory framework, and challenges related to the digitization of accounting and analytical processes.

5. Justify the feasibility of implementing unified approaches to the collection, processing, and presentation of environmental, social, and management indicators integrated into the enterprise's accounting and internal analytics system.

6. Develop a model for providing information on sustainable development that takes into account the current requirements of digital transformation, the needs of reporting users, and the tasks of ensuring economic, social, and information security.

This study stems from my desire to find an answer to the question: “Why, despite the active implementation of digital solutions, the expansion of international reporting standards, and growing public demand for corporate responsibility, does sustainability reporting remain fragmented, declarative, and ineffective?” I believe that without reliable and comprehensive financial, non-financial, and analytical information support, it is impossible to achieve a systemic transformation of business in accordance with the Sustainable Development Goals declared in the UN General Assembly Resolution (Sustainable Development Goals, 2019).

Integrated reporting today is a model of compilation and presentation logic based on principles. It is not based on a specific detailed standard of disclosure and measurement. This model allows each entity to compile its own report (Association of Chartered Certified Accountants, 2021). The change in the culture of information presentation should allow companies to better communicate the creation of added value to users than simply template disclosure of information in accordance with International Financial Reporting Standards (Beretta, Demartini, & De Villiers, 2025).

We take into account the rules of communication and interaction. After all, in countries with a straightforward culture, directness and honesty are valued. This may lead to more direct information in the reporting of such organizations (Bosi, Lajuni, Wellfren & Lim, 2022). In countries with an indirect culture, politeness and tact are valued. This may result in more indirect information in the reports of such organizations, which will be difficult for people from other cultures to understand (Wijaya, Wiratama & Kuswanto, 2023). The assumption that “more is better,” which is found in the concept of project management, will make it impossible to achieve the set goals (Amiruddin, Raharja & Purnomo, 2024). In reporting systems, fragility is expressed in receiving such a number of tasks that it becomes impossible to process them on time and without errors. Fragility arises when someone tries to make something big right away or tailor functionality to certain requirements that did not exist before (Jayasuriya & Sims, 2023). An effective tool for managing this risk is to divide a large whole into smaller parts if that whole is fragile.

International experience shows that leading companies are implementing digital tools for adaptive, scalable, and dynamic ESG reporting. Big Data, artificial intelligence, and cloud technologies significantly improve the efficiency of sustainable development data collection and analysis (Wavestone, 2024). Best practices include the use of specialized ESG platforms such as Enablon, Intelix, and Sphera to track metrics in real time and consolidate data from various sources (Google Cloud blog, 2022). This provides a holistic view of sustainability performance, and built-in report templates simplify data collection and analysis.

Companies are increasingly using Microsoft Azure and Google Cloud cloud solutions to store and process large volumes of ESG data. Cloud platforms provide scalability and automation of data entry, allowing for rapid analysis of large data sets and insights (Bean, 2021). This is especially useful for businesses with complex supply chains, as the cloud simplifies data sharing with stakeholders and increases transparency (Berardino & Vona, 2023).

This study aims to systematize the above issues and attempt to provide a scientifically sound answer to the question: “How can financial and non-financial information be integrated into a single accounting and analytical system for sustainable development? How can its adaptability, verifiability, and compliance with digital challenges be ensured?” The research also demonstrates that in the absence of a unified methodology for accounting for sustainable development, each enterprise is forced to seek its own, not always effective, solutions. As a result, the managerial value of reporting is lost.

To accomplish the research objectives, methods of logical analysis, synthesis, generalization, visualization, and comparative analysis of international approaches to reporting were used. The modeling method made it possible to propose a unified concept of accounting and analytical support for sustainable development that meets the current needs of users of reporting information, the requirements of digital transformation, and institutional accountability.

The link between modern requirements for transparency, business accountability, and the implementation of Sustainable Development Goals shows that financial indicators alone cannot reflect the full picture of a company's activities. The need to combine financial and non-financial information is becoming a key element of information support for sustainable development.

An analysis of scientific works on the theoretical foundations of accounting, the essence of integrated reporting, and its role in the management system allows us to substantiate the importance of scientific research specifically on information support for sustainable development. A review of the literature allows us to reveal socio-economic, organizational, and technological processes and phenomena. The global scientific discussion focuses on the quality, reliability, comparability, and timeliness of information on sustainable development, as well as the requirements of international standards.

An important component of the literature review is the study of the current state of accounting and reporting information systems, their capabilities and limitations, and an analysis of proposals for improving these systems. It is this perspective that allows us to identify the gaps that are the subject of the study.

The literature review section consists of subsections that sequentially examine: the historical development of accounting and integrated reporting theories; the evolution of the conceptual framework for sustainable development information provision; contemporary approaches to integrating non-financial indicators into the accounting system; and the assessment of the impact of digital technologies on reporting information processes.

In encyclopedic literature, development is seen as a process that changes the quality of something, moving from one quality to another, higher one (Great Explanatory Dictionary, 2005).

Development is not so much a question of what is, but rather of what can be done with what is. Growth and development are not at all similar concepts. Growth can occur with or without development (Berenda, 2013). The traditional paths to entrepreneurial growth are considered to be quantitative growth in production factors (production volume, labor force) and improvement in the financial and marketing performance of the enterprise (sales volume, profitability, market share compared to competitors) (Voloshchuk, 2011). Conscious stimulation of enterprise development involves improving the investment climate and selecting a strategic area of economic activity in the market with an appropriate operating strategy (Heiets, 2005).

From the perspective of a systematic approach, development is a targeted change in the qualitative state of an organization, its structure, composition, or properties, as well as quantitative or qualitative changes in the elements of the organization (Poberezhnyi, 2012).

We assume that the concept of sustainable development should be considered in the context of a territorial approach. The criteria for sustainable development of rural areas can be interpreted as the stable

development of rural communities that meets the criteria of economic, social, and environmental efficiency (Kuz, 2013).

Development is a process of passing through stages of economic growth. We divide possible development options into four independent categories: linear development; development through structural transformation; development through the smoothing of structural imbalances in the economic system; development from the position of the key role of free market (Tsepanskyi, 2009).

We identify evolutionary and revolutionary forms of development (Khvesyk, Bystriakov, Levkovska & Pylypiv, 2012). The evolutionary form is associated with gradual quantitative changes in the object, while the revolutionary form is characterized by qualitative changes in its structure.

We distinguish between progressive and regressive types of development (Tiukha, 2012). It is also proposed to divide development processes into sustainable and unsustainable (Tsybuliak, 2014).

National sustainable development strategies have different focuses: in the UK, it is the preservation of the natural environment; in Canada, it is basic human needs; in France, it is a list of various priority issues.

On the other hand, sustainable development is the development of a country's productive forces aimed at meeting the most important needs of not only the current but also future generations, while preserving the natural environment in a state that is favorable from the point of view of human health and maintaining a dynamic ecological balance (Sokil, 2017). The main goal of sustainable development is defined as the human being.

Contemporary views on the problem of sustainable development are most fully reflected in the tripartite concept of sustainable development, which we have systematized as a combination of three basic approaches: economic, social, and environmental.

Legal support for integrated reporting in international practice varies from country to country. Some jurisdictions have clearly established regulatory frameworks. In others, the use of integrated reporting remains voluntary.

These processes have gained particular momentum in the countries of the European Union. Under the influence of legislative initiatives, there has been a gradual unification of requirements for integrated and non-financial reporting (Makarenko, Serpeninova, Oleksich, Kostenko & Puhovkina, 2023).

An analysis of data for the period 2014-2024 shows a steady increase in the share of European companies that practice integrated reporting and sustainability reporting. I believe that this trend is related to the strengthening of the regulatory framework and the growing expectations of key stakeholders regarding the transparency of companies' activities.

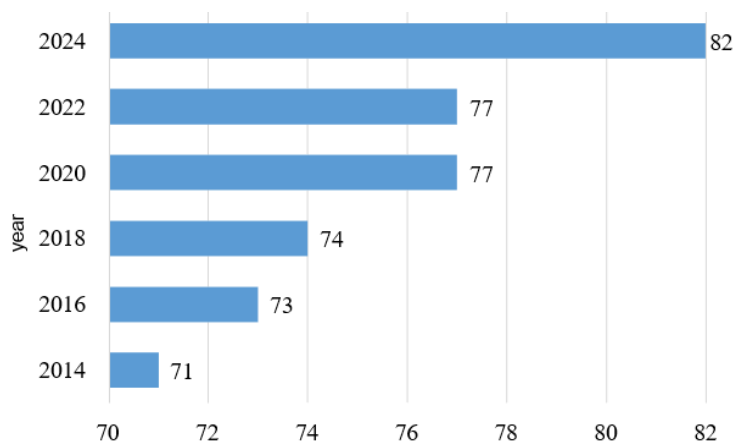


Figure 1. Share of European companies practicing integrated reporting and sustainability reporting for 2014-2024, %

For agricultural enterprises operating in specific conditions of seasonality, spatial dispersion, and a high level of natural and climatic dependence, it is especially important to ensure a comprehensive approach to the formation of information flows (Fang & Guo, 2025). A detailed analysis of the characteristics of financial and non-financial indicators is necessary in the context of the agricultural sector. This will allow identifying key differences between them and assessing their impact on the process of integrated reporting by agricultural enterprises.

The results of the analysis show that for agricultural enterprises, financial and non-financial information flows are interdependent and complementary components of an integrated management system.

They form the basis for a comprehensive assessment of their performance. Financial indicators reflect the level, structure, and dynamics of financial capital (Zou, Shi, Chen, Deng, Lei, Zeng, Yang, Tong, Xiao & Zhou, 2023). This is the basis for short-term performance. Non-financial information represents social, environmental, and management factors. These factors determine the long-term competitiveness and sustainable development capacity of an agricultural enterprise (Katz, Gu & Jiang, 2024).

The purpose of integrated reporting is to satisfy the maximum amount of information needs regarding a wide range of circumstances of business entities (Gull, Hussain, Khan, Khan & Saeed, 2023). It is necessary to develop information support that will help reduce the inefficient use of resources in the preparation, justification, implementation, and evaluation of business decisions. It will also increase the analytical capabilities of its use in the interests of stakeholders (Hertl & Maniora, 2024).

The introduction of ESG reporting into corporate governance requires the formation of an internal institutional infrastructure (tools, monitoring mechanisms, incentive policies, strategic integration of ESG metrics) (Wu, He & Duan, 2013).

The systematic introduction of ESG reporting in organizations is only possible if an adaptive model is developed that takes into account national characteristics, institutional immaturity, and the needs of different stakeholder groups (Bari, Chimhundu & Chan, 2022).

As a result of the analysis of literary sources, I came to the conclusion that the problem of integrating financial and non-financial information remains unresolved. Many authors only outline the need for a change in the accounting paradigm. However, they do not offer specific mechanisms for implementation.

The analysis showed that modern reporting is mainly focused on quantitative economic indicators. Environmental and social aspects remain outside the analytical field. In my opinion, this creates a distorted picture of the company's activities for internal and external users of reporting. It is obvious that without taking into account the full range of sustainability indicators, management decisions will be suboptimal.

The methodology for collecting and analyzing data within this study was based on an in-depth theoretical study of integrated reporting as a key tool for providing information on sustainable development accounting. A qualitative approach was chosen, aimed at identifying and systematizing existing scientific and regulatory approaches.

The study used methods of theoretical generalization, critical analysis, modeling, and logical abstraction to study the conceptual foundations of sustainable development accounting. Particular attention was paid to internal control mechanisms for reporting reliability, verification procedures, and analytical interpretation. This is necessary to ensure transparency and adaptability of reporting in the context of digital transformation.

Structural-logical modeling was used as one of the main research tools. This allowed for a systematic presentation of the interrelationship between financial and non-financial indicators. Comparative analysis was aimed at evaluating various models and standards of integrated reporting and internal control, particularly those developed by international organizations. Schematic interpretation included the development of functional diagrams (integration matrices, control modules). They supported the theoretical justification for building information support for sustainable development at the enterprise level.

The analysis covered materials presented in the form of tables, diagrams, and charts. These simulate an integrated information system for sustainable development accounting. This involved the decomposition of reporting components, the assessment of their internal links, and the construction of adaptive control mechanisms for verifying the reliability of information.

The proposed methodological basis made it possible to form a logically coherent and analytically sound structure for the integration of financial and non-financial information flows.

In this study, the analytical base was formed on the basis of a qualitative analysis of conceptual, normative, and methodological materials (Social Accountability International, SASB Standards). They concerned the information support for accounting for the sustainable development of business entities. The main focus was on modern scientific approaches to the construction of integrated reporting, internal control, and the digitization of accounting processes.

The structural components of information flows in the enterprise, the mechanisms for their integration, the reliability of reporting, and analytical mechanisms for data processing (UPL Sustainability Report, 2025) were analyzed. Particular emphasis was placed on key tools. These are compliance matrices, logical-structural diagrams, and reporting reliability control models. After all, they visualize the relationships between financial and non-financial indicators.

Data collection was carried out by generalizing theoretical approaches to organizing reporting in the context of sustainable development, analyzing the current regulatory framework (Ukraine Report, 2025). A review of developed practical solutions for information verification was also systematized. The data was structured into logical models that demonstrate ways to combine information from different sources. Internal reporting, analytical reports, and control indicators were taken into account.

This approach allowed for a comprehensive assessment of existing methodologies and their adaptation to the conditions of digital transformation. This approach allowed for the relevance and applied value of the study for further practical developments.

The context of the study was formed on the basis of a practical analysis of the activities of leading agro-industrial enterprises of Ukraine, which disclose information on aspects of sustainable development. To form the analytical basis of the study, enterprises were selected that publicly report on environmental, social and management indicators and demonstrate efforts to integrate non-financial data into the general management information system.

The study was based on the analysis of open reports and internal accounting systems of the following companies: Agro-industrial holding "ASTARTA", Group of companies "ATK", "Vayterra Ukraine", Company "IMK", Holding "Kernel" and PrJSC "MHP". The choice of these enterprises is due to their high degree of digitalization of accounting processes, active use of integrated reporting practices, representation of various forms of management in the agricultural sector.

Within the framework of this study, data collection was carried out using a questionnaire survey, analysis of reporting documentation of agricultural enterprises, as well as modeling of information flows. The main goal of the data collection stage was to identify the real state of integration of financial and non-financial information into the accounting and analytical system of agricultural enterprises. Also, to assess the effectiveness of existing internal control mechanisms and verification of reporting. The questionnaire was aimed at identifying practices in the formation of integrated reporting, the level of digital transformation of accounting, and the readiness of enterprises to disclose ESG information. The questionnaire contained both closed and open-ended questions and was formed taking into account the conceptual provisions of sustainable development, information transparency and requirements for data reliability. The questionnaire questions covered the following blocks: the structure of integrated reporting, the presence of internal regulations, the use of digital tools, control mechanisms, sources of information and procedures for its verification.

In parallel with the survey, an analysis of open reports and internal documents of enterprises was carried out, in particular integrated reports, ESG policies, internal audits and control procedures. This allowed for verification of the data obtained, as well as for detailing the procedures for generating accounting information.

The collected data was visualized using functional models. These are indicator integration matrices, reliability control schemes, structural models of the reporting cycle. The structural-logical modeling method was used to demonstrate the relationship between data sources, information exchange channels, internal control mechanisms, and verification tools.

The reporting system in different countries is developing unevenly. In developed countries (EU, USA, Canada), it is becoming more unified and digitalized. This is due to the introduction of agricultural technologies, satellite monitoring and automated accounting systems. In developing countries, reporting often remains fragmented and less standardized. This creates problems for agricultural producers in accessing financing, subsidies and international markets.

The European Green Deal system is being actively implemented in the EU, which aims to make Europe climate neutral by 2050. This strategic initiative covers various sectors and involves the implementation of sustainable agricultural practices, reducing greenhouse gas emissions, reducing the use of pesticides and fertilizers, supporting organic production, and protecting biodiversity.

Simplified or fragmented accounting and reporting systems prevail in African and Latin American countries. This is due to limited technical resources, institutional weakness, and low levels of digitalization, which complicates the implementation of integrated reporting and reduces the transparency of the agricultural sector.

Large agricultural holdings are forced to adapt to numerous international standards. Small farms often do not have the resources to maintain detailed accounting. The digitalization of reporting creates new challenges in terms of cybersecurity and data protection. In the future, we should expect further tightening of reporting requirements, especially in the area of environmental responsibility and transparency of financial flows.

The most comprehensive are the reports of PrJSC "MHP", "Astarta" and "Kernel", which include both financial and non-financial information: mission, vision, business model, risk analysis, social responsibility and environmental impact. The integrated report of PrJSC "MHP" is characterized by a high level of disclosure of social and environmental aspects, which is consistent with the current requirements of ESG reporting.

The reports of "Vaitterra Ukraine" and "IMK" are less detailed. They lack some of the key structural elements, such as strategy, risk analysis, business model. This may indicate that the companies focus mainly on financial reporting and less in-depth disclosure of non-financial aspects. At the same time, they still contain a management report and financial reporting, which provides a basic level of transparency.

A feature of the reporting of the A.T.K. Group of Companies is the presence of more structured financial information, but at the same time a less detailed description of the business model, strategy and risks. This may complicate the assessment of the company's development prospects from the point of view of investors and other stakeholders. Some companies, in particular Astarta and Kernel, include information on the impact of the Russian invasion on their activities, which is important in terms of transparency and consideration of economic and political risks. At the same time, such data is absent from the reporting of a number of other companies. This may indicate their approach to the disclosure of sensitive data or orientation towards international investors who focus more on financial indicators.

Disclosure of non-financial information is critically important for agricultural enterprises, as their activities directly affect natural resources, ecosystems and the well-being of society, and also depend on the sustainable use of land, water and biodiversity. In the context of the Sustainable Development Goals, agribusiness plays a key role in ensuring food security, combating climate change, preserving water resources and ecosystems. By disclosing non-financial indicators, enterprises declare the attraction of "green" financing, which improves their reputation in international markets and helps to implement innovative practices of sustainable agriculture, and ensures the long-term sustainability of the industry.

Thus, the analysis of non-financial components of the reporting of leading Ukrainian agricultural enterprises demonstrates a general trend towards the integration of ESG approaches into corporate governance and strategic planning.

In general, companies pay significant attention to environmental aspects of their activities, such as energy efficiency, CO₂ emissions, waste management and water use. These indicators are most fully covered in the reports of PrJSC "MHP", "Astarta" and "Kernel", which also contain information on land use, biodiversity and environmental policy. Social aspects, in particular occupational safety, personnel training, local communities and charitable activities, are an important component of the reporting of most companies. However, these aspects are most thoroughly disclosed in the reports of PrJSC "MHP" and "Astarta".

Common features of non-financial reporting of agricultural enterprises include mandatory disclosure of issues such as environmental performance, labor protection, personnel training and social responsibility to communities. Most companies also disclose data on business ethics and corporate governance, which indicates a desire to comply with international ESG standards.

The study shows the lack of a unified approach and imbalance in the naming of reporting that combines financial and non-financial indicators. At the same time, more than 85% of the analyzed reports of large and medium-sized agricultural enterprises use the name "Annual Report", which includes "Management Report", "ESG Report".

