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Controlling as a method for ensuring the financial stability of a family business

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Abstract. The study aimed to analyse the role of controlling as a method for ensuring the financial stability of family businesses and identifying effective methods of its implementation in enterprise management. The study conducted a comprehensive assessment of the impact of controlling the financial stability of family businesses using statistical data, descriptive analysis of the results of an expert survey and analysis of financial statements of real companies (Müller & Söhne GmbH, Bäckerei Schmidt KG, Weber Autoservice) to identify effective management methods and tools. The use of controlling efficiently managed financial flows, increased transparency of operations and improved planning. The analysis demonstrated that family businesses that use a budgeting and financial control system reduce the risks associated with insufficient liquidity and inefficient resource allocation. For instance, after implementing management accounting, Müller & Söhne GmbH reduced costs by 20%, increased net profit from 500,000 EUR to 600,000 EUR, and increased the current ratio from 1.2 to 1.4. At Bäckerei Schmidt KG, profitability increased by 12% over two years and overdue debts decreased from 8% to 4%. At Weber Autoservice GmbH, after the introduction of an early warning system, cash gaps were closed and cash flow from operations increased from 150,000 EUR to 180,000 EUR. Furthermore, the study demonstrated that the successful use of controlling separates personal and corporate finances, improving sustainability. Key tools were analysed, including strategic planning, Balanced Scorecard, key performance indicators and SWOT analysis. Companies that actively use controlling processes demonstrate higher profitability, better solvency and resilience to external risks

Keywords: budgeting; management accounting; profitability; transparency; strategic planning

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Introduction

Family businesses are substantial in the economy, forming the basis for many small and medium-sized enterprises. However, despite their importance, such companies often face financial management problems that can threaten their long-term sustainability. One of the main reasons is the lack of formalised management processes that would ensure transparency of financial flows and efficient allocation of resources. In this regard, controlling, as a management tool, becomes an integral part of the process of ensuring the financial stability of a family business. Controlling is a system of planning, accounting, analysis and control aimed at improving the efficiency of financial operations. In a family business, where there are often problems with the mixing of personal and corporate funds, controlling helps to create a clear framework for financial management, minimise risks and increase financial transparency. Effective use of controlling methods improves decision-making, manages liquidity, optimises costs and increases profitability (Berest & Sablina, 2024). The importance of implementing controlling in family businesses is particularly high in times of economic instability, when timely responses to changes in the external environment are critical.

The problem of ensuring the financial stability of family businesses through the implementation of controlling systems is relevant, as many family businesses face insufficiently structured management and inefficient use of resources. D. Dupuis *et al.* (2021) emphasised the importance of introducing controlling to optimise financial flows and improve the liquidity of family businesses. Without an effective system for controlling and accounting for cash flows, family businesses risked losing their financial stability and facing long-term problems. M. Matsoso *et al.* (2021) addressed the use of budgeting as a key tool for planning and controlling costs in small and medium-sized enterprises. A structured budget not only reduces expenses but also effectively allocates financial resources for growth and development. O. Ferraro & E. Cristiano (2021) analysed the role of cash flow analysis in monitoring cash flows and identifying hidden risks in family businesses. Regular monitoring of cash flows helped to respond quickly to financial problems and avoid crises. J. Vale *et al.* (2022) examined the implementation of a management accounting system to increase financial transparency and improve financial control in family businesses. Transparency in financial transactions helped to avoid conflicts and errors in the allocation of resources within the family. H. Moinzad & M. Akbarzadeh (2022) focused on the use of a balanced scorecard system to ensure strategic planning and improve overall business efficiency. This approach helped not only to analyse financial results but also to consider intangible assets, which contributed to the sustainable development of the company.

A study by J. Ferreira *et al.* (2021) highlighted the importance of strategic planning in the context of controlling for the long-term sustainability of family businesses. A clear strategic direction made it possible to avoid financial

problems in times of economic instability and ensure business growth. In their publication, J. Yan & M. Haroon (2023) analysed how controlling helped to separate personal and corporate financial flows, which contributed to the efficient allocation of resources. Without such separation, family businesses could face the misuse of funds, which threatened financial stability. K. Kandade *et al.* (2021) investigated the impact of controlling on increasing trust among family members and stakeholders in family businesses. The control and reporting system strengthened business relationships and reduced the risk of conflicts and misunderstandings within the family. K. Ngcobo *et al.* (2024) argued that the introduction of a management accounting system helped to improve cost control and optimise internal processes in family businesses. Such a system made it possible to avoid inefficient spending and improve the company's overall financial discipline. N. Messabia *et al.* (2022) demonstrated that the use of financial analysis tools in controlling significantly reduced the risk of financial errors and contributed to the successful overcoming of crises. Regular analysis of financial indicators made it possible to identify and eliminate potential threats promptly. However, existing studies do not pay sufficient attention to the specific features of the implementation of controlling in family businesses in different industries, as well as the influence of cultural and family factors on the effectiveness of such systems. Further study is needed on the impact of controlling the long-term transfer of business between generations and the optimisation of business processes in a changing external economic environment.

The study aimed to analyse the role of controlling as a tool to ensure the financial sustainability of family businesses, as well as to identify the main methods of its implementation in management practice. Research goals:

- to analyse the methods of budgeting and financial control on the example of family companies using data for 2019-2023;
- to assess the impact of strategic planning and management tools (Balanced Scorecard, key performance indicator, SWOT, risk analysis) on the efficiency of family businesses based on case studies and expert surveys;
- to study the peculiarities of using controlling to separate personal and corporate finances in family companies.

Materials and Methods

A comprehensive assessment of the impact of controlling on the financial stability of family businesses was conducted. To identify the real advantages and challenges of implementing controlling, the study analysed practical cases of German family companies such as Müller & Söhne GmbH (Germany) (North Data, n.d.a), Bäckerei Schmidt KG (2024) (Germany) and Weber Autoservice GmbH (Germany) (North Data, n.d.b). Successful examples were controlling increased financial transparency and profitability, as well as unsuccessful cases that demonstrate the consequences of the lack of systemic control over finances,

were analysed. This assessed the key risks and mistakes associated with managing family businesses.

Firstly, statistical data for the period from 2019 to 2023, which confirms the importance of controlling for optimising costs, increasing profits and improving the investment attractiveness of family businesses, was analysed. The data on the most popular controlling instruments provided by the German Institute for Family Business (n.d.), the German Institute for Economic Research (Schäfer *et al.*, 2015) and the German Federal Union of Small and Medium-sized Enterprises (n.d.) determined which ones have the greatest impact on the efficiency of family companies' management.

The study also used expert opinions obtained from surveys of specialists in the field of controlling and management of family businesses. The analysis of the results of surveys conducted by the German Association for Financial Management (n.d.) and the Institute of Public Auditors in Germany (n.d.) identified the most effective methods of implementing controlling and determined the main problems faced by family companies.