The costs of implementing integrated reporting are particularly critical for small and medium-sized agribusinesses that do not have the financial resources to invest in reporting transformation. Finally, lack of management awareness indicates a strategic risk, as it is the management that must initiate change and generate the demand for enhanced transparency of business processes. enterprises.

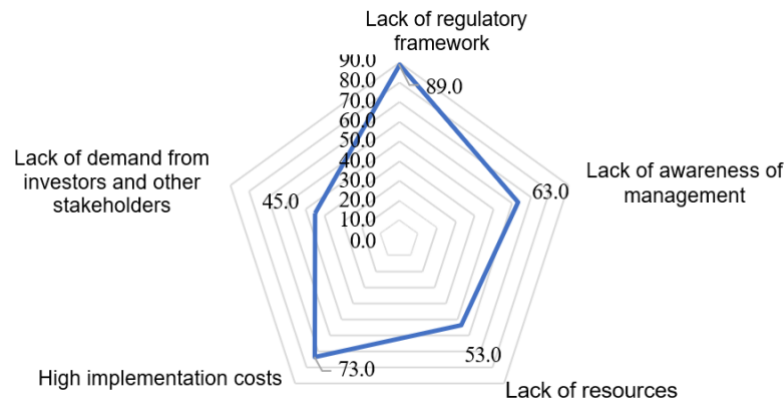


Figure 2. Expert opinion on the main barriers to the implementation of integrated reporting in agricultural enterprises, %

Thus, the results of the expert survey emphasize that the successful implementation of integrated reporting in the agricultural sector of Ukraine is impossible without the creation of a stimulating regulatory infrastructure, financial support for enterprises at the stage of reporting transformation, and increasing the level of awareness of management personnel.

For a business model to be positively assessed by stakeholders, the company must demonstrate dynamism and the ability to create value. In order for the company to be able to create value for itself, the business model must demonstrate a positive impact on different types of capital. The company's product is considered in integrated reporting as the main generator of created value.

Thus, improving the accounting system of agricultural enterprises on the basis of building an integrated policy requires a conceptual revision of approaches to reflecting economic transactions related to the transformation and return of individual types of capital. The traditional model, focused mainly on financial results, does not allow for adequate consideration of the impact of agricultural production on the environment, rural communities and ecosystems, and therefore does not provide for the formation of a complete information plane of value creation. That is why, in the context of the transition to sustainable development, the integration of new accounting approaches into the system of accounts, tools and methods is of particular importance.

First of all, this concerns the improvement of mechanisms for accounting for environmental costs, which should not only record direct costs for environmental protection, but also take into account preventive costs, restoration of natural capital and the impact of agricultural production on climatic conditions. In parallel, the development of social accounting ensures the reflection of costs associated with the development of human capital, corporate social responsibility, and participation in programs to support rural communities. The combination of such approaches allows us to form a comprehensive vision of the effects of agribusiness - both economic and non-financial.

Thus, the integration of financial, tax, management, environmental, social and strategic accounting within a single integrated accounting system, including accounting accounts, the transformation of the eight classical elements of its method, creates the basis for the preparation of high-quality, balanced and transparent integrated reports. Such reports not only reflect the financial results of agricultural enterprises, but also record their contribution to the preservation of the natural environment, the development of human potential and the support of social stability of rural communities, which in modern conditions are the defining characteristics of long-term business sustainability.

Integrated reporting in the modern world is the main tool for informational satisfaction of public interests and expectations of stakeholders, which makes it possible to communicate the business model and long-term value of an individual business entity. Integrated reporting, especially its non-financial part, plays a special role in the context of increasing challenges of sustainable development, which have recently become planetary in scale.

In these conditions, an obvious challenge is the problem of verifying indicators, ensuring their quality, as well as increasing stakeholder confidence in integrated reports. Therefore, the issue of control, providing guarantees and audit assurances regarding integrated reports becomes particularly relevant.

All integrated reports of agricultural enterprises in Ukraine that are freely available are compiled by public interest entities and contain relevant audit opinions, the main part of which concerns assurances regarding financial reporting. This was also confirmed by the results of a survey of experts, only 3% of whom confirmed their experience of undergoing an audit of integrated reporting. At the same time, 11% of respondents (except for representatives of large enterprises, including agricultural holdings) indicated that their enterprises plan to include an external audit of integrated reporting (or annual reporting, including its non-financial component) in the near future.

Thus, the issue of verification of integrated reporting indicators in Ukraine today is reduced to providing an audit opinion with assurances regarding the financial component, while providing assurances regarding the non-financial component of integrated reports in Ukraine is practically absent. In foreign practice, in contrast, it is usually practiced to provide financial reporting together with an auditor's opinion and a separate external audit confirmation (verification guarantee) of the integrated report.

According to the International Federation of Accountants (IFAC), an integrated reporting assurance is an expression of assurance that an integrated report, including the Board's Statement of Responsibility, complies with the International Standard (Framework) on Integrated Reporting. An integrated reporting assurance is an assurance of the "whole report" in relation to integrated reports or reports in an annual report prepared in accordance with the framework. The use of integrated and annual reports as a venue for sustainability disclosure has grown significantly. Due to corporate and investor demand in some jurisdictions to mandate integrated reporting in some form, the momentum for integrated reporting around the world has also increased.

The non-financial component of integrated reporting mainly covers information on social, environmental and governance aspects of the enterprise's activities that are important for its long-term sustainability and value. This component should be subject to some verification and quality control of indicators, answering the question of how non-financial factors contribute to the achievement of strategic goals and the creation of added value in accordance with the indicators specified in the reporting.

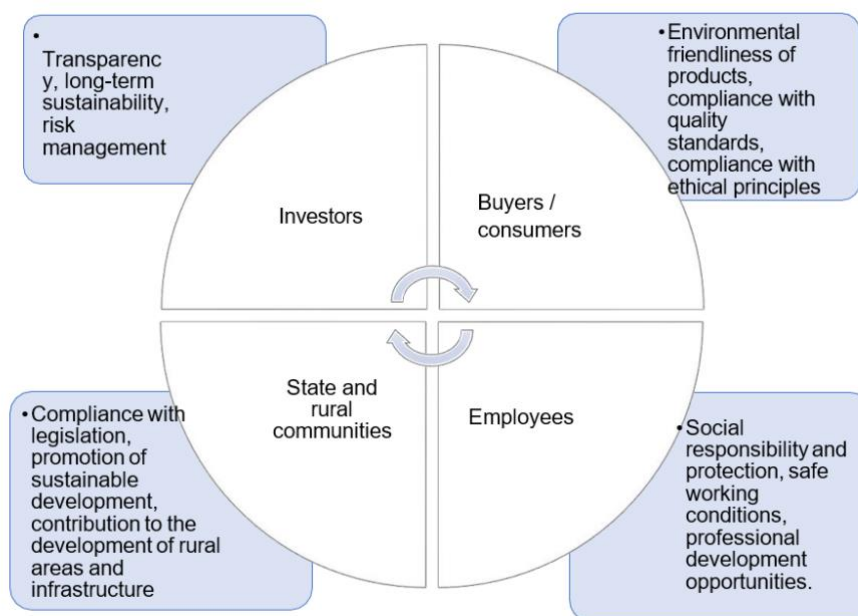


Figure 3. Expectations of key stakeholders that should be taken into account when preparing integrated reporting for agricultural enterprises

Taking into account the expectations of key stakeholders is critical for the preparation of integrated reporting of agricultural enterprises, as it ensures the alignment of the company's strategic priorities with the interests of its stakeholders. Investors expect transparency regarding financial stability, partners – a clear vision of sustainable development, communities – compliance with environmental and social standards, and consumers – responsibility in production.

Thus, the development of a specialized structure of an integrated report for an agricultural enterprise is due both to the specifics of agricultural production, which is characterized by seasonality, dependence on natural and climatic conditions and biological cycles, and to the need to implement a comprehensive information approach to reporting, focused on a wide range of stakeholders. At the same time, in the context of the approximation of national reporting practices to EU requirements, the formation of an adapted structure of integrated reporting becomes a strategically important step towards increasing the competitiveness of agricultural enterprises.

Among the priority measures, according to the expert community, the development and approval of a unified regulatory and methodological framework for integrated reporting, training and advanced training of accounting and management personnel, as well as providing state or institutional support for agricultural enterprises at the stage of implementing new standards were most highly rated.

Also, a significant step towards transforming the reporting of agricultural enterprises is the adoption of the Strategy for the Development of Agriculture and Rural Areas until 2030 and the approval of an operational plan of measures for its implementation in 2025–2027. The adoption of this Strategy is due to a number of problems associated with full-scale military operations on the territory of Ukraine, the ineffectiveness of measures to support novice farmers and newly established farms, loss of biodiversity, negative impact on ecosystems, etc. The outlined problems make sustainable development impossible, the restoration of production and negatively affect the level of social development, the well-being of the population and the state of the environment.

The purpose of this study was achieved by implementing a number of tasks, including: analyzing modern theoretical approaches to integrated reporting, assessing the current state of enterprise information systems, identifying barriers in the practice of sustainable development accounting, and developing practical recommendations for improving such systems.

In November 2024, the International Audit and Assurance Council published the International Standard on Sustainability Assurance 5000, a standard of general requirements for ensuring assurance regarding sustainable development information. The new standard should be applied to periods starting from December 15, 2026, and provides for assessing the acceptability of the criteria used to prepare non-financial information. Its adoption is an important step in creating uniform requirements for the verification of environmental, social and governance indicators in integrated reporting, which is directly related to the objectives of this study.

The analysis showed that integrated reporting should be not only a means of informing external users, but also a strategic management tool. It contributes to capital optimization, digital transformation and taking into account the impact of enterprise activities on agro-ecosystems, which corresponds to modern practices of environmental and social reporting in the European Union. The relationship between integrated reporting, transparency of agribusiness activities and increased investment attractiveness confirms the feasibility of strengthening state support for the standardization and digitalization of reporting systems, which become an element of effective industry management.

The empirical research results confirmed that agribusinesses should consider the specific environmental and social impacts of their activities, such as land use, biodiversity impacts, labor relations, and interactions with local communities. These aspects determine the increased importance of integrated reporting for the agricultural sector, since the activities of such companies are directly related to the management of natural, social, and financial capital.

Agricultural enterprises play a key role in the transformation of agroecosystems, as they are the main actors of land use and bioresource management. The identified trends, such as intensive use of agrochemicals, monoculture farming, soil degradation and biodiversity loss, indicate the need for an integrated approach to managing these risks through an accounting system that covers both financial and non-financial aspects.

The study confirmed that non-financial information should be systematically integrated into the accounting system of the enterprise. This allows not only to meet the requirements of stakeholders and legislation, but also to form reputational capital, increase access to "green" financing, ensure long-term sustainability of the business model and increase the competitiveness of business entities. Therefore, the results of the study confirm that a modern accounting and analytical system for sustainable development should be built on the principles of integration of financial and non-financial information, digital adaptability and proper data verification.

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CONCEPTUAL PRINCIPLES OF SUSTAINABLE CHANGE MANAGEMENT IN THE CONTEXT OF GLOBAL TRANSFORMATIONS

Serbina Anita

Assistant Lecturer of the Management Department named after Professor L. I. Mykhaylova, Sumy National Agrarian University

ORCID ID: 0009-0008-0131-3494

In the face of growing global uncertainty, climate challenges, and systemic socio-economic transformations, traditional models of change management, which have so far been based primarily on the principles of operational efficiency, process intensification, and profit maximization, are showing limited viability. In the modern globalized economy, transformational processes have lost the character of discrete (single) events, turning into a continuous process of organizational functioning. Classical paradigms of change management have historically focused on internal organizational optimization, cost minimization, and maintaining competitive advantages in stable environments. However, current challenges — in particular, the climate crisis, deepening social inequality, and increasing regulatory pressure — necessitate the formation of fundamentally new methodological approaches. Sustainable change management is defined in this study as a continuous preventive process of organizational transformation aimed at ensuring the strategic viability of the system by achieving a dynamic balance between economic performance, environmental responsibility and social inclusion.

Unlike reactive strategies focused on overcoming consequences, SCM is based on the principles of anticipatory (anticipatory) adaptation and systems thinking. Within this approach, change is viewed as a long-term evolutionary process determined by environmental constraints, stakeholder expectations and the requirements of international regulatory institutions, in particular the provisions of the European Green Deal and the UN Sustainable Development Goals [5].

This study is based on a qualitative conceptual approach that combines the analysis of classical theories of change management with modern foundations of sustainable development, such as ESG, the UN Sustainable Development Goals and the European Green Deal. Through a comparative analysis of traditional and sustainable management paradigms, the authors use conceptual modeling as the main research method. The developed model is theoretical in nature and serves as a structured basis for future empirical testing aimed at bridging the gap between classical management and the principles of sustainable consumption and production.

The transition to sustainable change management requires a rethinking of traditional linear models proposed by Kurt Lewin or John Kotter. Although these classical theories effectively focus on planning, implementing and stabilizing organizational transformations, they are often reactive in nature and do not take into account long-term environmental or social consequences. In contrast, sustainable change management views the organization as an open system, an integral part of a broader ecosystem. This approach involves integrating sustainability dimensions into core business processes, ensuring that economic growth does not come at the cost of environmental degradation or social instability. The proposed conceptual model of integrated change management is based on a systems-synergistic approach, where the organization is considered as an open dynamic system. Within this model, external determinants and environmental pressures are transformed into sustainable results through mechanisms of internal organizational processes based on the principles of ecosystem responsibility.

In modern scientific discourse, the functioning of organizations is viewed through the prism of the diffuse influence of multiple exogenous drivers, which act as catalysts for deep transformational processes. These vectors of influence not only stimulate adaptive changes, but also form hard determinants and strategic guidelines for long-term organizational development, defining a new paradigm for business viability.

Key factors of organizational transformations. Environmental imperatives and climate resilience. In the Anthropocene era, climate risks are of critical importance - both physical, caused by environmental change, and transitional, associated with the transformation of the economy. The growing scarcity of natural resources and the need to radically reduce the carbon footprint force business entities to integrate the concept of planetary boundaries into their operating models. This necessitates a fundamental transition from resource-intensive strategies to the principles of resource efficiency and a circular economy.

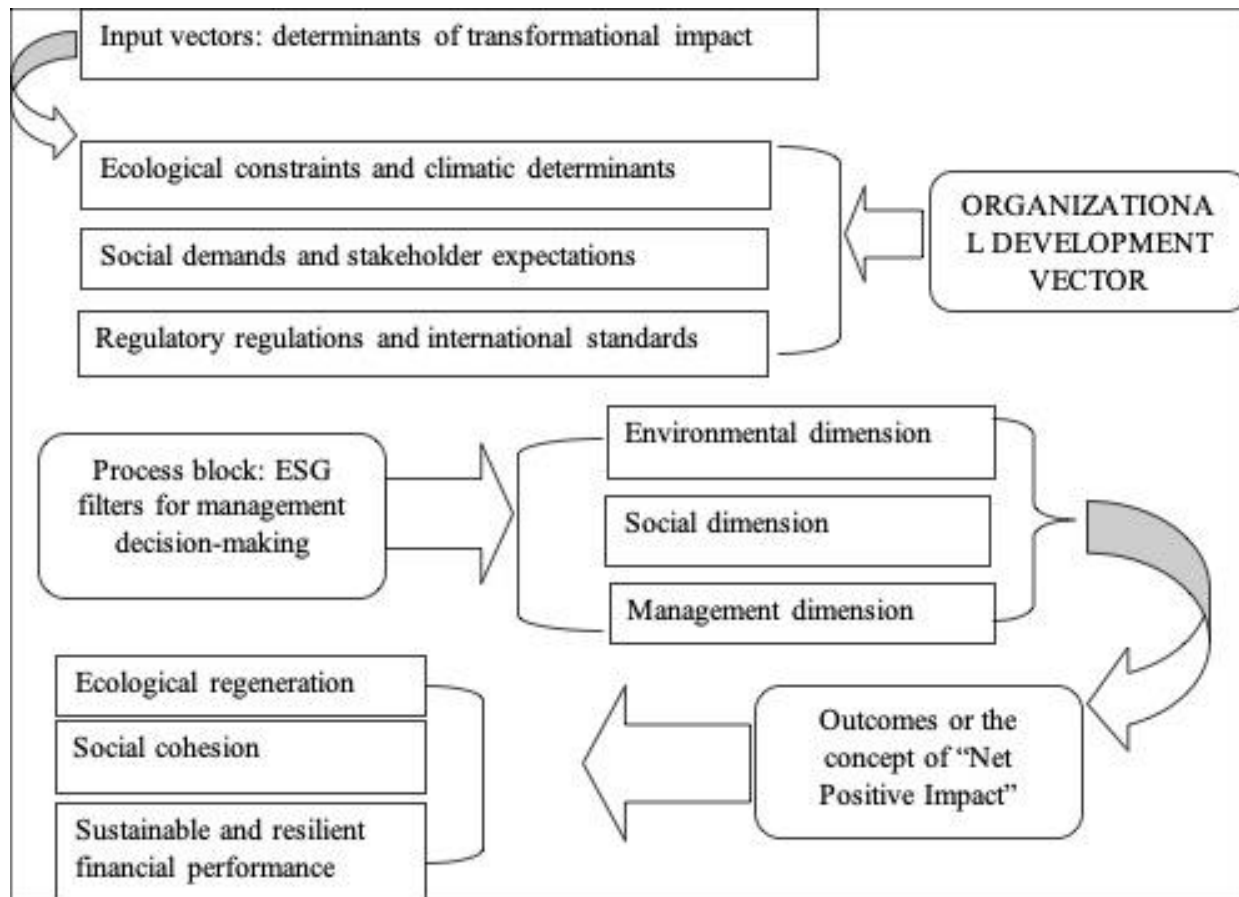


Figure 1. Conceptual model of integrated change management

Social Inclusion and Stakeholder Expectations. Modern management operates in the context of a growing public demand for ethics and social responsibility. Stakeholder demands are evolving from purely financial indicators to requirements for ensuring gender equality, inclusiveness and justice. Today, organizations are expected not only to generate profit or create jobs, but also to actively participate in ensuring a high quality of working life and a systematic positive contribution to the development of local and global communities.

Institutional and regulatory environment and global standardization. The formation of a company's strategic vector is strongly influenced by international regulatory protocols. Global initiatives, in particular the European Green Deal (EU Green Deal), the UN Sustainable Development Goals (SDGs) and the Corporate Sustainability Reporting Directive (CSRD), are creating a new regulatory reality. These tools transform the concept of sustainability, transforming it from a voluntary declaration into a mandatory and regulated standard for the functioning of any modern business entity.

Synthesis of influencing factors. The combined impact of these factors creates the prerequisites for the formation of a systemic approach to management, where economic efficiency becomes impossible without taking into account environmental neutrality and social legitimacy. Thus, modern organizations are forced to balance between efficiency and compliance with global ethical and environmental standards.

The scientific architecture of the sustainable management process block is based on the implementation of integrated ESG filters into the overall management decision-making system. This approach ensures the systematic transformation of external and internal impulses into targeted organizational actions through a multidimensional filtering mechanism, where each vector (environmental, social, management) acts as a mandatory checkpoint for the verification of strategic and operational initiatives.

Environmental determination This dimension involves the implementation of a preventive audit and an in-depth assessment of the potential environmental impact of each management act. The filtering process is based on quantitative and qualitative indicators, including monitoring greenhouse gas emissions, analysis of compliance with the principles of the circular economy (closed-loop efficiency), as well as an assessment of

risks to biodiversity. Rational water use and waste minimization become basic parameters that determine the admissibility of project implementation.

Social inclusion or social filter is aimed at preserving and increasing the human and social capital of the organization. Decisions are assessed through the prism of staff well-being, ensuring occupational safety standards and the systematic development of new generation professional competencies (the so-called "green skills"). An important aspect is also external analysis - forecasting and assessing the social effects that the organization's activities cause on the scale of local communities and society as a whole [2].

Institutional sustainability - the managerial dimension focuses on creating a reliable institutional framework based on the principles of transparency, accountability and ethical leadership. This filter ensures strict compliance of corporate governance with compliance standards, minimizing corruption risks and implementing accountability mechanisms at all levels of the organizational hierarchy. It acts as a guarantor that the culture of responsibility is integrated directly into the company's regulations and procedures.

The systematic application of these filters allows you to convert declarative sustainable development goals into a specific toolkit for daily management. Thus, any activity of a business entity — from large-scale strategic investments to routine operational purchases — undergoes a procedure of coordination with long-term imperatives of sustainable development. This ensures the convergence of the economic interests of the organization with general societal environmental and social priorities, creating the prerequisites for the formation of a sustainable competitive advantage in the conditions of the new global economic paradigm.

The conceptual dominant and resulting vector of the proposed management model is the achievement of the state of "Net Positive Impact", which marks the transition from strategies of minimizing harm to strategies of active restoration. This state characterizes such a mode of functioning of the organization, in which its total contribution to the well-being of society and the regeneration of ecosystems exceeds the amount of resources consumed in the process of life. Within this paradigm, the organization is considered not as an isolated economic entity, but as an active agent of positive changes in the global socio-ecosystem [1].

The implementation of the concept of Net Positive Impact involves the implementation of restorative practices aimed at the reclamation of natural capital and strengthening social sustainability. The key tool here is the systematic assessment of externalities, where each aspect of activity passes through the filter of creating added value for the environment. This requires management to rethink value chains in order to transform linear processes into cyclical ones capable of generating excess ecological resources. Economic efficiency in such a model is not leveled, but it becomes a derivative of the ability of the enterprise to create public good. An important aspect is the formation of regenerative corporate thinking, where innovations are aimed at solving global challenges, such as climate instability and social inequality. The end result is the formation of an organization whose presence in the market is a determinant of improving the state of the external environment.

Thus, Net Positive Impact acts as a new metric of success that integrates financial indicators with environmental and social performance. The organization is transformed into a system that not only levels its anthropogenic footprint, but also creates a net increase in biodiversity and social well-being. This approach provides long-term legitimization of business in conditions of strict environmental constraints and changing social expectations. Ultimately, the implementation of this concept allows overcoming the traditional antagonism between economic growth and environmental conservation, creating the prerequisites for the harmonious coexistence of the technosphere and the biosphere.

Within the framework of the developed model, the resulting block focuses on the fundamental transition from the passive concept of "harm minimization" to the strategy of active ecological regeneration. This paradigm assumes that the organization is transformed from a subject of consumption into a full-fledged agent of restoration of natural ecosystems. Ecological regeneration defines a new standard of organizational activity, where the priority is not just zero impact, but a positive increase in natural capital. Restoration processes are integrated directly into the operational cycle, turning each link in the value chain into a tool for supporting biodiversity. This approach requires the introduction of innovative technologies that can compensate for previous anthropogenic loads on the environment. The organization takes responsibility for the reclamation of territories, purification of water resources and restoration of soil fertility, which goes far beyond the boundaries of traditional environmental management. The key indicator of success here is the ability of the enterprise to generate resources that contribute to the resilience of local ecosystems to climate change [3, 8].

Regenerative activities ensure the long-term stability of the business model by creating a reliable foundation of natural resources for future periods. In scientific terms, this component means a change in focus from anthropocentric consumption to ecocentric coexistence of the technosphere and the biosphere. The

introduction of regenerative practices allows to level the negative consequences of industrial production through active carbon absorption and restoration of natural cycles.

Thus, ecological regeneration becomes a key factor of institutional legitimation in the conditions of the global ecological crisis. An organization that adheres to the principles of regeneration acquires the features of a self-regulating system that enhances the viability of the environment. This process leads to the formation of a new corporate identity, where an ethical attitude towards nature is an integral part of strategic success. Ultimately, the resulting block through ecological regeneration ensures the transition to a sustainable future, where economic activity is synonymous with ecological prosperity. Fulfilling these conditions allows us to achieve harmonization of the interests of industrial development and preservation of planetary health.

In the scientific architecture of the resulting block, social cohesion is considered as a fundamental characteristic of sustainable organizational development, which ensures the structural integrity of the social system. It involves the purposeful formation of an inclusive environment, where each social group has equal opportunities for self-realization and participation in decision-making processes. The central element of this component is an increase in the level of social trust, which acts as an invisible glue that minimizes transaction costs and conflict potential within the organization and beyond.

The process of harmonizing the interests of various stakeholders allows you to balance often conflicting requirements, transforming them into a synergy of joint action. Social cohesion becomes a basic resource for ensuring sustainable human development, focusing on expanding the potential of employees and members of local communities. In the context of the resulting block, this indicator indicates the success of the transition from the exploitation model to the co-creation of value model. Cohesion acts as an indicator of social sustainability, which allows the organization to effectively adapt to external sociodynamic challenges. Ensuring social justice and inclusion directly affects the loyalty of personnel and the institutional reputation of the business entity. The scientific approach to cohesion excludes the formal implementation of social programs, requiring deep integration of ethical standards into the corporate culture.

Through the prism of social cohesion, the organization becomes an active participant in the development of civil society, contributing to the reduction of inequality and overcoming social atomization. The result of such a strategy is the formation of a sustainable social ecosystem capable of self-reproduction and harmonious development in the long term. Ultimately, a high level of cohesion turns social capital into a real competitive advantage that is not amenable to simple copying. This component completes the integrity of the resulting block, combining ecological regeneration with anthropocentric goals of sustainable progress. Fulfilling these conditions allows achieving a state of Net Positive Impact in the social dimension, creating conditions for general well-being.

The concept of financial performance is undergoing a fundamental transformation, moving from maximizing short-term profit to ensuring sustainable and resilient viability in the long term. This model assumes that financial success is not an end in itself, but becomes a logical derivative of effective ESG risk management and strategic compliance with environmental and social standards. In the context of the turbulent BANI world, characterized by fragility and nonlinearity, the resilience of financial indicators is determined by the ability of the organization to withstand exogenous shocks and adapt to dynamic changes in the regulatory environment [10].

Sustainable financial performance is based on the deep integration of the principles of responsible investment into the capital structure of the enterprise. This necessitates a transition to new performance metrics that take into account not only direct income, but also capitalization based on intangible assets - reputation, stakeholder trust and intellectual capital. Resilience in this aspect acts as an organization's immunity to financial losses caused by climate risks or social conflicts.

An important element of the system is the minimization of transaction costs through transparent management and the implementation of high standards of ethical business. The financial model of sustainable development is focused on creating long-term value for shareholders without depleting the resource potential of future generations. Thus, economic viability is ensured by proactively identifying vulnerabilities and investing in regenerative technologies that reduce operating costs in the long term.

In a scientific sense, this approach eliminates the antagonism between environmental responsibility and economic benefit, proving their interdependence. The resulting block confirms that only a financially stable organization is able to generate resources for further environmental regeneration and social cohesion. This closes the cycle of sustainable management, where each earned capital works to support the integrity of the entire socio-ecosystem. Ultimately, resilient financial performance is a guarantee that an organization will not only survive in global instability, but also maintain its leadership position through its adaptability.

Within the framework of the presented scientific model, the first fundamental column — “Value Orientation” — proclaims the priority of viability over profit maximization, which radically changes the vector of strategic planning. This involves a transition from a narrowly specialized focus on financial indicators of the current period to a comprehensive provision of the organization’s sustainability in the long term. Viability is considered as the integral ability of a system to maintain its functionality and adapt to exogenous challenges without exhausting its internal resource. This approach determines the rejection of strategies of “predatory” depletion of assets for the sake of instant profit in favor of regenerative development models.

The scientific significance of this change lies in the introduction of the concept of “dynamic sustainability”, where financial performance is only one of the parameters, and not the only criterion for success. Orientation to viability requires the integration of ethical and environmental imperatives directly into the value DNA of the organization. This creates conditions for the formation of a high level of trust from all stakeholder groups, which is critical for survival in conditions of high uncertainty. Within this pillar, success is defined as the ability of an enterprise to create sustainable value that is not leveled by market fluctuations. Management is reoriented to create reliable buffers against the fragility inherent in modern economic systems. The priority of viability stimulates investments in innovations that have a longer payback period, but provide a higher level of systemic security. This value paradigm serves as the foundation for overcoming the “myopia” of the market and contributes to the harmonization of business goals with the global goals of sustainable development.

Ultimately, such a transformation of target benchmarks allows the organization to take a stable place in the ecosystem of the future, where the legitimization of business will depend on its ability to exist for a long time without harming the environment. Fulfilling the conditions of this pillar ensures the internal coherence of the entire change management model, making it resistant to manipulation of financial reporting indicators. Thus, viability becomes a new ontological basis of corporate existence in the era of global transformations.

The second fundamental pillar of the proposed model is based on the principles of inclusivity and co-creation, which fundamentally changes the hierarchical nature of organizational transformations. In scientific discourse, this approach is considered as a transition from subject-object relations in management to partnership interaction of all stakeholders. Active involvement of stakeholders in the processes of design and implementation of changes allows accumulating diversified experience and knowledge, which significantly improves the quality of management decisions. Inclusivity in this context means creating an open communication space, where the interests of not only shareholders, but also employees, consumers and local communities are taken into account. The mechanism of co-creation acts as a powerful tool for determining organizational commitment, since the participants in the process identify themselves with the results of joint developments. This allows for preventively eliminating psychological barriers and significantly reducing the level of destructive resistance to change, which is often a consequence of a lack of information or a feeling of alienation. Scientific research confirms that inclusive management models contribute to the formation of a high level of trust and social capital within the system. Co-creation stimulates the development of collective intelligence, which becomes a critical factor in the adaptability of the organization in conditions of high uncertainty. The implementation of inclusive practices allows transforming potential conflicts of interest into a constructive dialogue aimed at finding optimal eco-social solutions. This approach provides long-term legitimization of transformational processes, since they are based on broad public and corporate consensus.

Within this pillar, the organization is viewed as a living ecosystem, where sustainability is achieved through the density and quality of internal connections. Inclusivity ensures that changes will not be imposed from the outside, but will be the result of organic internal development supported by the majority of participants. This creates the prerequisites for sustainable human development and increasing the subjective well-being of employees in the work process. Ultimately, the co-creation paradigm transforms stakeholders from passive recipients of decisions to active architects of a shared future. Fulfilling the conditions of this pillar is the key to the integrity of the model, as it provides a social basis for the implementation of the organization's environmental and financial goals. The third fundamental pillar of the model, Eco-cyclicity, is based on the imperative of comprehensive assessment of organizational decisions through the prism of the full life cycle of products and processes. In a scientific context, this approach requires a transition from linear thinking to a systemic analysis of long-term environmental and structural consequences of activities. The concept of eco-cyclicity assumes that any management act is considered not as an isolated event, but as an element in a continuous chain of interaction with the biosphere. The central place here is occupied by the minimization of anthropogenic load by implementing the principles of a circular economy at all stages of value creation.

The study of eco-cyclicity within the model orients the organization to preserve the value of resources for as long as possible, stimulating the processes of regeneration, reuse and recycling. The scientific significance of this pillar lies in the recognition of the organization as an open system that functions within the framework of planetary determinants. Each strategic investment or operational procurement passes through the filter of the assessment of systemic impact, which prevents the emergence of deferred environmental debts. This allows to level out negative externalities at the stage of designing business processes, turning waste into resources for new cycles.

Eco-cyclicity stimulates the development of eco-innovations aimed at restoring natural capital, and not only at slowing down the rate of its degradation. The implementation of this concept requires management to take extended responsibility for the fate of the product even after the end of its service life. This approach ensures the harmonization of the technosphere with natural metabolic cycles, creating conditions for long-term environmental sustainability. Within this pillar, success is measured by the system's ability to self-renew and integrate into global biogeochemical processes.

Ultimately, eco-cyclicity becomes a guarantor of institutional resilience in conditions of resource scarcity and severe climate constraints. It closes the architecture of the model, combining value orientation and inclusivity with the physical boundaries of the environment. Fulfilling the conditions of this pillar allows the organization to achieve a state of harmonious functioning within the "green" standards of the future. Thus, eco-cyclicity acts as an ontological bridge between

Table 1 - Principles of Sustainable Change Management

The principle of prevention	involves a transition from reactive error correction to proactive adaptation through the identification of “weak signals” and hidden trends in the external environment. This approach allows the organization to develop strategic scenarios in advance and form resilience reserves, which minimizes risks and ensures stability in the dynamic conditions of the BANI world.
The principle of systemic integrity	requires maintaining a dynamic balance between economic viability, social justice, and ecological regeneration, viewing them as integral parts of a single structure. This approach ensures that the development of one dimension does not occur at the expense of the depletion of the others, thereby ensuring the long-term resilience and institutional stability of the organization.
The principle of transparency	involves moving to open communication models and implementing non-financial reporting (ESG reporting) as a tool to confirm the ethics of business processes. This allows strengthening stakeholder trust through public disclosure of information about the organization's impact on the environment and society, turning accountability into a strategic asset for the company.
The principle of adaptive governance	is to abandon rigid hierarchical structures in favor of flexible organizational models capable of rapid transformation in response to dynamic environmental challenges. This ensures high speed of decision-making and institutional plasticity, which allows the organization to function effectively in conditions of high uncertainty and constant change.

Source [4-6, 10]

The principle of prevention in sustainable change management is based on the paradigm of proactive adaptation, which involves identifying and mitigating potential risks before they fully materialize. In a scientific context, this principle requires the organization to develop sensitive mechanisms for scanning the external environment to identify “early signals” — weak indicators of future transformations. Prevention transforms the management system from a reactive one that only responds to crises to a proactive one that is able to model development scenarios and prepare appropriate strategic reserves. This approach allows the business entity not only to avoid the destructive consequences of market turbulence, but also to capitalize on new opportunities that arise at the early stages of change. The central element of preventive management is the integration of predictive analytics into decision-making processes, which provides scientifically sound forecasting of eco-social and economic trends. The implementation of this principle minimizes the costs of “fighting fires” and recovering from failures, since the organization already has developed protocols for adapting to the identified determinants. Preventiveness is closely related to the concept of organizational resilience, as early preparation strengthens the internal resistance of the system to unforeseen shocks.

Within the framework of the sustainable management model, this principle extends to environmental and social aspects, where preventing environmental damage is much more effective than subsequent reclamation. Proactivity requires leaders to have a high level of systems thinking and the ability to see non-linear relationships between current actions and future consequences. Preventive management also contributes

to maintaining a high level of trust among stakeholders, who see the company's ability to control its development trajectory in conditions of uncertainty.

The use of strategic foresight within this principle allows the organization to form alternative future scenarios and test its current business models against them. Thus, preventiveness acts as an intellectual shield for the organization, ensuring its institutional durability through constant readiness for change. The implementation of this principle is critical for the transition to sustainable development, since global environmental challenges are often irreversible, which makes reactive management ineffective. Ultimately, prevention ensures the harmonious integration of the organization into the dynamic context of the BANI world, transforming potential threats into vectors of targeted renewal. Fulfilling the conditions of prevention allows the system to maintain a strategic initiative in any market configurations.

The principle of system integrity in sustainable change management is based on the fundamental imperative of ensuring a dynamic balance between the economic, social and environmental dimensions of organizational activity. In the scientific paradigm of sustainable development, this principle denies the dominance of any one vector, arguing that long-term sustainability is possible only if they are harmoniously converged. System integrity requires considering the organization as a complex homeostatic mechanism, where the degradation of one component inevitably leads to the destabilization of the entire structure. This approach transforms the decision-making process, forcing management to evaluate each initiative through the prism of three-dimensional impact.

Economic capacity within this principle ceases to be an autonomous goal and becomes a resource for supporting ecological regeneration and social cohesion. At the same time, social well-being and environmental neutrality are viewed not as expenditure items, but as critical prerequisites for financial resilience in the long term. The scientific justification of systemic integrity is based on the theory of systems, where a synergistic effect is achieved only through the qualitative interaction of all subsystems.

The implementation of this principle allows the organization to avoid strategic distortions that often arise with excessive focus on quick financial results at the expense of social capital or the environment. Systemicity involves the development of integrated performance indicators that reflect the real value created in all three areas simultaneously. This requires leaders to be able to work with multi-criteria tasks and resolve internal contradictions between the interests of different groups of stakeholders.

In addition, systemic integrity provides institutional legitimization of business, since the organization's activities become transparent and ethically balanced in the eyes of society. In conditions of global instability, this principle is the guarantor that the organization will not lose its functionality due to critical depletion of resources in one of the dimensions. It forms the architecture of a "healthy" organization capable of self-reproduction in a changing socio-economic landscape.

Ultimately, systemic integrity closes the loop of sustainable management, transforming disparate initiatives into a single, logically consistent strategy. Fulfilling the conditions of this principle is mandatory for achieving a state of Net Positive Impact, where the positive effect in each dimension mutually reinforces the overall result. Thus, systemic integrity becomes the ontological core of the modern management paradigm, ensuring the transition from exploitation to harmonious coexistence.

The principle of transparency in sustainable change management is based on the implementation of open communication systems and non-financial reporting tools as fundamental means of institutional legitimization. In scientific discourse, transparency is considered not simply as a formal disclosure of data, but as a strategic mechanism for reducing information asymmetry between an organization and its stakeholders. The use of non-financial reporting standards, such as GRI or CSRD, allows us to objectify the results of environmental and social activities, transforming qualitative changes into verified indicators [5].

Open communication ensures the creation of a trusting environment where stakeholders receive truthful information about the real impact of the company on the ecosystem and society. This approach stimulates increased management responsibility, since each stage of transformation becomes the object of public and expert monitoring. Transparency is a critical factor in attracting "green" investments, since modern investors focus on companies with a high level of ESG data disclosure.

The scientific justification for this principle is based on the concept of accountability, where an organization voluntarily assumes the obligation to report on the use of common natural and social goods. The introduction of non-financial reporting allows you to integrate sustainable development into the corporate governance system, making it part of the daily operating culture. This helps to overcome the practice of "greenwashing", since the openness of data allows external auditors to verify the compliance of declarations with real affairs.