Furthermore, the financial statements of real family businesses, including Hoffmann Textil GmbH (n.d.) and Schneider Möbel GmbH (n.d.), were evaluated to demonstrate how controlling affects liquidity, debt levels and business profitability. The analysis of how the use of controlling instruments affects the level of operational risks, the degree of financial transparency and the competitiveness of family companies was emphasised.

The study analysed the impact of strategic planning and the use of balanced scorecards on the performance of family businesses. The key tools such as strategic planning, Balanced Scorecard, key performance indicators, SWOT analysis and risk analysis that improve management decision-making were evaluated. The analysis of these methods highlighted their role in enhancing the long-term sustainability of the business, improving its financial performance and adapting to changes in the external environment. The study also developed an approach to adapting controlling tools, such as the Balanced Scorecard, to the specifics of family businesses to achieve maximum efficiency. The methods of budgeting and financial control used in the management of family enterprises were also studied. This identified their impact on cost optimisation, increased financial transparency and improved business sustainability through effective planning and cash flow control.

Results

Family businesses are key in the economies of many countries, providing jobs and contributing to sustainable development. However, such companies often face financial management challenges due to their informal structure, lack of transparency and difficulties in transferring business between generations. In this context, controlling becomes an important tool for maintaining the financial stability of family businesses. Controlling is the most substantial method for managing an enterprise, not only controlling current operations but also strategically guiding business

development. In the context of family business, where financial management is traditionally less formalised, controlling plays a key role in ensuring the stability and long-term sustainability of the company. This system combines elements of financial planning, data analysis and resource control, helping business owners make informed decisions and reduce risks (Trzeciak *et al.*, 2022).

One of the central functions of controlling a family business is financial planning and forecasting. Family companies often face the problem of short-term capital management, which makes them vulnerable to economic crises and changes in market conditions. Controlling not only provides forecasts of future income and expenses but also creates the financial reserves necessary for sustainable development. Liquidity planning systems, cash flow analysis and scenario modelling help family businesses avoid cash flow gaps and working capital shortages.

Cost control and resource optimisation are also substantial. Family businesses often have limited financial and material resources, which requires a careful approach to cost management. Controlling identifies inefficient cost items, optimises production processes and reduces costs without compromising the quality of products or services. Analysis of the cost and profitability of individual business lines can quickly adjust the company's strategy, reallocate resources and minimise losses.

Another key function of controlling is the analysis of key performance indicators. In a family business, where management decisions are often made intuitively, the use of quantitative indicators becomes particularly important. Controlling helps to systematically monitor profit, profitability, accounts receivable and accounts payable, and evaluate the effectiveness of investments. This not only determines the current financial position of the company but also develops strategies for further growth (Aithal & Aithal, 2023).

Early detection of risks is another important controlling function, especially relevant for family businesses. In addition to standard financial risks, such as liquidity crises or increased debt, family businesses are exposed to specific threats, such as internal conflicts between generations, insufficient formalisation of management processes and dependence on a small number of clients or partners. Controlling identifies potential threats in advance, analyses the external and internal environment and develops anti-crisis strategies.

The application of controlling in a family business requires consideration of its specifics. In contrast to large corporations, where financial analysis and control systems are a mandatory part of management, family businesses are often dominated by traditional approaches based on the personal experience of the owners. As a result, many businesses miss opportunities for optimisation and long-term planning. The introduction of controlling can form of a structured approach to financial management, increases business transparency and ensures its development based on objective data (Einhorn *et al.*, 2021).

The study, conducted by the German Association for Financial Management (n.d.), interviewed 50 experts working in the field of controlling and managing family companies. The results of the survey showed that 85% of respondents consider management accounting to be a key tool for increasing financial transparency in family businesses. This helps not only to track current expenses but also to predict future cash flows, which is crucial for making informed management decisions. In turn, 78% of respondents indicated that budgeting reduces untargeted expenses and optimises the allocation of financial resources in the company, which directly affects the improvement of financial discipline and long-term sustainability.

Furthermore, a study conducted by the Institute of Public Auditors in Germany (n.d.) showed that the most effective controlling methods for family businesses are budgeting, SWOT analysis and liquidity ratio analysis. According to the study, 70% of family businesses consider budgeting to be the most important tool that helps them effectively plan financial flows and control costs. SWOT analysis helps to improve strategic planning, as in 60% of cases it helps to identify the strengths and weaknesses of the business, as well as external threats and opportunities

for development. An important tool is also the liquidity ratio analysis, which, according to the study, reduces the risk of cash gaps by 45%, ensuring cash flow stability and preventing financial crises.

Thus, controlling in a family business performs several functions at once: from financial planning and cost control to key performance indicator analysis and risk management. Its implementation helps not only to improve management efficiency but also to strengthen the business's resilience to external and internal challenges. As economic instability requires flexibility and precision in management, controlling becomes substantial for the successful running of a family business.

The financial sustainability of a family business largely depends on the specifics of its management, which is often based on traditions and personal connections rather than formalised control systems. This creates several problems related to subjectivity of decisions, mixing of personal and corporate finances, and difficulties in transferring the business to the next generations. In these circumstances, controlling becomes crucial for addressing weaknesses in management, increasing transparency of financial flows and ensuring the company's long-term sustainability (Table 1).

Table 1. Features of controlling for separating personal and corporate finances in family businesses

Peculiarity	Description	Impact on family business management	Notes
Separation of budgets	Separation of personal and corporate finances through the creation of separate financial plans	Increase transparency, simplify cost control	Boundaries between personal and business expenses should be set
Management accounting	Keeping records of business income and expenses separately from the owners' expenses	Provides accurate information on the financial position of the business	Minimises confusion and accounting errors
Creation of separate accounts and cards	Introduction of separate bank accounts for personal and corporate needs	Prevention of the mixing of funds, simplifying financial reporting	Mandatory to prevent the misuse of funds
Transparent financial reporting	Regular reporting of corporate income and expenses only	Improved confidence of investors and partners	Requires proper organisation and competent financial accounting
Implementation of automated systems	Using software solutions for personal and corporate finance	Automate processes, reduce errors and increase efficiency	Software solutions can be adapted to business specifics

Source: compiled by the authors based on M. Almashhadani & H.A. Almashhadani (2022)

One of the key features of family businesses is the influence of the emotional factor on management decisions. Owners of such businesses often make decisions based on family values, traditions or personal preferences rather than objective economic indicators. This can lead to the preservation of unprofitable business lines, inefficient allocation of resources or ignoring market changes. Controlling helps implement rational decision-making approaches based on data analysis, financial modelling and objective performance indicators. The use of the Balanced Scorecard system incorporates not only financial results but also other important aspects of the company's operations, such as customer satisfaction, innovative development and the efficiency of internal processes (De-Almeida-e-Pais *et al.*, 2023).

Another typical problem of family businesses is the mixing of personal and corporate finances. In many family-owned

companies, owners use business resources for personal needs, which complicates financial management and can negatively affect the sustainability of the company. Controlling delineates budgets formalises financial flows and prevents misuse of funds. The introduction of a management accounting system separates business and family income and expenses, and the use of separate accounts and transparent reporting reduces the risk of financial losses. As a result, the company receives a more stable financial base, and owners can plan personal and corporate expenses more effectively (King *et al.*, 2022).