Transparency also plays the role of an internal catalyst for change, helping employees better understand strategic goals and their contribution to their achievement. In the context of digital transformation, open communication becomes interactive, which allows you to receive prompt feedback from the public and adapt management decisions. This principle ensures the harmonization of internal processes with external expectations, creating the prerequisites for sustainable social partnership.

Ultimately, a high level of transparency turns information openness into a competitive advantage that strengthens the reputational capital of the organization. Fulfilling the conditions of this principle completes the ethical architecture of the sustainable management model, making it understandable and acceptable to the global community. Thus, transparency becomes the ontological boundary between traditional closed management and the modern model of responsible leadership [7].

The principle of adaptive governance in the system of sustainable change management is based on the implementation of a high level of flexibility of organizational structures for effective functioning in conditions of nonlinearity and uncertainty. In the scientific field, this principle involves a departure from rigid mechanistic models of hierarchy in favor of organic, diffuse structures capable of self-organization. Adaptive governance allows an organization to dynamically redistribute resources and powers depending on the nature of the challenges arising in the external environment. The central element of such a model is the decentralization of decision-making processes, which significantly increases the speed of response to critical changes.

The flexibility of structures provides institutional plasticity, allowing the company to transform without losing its functional integrity. The scientific justification of adaptability is based on the theory of complex adaptive systems, where viability is determined by the ability of the internal architecture to respond to the complexity of input impulses. This requires the introduction of cross-functional teams and networks that replace outdated functional “silos”.

Within the framework of the sustainable management model, adaptive governance promotes the integration of ESG priorities into all levels of management, making them part of flexible strategic iterations. This approach minimizes bureaucratic inertia, which often becomes a major obstacle to the implementation of environmental and social innovations. Adaptability also involves the development of a culture of continuous learning, where the organizational structure evolves along with the acquisition of new experience and knowledge.

Flexible governance models provide a high level of resilience to cascading crises inherent in today’s BANI world. An important aspect is the ability of the structure to scale and reconfigure within global value chains. Adaptive governance creates the conditions for the rapid scaling of successful sustainable practices throughout the organization. This principle ensures the harmonization of formal procedures with informal networks of interaction, which strengthens the company’s social capital.

Ultimately, the transition to flexible governance structures is a necessary condition for the implementation of the Net Positive Impact paradigm in the long term. Fulfilling the conditions of adaptability completes the formation of management tools, making the organization ready for the challenges of the future. Thus, adaptive governance acts as a guarantor of dynamic sustainability, where flexibility becomes the main source of competitive advantage [11].

Summarizing the results of the study, it can be stated that in the conditions of global instability and systemic environmental challenges, traditional change management models focused exclusively on financial maximization have exhausted their adaptive potential. The proposed paradigm of sustainable change management (SCM) offers a fundamental transition from reactive coping to proactive adaptation and systems thinking. The main scientific result is the development of a conceptual model where the success of an organization is defined through the state of Net Positive Impact, in which the business entity becomes an active regenerator of natural and social capital.

It has been established that the integration of ESG filters directly into the decision-making architecture allows converting external institutional requirements, such as the European Green Deal, into specific operational advantages. The three fundamental pillars of the model — value orientation on viability, inclusive co-creation and eco-cyclicity — create a reliable theoretical foundation for overcoming the “myopia” of classical management. The principle of prevention ensures the formation of an intellectual shield of the organization through the recognition of “weak signals” of the BANI world, while systemic integrity guarantees the continuity of economic, social and environmental dimensions.

An important conclusion is that financial performance in the modern economy is becoming a derivative of the quality of ESG risk management and the level of stakeholder trust. Transparency and non-financial reporting cease to be voluntary initiatives, turning into tools for institutional legitimization of business.

Adaptive governance and flexibility of organizational structures are identified as critical conditions for overcoming inertia and implementing “green” innovations. The study proves that the transition to sustainable change requires a complete transformation of corporate identity, where ethical leadership becomes the main driver of development.

Ultimately, the proposed model serves as a strategic reference point for businesses seeking to ensure their own long-term resilience. It closes the management loop by combining predictive analytics with regenerative practices of environmental restoration. The implementation of these approaches allows harmonizing the interests of the technosphere and the biosphere, creating the prerequisites for sustainable progress. Thus, the study paves the way for further empirical explorations in the field of Agri-Management 4.0 and the digital transformation of sustainable systems.

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LEADERSHIP AND MANAGEMENT OF TEAM INTERACTION IN AGRICULTURAL ENTERPRISES

Oriekhova Alvina

Doctor of Sciences (Economics), Professor, Sumy National Agrarian University, Ukraine
ORCID ID: 0000-0003-1016-3287

In the current conditions of globalization and turbulence of the agricultural market, the paradigm of agricultural enterprise management is undergoing fundamental transformations, shifting the emphasis from purely technological support of production processes to the development of strategic leadership and the construction of effective command structures. The specificity of the agricultural sector, due to seasonality, territorial dispersion of resources and a high level of dependence on natural and climatic factors, places special demands on management entities, where classical administration gives way to adaptive leadership.

The effectiveness of modern agribusiness today is determined not only by the level of technical equipment or the volume of the land bank, but primarily by the ability of management to form synergistic interaction within multifunctional teams. In this context, leadership is viewed not as a hierarchical position, but as a dynamic process of social influence, ensuring the alignment of individual goals of employees with the vector of sustainable development of the enterprise. The transition from transactional to transformational leadership, which is able to initiate innovative changes and maintain high motivation of personnel in the conditions of digital transformation of the industry, is of particular relevance.

The study of the mechanisms of team interaction management in the agricultural sector allows us to identify critical points of contact between corporate culture, psychological climate and economic performance. The formation of trust, delegation of authority and the introduction of participatory management tools become the levers that transform a disparate group of specialists - from agronomists to engineers and analysts - into a holistic team organism capable of self-organization and prompt response to the challenges of the external environment. This section of the monograph is devoted to a comprehensive analysis of the theoretical and methodological foundations of leadership potential and the development of applied recommendations for optimizing team processes as a key factor in the competitiveness of modern agricultural enterprises.

Despite the significant number of scientific works devoted to leadership and team interaction, the problem of their comprehensive study and adaptation to the modern realities of Ukrainian agricultural enterprises remains relevant. Special attention is required to study the relationship between leadership styles, the dynamics of team processes and the results of the organization's activities.

In today's fast-paced world, where innovation and adaptability are key to survival and success, the role of leadership and effective team interaction becomes paramount.

The concept of leadership has come a long way from ideas about innate traits to complex models that take into account context, situation, and interactions with followers. Initially dominated by theories of great people, which postulated that leaders are born with certain unique qualities, empirical research has not been able to unequivocally confirm the existence of a universal set of leadership traits.

They were replaced by behavioral theories of leadership that focused on the actions of the leader. Two main styles were distinguished: task-oriented and people-oriented. Although these theories expanded the understanding of leadership, they also proved to be insufficient, since the effectiveness of the style depended on the specific situation.

Later, situational and contingent theories of leadership emerged, emphasizing the importance of matching leadership style to the specifics of the situation, followers' characteristics, and the specifics of the task. Models such as Hersey-Blanchard's situational theory and Fielder's contingent model demonstrated that there is no single best leadership style.

Modern approaches to leadership focus on transformational leadership, which is characterized by the leader's ability to inspire and motivate followers to achieve higher goals, going beyond their own interests. Such a leader creates a shared vision, stimulates intellectually and individually takes into account the needs of each team member. In parallel, the concept of servant leadership is developing, where the leader primarily serves the needs of his followers, helping them develop and realize their potential. These modern approaches emphasize the importance of emotional intelligence, empathy and the ability to build trust. The modern understanding of leadership in the field of personnel management encompasses a number of interdependent aspects, including psychological competence, social interaction, strategic vision, the ability to adapt to change and the ability to inspire a team. In the conditions of a dynamic labor market, growing competition and

digitalization, the role of a leader goes far beyond the classic manager. In recent years, the scientific literature has tended to view leadership as a set of competencies. This is consistent with the competency-based approach, which states that an effective leader must possess both professional and interpersonal skills.

Key competencies of a modern leader (according to D. Goleman):

- emotional awareness,
- emotion management,
- motivation of oneself and others,
- empathy,
- social interaction skills.

Modern approaches to leadership in personnel management involve considering not only managerial qualities, but also psychological characteristics, the ability to adapt, communicate, resolve conflicts, and emotional intelligence.

The most common differentiation is between transactional (focused on reward for achievement) and transformational (focused on development and change) leadership (Table 1).

Table 1. Comparative characteristics of transactional and transformational leadership

Parameter	Transactional leadership	Transformational leadership
Employee motivation	Material incentives	Inspiration, vision of the future
Communication	One-sided	Dialogue, feedback
Attitude towards change	Perceives as a threat	Initiates change
Orientation	On processes	For development
Example of a leader	Control Manager	Visionary, inspirer

A comparison of transactional and transformational leadership demonstrates that in conditions of constant change and high competition, transformational approaches are more effective.

They contribute to a deeper involvement of employees in the decision-making process, stimulate innovation and provide emotional leadership. However, in some situations it may be appropriate to combine both types of leadership. Thus, in the conditions of the modern market, transformational leadership has more advantages, as it allows you to adapt to changes and stimulate the creativity of employees. For agricultural enterprises operating in conditions of instability, this approach is especially relevant.

The successful functioning of an organization directly depends on how the team works. A team is not just a group of people working together; it is a collection of individuals who are united by a common goal, interdependent in their activities and collectively responsible for the results. The effectiveness of a team largely depends on the quality of team interaction, which includes communication, cooperation, conflict resolution and mutual support.

The dynamics of team interaction are often described through a model of team development stages. Each stage presents its own challenges and opportunities for the leader:

- formation - team members get to know each other, define roles and expectations. It is important for the leader to create an atmosphere of trust and clarity;
- storming - conflicts and clashes of views arise when team members start to defend their positions. The role of the leader is to facilitate constructive conflict resolution and direct energy into productive channels;
- rationing - the team develops norms of behavior, rules of interaction, and procedures. The leader helps to establish clear standards and strengthen cohesion;
- execution - the team works together and effectively to achieve the set goals. The leader can delegate authority and focus on strategic leadership;
- completion - the team disbands after the task is completed. The leader evaluates and recognizes everyone's contribution.

Team interaction is a dynamic process that involves coordinating efforts, assigning roles, managing conflicts, and building trust. Models of effective interaction allow for diagnosing problems and optimizing team structures (Table 2).

Table 2. Main models of team interaction and their characteristics

Model	Main stages/elements	Application in practice
Tuckman's model	Formation, conflict, norming, productivity	Diagnostics of team development stages
Lancioni model	Trust, conflict, commitment, responsibility	Identifying dysfunctions in teams
Belbin Model	9 team roles	Optimization of role distribution

*Source: compiled by the author

One of the most famous is B. Tuckman's team formation model, which describes the stages of team development: formation, conflict, norming, performance, and termination. It is also important to consider Lancioni's model, which emphasizes the following key factors: lack of trust, fear of conflict, avoidance of responsibility, lack of commitment, and inattention to results.

Several key factors influence the quality of team interaction. The first is a clear definition of goals and roles. Each team member must understand their own role and contribution to the overall result. The second factor is open and effective communication. Thanks to such communication, information should circulate freely within the team. The third factor is mutual trust and respect. This implies that team members trust one another and respect different points of view. The fourth factor is constructive conflict resolution. Conflicts are inevitable, but it is important to resolve them in a way that promotes development rather than destroying relationships. The fifth and final factor is psychological safety. This means creating an environment where each team member feels comfortable expressing their ideas and concerns without fear of judgment.

In real-world business environments, it is important to combine different approaches. For example, agricultural enterprises often form a seasonal team that goes through all stages of the Tuckman model in a short period of time, which requires a flexible approach to management from the leader.

The research methodology in this area is based on an interdisciplinary approach, which includes methods from organizational psychology, management, sociology, and economics. The most common methods are:

- 1) Questionnaire – to identify leadership styles and team relations;
- 2) SWOT analysis – to assess internal and external factors that affect team interaction;
- 3) Case study method – for analyzing specific situations from the experience of the enterprise;
- 4) Interviews with managers and employees – to collect qualitative information;
- 5) Sociometric method – to determine the structure of informal leaders and relationships in the team.

Generalized data on the methodological tools are presented in Table 3.

A carefully selected methodology allows you to form a holistic picture of leadership and team effectiveness at the enterprise.

Forming an effective team in a modern enterprise is a complex and multi-level process, in which the leader plays a key role. Not only the effectiveness of joint work, but also the microclimate in the team, the level of motivation and cohesion of employees depend on his managerial, communicative, and personal qualities.

Table 3. Methodological tools for researching team interaction

Method	Characteristic	Strengths
Questionnaire	Collecting statistical data from respondents	Speed, quantitative analytics
Sociometry	Identifying relationships in a group	Visualization of the informal structure
SWOT analysis	Identifying team strengths/weaknesses	Strategic planning
Case studies	Analysis of real examples	Practicality, depth
In-depth interview	Research on employee motivation and attitudes	Flexibility, emotional interpretation

*Source: compiled by the author

The role of a leader in forming an effective team can be characterized by several key aspects:

1. The leader as the initiator of the team structure - it is the leader who determines the composition of the team, taking into account not only the professional qualities of the candidates, but also their psychological compatibility. An effective team is not just a collection of specialists, but a balanced system with clearly distributed roles, where everyone feels their significance.

2. The leader as a motivator - a modern leader must be able to stimulate team members not only materially, but also morally. Recognizing achievements, supporting initiatives, creating conditions for professional growth - all this is critically important for maintaining high efficiency.

3. The leader as a communication facilitator - in a team that functions effectively, feedback must be established. The leader must be able to listen and hear, create an atmosphere of trust and openness, and resolve conflicts constructively.

4. The leader as a role model - the leader's behavior, attitude towards work, ethical principles and responsibility shape the corporate culture. If the leader demonstrates honesty, determination, openness - the team adopts these qualities.

5. The leader as a strategic thinker - especially in the agricultural sector, where seasonality and market instability dictate their conditions, the leader must think several steps ahead. His task is not only operational management, but also ensuring the stability of the enterprise's development.

In the world of management science, three main paradigms of leadership have been formed: personal (leadership traits), behavioral (leadership styles), and situational (adaptation to the context). Each of them offers valuable tools for analysis, but the direct transfer of these models to the soil of Ukrainian agricultural enterprises encounters a number of limitations.

First, most classical theories were developed on the basis of research on industrial or service companies with a relatively stable external environment. The agricultural sector of Ukraine, on the contrary, operates in conditions of high uncertainty: weather and climate risks, fluctuations in prices on world markets, delays in budget VAT reimbursement, changes in customs and land legislation, and now also security threats. Situational theories of leadership (Fiedler, Hersey-Blanchard) formally take into account the context, but the matrices they propose ("maturity of subordinates", "structure of the task") are difficult to operationalize in field conditions, where the foreman and the mechanic often have the same informal authority, but different formal status.

Secondly, the Ukrainian agricultural enterprise is characterized by a peculiar combination of industrial and pre-industrial management practices. On the one hand, large agricultural companies use ERP systems, satellite monitoring of fields and precision farming. On the other hand, a significant part of operational management is based on personal agreements, oral orders and "manual" control. A leader in such an environment is forced to constantly balance between transformational inspiration (which requires time and trust) and transactional management (which ensures quick execution, but depletes motivation). This creates the problem of "double optics": a researcher or practitioner cannot unambiguously attribute the leader's style to democratic or authoritarian - more often it is necessary to record hybrid, internally contradictory configurations.

Thirdly, the issue of leadership in agricultural enterprises is closely related to the phenomenon of informal power, which is based not on position, but on professional experience, territorial proximity or family ties (especially in farms). This phenomenon is practically not taken into account by classical theories of leadership, but in the agricultural context it often determines the real ability of a manager to implement changes.

Thus, a theoretical understanding of leadership in agricultural enterprises requires not simply choosing one of the known models, but developing a context-sensitive approach that would integrate:

- taking into account seasonality of production and associated peak loads on communication;
- analysis of the distribution of formal and informal authority in teams with a long history of working together;
- assessment of staff readiness for autonomous decisions (given the long tradition of directive management).

The concept of "team" in management implies a common goal, complementary roles, shared responsibility, and a synergistic effect that cannot be achieved by the sum of individual efforts. However, the direct application of this concept to agricultural enterprises encounters a number of significant caveats.

The first problem is related to the technological division of labor. In crop production, a significant part of the work (plowing, sowing, fertilizing, harvesting) is performed by mechanized units, which often work at a considerable territorial distance from each other. Such spatial dispersion objectively complicates operational

feedback and the formation of a common "team spirit". Moreover, in many cases, teams perceive themselves not as a single farm team, but as autonomous detachments, the competition between which is maintained even at the level of the labor remuneration system (piecework uniform). In animal husbandry, on the contrary, there is a high interdependence of milking parlor operators, veterinarians, feed suppliers and zootechnicians. However, this interdependence is often not so much of a team as of a conveyor belt nature: a failure in one area stops the entire process, but this does not stimulate a joint search for solutions, but instead gives rise to mutual accusations.

The second problem concerns the motivational structure of employees of agricultural enterprises. Team interaction assumes the presence of internal motivation, readiness to take on additional responsibility for the overall result. At the same time, empirical observations show that for a significant part of agricultural workers (especially grassroots workers) external motivation dominates, focused on stable wages and minimizing efforts. This is not an anomaly - it is a rational adaptation to many years of practice, when management assessed the result by formal indicators (for example, "hectares processed"), and not by participation in improving processes.

The third problem is the uncertainty of the boundaries of the team. In classical management, a team is clearly identified: it is a group of people working on a common task under the leadership of a leader. In an agricultural enterprise, the boundaries of the "team" are blurred. Should the entire farm team be considered a team? Or only a team of 5–7 people who interact directly? Or temporary groups created for the harvesting campaign (where the composition changes daily due to the involvement of seasonal workers)? The theory does not give unambiguous answers to these questions, but without their solution it is impossible to develop methods for assessing the effectiveness of team interaction.

In addition, it is necessary to pay special attention to the problem of seasonal workers, which is unique to the agricultural sector. A significant part of the labor resources is involved for periods from several weeks to several months (sowing, harvesting). These people often do not identify with the enterprise, do not have a sufficient level of trust in permanent employees and, accordingly, are not included in team interaction at the level of shared values. Managing such a "temporary" team requires separate mechanisms that are practically absent in the scientific literature.

The complexity of the simultaneous study of leadership and team interaction in agricultural enterprises is due to the fact that these phenomena belong to different analytical levels. Leadership is traditionally studied at the level of the personality (traits, styles, behavior) or the dyad "leader - follower". Team interaction, in turn, is a group phenomenon that is not reduced to the sum of individual characteristics. Comprehensive research requires methodological integration - a combination of individual-psychological, social-psychological and organizational-management methods.

However, in practice, researchers face a number of obstacles.

The problem of measuring "informal leadership". Most existing leadership questionnaires (MLQ, LPI, etc.) are focused on formal managers. In agricultural enterprises, informal leaders (for example, the most experienced tractor driver, whose opinion everyone listens to) can have a decisive influence on decision-making, but they cannot be "measured" by standard methods, since they do not hold management positions. Attempts to apply sociometric methods (who turns to whom for advice) encounter the reluctance of respondents to answer honestly in conditions where management can access the results.