Controlling is also substantial in succession and strategic planning. The transfer of a family business to the next generation requires not only legal and organisational preparation but also in-depth financial analysis. Many companies face problems when changing ownership due

to insufficient transparency of accounting, lack of a clear development strategy and conflicts within the family. Controlling assesses the real value of a business, forecasts its financial prospects and develops mechanisms for transferring assets with minimal risks. Furthermore, the use of strategic planning in controlling defined the company's long-term goals, incorporated potential threats and formed a management system that will be effective not only for the current generation of owners but also in the future.

Another feature of family businesses is the need to balance traditional management methods with modern market requirements. Many family business owners take a conservative approach, which can limit business development and reduce its competitiveness. Controlling can introduce modern financial management methods while preserving the unique values and traditions of a family business.

Analysis of key performance indicators identifies weaknesses in a timely manner and adapts the company's strategy to changing market conditions (Ge & Campopiano, 2022).

An example of the successful implementation of controlling in a family business is Müller & Söhne GmbH, a Bavarian construction materials company (Table 2). In 2019, the company faced problems with suboptimal budget allocation, which led to an increase in costs and a decrease in profits. The lack of effective cost control and cash flow planning had a negative impact on the company's financial stability. After implementing flexible budgeting and a management accounting system, the company was able to optimise its financial processes, which reduced costs by 20% and increased the transparency of its financial flows. These measures improved decision-making and increased overall business efficiency (North Data, n.d.a).

Table 2. Müller & Söhne GmbH – before and after the implementation of controlling

Metric	Until 2019 year	After 2019 year
Return on sales	5%	6%
Return on assets	3%	4%
Return on equity	8%	10%
Current liquidity	1.2	1.4
Fast liquidity	0.8	1
Absolute liquidity	0.3	0.5
Total expenses (% of previous level)	100	80
Operating expenses	60%	50%
Administrative expenses	25%	20%
Net profit (EUR)	500,000	600,000
Accounts receivable to revenue	30%	25%
Average maturity of receivables (days)	45	30
Overdue liabilities	10%	5%
Cash Flow (operating) (EUR)	200,000	250,000
Cash Flow (investing) (EUR)	-50,000	-40,000
Cash Flow (financial) (EUR)	100,000	120,000
Instruments: Budgeting, key performance indicators, management accounting, ratio analysis	Not used	Used

Source: compiled by the authors based on North Data (n.d.a)

Another example of the use of controlling is the bakery chain Bäckerei Schmidt KG (2024) in Hamburg (Table 3). The owner of the company had long combined personal and corporate finances, which caused many problems, including an imbalance of budget and difficulties with tax reporting. This negatively affected financial discipline and hindered business development. In 2021, after the

implementation of the controlling system, separate accounts were created for business and personal expenses, which significantly improved cash flow control. As a result, the company's profitability grew by 12% in two years, and financial discipline was significantly improved. This case highlights the importance of separating personal and corporate finances in the management of family businesses.

Table 3. Bäckerei Schmidt KG before and after the introduction of controlling

Metric	Until 2021 year	After 2021 year
Return on sales	8%	9%
Return on assets	6%	7%
Return on equity	7%	8%
Current liquidity	1.3	1.5
Fast liquidity	0.9	1.1
Absolute liquidity	0.4	0.6
Total expenses (% of previous level)	100	85
Operating expenses	50%	45%

Table 3, Continued

Metric	Until 2021 year	After 2021 year
Administrative expenses	25%	20%
Net profit (EUR)	800,000	900,000
Accounts receivable to revenue	20%	15%
Average maturity of receivables (days)	40	35
Overdue liabilities	8%	4%
Cash Flow (operating) (EUR)	350,000	400,000
Cash Flow (investing) (EUR)	-30,000	-25,000
Cash Flow (financial) (EUR)	80,000	100,000
Instruments: Balanced Scorecard, key performance indicator, separate business accounts	Not used	Used

Source: compiled by the authors based on Bäckerei Schmidt KG (2024)

An unfortunate example was noted in the Weber Autoservice GmbH car service network, where the lack of a controlling system caused cash gaps and debt accumulation (North Data, n.d.b). Without effective cash flow control, the company could not maintain stability in its business. Cash gaps and financial problems accumulated, which threatened the company's continued existence. However,

in 2023, after implementing an early warning system for financial risks and regular analysis of key indicators, the company was able to restore its solvency. These analyses identified problems in a timely manner and determined measures to restore financial stability, which highlighted the importance of a systematic approach to controlling the management of family businesses.

Table 4. Weber Autoservice GmbH before and after the introduction of controlling

Metric	Until 2023 year	After 2023 year
Return on sales	4%	4%
Return on assets	2%	3%
Return on equity	5%	5%
Current liquidity	0.9	1.1
Fast liquidity	0.6	0.8
Absolute liquidity	0.2	0.4
Total expenses (% of previous level)	100	95
Operating expenses	55%	50%
Administrative expenses	30%	25%
Net profit (EUR)	200,000	250,000
Accounts receivable to revenue	35%	30%
Average maturity of receivables (days)	50	40
Overdue liabilities	15%	8%
Cash Flow (operating) (EUR)	150,000	180,000
Cash Flow (investing) (EUR)	-60,000	-50,000
Cash Flow (financial) (EUR)	70,000	90,000
Instruments: early warning system, key performance indicator analysis, ratio analysis	Not used	Used

Source: compiled by the authors based on North Data (n.d.b)

Thus, controlling in a family business performs several important functions: it facilitates objective decision-making, helps separate personal and corporate finances, ensures management continuity and maintains a balance between tradition and efficiency. Its implementation helps to increase business transparency, minimise risks and ensure the financial stability of the company for many years. In an unstable economy and growing competition, family-owned companies using controlling instruments gain a significant advantage as they can adapt to changes more quickly and make informed management decisions.

Effective management of a family business requires the use of modern controlling to systemise financial

management, minimise risks and increase the sustainability of the enterprise. In contrast to large corporations, family businesses often operate in a less formalised environment where decisions are made intuitively, and financial records are kept without clear standards. The introduction of controlling tools helps owners and managers to plan resources more consciously, analyse current results and forecast future development (Table 5).

One of the key controlling tools is budgeting, which controls expenses, income and financial flows. For a family business, it is necessary to keep track of receipts and payments to avoid cash gaps and ensure long-term financial stability. Budgeting helps identify priority areas

for spending, forecast the company's financial needs and avoid inefficient spending. In addition, budgeting helps distinguish between personal and corporate finances,

which is especially important for family companies, where owners often use business resources for personal needs (Okeke *et al.*, 2024).

Table 5. Budgeting and financial control methods used in the management of family businesses

Method	Description	Advantages	Notes
Traditional budgeting	Based on annual budgeting based on experience and forecasts	Simplify planning, identify key costs	May not consider rapid changes in the environment
Flexible budgeting	The budget is reviewed depending on changes in business conditions	More accurate reflection of the real situation, adaptation to changes	Requires regular data updates and analysis
Line-item budgeting	Allocation of expenses and income to specific items (e.g., marketing, procurement)	Cost detail, ability to optimise individual categories	Can be time-consuming for small companies with limited resources
Zero-based budgeting	Each year, the budget is drawn up from scratch, without considering past expenditures	Evaluation of all expenses and their justification, elimination of inappropriate spending	Requires considerable effort to analyse all processes
Cash budgeting	Forecasting cash receipts and payments, controlling liquidity	Controlling cash flows, preventing cash gaps	May not incorporate long-term financial needs

Source: compiled by the authors based on K. Kapiyangoda & T. Gooneratne (2021)

Cash flow analytics is another important tool for managing liquidity and cash flow. Determination of the structure of cash flows can identify the most important sources of cash, assess the reliability of cash flows, and analyse the company's financial position and ability to meet its obligations. In family businesses, where financial stability often depends on a limited number of customers or suppliers, regular cash flow analysis helps to avoid unexpected liquidity problems and ensures financial stability (Kotios *et al.*, 2022).

To increase the transparency of financial flows, family businesses actively use management accounting. In contrast to accounting, which emphasises external reporting and tax liabilities, management accounting is designed for internal analysis and decision-making. It provides business owners with a better insight into income and expense structures, enabling analysis of the profitability of individual business lines and identification of areas of inefficiency. The implementation of management accounting systems is particularly beneficial for family businesses, where financial information is often communicated informally and may be fragmented (Leotta *et al.*, 2023).

SWOT analysis is used for strategic planning and identification of internal and external factors affecting a family business. This identified the company's strengths and weaknesses and assessed opportunities and potential threats. The strength of a family business may be customer loyalty and stable partnerships, while the weakness could be the lack of professional financial management. SWOT analysis can be used in management to develop strategic decisions aimed at eliminating shortcomings and using competitive advantages (Benzaghta *et al.*, 2021).

Ratio analysis, which includes the calculation of liquidity, profitability and asset turnover, plays an important role in assessing the financial stability of family companies. The current ratio determines whether a company has sufficient working capital to cover its short-term liabilities.

Profitability ratios show how efficiently a business uses its resources to generate profit. This tool can be used by owners of family businesses to respond promptly to changes in the company's financial position and adjust the management strategy (Al-Qardhawi & Besar, 2024).

A comprehensive approach to family business management is provided by the Balanced Scorecard system. This controlling tool can be used to evaluate not only financial indicators, but also other key aspects of the company's activities, such as customer satisfaction, the effectiveness of internal business processes, and growth prospects. In family businesses, where owners strive not only to maximise profits but also to preserve the company for future generations, Balanced Scorecard helps form a balanced development strategy (Dwivedi *et al.*, 2021).

An example of the use of financial statements in controlling is the case of Hoffmann Textil GmbH (n.d.), a family-owned company specialising in the production of fabrics. Until 2020, the company did not keep records of cash flows, which caused uneven allocation of resources and difficulties in managing liquidity. As a result, the company often faced problems of cash shortages to cover current liabilities. However, after the introduction of an automated accounting system and regular financial analysis, the situation changed dramatically. This significantly improved financial performance: the liquidity ratio has increased from 1.2 to 1.8, indicating an increase in the company's ability to cover its short-term liabilities. Accounts receivables were also reduced by 25%, which improved working capital, and business profitability increased by 15% over two years. The introduction of controlling and the regular use of financial reports helped the company to allocate resources more efficiently and make more informed management decisions.

Another example is Schneider Möbel GmbH (n.d.), a furniture manufacturer. The analysis of cash flow management determined that the company was losing up to 8% of

its profits annually due to inefficient working capital management. The problem was too long payment terms for invoices, which reduced financial stability and increased the need for borrowed funds. The introduction of receivables control and improved cash flow management has significantly reduced invoice payment terms from 60 to 30 days. This significant improvement in financial processes increased the liquidity of the company, reduced debt and improved its financial performance, which contributed to its economic sustainability.

Thus, the use of controlling tools in family businesses improved financial management, increased process transparency and ensured the long-term sustainability of the company. Budgeting, cash flow analysis, management accounting, SWOT analysis, ratio analysis, and the Balanced Scorecard are key methods that help family business

owners make informed decisions and adapt effectively to changes in the external environment. The implementation of these tools not only improves financial discipline but also strengthens the competitive position of family businesses in a dynamic market environment.

Controlling is an important management instrument that helps family businesses organise their decision-making process based on objective data, increase efficiency and reduce financial risks. In unstable economic environment and competition, implementing a controlling system is becoming strategically important for ensuring the financial stability of family businesses. The application of controlling contributes to a range of positive changes, including increased financial transparency, improved strategic planning, elimination of inefficient expenses, increased investment attractiveness and long-term business sustainability (Table 6).

Table 6. The impact of strategic planning and the use of balanced scorecards on the performance of family businesses

Indicator	Description	Impact on business efficiency	Notes
Strategic planning	Setting long-term goals and developing plans to achieve them	Improving long-term sustainability and profitability	Requires a clear statement of the company's mission and vision
Balanced Scorecard	A balanced scorecard that incorporates financial and non-financial aspects	Balanced development, and improvement of all aspects of the business	Requires proper adaptation to the specifics of a family business
Financial indicators	Assessment of performance through key indicators such as profitability, liquidity	Assists in informed decisions and improves financial stability	Both short-term and long-term goals should be accounted for
SWOT analysis	Assessment of strengths, weaknesses, opportunities and threats	Identification of strategic areas for business improvement	Necessary for analysing external and internal factors
Risk analysis	Identification and assessment of potential threats and opportunities	Preparing for external crises, improving business resilience	Risks should be detailed and analysed at all levels

Source: compiled by the authors based on G. Vlasic (2023)

One of the main benefits of implementing controlling is increased financial transparency. Family businesses tend to have informal accounting and management processes, which can create problems with cash flow control and the efficiency of resource allocation. Implementing a controlling system based on regular analysis and reporting separates personal and corporate finances, which contributes to the accuracy of monitoring of all aspects of the business. These increases trust not only among internal stakeholders but also external partners, including banks, investors and lenders, providing an opportunity to obtain more favourable financing terms. In addition, financial transparency helps avoid mismanagement, increase efficiency and reduce the risks associated with managerial errors.

Improved strategic planning is another important advantage of implementing controlling. Family-owned companies often face the problem of short-term planning focused on current needs, which hinders long-term business development. Controlling can efficiently forecast the future, develop development strategies, and incorporate external and internal factors such as economic trends, customer needs and competitive threats. The use of tools such as cash flow forecasting, profitability analysis and risk

assessment helps family business management make informed decisions. As a result, the business becomes more flexible and ready to respond quickly to changes in the market environment.