The problem of seasonal dynamics. Team interaction is not static - it changes depending on the phase of the production cycle. During preparation for sowing, planning and resource allocation dominate, in the midst of field work - operational response and interchangeability, after the cycle is completed - analysis of results. Most studies record the state of interaction at one point in time (cross-sectional design), which gives a distorted picture. For agricultural enterprises, longitudinal studies are needed that would cover at least one full production cycle (year), but such studies are expensive, time-consuming and sensitive to staff turnover.

The problem of contextual dependence of tools. Questionnaires developed in Western academia often contain statements that lose their meaning or take on a different meaning in the Ukrainian agrarian context. For example, the statement "my supervisor encourages me to express my own opinion, even if it contradicts his position" may receive socially desirable responses, but in real interaction such encouragement is absent. Adaptation of instruments requires not just translation, but cultural and contextual validation, which is a separate scientific task.

The problem of integrating qualitative and quantitative data. Leadership and team interaction have both measurable (number of conflicts, decision-making time, group productivity) and deeply meaningful aspects (trust, identification with the team, perception of justice). Quantitative methods allow for statistically generalized results, but often lose context. Qualitative methods (interviews, observations) provide rich material, but their results are difficult to extend to the general population. A comprehensive study requires a mixed design, but in Ukrainian agricultural science this approach is still used extremely rarely due to the lack of an appropriate methodological culture and time resources.

The main contradiction that determines the need for adaptation is the gap between formal management structures (job descriptions, orders, staffing) and real interaction practices (personal agreements, paternalistic expectations, informal adjustment of tasks).

Let us highlight several key problems that require scientific understanding and practical solutions.

1. The legacy of the administrative-command system. Despite decades of market transformations, significant inertia of managerial thinking remains in Ukrainian agricultural enterprises. Older generation managers often tend to identify leadership with tight control and single-handed decision-making. Team interaction is perceived by them as a threat to their own authority ("if they start discussing, I will lose respect"). At the same time, younger managers (under 35–40 years old), who have received modern business education, face misunderstanding from subordinates who expect clear directives, not questions "what do you think?" This intergenerational gap in the understanding of leadership creates communication barriers that none of the existing models fully describes.

2. The impact of war and security factors. The full-scale invasion has radically changed the conditions for the functioning of agricultural enterprises. Field mining, logistical blockades, mobilization of workers, risks of rocket attacks - these factors have created an unprecedented level of stress and uncertainty. In such conditions, classic recommendations for delegation of authority and participatory leadership need to be corrected: excessive democratization of decision-making can lead to loss of time that does not exist, and excessive centralization - to burnout of the leader. Adaptation must take into account the emergence of new functions of the leader: psychological support of the team, coordination with military administrations, management of security risks.

3. Low level of horizontal mobility. Effective team interaction requires the possibility of role rotation, interchangeability, and redistribution of tasks between group members. However, in agricultural enterprises, such mobility is limited by objective reasons: narrow specialization (a tractor driver cannot replace an agronomist, and a milking parlor operator cannot replace a veterinarian) and territorial binding (a team working in one field cannot quickly move to another due to distances and the state of equipment). This creates the problem of a "rigid structure", where team interaction is possible only within narrow functional groups, and intergroup coordination remains weak.

4. Institutional weakness of trade unions and other forms of collective representation. In classical management, team interaction is supported by institutions that represent the interests of employees (trade unions, work councils). In Ukrainian agricultural enterprises, these institutions are either absent or perform purely declarative functions. As a result, employees do not have legitimate channels of influence on management decisions, which reduces their involvement in teamwork. Leadership is reduced to "top-down" influence, and "bottom-up" feedback is unsystematic.

The described limitations lead to the conclusion that improving the leadership system in an agricultural enterprise does not consist in switching to any one "correct" style, but in developing the situational flexibility of the leader. In other words, an effective leader must be able to apply different styles depending on the situation:

- in crisis situations (equipment breakdown during cleaning, threat of contract termination, security incident) - authoritarian (quick one-man decision, strict control);
- during planning periods (preparation for the season, allocation of budgets, setting priorities) - democratic (collecting proposals from foremen, agronomists, mechanics);
- in learning situations (transferring experience to young employees) - mentoring (combination of support and control);
- in routine operations (execution of technological maps) - instrumental (clear instructions, monitoring of deviations).

Such style flexibility is not an innate trait; it is formed through conscious reflection, feedback from the team, and targeted learning. This means that the leadership development system in an agricultural enterprise

should include not only theoretical seminars, but also practical cases, analysis of specific situations, and individual development plans for managers at different levels.

If leadership describes mainly the position of the leader, then team dynamics covers the processes that occur within the group: communication, role distribution, conflicts, decision-making, formation of norms and trust. The most famous model of team dynamics is the model of B. Tuckman, which distinguishes the stages of forming, storming, norming, performing and adjourning. Analysis of agricultural enterprises through the prism of this model allows us to identify specific features.

In many agricultural enterprises, especially those that involve a significant number of seasonal workers, teams are actually re-formed every season. Permanent workers form a core, and temporary groups are formed around it for the sowing or harvesting period. This means that the formation and storming stages (getting to know each other, distributing roles, conflicts due to uncertainty) occur anew each time, and the team often does not have time to reach the performing stage before the end of the peak period. The result is a chronic decrease in productivity at the beginning of each season. This decrease is often perceived as an "unavoidable expense". However, it can be partially overcome through several measures. These measures include: creating a database of seasonal workers (recording who worked where, what results they showed, and with whom they interacted effectively). They also include providing preliminary information about the rules, norms, and communication channels before the season starts. Finally, they include assigning a mentor from among the permanent workers to each new employee.

An effective team requires both a clear division of roles (who is responsible for what) and a certain interchangeability (who can replace whom in case of absence). In agricultural enterprises, there is a bias towards hyperspecialization, which makes the team vulnerable to the departure of individual members. For example, if only one mechanic has the skills to diagnose the electronic systems of a modern tractor, his illness or mobilization stops the work of several units.

Improving team interaction in this aspect involves systematic work on the formation of so-called "T-shaped" competencies (deep knowledge in one area + basic knowledge in related ones). This is achieved through in-house training (knowledge exchange between employees of different specialties); creation of "skills matrix", where it is visualized who knows what; planning rotations and "double training", when an experienced employee prepares a replacement.

However, it is important to recognize that in agricultural production, complete interchangeability is not possible due to the specifics of equipment, licensing requirements (for example, for working with pesticides), and physical limitations. Therefore, the challenge is not to achieve universality, but to reduce the criticality of individual points of failure.

Conflicts are an integral part of team dynamics. In agricultural enterprises, the most common sources of conflict are:

- resource (distribution of equipment, fuel, fertilizers, working hours between teams);
- communication (untransmitted or distorted information about the condition of the fields, weather, tasks);
- role-playing (misalignment of areas of responsibility, especially at the joints - for example, between an agronomist and a mechanizer regarding cultivation depth);
- status (confrontation between "old-timers" and new employees, between employees of different age groups).

An important observation is that in many agricultural enterprises, conflicts are either silenced or escalated to the level of the manager for an authoritarian solution. Both strategies are ineffective: silence leads to the accumulation of tension and explosive forms of discharge; authoritarian solutions do not eliminate the causes, but only transfer the conflict to a latent phase.

Improving the team interaction management system involves developing a constructive attitude towards conflict as a signal of a problem that needs to be solved, rather than as a reason for punishment. Practical steps can include: introducing regular "post-mortems" after the completion of key stages, where processes rather than individuals are discussed; training middle managers in mediation skills in industrial conflicts; creating anonymous feedback channels where employees can report problems without fear of punishment.

Trust in a team is the expectation that other members of the group will act predictably, honestly, and with common interests in mind. In agricultural enterprises, the level of trust is often low for several reasons: high staff turnover (no time to build a reputation), episodic breaches of obligations (due to objective force majeure), information asymmetry (management knows more about the financial situation than employees).

However, trust is the intangible asset that allows a team to work effectively without excessive control. Mechanisms for strengthening trust in the agricultural context are the predictability of management actions (the same rules for everyone, fulfillment of promises); transparency of evaluation criteria (the employee understands what he is receiving a bonus or reprimand for); recognition of mistakes (when a manager publicly admits his mistake, it increases, not decreases, trust, since it demonstrates honesty); delegation of real responsibility (not just “responsible”, but “responsible and have the right to decide”).

The central question is to study how leadership styles and team dynamics affect the results of an agricultural enterprise. Based on available scientific sources and observations, several typical relationships can be described.

The impact of leadership on outcomes is rarely direct. Most often, it is mediated through the state of team processes (communication, trust, conflict resolution) and individual employee states (engagement, satisfaction, motivation). Schematically, this relationship can be depicted as follows:

Leadership style → Team climate (norms, trust, openness) → Quality of team processes (speed of decisions, coordination) → Operational indicators (productivity, quality of work, downtime) → Financial results (profit, profitability)

Each link in this chain can be weakened or strengthened depending on the context. For example, an authoritarian style can provide good operational performance in the short term (high productivity during the harvest), but at the same time worsen the climate in the team, which in the long term will lead to staff turnover and increased absenteeism.

Generalizing the practice of agricultural enterprises allows us to identify several patterns that do not claim to be universal, but are typical.

Pattern 1: "hard hand". The manager uses a predominantly authoritarian style. Results in stable conditions (typical weather, standard set of operations) are above average. Results in unstable conditions (sudden weather changes, new technologies, crisis situations) are below average, as the team is not used to thinking independently. Staff turnover is high, especially among young employees with higher education. Loyalty is low, based on fear or habit.

Pattern 2: "democrat on schedule". The leader consciously switches between styles: during planning periods, he involves the team, during execution periods, he switches to authoritarian control. The results are consistently high, since the team understands the logic of decisions (thanks to participation in planning) and does not relax during execution. Fluidity is moderate, higher among those who are not ready for the "dual reality" (where today you are asked for your opinion, and tomorrow you are ordered without discussion). This pattern requires a high communicative culture of the leader and maturity of the team.

Pattern 3: "good uncle". The leader tries to be democratic and supportive, avoiding tough decisions. Results are average or below average, especially in periods that require quick and unpopular decisions. The team may perceive such softness as weakness, leading to a decrease in discipline. Turnover can be either low (employees are comfortable) or high (ambitious employees go where "something is really done"). This pattern often occurs when the leader tries to imitate Western models of leadership without taking into account the context.

Pattern 4: "chaotic". The leader does not have a conscious style, reacts impulsively, his requirements contradict each other. Results are unstable, depend on random factors. Team dynamics are characterized by a high level of stress, political games and shifting of responsibility. This is the most problematic pattern, which requires either an urgent change of the leader or his systematic training.

The described patterns show that the best results are achieved not by those leaders who adhere to one "correct" style, but by those who consciously adapt their style to the situation and invest time in developing team processes (trust, communication, conflict resolution).

Not all indicators of an agricultural enterprise's performance depend equally on leadership and team interaction. There are three groups of indicators.

The first group is weakly dependent: gross harvest, yield (determined more by weather, soils, genetics, technologies than by the quality of teamwork).

The second group is moderately dependent: operational efficiency (fuel consumption, downtime, speed of work), quality of operations, number of technological violations. Here the influence of team interaction is already noticeable.

The third group is highly dependent: the ability to implement changes (for example, switching to a new precision farming system), the level of innovative activity (who suggests ideas), adaptability to crises (how

quickly the team is restructured in response to changing conditions), staff turnover, especially among qualified employees.

It is the indicators of the third group that become critical in the long term, determining the sustainability and competitiveness of the enterprise. Therefore, improving leadership and team interaction makes sense primarily for those agricultural enterprises that are focused on long-term development, rather than on obtaining quick profits at any cost.

Based on the above analysis, several areas of improvement can be outlined, which are not recipes, but rather guidelines for managers of agricultural enterprises and their teams.

An effective leader is not born, but is formed in the process of learning, self-development and gaining experience. Improving leadership in an enterprise should be a continuous process and include the following key areas (Table 4).

The implementation of the above management measures in the organization is not only expedient, but also a strategically necessary step to ensure the effective functioning of enterprises in modern conditions. All recommended changes are of a comprehensive nature, covering both intra-organizational processes and the system of interpersonal interaction, which is key to forming a strong, cohesive and effective team.

Table 4. Key areas for improving leadership in the enterprise

Direction	Content
Leadership development training and education	- Emotional intelligence development programs (a participative leader must be able to recognize and manage their own emotions, as well as understand the emotions of others. Training in empathy, self-regulation, and social skills is critical. - Developing situational leadership skills (managers must be able to adapt their management style to the specific situation, the maturity level of subordinates, and the complexity of the task. This includes learning to be flexible between directive, coaching, supportive, and delegating styles. - Transformational and servant leadership trainings (learning how to inspire employees, build a shared vision, stimulate intellectually, and serve the needs of the team is key to creating a high-performance environment. - Development of strategic thinking and visionary thinking (the leader must see the big picture, formulate clear goals, and communicate them to the team.)
Mentoring and coaching	- Mentoring programs (experienced managers can act as mentors for young leaders, sharing their experience, knowledge and helping them in their professional growth). - Individual coaching (engaging external or internal coaches to work individually with managers allows them to realize their strengths and weaknesses, develop individual development plans, and increase their effectiveness).
360-degree feedback systems	Implementing regular leadership competency assessments, where feedback is provided not only from management but also from colleagues and subordinates, allows leaders to gain a comprehensive view of their effectiveness and identify areas for development.
Creating a culture of leadership at all levels	Encouraging leadership not only at the top level, but also among ordinary employees, creating opportunities for initiative and responsibility. This forms a personnel reserve and increases the overall adaptability of the enterprise.

*Source: compiled by the author

Modern management is impossible without the constant development of managers. That is why the emphasis on the development of leadership competencies, the expansion of managerial thinking, the stimulation of initiative and the increase in staff involvement is justified and justified. In conditions when the external environment is characterized by instability, and the agricultural sector is characterized by a high level of seasonal risks, staff becomes the main driver of organizational flexibility. The formation of a strong management culture allows the enterprise not only to effectively respond to external challenges, but also to prevent internal problems at the early stages of their occurrence.

In addition, special attention deserves the introduction of modern communication tools, such as corporate portals, feedback systems, electronic platforms for internal interaction. Combined with a systematic approach to assessing the effectiveness of teamwork and building a psychologically comfortable environment,

this will allow organizations to form a stable management core on which all decision-making processes will be based.

The application of the proposed approaches does not require a radical reform of the organizational structure of the enterprise. Instead, they provide for a gradual but consistent transformation of management approaches towards greater openness, transparency, trust and team interaction. The expected effects include increased employee satisfaction, reduced staff turnover, increased productivity and, as a result, improved financial and economic results of the enterprise.

For effective implementation of leadership functions and improvement of personnel management and team interaction in organizations, it is necessary not only to formulate appropriate measures, but also to competently choose a strategy for their implementation. Since organizations operate in a dynamic environment, increased seasonality and the need for quick decision-making, it is important to rely on specific methods of evaluating and comparing strategic alternatives.

Choosing a management strategy is always a multifactorial process that must take into account the internal capabilities of the enterprise, its organizational structure, human resources, financial resources, as well as external conditions, such as the market situation, economic risks, and the level of competition. Therefore, in this context, the application of clearly defined methods of analysis and comparison of options makes it possible to reasonably determine the most effective approaches to managing leadership processes. It also significantly reduces the risks of erroneous management decisions. Furthermore, it ensures the necessary transparency and objectivity in the process of making these decisions. Finally, it provides a clear vision of the potential results from each of the considered alternatives.

That is why the following is a list of methods that can be used in practice specifically in agricultural enterprises. These methods take into account the specifics of the agricultural enterprise, as well as the peculiarities of the management culture of the organization, which is at the stage of active development and modernization.

1. Personnel and role map method. This method involves creating an interactive role map of all key managers of the enterprise, identifying their leadership functions, areas of influence, level of responsibility, and communication links. Analysis of such maps allows:

- identify duplication of functions;
- assess the degree of influence of the leader on specific groups of personnel;
- visualize weaknesses in the management structure.

The method helps to make decisions about the need for retraining, delegation, or a change in management style.

2. Agro-focused SWOT analysis. The uniqueness of this approach is the adaptation of SWOT to agricultural specifics. To the standard four blocks (strengths, weaknesses, opportunities, threats) are added:

- seasonal risks(weather factors, sowing/harvesting rhythm);
- dependence on government regulation;
- the influence of the human factor in production processes. This allows for a more accurate assessment of the potential impact of changes in management styles on the effectiveness of the enterprise.

3. Leadership Potential Index (LPI) method. It is proposed to use a simplified LPI form for internal evaluation of management employees in five areas:

- the ability to inspire;
- ability to listen;
- ability to adapt;
- decision-making;
- building trust. Each manager is rated on a scale of 1–5 points. This makes it possible to compare potential and form individual development plans.

4. Method of comparative diagnostics of communication channels. It consists of recording all internal communication channels (meetings, telephone, messengers, verbal instructions, etc.), their frequency and effectiveness. Then, the following is assessed:

- speed of information transfer;
- number of errors in completing tasks;
- feedback. This allows decisions to be made on the implementation of new digital solutions (for example, a corporate portal or CRM for communications).

5. Matrix analysis of management scenarios. For each strategic alternative, a table is created with possible scenarios: optimistic, realistic, pessimistic. Each scenario is accompanied by a description:

- expected changes in the team structure;
- training/restructuring costs;
- impact on labor productivity. Such a matrix allows you to make informed decisions taking into account risks.

6. Method of practical testing of changes in a pilot unit. Before large-scale implementation of changes (new management style, motivation tools, etc.), the selected strategic alternative is tested in one unit (for example, in technical or logistics). Within 1–3 months, the following are recorded:

- changes in production indicators;
- level of conflict;
- employee feedback. The method allows you to objectively assess the effectiveness of the proposed changes.

The success of a modern agricultural enterprise largely depends on the effectiveness of its leaders and the coherence of team interaction.

Effective team interaction is a synergistic effect that results from the coordinated work of individuals. To optimize it, it is necessary to use an integrated approach (Table 5).

Improving leadership and team interaction are inextricably linked and should be considered as a single system. In this system, the leader plays a key role in shaping and maintaining effective work by creating an appropriate culture and environment. The leader acts primarily as a facilitator of team processes. This means that he not only sets tasks, but also helps the team to complete them by removing obstacles, providing the necessary resources, and in every way facilitating internal communication. At the same time, he ensures the creation of a culture of cooperation. Through his own example and system of incentives, he forms an environment in which mutual assistance, collective responsibility, and the desire for synergy become the norm. This approach is complemented by the strategic use of team diversity. An effective leader is deeply aware of the value of differences in the thoughts, experience, and skills of his subordinates and is able to skillfully use this intellectual potential to generate better management decisions and implement innovations.

Ways to improve leadership and team management in an enterprise are a long-term investment in human capital. A systematic and consistent approach to these issues allows not only to increase current efficiency, but also to lay a solid foundation for the sustainable development of the organization, its ability to innovate and adapt in conditions of constant change.