Controlling is also key in eliminating inefficient spending. Family businesses often rely on intuitive decisions and personal experience when allocating resources, which can lead to excessive spending, inefficient investments and reduced profits. Controlling systems can closely monitor and control each expense item, identify unnecessary expenses and direct funds to the most profitable areas. Budgeting and cost analysis, the use of profitability ratios and other financial indicators help to promptly adjust the strategy and eliminate losses, improving overall business performance.

One of the most significant results of controlling is an increase in investment attractiveness. Family businesses, especially in the early stages of their development, often face difficulties in attracting external investment due to a lack of transparency and a lack of a systematic approach to management. Controlling helps create a clear picture of a business's financial position, making it more attractive to investors and creditors. Detailed financial statements,

regular cash flow forecasts, and the use of profitability and liquidity indicators help investors better understand the company's risks and prospects, which simplifies financing (Jafarov & Babayev, 2024).

Lastly, the implementation of controlling contributes to the long-term sustainability of the business and reduces the risk of bankruptcy. Family businesses often suffer from a lack of structured management and insufficient preparation for external crises. Controlling helps not only to optimise current financial flows but also to build long-term strategies aimed at minimising risks. Regular monitoring of financial indicators and timely identification of possible threats, such as a drop in liquidity or an increase in debt, enabling a company to respond quickly to changes and take measures to prevent bankruptcy. This enhances financial stability and enables the business to develop steadily even in the face of economic uncertainty.

According to a study by the German Institute for Family Business (n.d.), about 67% of family businesses face financial difficulties due to a lack of transparency in financial management, mixing of personal and corporate funds, and inefficient budget planning. These problems create difficulties in managing financial flows, lead to irrational allocation of resources and increase the risk of financial losses. The introduction of a controlling system, which includes tools such as budgeting, cash flow management and financial performance analysis, enables such companies to reduce operating costs by an average of 15% and increase net profit by 10% during the first three years of operation. This confirms that the systematic use of controlling helps improve financial stability and reduce the risks associated with insufficient transparency in management.

Furthermore, a study by the German Institute for Economic Research demonstrated that family-owned companies that use management accounting and budgeting are 25% less likely to experience cash gaps (Schäfer *et al.*, 2015). This is due to more accurate cash flow forecasting and improved cost control, which reduces the likelihood of situations where the company cannot cover its obligations. Such companies are also 30% more successful in attracting investment than companies that do not use a controlling system. This confirms the importance of implementing effective management tools that not only improve financial stability but also increase investor confidence.

The popularity of controlling tools is also confirmed by statistics from the German Federal Association of Small and Medium-Sized Enterprises (n.d.). According to this study, 80% of family businesses use budgeting as a key financial planning tool, which helps them manage their cash flows more effectively, set spending priorities and achieve their financial goals. Most companies (68%) use analytical tools for cash flow management (cash flow analytics), which enables a better control inflows and outflows and minimise financial risks. Lastly, 52% of family businesses have implemented a Balanced Scorecard for strategic management, which promotes a comprehensive approach to assessing both financial and non-financial performance,

ensuring balanced business development and improving long-term sustainability.

The introduction of controlling in a family business is an important step towards improving its efficiency and sustainability. This management tool addresses many of the challenges faced by family businesses, such as low financial transparency, inefficient use of resources and difficulties in attracting investment. With the help of controlling, family businesses can not only improve their financial situation but also become more competitive, flexible and ready for long-term development.

Discussion

The analysis of the use of controlling for ensuring the financial stability of family businesses identified significant results that confirm the importance of its implementation in the management of small and medium-sized enterprises. As such, controlling not only organises systematic planning and accounting but also creates a transparent financial picture of the business, which is especially important for family businesses, where there is often confusion between personal and corporate finances. This ensures asset safety, which is especially relevant in times of uncertainty.

This problem was also investigated by P. Berrone *et al.* (2022), confirming that the introduction of controlling in family businesses contributes to the improvement of financial and operational processes. This improves tracking of income, expenses, and the efficiency of use of resources, which is important for business sustainability in uncertain conditions. Controlling helps managers make informed decisions, minimising financial risks and increasing profitability. A. Calabrò *et al.* (2021) also demonstrated that controlling family businesses becomes the foundation of financial stability, creating transparency and control over cash flows. It improves allocation of resources, debt management and minimisation of unnecessary costs, ensuring long-term sustainability. The introduction of controlling also contributes to the preservation of business values focused on long-term development and strengthening of the financial base.

Notably, the implementation of controlling in a family business may face several challenges, such as resistance to change on the part of family members or their lack of knowledge in financial management. Importantly, the process of implementing controlling is accompanied by training and engagement of qualified specialists who can adapt the system to the specifics of the family business. At the same time, successful implementation of controlling requires clear communication between all business participants and readiness for long-term integration of new management methods (Quliyev *et al.*, 2024).

As a result of implementing controlling, family companies can manage cash flows more efficiently, which ensures business stability and reduces liquidity risks. Family businesses often face the challenge of managing financial resources in the face of limited information and human resources. Controlling in such situations' "shield" from

erroneous financial decisions due to insufficient information or excessive emotional attachment to the business.

A. Toumeh *et al.* (2023) concluded that controlling is substantial in cash flow management by analysing and planning cash transactions. Through regular monitoring and forecasting of cash flows, a company can avoid liquidity shortages and ensure timely payments to counterparties. This not only maintains financial stability but also responds efficiently to external changes, minimising possible financial losses. A. Raz *et al.* (2022) determined that the reduction of liquidity risks through controlling is achieved by optimising cash management processes and timely identification of problem areas. Implementation of controlling can establish control over receipts and expenses, prevent overloading of liabilities and improve the ratio of short-term assets and liabilities. Thus, controlling not only helps maintain liquidity but also ensures strategic cash flow management, which is an important factor for business growth.

These results confirm the aforementioned study, demonstrating a direct correlation between the effectiveness of cash flow control and a reduction in liquidity risks. As the analysis demonstrated, the implementation of control systems enabled companies to forecast their cash flows more accurately and minimise periods of insufficient liquidity. This, in turn, contributes to improving financial stability and reducing the likelihood of crises associated with a lack of working capital.

Controlling also significantly improved financial transparency, which negated many financial mistakes. Family businesses, especially those in the first generation, may have difficulty separating personal and corporate funds. The introduction of systematic accounting and control methods, such as budgeting and cash flow analysis, has delineated funds and reduced the probability of financial "leakage", which is important for long-term stability.

The study by N. Dincer *et al.* (2022), which also determined that financial transparency and separation of funds is key in successful business management, especially regarding family businesses, is notable. Controlling separates personal and business finances, demonstrating current financial flows and preventing conflicts of interest between family members. This promotes a more rational use of resources and reduces the probability of errors associated with the misallocation of funds. S. Cosma *et al.* (2023) concluded that the prevention of financial errors through controlling is achieved through systematic monitoring of all transactions and regular auditing of cash flows. Controlling enables early detection of discrepancies or misallocation of funds, minimising financial losses and reducing risks. Notably, timely intervention by controllers helps adjust financial management strategies, improving overall financial discipline and supporting long-term business stability.

These findings are consistent with the thesis presented in the previous section, as they confirm the importance of financial transparency for effective management of funds. The introduction of controlling contributes to the separation of personal and business finances, which, as

the results show, minimises the risks of errors in the allocation of resources. Thus, the creation of a clear financial control structure has a direct impact on the reduction of the probability of financial errors and improving overall financial discipline.

Furthermore, controlling helps not only in managing current financial flows but also in strategic planning. Family-owned companies, often focused on short-term goals, began to pay attention to long-term forecasts and investment strategies. The introduction of controlling provided a systematic approach to strategic planning, which enables efficient use of resources and prevention of risks associated with unexpected changes in the external environment, such as economic crises or fluctuations in demand (Nitsenko *et al.*, 2024).

L. Zapata-Cantu *et al.* (2023) also conducted a study, confirming that controlling and strategic planning in family businesses are essential components for achieving sustainable growth and development. Controlling can be used to analyse current financial indicators, which facilitates more accurate forecasting of future results and the development of long-term strategies. This enables family businesses to adapt to market changes and increase their competitiveness. H. Gong *et al.* (2021) also determined that long-term forecasting through controlling addresses possible risks and uncertainties, which is important for the development of effective strategies. Regular analysis of financial data and trends improves the accuracy of predicting changes in revenues and expenses, as well as adjusting plans promptly. Implementation of controlling makes it possible not only to prevent financial problems but also to identify new opportunities for growth and optimisation of processes in the long term.

A comparison of the data obtained during the research determined that the use of controlling significantly improves the strategic planning process in a family business. Regular analysis of financial indicators improves the accuracy of assessment of current and future financial needs, which contributes to more informed decisions in the long term (Kviatko, 2023). These results confirm the importance of implementing controlling as a tool for optimising strategies and managing risks in an environment of uncertainty.

Positive changes in financial decision-making were also identified. By implementing a management accounting system and using various analytical tools, such as ratio analysis or key performance indicator analysis, family entrepreneurs began to make more informed and rational decisions. This, in turn, increased business profitability and contributed to improved financial performance. Controlling also raised awareness of the company's current position and avoided financial disasters caused by underestimating risks. P. Picone *et al.* (2021) concluded that controlling has a significant impact on the financial decisions of family entrepreneurs, providing a basis for more informed decision-making. The systematic collection and analysis of data on financial flows enables business owners not only to monitor current financial performance

but also to predict potential changes in the future. This minimises financial risks and facilitates a more rational allocation of resources, which is especially important for the stability of a family business.

U. Lone & S. Bhat (2022) determined that the validity and rationality of financial decisions due to controlling are manifested in the ability of entrepreneurs to adapt their strategies in real time. Controlling makes it possible to identify the strengths and weaknesses of the business, assess the effectiveness of investment projects and make decisions based on evidence rather than intuition. Thus, the introduction of controlling into financial decision-making processes helps to increase management efficiency and business sustainability in the long term. The analysis of the study results determined that the introduction of controlling significantly increases the validity of the financial decisions of family entrepreneurs. The use of detailed financial data and forecasts mitigates spontaneous and unjustified decisions, minimising risks and improving strategic planning. These results confirm the importance of controlling to ensure a rational and balanced approach to managing financial resources in a family business.

Lastly, the analysis demonstrated that the use of controlling not only improves financial stability but also contributes to the improvement of corporate culture. In families where the business is passed down from generation to generation, controlling helps establish rules and procedures, which defines the role of each family member in the decision-making process. This improves interaction within the family and minimises internal conflicts, creating the conditions for a harmonious and long-term business operation.

Conclusions

The study results confirmed the importance of controlling to ensure the financial stability of family businesses. The introduction of controlling provided a systematic approach to financial resource management. In family businesses, where it is often difficult to separate personal and corporate finances, controlling delineated these flows, prevents the misuse of funds. This increased financial transparency and minimised the risks associated with inefficient resource allocation.

After implementing controlling, family businesses demonstrated a noticeable improvement in key financial indicators. Müller & Söhne GmbH reduced costs by 20% and increased net profit from EUR 500,000 to EUR 600,000. At Bäckerei Schmidt KG, profitability increased by 12% and the level of overdue liabilities reduced

from 8% to 4%. At Weber Autoservice GmbH, current liquidity increased from 0.9 to 1.1, and net profit grew by 25%. These results confirm the effectiveness of controlling in improving the profitability, transparency and financial stability of family businesses.

Controlling improved cash flow management. Family businesses that employed controlling methods were more effective in planning and forecasting their financial needs. This mitigated cash gaps and ensured the necessary liquidity for the normal functioning of their business. This approach reduced the probability of financial crises and unexpected expenses.

Furthermore, the introduction of controlling improves the accuracy and validity of financial decisions. By using analytical tools such as ratio analysis or key performance indicator analysis, family entrepreneurs could employ a more informed approach to decision-making. This, in turn, improved business profitability and long-term stability. The impact of controlling on strategic planning is also important. Family businesses, using controlling methods, assessed long-term risks and opportunities more carefully. Hence, family businesses successfully adapted to changes in the external environment, such as economic crises, market fluctuations and other unpredictable factors.

Thus, the results of the study confirm that controlling not only contributes to the financial stability of a family business but also helps improve corporate culture and organisation of management processes. It established procedures for all family members, which reduced internal conflicts and promoted effective interaction. This, in turn, strengthened long-term competitiveness and contributed to the successful development of family businesses in a changing economic environment.

A limitation of the study is the small sample of family businesses, which may not reflect all the specifics of controlling in different industries and countries. For deeper research on the impact of controlling the financial sustainability of family businesses, it is necessary to study the impact of corporate culture and intergenerational relations on the effectiveness of controlling in such enterprises.

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Контролінг як метод забезпечення фінансової стійкості сімейного бізнесу

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Анотація. Метою дослідження був аналіз ролі контролінгу як методу забезпечення фінансової стійкості сімейного бізнесу та визначення ефективних методів його впровадження в управління підприємством. У дослідженні проведено комплексну оцінку впливу контролінгу на фінансову стійкість сімейного бізнесу з використанням статистичних даних, описового аналізу результатів експертного опитування та аналізу фінансової звітності реальних компаній (Müller & Söhne GmbH, Bäckerei Schmidt KG, Weber Autoservice) для виявлення ефективних методів та інструментів управління. Використання контролінгу дозволило ефективно управляти фінансовими потоками, підвищити прозорість діяльності та покращити планування. Аналіз показав, що сімейні підприємства, які використовують систему бюджетування та фінансового контролю, знижують ризики, пов'язані з недостатньою ліквідністю та неефективним розподілом ресурсів. Наприклад, після впровадження управлінського обліку компанія Müller & Söhne GmbH скоротила витрати на 20 %, збільшила чистий прибуток з 500 000 євро до 600 000 євро та підвищила коефіцієнт поточної ліквідності з 1,2 до 1,4. У Bäckerei Schmidt KG за два роки прибутковість зросла на 12 %, а прострочена заборгованість зменшилася з 8 % до 4 %. У Weber Autoservice GmbH після впровадження системи раннього попередження касові розриви були закриті, а грошовий потік від операційної діяльності збільшився з 150 000 євро до 180 000 євро. Крім того, дослідження продемонструвало, що успішне використання контролінгу розділяє особисті та корпоративні фінанси, покращуючи стійкість. Було проаналізовано ключові інструменти, включаючи стратегічне планування, збалансовану систему показників, ключові показники ефективності та SWOT-аналіз. Компанії, які активно використовують процеси контролінгу, демонструють вищу прибутковість, кращу платоспроможність та стійкість до зовнішніх ризиків.