Summing up the results of the study of the role of leadership and mechanisms for managing team interaction in the agricultural sector, it should be noted that in the conditions of global instability and digitalization of agricultural production, the classical hierarchical management model is finally giving way to the paradigm of distributed leadership. The analysis has proven that the effectiveness of a modern agricultural enterprise is directly correlated with the ability of management to transform individual competencies of employees into a synergistic team resource.

Key aspects of strategic team management in the agricultural sector primarily include the adaptability of leadership styles. The specifics of agricultural business, due to seasonality and dependence on natural and climatic factors, require the manager to possess high cognitive flexibility. This includes the ability to quickly switch from a directive style during peak sowing or harvesting periods to coaching and democratic styles during strategic planning. This adaptability is closely intertwined with the integration of "green" human capital. Leaders who adhere to the values of sustainable development (ESG) form proactive environmental thinking in their subordinates. This not only minimizes reputational risks but also stimulates internal innovations and kaizen proposals for resource conservation. Furthermore, the digital transformation of interaction through the implementation of precision farming systems and ERP solutions is completely changing the architecture of team communication. These changes require leaders to have skills in managing virtual and hybrid teams. In such teams, trust is based not on physical control, but on data transparency and KPI performance.

Table 5. A comprehensive approach to improving team interaction

Direction of work	Stage	Content
Clear definition of roles and responsibilities	Development of functional responsibilities and areas of responsibility	Each team member should clearly understand their role, expectations, and contribution to the overall outcome. Using responsibility matrices (e.g., RACI matrix) can be helpful.
	Setting team goals (SMART goals)	Shared, specific, measurable, achievable, relevant, and time-bound goals help the team stay focused and working in the same direction.
Developing effective communication	Implementing regular and structured meetings	A clear agenda, facilitation of discussions, and recording of decisions are key.
	Using modern communication platforms	Corporate messengers, collaboration platforms (e.g. Microsoft Teams, Slack) can improve the exchange of information and documents.
	Open feedback culture	Encouraging regular and constructive feedback between team members and between the manager and subordinates.
Building trust and psychological safety	Teambuilding activities	Regular events aimed at strengthening team spirit, informal communication, and overcoming internal barriers.
	Transparency in decision-making	Leaders must explain the reasons for decisions made, even if they were not popular.
	Encouraging openness and risk-taking	Creating an environment where employees are not afraid to express unconventional ideas or admit mistakes.
Conflict management	Training in conflict resolution skills	Conducting training for managers and team members on constructive conflict resolution, compromise-finding, and mediation.
	Implementing clear dispute resolution procedures	The presence of clear rules and mechanisms for resolving conflict situations.
Recognizing and encouraging team achievements	Collective bonus systems	Introducing bonuses or other incentives that depend on the overall success of the team, not just individual performance.
	Public recognition of successes	Regularly celebrating team achievements, which increases motivation and maintains a positive attitude.

*Source: compiled by the author

Effective team interaction in agricultural holdings and farms today is based on three founders: psychological safety, which allows personnel to initiate changes; technological equipment, which ensures the accuracy of decisions; and value orientation, where the leader acts not as a controller, but as an architect of the organizational environment.

A promising direction for further exploration is to study the impact of neuroleadership on labor productivity in conditions of high intensity of field work and to develop a methodology for assessing the intellectual capital of agricultural enterprises as a key component of their market value.

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INFORMATION-EXTREME EVALUATION OF FEATURE INFORMATIVENESS FOR EDUCATIONAL CONTENT ADAPTATION TO LABOR MARKET REQUIREMENTS

Shelehov Igor

*Doctor of Philosophy (PhD) in Technical Sciences, Associate Professor, Sumy National Agricultural University, Ukraine
ORCID ID: 0000-0003-4304-7768*

The rapid development of digital technologies has fundamentally transformed the structure and functioning of modern educational systems. In recent years, particularly under conditions of global instability and accelerated digitalization, higher education institutions have faced the urgent need to continuously adapt their educational programs to dynamically changing labor market requirements. This challenge is especially relevant in the context of emerging economies and post-crisis recovery, where the mismatch between acquired competencies and market demands can significantly hinder economic development and workforce competitiveness.

One of the key problems in this context is the so-called skills gap [1], which reflects the discrepancy between the competencies provided by educational institutions and those required by employers. Traditional approaches to curriculum design are often based on expert judgment, static standards, and infrequent updates, which makes them insufficiently responsive to rapid technological changes and evolving professional requirements. As a result, educational content may become partially outdated, redundant, or misaligned with actual labor market needs.

The transition to digital learning environments, including learning management systems (LMS), online courses, and adaptive educational platforms, creates new opportunities for addressing this problem [2]. In particular, the availability of large volumes of educational and labor market data enables the application of formal methods for analyzing, evaluating, and optimizing educational content. However, despite these opportunities, there remains a lack of rigorous, mathematically grounded approaches for assessing the quality and relevance of educational content in terms of its contribution to learning outcomes and labor market alignment. A promising direction for solving this problem is the application of feature-based analysis, where educational content is described by a set of measurable characteristics (features), and its quality or relevance is evaluated through classification and optimization procedures. Within this framework, a critical task is the evaluation of feature informativeness, i.e., determining the extent to which individual characteristics contribute to the correct classification of educational content according to predefined quality criteria [3].

In this regard, information-extreme approaches [4], originally developed for pattern recognition and decision support systems, offer a powerful theoretical and methodological foundation. These approaches are based on the optimization of information criteria that reflect the functional efficiency of classification systems and allow for the identification of the most informative features while eliminating redundant or misleading ones.

The application of information-extreme evaluation methods to educational content adaptation represents a novel and promising line of research [5]. It enables not only the classification of educational materials by quality level but also the optimization of their structure by selecting the most relevant and informative characteristics. This, in turn, supports the development of adaptive educational programs that are better aligned with labor market requirements.

The aim of this chapter is to develop and investigate an information-extreme approach to evaluating the informativeness of educational content features and to apply this approach to the problem of adapting educational programs to labor market requirements.

To achieve this aim, the following objectives are addressed:

- to formalize educational content as an object of feature-based analysis;
- to define quality classes reflecting the degree of alignment with labor market needs;
- to develop a mathematical model for evaluating feature informativeness based on information-extreme criteria;
- to propose algorithms for feature selection and content optimization;
- to demonstrate the applicability of the proposed approach through a case study.

In order to formalize the problem of adapting educational content to labor market requirements, it is necessary to represent educational programs in a structured and analyzable form. Within the proposed approach, educational content is considered as a set of objects (courses, modules, or learning units), each of which is described by a vector of features reflecting its qualitative and quantitative characteristics.

Let us define a set of educational content objects:

$$\mathcal{Y} = \{Y_1, Y_2, \dots, Y_K\}, \quad (1)$$

where each object Y_k represents a specific course or module within an educational program. Each object is characterized by a set of features:

$$\Omega = \{\omega_1, \omega_2, \dots, \omega_N\}, \quad (2)$$

where each feature ω_i corresponds to a measurable characteristic of the content. These features may include, for example:

- relevance to current technologies and industry standards;
- presence of practical tasks and real-world case studies;
- alignment with job market skill requirements;
- level of complexity and depth;
- degree of interactivity and digital integration.

Thus, each content object Y_k is represented by a feature vector:

$$y_k = \{y_{k,1}, y_{k,2}, \dots, y_{k,N}\} \subseteq \mathbb{R}^N, \quad (3)$$

where $y_{k,i}$ denotes the value of feature ω_i for object Y_k .

To evaluate the quality of educational content, a set of classification classes is introduced:

$$\mathcal{C} = \{C_1, C_2, \dots, C_M\} \quad (4)$$

which represent different levels of alignment with labor market requirements. For example, these classes may correspond to:

- high-quality (fully aligned with labor market needs),
- medium-quality (partially aligned),
- low-quality (not aligned).

The assignment of content objects to these classes may be based on expert evaluation, empirical data (e.g., graduate employment rates), or a combination of both.

Within this framework, the problem can be formulated as a classification task: given a feature vector y_k , determine the class C_m to which the content object belongs. However, a central challenge in this task is that not all features contribute equally to classification accuracy. Some features may be highly informative, while others may be redundant or even negatively affect the classification process.

Therefore, a key problem is the evaluation of feature informativeness [6], which can be defined as the contribution of a given feature to the overall effectiveness of the classification system. Formally, this involves assessing how the inclusion or exclusion of a feature affects a chosen information criterion that reflects the functional efficiency of the system.

Based on this, the main research problems addressed in this chapter are:

1. Feature informativeness evaluation: to determine the contribution of each feature ω_i to the accuracy and reliability of content classification.
2. Feature space optimization: to reduce the dimensionality of the feature space by eliminating non-informative or misleading features while preserving or improving classification performance.
3. Educational content classification: to develop a model that assigns content objects to quality classes based on the most informative features.
4. Content adaptation and optimization: to use the results of feature evaluation and classification to improve the structure and content of educational programs in accordance with labor market requirements.

To solve these problems, this chapter proposes the use of an information-extreme approach, in which the effectiveness of the classification system is evaluated using an information criterion, and feature informativeness is determined based on its impact on this criterion. This approach allows for the systematic

identification of the most significant characteristics of educational content and provides a formal basis for its optimization.

The evaluation of feature informativeness is a fundamental problem in the design of intelligent systems for classification and decision support. In the context of educational content adaptation to labor market requirements, this problem becomes particularly significant, as it determines which characteristics of educational content have the greatest impact on its quality assessment and alignment with external demands.

Feature informativeness can be generally defined as the degree to which a given feature contributes to the discrimination between classes of objects – in this case, levels of educational content quality or relevance to labor market needs. The effectiveness of classification, and consequently the validity of decisions regarding curriculum adaptation, depends directly on the selection of informative features.

Existing approaches to feature informativeness evaluation can be broadly divided into two main categories [6]: filter methods and wrapper methods.

Filter methods evaluate feature informativeness independently of a specific classification algorithm. They rely on general statistical or information-theoretic properties of the data and are typically applied as a preprocessing step.

The main advantage of filter methods is their computational efficiency and universality. Since they do not depend on a particular classifier, they can be applied to a wide range of problems, including those where the final classification model is not yet defined. However, their primary limitation is the inability to directly account for the interaction between features and the classification model, which may reduce their effectiveness in complex tasks.

In the context of educational content analysis, filter methods can be used to preliminarily assess which characteristics – such as relevance to industry standards, presence of practical components, or alignment with job market skills – contain useful information for distinguishing between different quality levels.

Wrapper methods, in contrast, evaluate feature informativeness based on the performance of a specific classification model. In this case, the quality of a feature (or a set of features) is determined by how well the classifier performs when using that feature subset.

The key advantage of wrapper methods is their ability to account for the interaction between features and the classification algorithm. As a result, they often provide more accurate and task-specific evaluations of informativeness. However, this comes at the cost of significantly higher computational complexity, as the classification model must be trained and evaluated multiple times for different feature subsets.

For the problem of educational content adaptation, wrapper methods are particularly valuable because they allow for the direct assessment of how specific content characteristics influence the correctness of classification into quality or relevance classes. This makes them suitable for identifying not only informative features but also those that may negatively affect classification performance.

Feature informativeness can be quantified using different types of measures, which can be grouped into several categories depending on their underlying principles.

1. Distance-Based Measures

Distance-based measures evaluate informativeness by analyzing the separability of classes in the feature space. The basic idea is that informative features increase the distance between objects belonging to different classes while reducing the distance between objects of the same class.

Typical examples include metrics based on Euclidean distance or other similarity measures. These methods are characterized by low computational complexity and general applicability. However, they may not fully capture complex statistical dependencies between features.

In educational content analysis, such measures can be used to assess how well certain characteristics differentiate between high-quality and low-quality content.

2. Information-Theoretic Measures

Information-theoretic measures evaluate feature informativeness based on the concept of uncertainty reduction. A feature is considered informative if its inclusion reduces the uncertainty about the class membership of an object.

Common measures include entropy-based criteria, such as Shannon entropy, and divergence measures, such as Kullback–Leibler divergence. These measures provide a natural and theoretically grounded way to quantify informativeness and are widely used in feature selection tasks.

In the considered problem, information-theoretic measures allow for the evaluation of how much information about the quality or labor market alignment of educational content is gained by considering a particular feature.

3. Correlation-Based Measures

Correlation-based measures assess informativeness by analyzing dependencies between features and between features and class labels. The goal is to identify features that are strongly correlated with the target variable (class) but weakly correlated with each other.

These methods help to eliminate redundant features that do not provide additional information. While they are relatively simple and computationally efficient, they may not capture nonlinear relationships.

In educational applications, correlation-based approaches can be used to identify overlapping or redundant content characteristics, such as multiple indicators of similar competencies.

4. Consistency-Based Measures

Consistency-based measures evaluate the informativeness of features based on the consistency of the data representation. A feature subset is considered informative if it allows for consistent classification of objects with minimal contradictions.

These methods often rely on the concept of the minimal representative subset of features that preserves classification accuracy. They provide a balance between computational complexity and evaluation quality.

In the context of educational content, such measures can be used to determine the minimal set of characteristics required to reliably assess content quality.

5. Classifier-Based Measures

Classifier-based measures directly evaluate informativeness through the accuracy or error rate of a classification model. These measures are typically used within wrapper methods and provide the most direct assessment of feature usefulness.

They are characterized by high accuracy and relevance to the specific task but require significant computational resources. Importantly, they allow for the estimation of classification performance already at the stage of feature selection.

For educational content adaptation, classifier-based measures are particularly important, as they enable the identification of features that directly contribute to correct classification into quality or relevance categories.

The analysis of existing methods shows that there is a trade-off between computational efficiency and evaluation accuracy. Filter methods provide fast and general estimates of feature informativeness but may lack precision in specific tasks. Wrapper methods, on the other hand, offer higher accuracy but require more computational resources.

Given the complexity of educational content as an object of analysis and the importance of accurate classification for decision-making, it is reasonable to prioritize methods that take into account classification performance. In this context, approaches based on classifier performance and information criteria are particularly relevant.

The information-extreme approach combines the advantages of information-theoretic and classifier-based methods. It evaluates feature informativeness through its impact on an information criterion that reflects the functional efficiency of the classification system. This allows not only for the identification of informative features but also for the detection of redundant or misleading ones.

Therefore, the information-extreme framework provides a suitable methodological basis for evaluating feature informativeness in the problem of educational content adaptation to labor market requirements.

The evaluation of feature informativeness is closely related to the problem of feature space optimization, which aims to construct a subset of features that ensures the highest possible classification performance while minimizing redundancy and dimensionality. In the context of educational content adaptation, this problem corresponds to identifying the most relevant characteristics of learning materials that determine their quality and alignment with labor market requirements.

The initial feature space, formed during the problem formulation stage, typically includes a wide range of characteristics describing educational content. These may encompass pedagogical, technological, and labor market-related attributes. However, not all features contribute equally to classification accuracy. Some may be weakly informative, redundant, or even negatively affect the performance of the classification system.

Therefore, the task of feature space optimization can be defined as the selection of an optimal subset of features $\Omega^* \subseteq \Omega$, such that the effectiveness of the classification system, evaluated by a chosen criterion, is maximized.

The optimization of the feature space pursues several interrelated objectives [7]:

1. Reduction of dimensionality. Eliminating non-informative features reduces computational complexity and improves the efficiency of data processing.

2. Elimination of redundancy. Features that duplicate information provided by others do not contribute to improved classification and may introduce noise.

3. Improvement of classification accuracy. Removing irrelevant or misleading features can increase the separability of classes and enhance decision reliability.

4. Interpretability of results. A reduced set of meaningful features facilitates the interpretation of results and supports decision-making in educational management.

In the considered problem, these objectives are directly linked to improving the quality of decisions regarding curriculum design and adaptation.

Feature space optimization methods are commonly classified into three main groups: filter, wrapper, and embedded methods.

In filter-based approaches[7], features are ranked according to a selected informativeness criterion, and only the top-ranked features are retained. This method is computationally efficient and suitable for preliminary dimensionality reduction.

However, since filter methods do not account for interactions between features, they may retain redundant features or discard combinations that are informative only when considered jointly.

Wrapper methods [7] evaluate subsets of features by training and testing a classification model. The optimal subset is selected based on the classification performance.

These methods provide higher accuracy but require significantly more computational resources, especially when the number of features is large. The search for the optimal subset is often performed using heuristic strategies, such as forward selection, backward elimination, stepwise selection.

Embedded methods [7] integrate feature selection directly into the model training process. Examples include regularization techniques and tree-based models that inherently evaluate feature importance.

While these methods are efficient and effective in many applications, they are often tied to specific model architectures and may lack generality.

Given the combinatorial complexity of the feature selection problem, exhaustive search is typically infeasible. Therefore, sequential selection strategies are widely used [8].

Forward Selection: the process begins with an empty feature set and iteratively adds features that provide the greatest improvement in the evaluation criterion.

Advantages:

- simplicity,
- efficiency for large feature spaces.

Limitations:

- may miss optimal combinations due to greedy nature.

Backward Elimination: the process starts with the full feature set and iteratively removes features that contribute the least to the evaluation criterion.

Advantages:

- considers full feature interactions initially.

Limitations:

- computationally expensive,
- sensitive to initial feature set quality.

Hybrid approaches combine forward and backward procedures to balance exploration and computational cost.

Within the information-extreme approach, feature space optimization is performed based on the maximization of an information criterion that reflects the functional efficiency of the classification system.

In this framework, the informativeness of a feature is evaluated by analyzing how its inclusion or exclusion affects the value of the information criterion. This allows for a principled selection of features that contribute positively to class separability.

A key advantage of this approach is the ability to identify not only non-informative features, but also negatively informative features, i.e., those that degrade classification performance.

This property is particularly important in the analysis of educational content, where certain characteristics may introduce bias or distort the assessment of quality.

In the context of adapting educational programs to labor market requirements, feature space optimization has a clear practical interpretation.

The selected optimal feature subset Ω^* represents the most significant characteristics of educational content, which determine its relevance to current industry needs, influence learning outcomes, or contribute to successful employment of graduates.

Conversely, features excluded from the optimal subset may correspond to outdated content elements, redundant topics, ineffective pedagogical approaches.

Thus, feature space optimization provides a formal mechanism for revising curriculum structure, prioritizing key competencies, eliminating unnecessary or low-impact content.

The analysis of feature space optimization methods indicates that no single approach is universally optimal. Filter methods are efficient but may lack precision, while wrapper methods are accurate but computationally expensive.

The information-extreme approach offers a balanced solution by integrating feature evaluation with classification performance, using a unified information criterion, and enabling the detection of both redundant and misleading features.

Therefore, it is well-suited for solving the problem of educational content adaptation, where both accuracy and interpretability are critical.

The information-extreme approach represents a class of methods for modeling intelligent decision-making systems based on the optimization of information criteria that reflect the functional efficiency of classification processes. Originally developed for pattern recognition and diagnostic systems, this approach is characterized by its ability to operate under conditions of uncertainty, limited data, and overlapping classes.