Ключові слова: бюджетування; управлінський облік; прибутковість; прозорість; стратегічне планування

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Organisation and areas of development of international audit in the digital economy

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Abstract. The purpose of this study was to analyse the impact of digital technologies on international auditing practice. An integrated approach was employed, incorporating a comprehensive literature review, case study analysis of major audit firms, and an examination of international regulatory standards to evaluate this impact. This study addressed the urgent need for international auditing to adapt to digital transformation, enhancing financial transparency, cost efficiency, fraud prevention, and global market stability through the integration of blockchain, artificial intelligence, and big data analytics. It was identified challenges related to the need to adapt to new technologies such as blockchain and big data analysis, the impact of global economic trends on financial statements, and different approaches to unifying audit standards and ethics internationally. The study identified how these technologies contribute to reducing audit costs, increasing operational efficiency, and improving financial transparency, which in turn strengthens investor confidence and enhances the stability of financial markets. It was noted that the integration of blockchain ensures fraud

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prevention and the reliability of financial data, reducing economic risks associated with financial misstatements and corporate fraud. Big data analysis was proven to improve risk assessment and predictive financial analytics, allowing businesses to make more informed investment and strategic decisions. The results can serve as a basis for developing strategies and tactics for introducing digital innovations into the practice of international auditing, providing audit companies, regulators, and organisations with tools and recommendations

Keywords: technological progress; cybersecurity; blockchain technologies; big data analysis; standards; international audit

Introduction

In an era when digital technologies are becoming an integral part of the business environment and global economic ties are increasingly intensifying, international auditing is becoming important to ensure transparency and trust in the financial reporting of companies around the world. The introduction of digital innovations and the increase in business scale provide audit practices with new challenges that require careful analysis and adaptation. Notably, not only the methods of conducting an audit, but also its objectives are undergoing changes under the influence of modern trends. The development of technology and globalisation necessitate the revision of international audit strategies in order to consider new challenges and opportunities. In this context, the study of the organisation and prospects for the development of international auditing becomes not only relevant, but also a strategically important step for adapting auditors to a rapidly changing reality. It is important to emphasise that these changes relate not only to aspects of the technical implementation of auditing, such as cybersecurity and the use of the latest technologies (for example, blockchain and big data analysis), but also to the very essence of auditing standards and approaches. The rapid development of the digital economy requires auditors not only necessary skills, but also flexibility in adapting to new conditions and challenges facing global business.

N. Musayeva *et al.* (2022) analysed in detail the main trends and challenges associated with the processes of digital transformation in international auditing. The researchers investigated how rapidly developing technologies affect established standards and conventional audit methods. The results highlight key aspects such as changes in standards, changes in audit methods, and the need for close attention and possible revision of current approaches to the organisation of audit processes. M.A. Alnaimat *et al.* (2023) argued that success in international auditing is closely linked to the successful implementation of modern technologies. The researchers substantiated the importance of using innovative tools such as blockchain and big data analysis, and emphasise their ability to improve the efficiency and reliability of audit processes. Authors provided specific examples of the successful application of these technologies in auditing practice. R.H. Shikhaliyev (2023) researched the impact of cybersecurity on auditing activities. This analysis focused on the dangers associated with storing and transferring financial information in the digital economy, suggesting specific strategies and methods to ensure data security. The study highlighted key aspects of cybersecurity that require

the attention of auditors to ensure the reliability and confidentiality of customer data. S. Agamamed *et al.* (2023) drew attention to global economic trends and their impact on international auditing standards. The analysis conducted by the researchers covers how changes in the global economy can affect the business processes of organisations, requiring an appropriate revision of audit methods to adapt to new realities. R. Allahyarov (2023) focused on strategies for adapting auditors to the challenges of the digital economy. The researcher considered which competencies and skills are becoming critical in the new digital landscape, and also offers recommendations for training and staff development in audit companies.

Researchers D. Barr-Pulliam *et al.* (2022) analysed the impact of individual, task and external factors on digital transformation and innovation in audit practice. The authors focused on studying how different factors affect the introduction of digital technologies in the audit and innovation processes in this sector. The authors found that the adoption of digital technologies in audit practice depends on three main groups of factors: individual characteristics of auditors, specifics of the tasks performed, and the external environment, including technological infrastructure and economic conditions. The purpose of the study by A. Eltweri *et al.* (2022) was to study the process of adopting International Standards on Auditing (ISA) from an institutional perspective. The authors analysed the factors that influence the adaptation of ISAs in different countries and organisations, as well as their impact on the practice of international auditing. The study showed that the adoption of International Standards on Auditing depends on institutional conditions in different countries, including the legal system, cultural factors, and the level of economic infrastructure.

Previous studies together provide an extensive overview of current issues and prospects in international auditing in the digital economy. However, specific strategies for adapting auditors to these challenges and evaluating their effectiveness in practice were rather neglected. The purpose of this study was to analyse the strategies used by auditors to successfully adapt to digital changes in the context of international auditing.

Materials and Methods

A comprehensive literature review was conducted to analyse the key trends, challenges, and innovations shaping the development of international auditing in the digital era. This review served as the foundation for understanding

how digital technologies, such as blockchain, artificial intelligence (AI), and big data analytics, are transforming auditing practices and the ethical implications of their integration. The analysis of blockchain technology by C. Cheng & Q. Huang (2020) highlighted its role in ensuring transparency and preventing financial data manipulation. Blockchain's ability to provide auditors with continuous access to an immutable transaction history reinforces trust in financial reporting and strengthens fraud detection mechanisms. Research on AI applications in auditing by I. Munoko *et al.* (2020) demonstrated its effectiveness in automating routine audit tasks, improving efficiency, and enhancing risk detection. Machine learning algorithms streamline data collection and classification, allowing auditors to shift their focus to strategic analysis and deeper financial assessments. Studies on big data analytics by G. Salijeni *et al.* (2019) emphasised its capacity to uncover hidden trends and anomalies in financial statements, providing auditors with advanced tools for risk identification and predictive analysis. The application of big data methodologies facilitates a shift from retrospective audits to real-time monitoring, significantly improving audit responsiveness. The review also explored the impact of globalisation and ethical standards in auditing (Eltweri *et al.*, 2021), underscoring the need for standardised international frameworks to enhance financial statement comparability across jurisdictions. The growing importance of ethical auditing principles, influenced by public scrutiny and corporate accountability demands, was identified as a key factor shaping modern auditing practices. A significant focus was placed on cybersecurity in international auditing (Lois *et al.*, 2021), addressing the increasing risks associated with digitalisation. Research findings highlighted the necessity of robust security measures, regular audits, and compliance with cybersecurity standards such as GDPR (2016) and ISO 27001 (2019) to mitigate cyber threats and protect financial data integrity.