In the context of educational content adaptation to labor market requirements, the information-extreme approach provides a formal framework for evaluating the informativeness of content characteristics, constructing optimal feature spaces, ensuring reliable classification of educational content according to quality and relevance criteria.

The core idea of the information-extreme approach is to maximize the informational separability of classes in the feature space. This is achieved by optimizing a criterion that reflects the balance between:

- inter-class distance (distance between different classes),
- intra-class compactness (similarity within the same class).

In contrast to traditional statistical methods, the information-extreme approach does not rely on strict assumptions about data distribution. Instead, it focuses on the structural organization of data in the feature space and the ability of the system to correctly classify objects under varying conditions.

In the considered problem, educational content objects [9] are represented as feature vectors, and the goal is to construct a classification system that maximizes the distinguishability between different quality levels or degrees of alignment with labor market requirements.

Let the set of educational content objects be represented as (1), where each object is described by a feature vector (3). Each object belongs to one of the predefined classes (4), which correspond to different levels of educational content quality or alignment with labor market requirements.

Within the information-extreme framework, each class is associated with a reference (prototype) vector, which serves as a representative of the class in the feature space. The classification process is based on comparing an object with these reference vectors using a selected similarity or distance measure.

A key element of the approach is the definition of decision rules, which determine class membership based on the position of an object in the feature space relative to class boundaries.

A central component of the information-extreme approach is the information criterion, which serves as a measure of the functional efficiency of the classification system.

This criterion reflects the system's ability to correctly classify objects belonging to different classes, maintain stability under variations in feature values, minimize classification errors.

In general, the information criterion is defined as a function of classification accuracy and reliability. It takes into account both correct and incorrect decisions, as well as the distribution of objects in the feature space.

The optimization process aims to find such parameters of the classification system (including feature subsets and decision thresholds) that maximize the value of the information criterion.

The learning process in the information-extreme approach involves the iterative adjustment of system parameters in order to maximize the information criterion.

This process includes:

1. Formation of the training sample. A set of labeled educational content objects is used to construct the model.

2. Initialization of parameters. Initial values of feature thresholds, class boundaries, and reference vectors are defined.
3. Iterative optimization. System parameters are adjusted step by step to improve the value of the information criterion.
4. Evaluation of feature informativeness. The contribution of each feature is assessed based on its impact on the information criterion.
5. Selection of optimal parameters. The final model is chosen as the one that achieves the maximum criterion value.

An important property of this learning process is its ability to identify informative features, redundant features, negatively informative features.

To apply the information-extreme approach to the problem of educational content adaptation, it is necessary to reinterpret its key components (Table 1)

Table 1. Adaptation of classical interpretation of information-extreme key components

Classical interpretation	Adapted interpretation
Object	Educational content unit
Feature	Content characteristic
Class	Quality / labor market alignment level
Decision rule	Content classification rule

Within this framework, the learning process corresponds to the analysis of educational content and the identification of those characteristics that most strongly influence its classification.

The optimization of the feature space leads to the identification of a subset of characteristics that define the effective structure of educational content in terms of labor market relevance.

The application of the information-extreme approach to educational content analysis provides several important advantages:

- High sensitivity to feature informativeness. The method allows for precise identification of features that influence classification performance.
- Detection of negatively informative features. Unlike many traditional methods, it identifies features that degrade system performance.
- Interpretability. The results can be directly interpreted in terms of educational content characteristics.
- Adaptability. The approach can be applied to different domains and updated as new data becomes available.
- Suitability for decision support. The method provides a formal basis for optimizing educational programs and aligning them with labor market needs.

Despite its advantages, the information-extreme approach has certain limitations:

- it requires a representative training dataset;
- the quality of results depends on the correctness of feature definition;
- computational complexity may increase with the number of features;
- periodic model updating is necessary due to changes in labor market requirements.

However, these limitations are typical for most data-driven approaches and can be mitigated through proper system design and data management.

The information-extreme approach provides a robust theoretical and methodological foundation for evaluating feature informativeness and optimizing educational content. Its ability to integrate feature selection with classification performance makes it particularly suitable for solving the problem of adapting educational programs to labor market requirements.

Within the proposed approach, educational content is represented as a structured set of objects described in a multidimensional feature space. Each object corresponds to a unit of educational content (course, module, or topic), characterized by a vector of features reflecting its qualitative and quantitative properties.

Let the set of educational content objects be defined as (1). Each object Y_k is represented by a feature vector (3), where $y_{k,i}$ denotes the value of the i -th feature $\omega_i \in \Omega$, and (2) is the feature space. The feature values may be binary, discrete, or continuous, depending on the nature of the educational content

characteristics (e.g., presence of practical tasks, level of alignment with labor market skills, degree of interactivity).

To evaluate the relevance of educational content to labor market requirements, a set of classes is introduced (4), where each class represents a level of quality or alignment, for example:

- C_1 : high alignment,
- C_2 : partial alignment,
- C_3 : low alignment.

Each object Y_k in the training set is associated with a class label $\lambda_k \in \{1, 2, \dots, m\}$. The labeled dataset forms the basis for training the classification model and evaluating feature informativeness.

In contrast to conventional approaches where class prototypes are defined as mean vectors in a continuous feature space, the information-extreme approach employs a binary representation of features obtained through a system of control tolerances. This transformation plays a key role in ensuring robustness and improving class separability.

Let the original feature vector of an educational content object be defined as (3). Each feature $y_{k,i}$ is transformed into a binary value using a system of control tolerances:

$$\delta_i = [y_i^{low}, y_i^{up}],$$

which defines the admissible range of values for feature ω_i .

The binarized feature $x_{k,i}$ is defined as:

$$x_{k,i} = \begin{cases} 1, & \text{if } y_{k,i} \in \delta_i, \\ 0, & \text{if } y_{k,i} \notin \delta_i. \end{cases} \quad (5)$$

Thus, each educational content object is represented by a binary vector:

$$x_k = \{x_{k,1}, x_{k,2}, \dots, x_{k,N}\} \subseteq \{0, 1\}^N. \quad (6)$$

This transformation allows the system to operate in a discrete feature space, which simplifies the construction of decision rules and enhances robustness to noise and variability in the data. Within the binary feature space, each class C_m is represented by a reference (prototype) vector:

$$x_m^* = \{x_{m,1}^*, x_{m,2}^*, \dots, x_{m,N}^*\} \subseteq \{0, 1\}^N \quad (7)$$

The reference vector is constructed based on the binarized training samples belonging to class C_m . In the simplest case, it can be defined as the result of aggregation (e.g., majority rule or mean with thresholding):

$$x_{m,i}^* = \begin{cases} 1, & \text{if } \frac{1}{n} \sum_{\lambda_k=m} x_{k,i} \geq \rho, \\ 0, & \text{otherwise,} \end{cases}$$

where ρ is a threshold parameter, n is a number of objects in training set with label $\lambda_k = m$.

Thus, the reference vector represents the typical binary pattern of features associated with a given class of educational content.

In the binary feature space, each class can be interpreted as a region defined around its reference vector. The distance between an object and a class is typically evaluated using a discrete metric, such as the Hamming distance.

This representation enables clear separation of classes, construction of decision regions, and efficient computation of classification rules.

The system of control tolerances δ_i is not fixed but is subject to optimization within the learning process. By adjusting the tolerance ranges, the model effectively reshapes the binary feature space and influences class separability.

This leads to a two-level optimization problem:

1. optimization of tolerance parameters δ_i ;
2. optimization of the feature subset Ω^* .

The joint optimization of these parameters allows the system to achieve maximum classification efficiency according to the information criterion.

In the context of educational content adaptation, the binarization process has a clear interpretation:

- $x_{k,i} = 1$ indicates that the content characteristic satisfies the required standard or falls within an acceptable range;

- $x_{k,i} = 0$ indicates a deviation from desired criteria.

Thus, the reference vector defines a target profile of educational content, corresponding to a specific level of alignment with labor market requirements.

The optimization of tolerances allows the system to adapt to varying requirements, account for acceptable deviations, and ensure flexibility in content evaluation.

Within the information-extreme framework, the classification of educational content objects is performed in a binary feature space using distance-based decision rules. After binarization of features through the system of control tolerances, each object is represented as a binary vector (6). Each class C_m is associated with a binary reference vector (7).

The similarity between an object and a class is evaluated using the Hamming distance, defined as:

$$d_H(x_k, x_j) = \sum_{i=1}^N |x_{k,i} - x_{j,i}|.$$

This distance measures the number of mismatched components between the object and the class prototype.

In the information-extreme approach, each class C_m is represented not only by a reference vector but also by a container (a hypersphere in binary space) K_m , defined by a center x_m^* and a radius d_m^* . Thus, the container K_m of class C_m is defined as:

$$K_m = \{x_j \subseteq \{0,1\}^N \mid d_H(x_m^*, x_j) \leq d_m^*\}.$$

An object belongs to class C_m if its binary representation lies within the corresponding container. The classification decision for an object X_k is made according to the following rule:

$$X_k \in C_m \text{ if } \mu_m = 1 - \frac{d_H(x_m^*, x_j)}{d_m^*} \geq 0.$$

If multiple containers include the object, additional selection criteria may be applied, such as choosing the class with the maximum μ_m :

$$\lambda_j = \arg \max_m \mu_m.$$

If the object does not belong to any container $\forall m \mu_m < 0$, it may be classified as unknown, or assigned to the nearest class based on minimum distance $d_H(x_m^*, x_j)$.

The radii d_m^* are not fixed and are determined during the learning process. Their values are selected in such a way as to maximize the information criterion.

The choice of d_m^* affects classification accuracy, class separability and robustness to noise.

Thus, the optimal radii are obtained as a result of a trade-off, formalized through the maximization of the information criterion.

A key component of the model is the information criterion, which evaluates the effectiveness of the classification system.

Let:

- P_t be the probability of correct classification,
- P_f be the probability of error.

The information criterion E is defined as a function:

$$E = f(P_t, P_f) = 0.5 \log_2 \left(\frac{P_t}{P_f} \right) (P_t - P_f),$$

which increases with higher classification accuracy and decreases with higher error rates.

In the information-extreme framework, the goal is to $E \rightarrow \max$ by optimizing system parameters, including radii d_m^* , system of control tolerances δ_i^* , feature subsets Ω^* :

$$d_m^* = \arg \max_{d_m \in \{0,1,\dots,N\}} E(d_m), \quad (8)$$

$$\delta_i^* = \arg \max_{\delta_i \in [0,\delta_{max}]} \frac{1}{M} \sum_{m=1}^M \max_{d_m \in \{0,1,\dots,N\}} E(d_m), \quad (9)$$

$$\Omega^* = \arg \max_{\Omega_p \subseteq \Omega} \left[\max_{\delta_i \in [0,\delta_{max}]} \frac{1}{M} \sum_{m=1}^M \max_{d_m \in \{0,1,\dots,N\}} E(d_m) \right]. \quad (10)$$

The criterion reflects the ability of the system to distinguish between classes of educational content based on their characteristics.

In the context of educational content adaptation:

- the reference vector represents an ideal profile of content corresponding to a specific quality level;
- the container radius defines the permissible level of deviation from this profile;
- the Hamming distance measures the degree of mismatch between actual content characteristics and the desired profile.

Thus objects inside the container correspond to content that meets the required quality level, and objects outside indicate insufficient alignment with labor market requirements. This interpretation allows decision-makers to identify content that meets standards, detect deviations, and prioritize improvements. The use of Hamming distance and class containers provides computational efficiency, robustness to noise, clear geometric interpretation, compatibility with binary feature representation. These properties make the approach particularly suitable for applications involving structured evaluation criteria, such as educational content quality assessment.

The informativeness of a feature ω_i is defined as its contribution to the value of the information criterion. Formally, the informativeness can be evaluated as:

$$\Delta E_i = E_\Omega - E_{\Omega/\omega_i}, \quad (11)$$

where E_Ω is the criterion value using the full feature set, E_{Ω/ω_i} is the criterion value after removing feature ω_i .

This definition allows for the systematic identification of features that improve or degrade classification performance.

The optimal feature subset is defined as (10), subject to constraints on dimensionality or computational cost. Due to the combinatorial nature of the problem, sequential optimization strategies are typically used, such as forward selection and backward elimination. At each step, the inclusion or exclusion of features is evaluated based on its effect on the information criterion.

In the context of educational content, the proposed model enables:

- identification of key content characteristics that determine alignment with labor market requirements;
- elimination of redundant or outdated features;
- detection of misleading characteristics that negatively affect quality assessment;
- construction of an optimized representation of educational programs.

Thus, the model provides a formal basis for adapting educational content by focusing on the most informative attributes that influence its practical relevance.

The proposed model has the following properties scalability: applicable to large sets of educational content, interpretability: results are expressed in terms of meaningful features, adaptability: can be updated as labor market requirements evolve, robustness: does not rely on strict assumptions about data distribution

The proposed algorithm implements the information-extreme approach to evaluating feature informativeness and optimizing educational content representation. It integrates three interconnected processes:

- binarization of features using control tolerances,
- construction of class containers in binary space,
- maximization of the information criterion.

The algorithm operates on a labeled dataset of educational content objects and produces an optimal feature subset, tolerance system, and classification model.

Input Data and Parameters

Input:

- set of educational content objects $\{Y_1, Y_2, \dots, Y_K\}$,
- feature vectors $y_k = \{y_{k,1}, y_{k,2}, \dots, y_{k,N}\}$
- class labels $\{\lambda_1, \lambda_2, \dots, \lambda_K\}$
- initial tolerance ranges δ_i

Output:

- optimal container $K_m(x_m^*, d_m^*)$ of class C_m ,
- optimal system of control tolerances δ_i^* ,
- optimal feature subsets Ω^* ,
- evaluation of feature informativeness ΔE_i .

Algorithm Structure

The algorithm consists of iterative optimization cycles, each aimed at improving the value of the information criterion.

Step 1. Initialization

1.1. Define the initial feature space Ω .

1.2. Initialize tolerance system $\delta = \{\delta_i\}$.

Step 2. Binarization of Feature Space

For each object Y_k and feature ω_i construct binary dataset X_k based on (5).

Step 3. Formation of Class Prototypes

For each class C_m

3.1. Aggregate binary vectors of training samples.

3.2. Construct reference vector x_m^* using thresholding.

Step 4. Optimization of Container Radii

For each class C_m :

4.1. Vary radius d_m within range $\{0, 1, \dots, N\}$.

4.2. For each value of d_m , compute number of correctly classified objects, number of misclassified objects and estimate P_t be the probability of correct classification, P_f be the probability of error.

4.3. Evaluate information criterion $E = f(P_t, P_f)$.

4.4. Select optimal radius d_m^* based on (8).

Step 5. Optimization of Control Tolerances

For each feature ω_i :

5.1. Adjust tolerance parameters δ_i

5.2. Recompute binary representation.

5.3. Re-evaluate information criterion E_{δ_i} .

5.4. Select optimal tolerance δ_i^* based on (9).

Step 6. Evaluation of Feature Informativeness

For each feature ω_i :

6.1. Compute criterion using full feature set E_Ω .

6.2. Remove feature ω_i and recompute E_{Ω/ω_i} .

6.3. Compute informativeness ΔE_i based on (11).

6.4. Classify feature:

- $\Delta E_i > 0$: the feature is informative,
- $\Delta E_i = 0$: the feature is non-informative,
- $\Delta E_i < 0$: the feature is negatively informative.

Step 7. Feature Space Optimization

7.1. Remove negatively informative features.

7.2. Optionally remove weakly informative features.

7.3. Update feature space $\Omega \rightarrow \Omega^*$ based on (10).

Step 8. Iterative Optimization Loop

Repeat Steps 2–7 until:

- convergence of information criterion,
- or reaching stopping condition.

Step 9. Final Model Construction

9.1. Fix optimal parameters $(\Omega^*, \delta_i^*, x_m^*, d_m^*)$.

9.2. Construct final classification model.

To evaluate the effectiveness of the proposed information-extreme approach for educational content adaptation, an empirical dataset was constructed based on the assessment of educational materials developed by the Department of Computer Science at Sumy State University.

The dataset was formed using survey-based evaluations provided by three groups of stakeholders:

- employers,
- graduates,
- current students.

These groups were selected to ensure a comprehensive and balanced assessment of educational content from both academic and labor market perspectives.

Each respondent evaluated individual educational modules using a quantitative scale ranging from 0 to 100 points. The collected data reflect subjective yet structured judgments regarding the quality and relevance of educational content.

All responses were aggregated and stored in a centralized database, forming the basis for the training and evaluation of the classification system.

To provide a more detailed and realistic assessment of educational content quality, the classification scheme was extended from three to four classes. This allows for finer differentiation between levels of alignment with labor market requirements and educational standards.

The set of classes is defined as $\mathcal{C} = \{C_1, C_4\}$, where C_1 : satisfactory content (acceptable level) – partially aligned, requiring improvement; C_4 : unsatisfactory content (low level) – poorly aligned or outdated, requiring substantial revision.

The assignment of objects to classes was performed based on thresholding of aggregated scores. This labeling serves as ground truth for training the information-extreme classification model.

To represent educational content in a structured and analyzable form, a feature dictionary consisting of 28 characteristics was defined. Each feature reflects a specific aspect of content quality, relevance, and effectiveness in the context of alignment with labor market requirements.

The feature space is defined as $\Omega = \{\omega_1, \omega_2, \dots, \omega_{28}\}$. Each feature ω_i corresponds to a measurable attribute evaluated on a quantitative scale and subsequently transformed within the information-extreme framework. For clarity and interpretability, the feature dictionary is organized into five thematic groups: content quality, methodological quality, technical quality, assessment and feedback, and pedagogical value.

Table 2. Description of feature dictionary

No.	Indicator	Group
1	Compliance of content with the educational program	Content Quality
2	Alignment of content with learning outcomes	Content Quality
3	Relevance of learning information	Content Quality
4	Appropriateness to learners' educational level	Content Quality
5	Consideration of labor market needs	Content Quality
6	Compliance with general educational requirements	Technical Quality
7	Completeness and coverage of topics	Content Quality
8	Interdisciplinary connections of the material	Content Quality
9	Clear structuring of learning content	Methodological Quality
10	Correctness of references and bibliography	Content Quality
11	Compliance with educational standards	Content Quality
12	Clarity of instructional wording	Methodological Quality
13	Diversity of content delivery methods	Methodological Quality
14	Use of real-life examples and case studies	Methodological Quality

15	Quality and relevance of learning tasks	Methodological Quality
16	Accessibility of presentation for different learner groups	Methodological Quality
17	Use of active learning methods	Methodological Quality
18	Integrated evaluation of methodological design of materials	Methodological Quality
19	Stimulation of critical thinking	Methodological Quality
20	Development of learners' creativity	Methodological Quality
21	Quality of multimedia support	Technical Quality
22	Compatibility of materials across platforms	Technical Quality
23	Motivational value of content	Pedagogical Value
24	Inclusiveness of learning materials	Pedagogical Value
25	Systematic nature of feedback	Assessment & Feedback
26	Possibility of individualization of learning	Pedagogical Value
27	Flexibility of content updating	Pedagogical Value
28	Consistency of assessment checkpoints	Assessment & Feedback

At the initial (zero) iteration, the optimization of the feature dictionary was performed using the sequential backward selection algorithm. At the first step, the informativeness of each feature from the initial dictionary was evaluated by generating reduced variants of the feature set, each having one feature less than the current dictionary.

For each such variant, the training parameters were optimized, and the maximum averaged value of the information criterion was calculated. The obtained values for the feature set variants at the first step of training are presented in Fig. 1

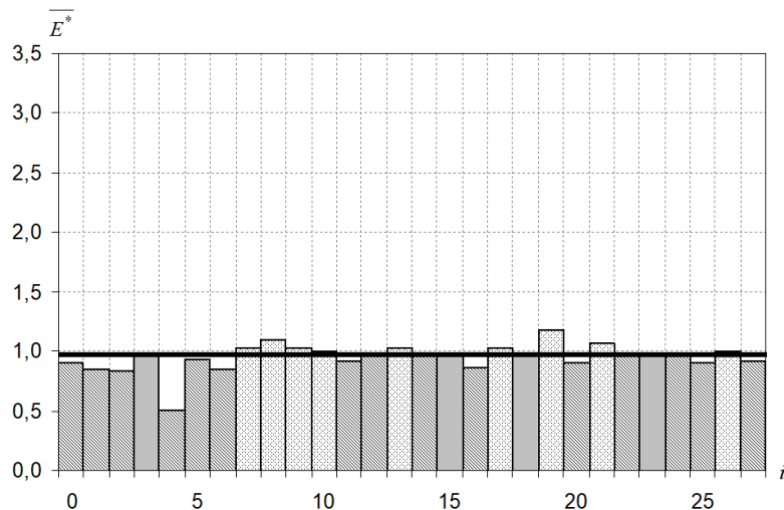


Figure 1. Maximum averaged value of the information criterion for feature set variants at the first step of optimization

In Fig. 2, the gray color indicates feature sets whose criterion values coincide with the averaged maximum value for the current feature set. Single-direction shading denotes variants for which the criterion value decreased relative to the current set, while double-direction shading indicates variants for which the criterion value increased.

As a result, the feature set selected for further iterations was obtained by removing 19 features from the current dictionary. The dynamics of the change in the information criterion are shown in Fig. 2.

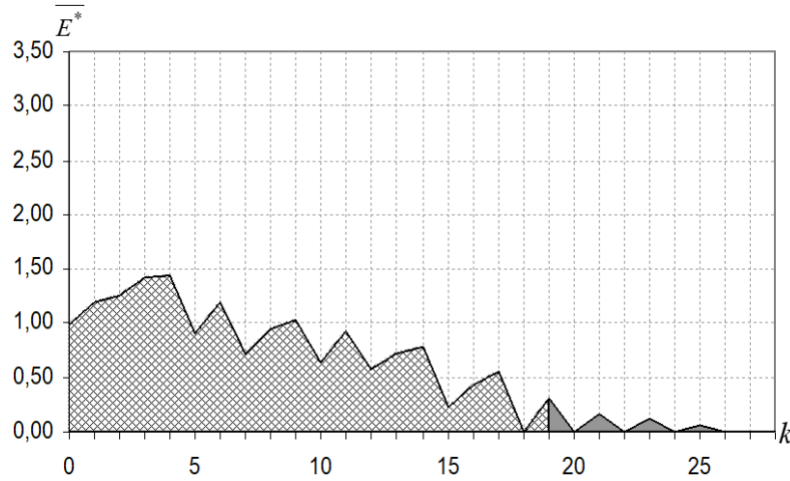


Figure 2. Dynamics of the maximum averaged information criterion value

The analysis of Fig. 2 indicates that the optimal feature set was obtained at the fourth iteration step. After this point, the value of the information criterion decreased significantly, although the process was non-monotonic. This behavior suggests that feature space optimization should continue even when intermediate feature sets demonstrate lower criterion values, as subsequent iterations may lead to new maxima.

The optimal feature set was formed by removing features 18, 19, 23, and 24 from the initial dictionary. The optimal value of the tolerance parameter was $\delta^* = 34$. The optimal geometric parameters of the classification model were determined as follows: for the base class $d_1^* = 8$, for the neighboring class $d_2^* = 9$, and the inter-center distance $d_c^* = 10$.

The maximum values of the information criterion and accuracy characteristics were obtained as: for the base class C_1 : $E_1^* = 2.13037$ ($P_t^* = 0.90$, $P_f^* = 0.10$).

The evaluation of feature informativeness using the modified algorithm was carried out similarly, by generating reduced feature sets and optimizing training parameters, including the feature subset itself. For each variant, the maximum averaged value of the information criterion was computed. The dynamics of the information criterion during this process are presented in Fig. 3.

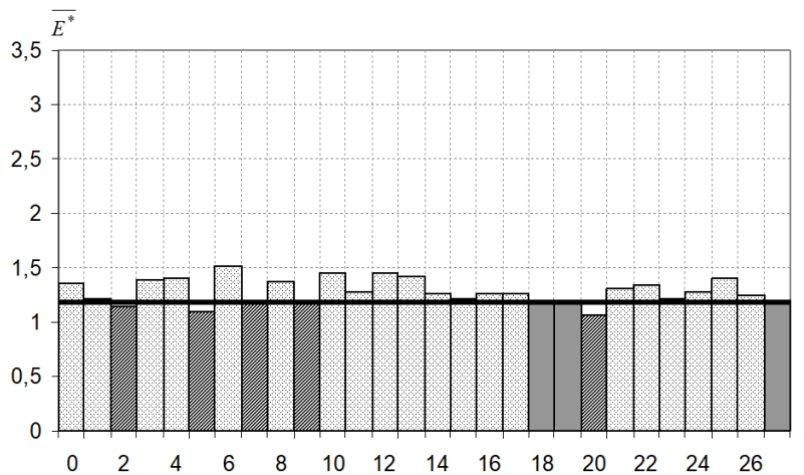


Figure 3. Dynamics of the maximum averaged information criterion during feature informativeness evaluation using the modified algorithm

The analysis of Fig. 3 shows that only five features are informative for the classification system as a whole. Three features are non-informative, as their removal does not affect the value of the information criterion. All remaining features are considered interfering, indicating that the corresponding test items require revision.

The most informative feature is feature 5, with an informativeness value of 0.09767. Its removal leads to changes in the optimal geometric parameters: $d_1^*=7$, $d_2^*=7$, $d_c^*=8$. The performance indicators remain unchanged for the base class but degrade for the neighboring class.

The most negatively informative (interfering) feature is feature 6, with an informativeness value of -0.32173 . Its removal results in improved performance indicators for the base class: $E_1^*=2.98974$ ($P_t^*=0.95$, $P_f^*=0.05$).

The evaluation of feature informativeness using the modified algorithm was carried out similarly, by generating reduced feature sets and optimizing training parameters, including the feature subset. For each variant, the maximum averaged value of the information criterion was computed. The dynamics of the information criterion during this process are presented in Fig. 4.

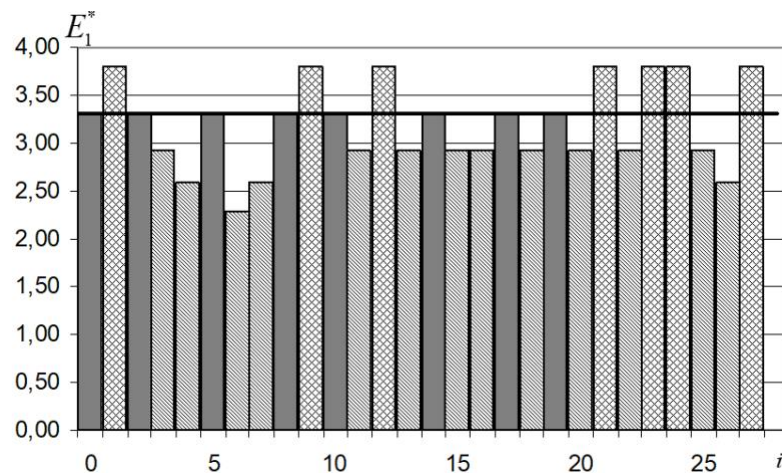


Figure 4. Dynamics of the maximum averaged information criterion during feature informativeness evaluation using the modified algorithm

The analysis shows that the number of non-informative features increased to 7, while the number of informative features decreased to 13, and the number of interfering features increased to 6. Given that error-free classification was achieved for the first and second classes, but not for the base and third classes, the initial feature set for these classes can be considered redundant. Further analysis confirmed that all features for these classes are non-informative. The results of the extended evaluation for the corresponding class are presented in Fig. 5.

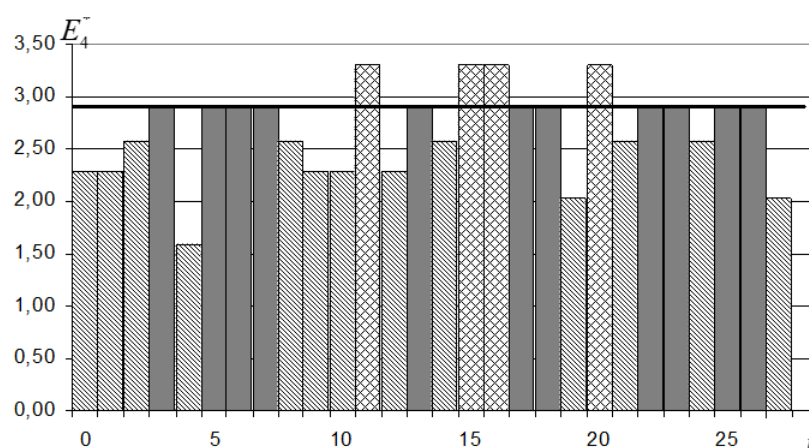


Figure 5. Results of extended feature informativeness evaluation for the corresponding class

The analysis indicates that the number of non-informative features is 11, informative features – 13, and interfering features – 4.

A summary of the feature informativeness evaluation results is presented in Table 3.

Table 3. Summary results of feature informativeness evaluation

Feature				Feature	Informativeness		
	C_1	C_4	Avg		C_1	C_4	Avg
1	0,00	0,63	0,31	15	0,00	0,34	0,17
2	-0,48	0,63	0,08	16	0,39	-0,39	0,00
3	0,00	0,34	0,17	17	0,39	-0,39	0,00
4	0,39	0,00	0,20	18	0,00	0,00	0,00
5	0,73	1,32	1,03	19	0,39	0,00	0,20
6	0,00	0,00	0,00	20	0,00	0,89	0,44
7	1,02	0,00	0,51	21	0,39	-0,39	0,00
8	0,73	0,00	0,36	22	-0,48	0,34	-0,07
9	0,00	0,34	0,17	23	0,39	0,00	0,20
10	-0,48	0,63	0,08	24	-0,48	0,00	-0,24
11	0,00	0,63	0,31	25	-0,48	0,34	-0,07
12	0,39	-0,39	0,00	26	0,39	0,00	0,20
13	-0,48	0,63	0,08	27	0,73	0,00	0,36
14	0,39	0,00	0,20	28	-0,48	0,89	0,20

The results of feature informativeness evaluation reveal a complex and non-trivial structure of the feature space, in which not all characteristics contribute equally to the classification of educational content quality. The elimination of certain features, in particular Feature 6 (compliance with general educational requirements) and Feature 18 (integrated evaluation of methodological design), can be explained by their low discriminative ability. These indicators tend to exhibit minimal variation across quality classes, since most educational materials formally satisfy general institutional and methodological requirements. As a result, they do not provide meaningful differentiation between high- and low-quality content. In addition, such features are typically standardized at the regulatory or accreditation level, which further reduces their sensitivity to actual differences in educational effectiveness. Consequently, their contribution to the information criterion is negligible, leading to their exclusion from the optimal feature subset.

A number of features, including Features 2, 10, 12, 13, 16, 17, 21, 22, 25, and 28, demonstrated mixed informativeness, being useful for certain classes while negatively affecting classification performance for others. This behavior can be attributed to several factors. First, many of these indicators are inherently subjective, as they depend on the perceptions of different stakeholder groups such as students, graduates, and employers. For example, clarity of instructional wording, diversity of content delivery methods, and accessibility of presentation may be interpreted differently depending on individual experience and expectations. Second, some features are context-dependent, meaning that their importance varies depending on the format or conditions of learning. Indicators such as multimedia quality or platform compatibility may be critical in online environments but less relevant in traditional settings, which reduces their overall informativeness. Third, certain features suffer from weak formalization, particularly those related to creativity, feedback, or learner engagement, which are difficult to quantify objectively and therefore introduce noise into the feature space. Finally, redundancy and correlation between features also play a significant role. For instance, alignment with learning outcomes overlaps conceptually with compliance with the educational program, while consistency of assessment checkpoints is partially reflected in feedback-related characteristics. Such overlaps reduce the marginal contribution of individual features to the overall classification performance.

At the same time, the remaining subset of features forms a stable and informative core that ensures effective separation of quality classes. These features are characterized by a direct connection to learning outcomes, a higher degree of measurability, and reduced subjectivity. They also exhibit significant variability across classes, thereby enhancing their contribution to the information criterion. Importantly, many of these characteristics are closely related to the practical applicability of knowledge and skills, which is a key factor in aligning educational materials with labor market demands.

From the perspective of content adaptation, the obtained results indicate that the most informative characteristics are those associated with real-world applicability, completeness of knowledge representation, and alignment with professional competencies. This suggests that instructional design should prioritize

outcome-oriented principles rather than formal compliance with standards. At the same time, the relatively low informativeness of regulated indicators implies that strict adherence to general requirements does not necessarily improve employability-oriented quality. The findings also highlight the need for improved formalization of complex educational characteristics such as creativity, critical thinking, and feedback mechanisms, as their current representation limits their contribution to the classification process [10]. Furthermore, the identification of interfering features provides diagnostic insights into weaknesses in course design. Such characteristics reflect inconsistencies in structure, ambiguity in evaluation criteria, or instability in the learning experience and can serve as indicators for targeted improvement. From a strategic perspective, the results demonstrate that not all traditionally emphasized characteristics are equally important for labor market alignment. Priority should be given to those that directly support the development of practical competencies. In this context, feature selection becomes a powerful tool for curriculum optimization, enabling a data-driven approach to refining educational programs[11].

The proposed information-extreme approach can be effectively implemented within the operational processes of higher education institutions, particularly at the level of graduating departments responsible for curriculum design and continuous improvement. Its practical application is based on transforming stakeholder evaluations into a formalized feature space, followed by automated classification into predefined quality categories. Each educational unit, such as a course or module, is assessed using the defined feature set, forming a quantitative representation processed within the model. The system performs binarization using optimized tolerance parameters, constructs feature vectors, and assigns the content to a corresponding class based on decision rules in the Hamming space. One of the key application scenarios is the periodic assessment of educational programs. In this case, evaluation data are collected from students, graduates, and employers, aggregated, and used as input for the model. The system produces a classification result for each course, providing an objective and interpretable assessment of its alignment with academic standards and labor market expectations. A major advantage of the system is its ability not only to classify content but also to identify specific weaknesses. By analyzing feature informativeness, it determines which characteristics negatively or insignificantly affect the overall evaluation, enabling targeted improvements. For example, if a course is classified as satisfactory or unsatisfactory, the system can indicate deficiencies in practical relevance, alignment with labor market needs, or assessment design. As a result, evaluation evolves from a descriptive process into a diagnostic and decision-support tool. Another important application scenario is adaptive course redesign. Based on classification results and feature analysis, instructors can refine materials by focusing on the most impactful characteristics. Enhancing practical tasks, incorporating real-world cases, or strengthening competency alignment can directly improve quality classification. The iterative use of the model enables tracking the effectiveness of such changes, forming a continuous improvement loop.

The approach can also be integrated into learning management systems, such as Moodle. In this case, evaluation becomes partially automated through the use of data from assessments, student feedback, and learning analytics. The classification module can function as an analytical layer, generating reports for instructors and administrators and enabling real-time monitoring. From an administrative perspective, the system supports strategic curriculum management by identifying systemic weaknesses and highlighting best practices across courses. The approach is particularly relevant in labor market-driven education, where content must be continuously validated against external requirements. Incorporating employer feedback ensures that evaluation reflects real-world expectations rather than purely academic criteria, thereby enhancing graduate employability and strengthening collaboration with industry. The ontological representation of the domain further supports the development of intelligent and explainable systems. Each classification decision can be traced back to specific features, ensuring transparency and interpretability. This is especially important in educational environments, where accountability and trust are essential. The model can be adapted to different domains, extended with new features, and applied to large datasets, enabling the creation of centralized systems for monitoring and improving educational quality at institutional or national levels. An important aspect of implementation is the formalization of the operational workflow. In practice, the process can be organized as a cyclic procedure including data collection, preprocessing, model execution, and decision support. Evaluation data are collected using standardized instruments, normalized, and transformed into binary representations using control tolerances. The classification results are visualized through dashboards and reports, ensuring reproducibility and continuous monitoring over time. A key benefit of the approach is the possibility of quantitative interpretation of improvements. Any modification of the content can be linked to measurable changes in the information criterion, allowing validation of improvements and shifting content development toward evidence-based optimization. The system also enables scenario-based analysis, allowing simulation of potential changes prior to implementation and supporting proactive decision-making in curriculum design. In

addition, explainability is inherently supported, as the contribution of each feature to classification decisions can be traced.

Despite these advantages, several challenges must be considered. The effectiveness of the model depends on data quality and representativeness, while parameter selection requires careful calibration. Organizational factors, such as resistance to change, may also affect implementation and require gradual integration. The approach can be further enhanced through integration with advanced analytics and artificial intelligence tools. Extending the feature space with automatically extracted learning data enables the construction of more comprehensive evaluation models, while the ontology-based representation supports interoperability with semantic systems and knowledge graphs. Long-term application allows accumulation of historical data for trend analysis and forecasting, transforming the system into a strategic tool for continuous development rather than a one-time evaluation mechanism.

Overall, the proposed framework provides a comprehensive solution for evaluating, diagnosing, and improving educational content. It supports continuous adaptation to labor market requirements, enhances decision-making, and contributes to the development of competency-oriented educational programs. The results confirm that the information-extreme approach offers a theoretically grounded and practically applicable solution for content evaluation. By combining feature selection, parameter optimization, and interpretable decision rules, it enables effective classification while reducing feature redundancy. The findings also highlight limitations of traditional evaluation approaches and emphasize the importance of selecting informative features. At the same time, the need for improved formalization of complex educational characteristics remains an important research challenge. Future research should focus on expanding the feature space, automating optimization procedures, and integrating the model into digital learning environments. The development of hybrid approaches combining interpretability and predictive capabilities represents a promising research direction. Additionally, longitudinal studies are required to assess long-term impact on educational quality and employability. In summary, the proposed approach provides a robust and flexible framework for educational content evaluation, supporting explainable decision-making and continuous improvement in dynamic environments.

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**TRANSFORMATION, SOCIO-ECONOMIC PRINCIPLES OF POST-WAR
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DIGITALIZATION IN THE CONDITIONS OF SUSTAINABLE
DEVELOPMENT**

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