Among the technological advancements examined in this study, particular attention was given to blockchain, AI, big data analytics, and cybersecurity innovations. Blockchain technology was analyzed for its ability to enhance transparency, prevent financial data manipulation, and improve trust in financial reporting through immutable transaction records. AI applications, especially machine learning algorithms, were studied in the context of automating routine audit processes, improving risk detection, and increasing the accuracy of financial assessments.

In addition to academic sources, the study incorporated materials from leading audit firms and regulatory institutions to provide a more practical perspective on digital transformation in auditing. Reports and case studies from Klynveld Peat Marwick Goerdeler (KPMG) (n.d.), Deloitte (Deloitte Ukraine Impact Report 2023-2024, 2025), and PricewaterhouseCoopers (PwC) (n.d.) were analysed to understand how major audit firms integrate cutting-edge technologies into their practices. These sources provided real-world examples of AI-driven automation, blockchain

implementation, and big data utilisation, demonstrating the practical applications of digitalisation in auditing. The research also relied on relevant information from industry reports, policy documents, and professional auditing organisations, but no direct data from general informational websites were used.

During the research, an integrated approach was used to investigate the strategies of auditors' adaptation to the challenges of the digital economy in international auditing. Examples of successful technology integration into auditing practice from large firms such as KPMG (n.d.), PwC (n.d.) and Deloitte were used (Deloitte Ukraine Impact..., 2025). These examples showed the practical effectiveness of the introduction and use of digital innovations such as AI, big data analysis, and cybersecurity. KPMG, which originates from the Netherlands, is one of the largest audit firms globally and has incorporated cutting-edge technologies like AI and data analytics into its auditing processes. Deloitte, based in the United States, has implemented blockchain technology and advanced cybersecurity measures to enhance audit quality and data protection. PwC, headquartered in the United Kingdom, has focused on integrating big data tools and machine learning algorithms to streamline audit tasks and ensure the accuracy of financial reporting. Through the review of their materials, it became clear how digital innovations have reshaped international auditing practices, offering more efficient solutions for complex auditing tasks and strengthening cybersecurity in the auditing process.

The study also used current standards such as General Data Protection Regulation (GDPR) (2016) and ISO 27001 (2019) to understand cybersecurity and data protection requirements in the context of auditing. All these materials provided a solid basis for the analysis and conclusions presented in the study and provide a holistic understanding of current challenges such as the need for auditors to adapt to new digital technologies, including blockchain and big data analytics, the impact of global economic trends.

Results

International audit, as an integral part of the financial infrastructure, is undergoing constant transformations, responding to the changing business environment, global economic shifts, and technological innovations. One of the main trends shaping the industry is digital transformation, which redefines auditing methods and approaches while significantly impacting financial stability and business efficiency. The integration of advanced technologies such as blockchain, AI, and big data analysis enhances audit accuracy and operational efficiency, reducing costs for companies and increasing the speed of financial reporting (Barr-Pulliam *et al.*, 2022). However, these innovations also introduce new economic challenges, including the costs of implementing advanced technologies, ensuring compliance with international regulatory frameworks, and maintaining competitiveness in a rapidly evolving global market.

Globalisation and harmonisation of auditing standards further underscore the economic necessity of unified

approaches across different countries. Consistent and comparable financial reporting strengthens investor confidence, facilitates cross-border investments, and enhances the stability of international capital markets. Auditors must now navigate complex regulatory environments while considering economic policies and financial risks specific to different jurisdictions. The establishment of ethical standards has become a crucial factor in maintaining financial credibility, as adherence to transparency and integrity directly influences market stability and corporate reputation (Eltweri *et al.*, 2022). Increasing public scrutiny and corporate responsibility expectations compel auditors to integrate ethical considerations into their decision-making processes, ensuring sustainable financial governance.

The growing emphasis on cybersecurity in international auditing reflects the economic risks associated with digital vulnerabilities. Cyber threats pose substantial financial consequences, including fraud, loss of sensitive financial data, and reputational damage that can impact global financial markets. As a result, significant investments in cybersecurity infrastructure and risk management frameworks are becoming indispensable. Moreover, workforce training and development play a pivotal role in adapting to new economic and technological realities. Upskilling auditors in data analytics, cybersecurity, and regulatory compliance is now a strategic imperative to maintain financial integrity and trust in the auditing profession (Slapničar *et al.*, 2022). Ultimately, the convergence of technological innovations, ethical governance, and global economic

considerations ensures the resilience and reliability of international auditing in the digital economy, reinforcing financial stability and fostering sustainable economic growth.

Digital technologies such as blockchain, AI, and big data analysis are dramatically reshaping auditing practices, providing new opportunities to improve the efficiency and reliability of international auditing. Blockchain, with its distributed data structure and the impossibility of falsification, plays a key role in improving transparency and trust in international auditing. This technology provides network participants with simultaneous access to a common registry, which significantly improves verification processes. However, the more important aspect is its ability to prevent data falsification. The unique hash codes in each block create a chain of dependencies, making manipulation of information noticeable and extremely difficult. The continuous transaction history provided by the blockchain is another important aspect for auditors. This allows them to have a complete overview of the company's financial operations since its inception. Such detailed transparency improves the analytical capabilities of auditors, allowing them to identify trends and risks (Han *et al.*, 2023). The use of blockchain in auditing also helps to prevent fraud and confirm the authenticity of data. Any changes in the block are instantly visible to all network participants, which creates an additional level of security. In the context of international auditing, where falsification of financial data can pose serious risks, such technological protection becomes very valuable (Table 1).

Table 1. Impact of audit digitalisation on the global economy and financial stability

Parameter	Traditional audit	Digital audit	Economic effect
Audit Duration	3-6 months	1-3 months	Reduction of company audit costs
Audit Costs	High due to labor intensity	Reduction due to automation	Increased business profitability
Accessibility for Small Businesses	Limited due to high cost	Increases due to automation	Expansion of the audit market
Fraud Risk	High	Decreases due to blockchain and AI	Increased trust in financial reporting
Regulatory Burden	High	Decreases due to automation	Simplification of compliance with standards

Source: compiled by the authors

The Table 1 presents a comparative analysis of traditional and digital audit practices, highlighting their impact on the global economy and financial stability. Digital audit significantly reduces the time required for auditing, from 3-6 months in traditional methods to 1-3 months, which leads to lower costs for companies. Automation plays a crucial role in reducing audit expenses, improving overall business profitability, and making auditing services more accessible to small businesses. The integration of blockchain and AI technologies helps mitigate fraud risks, increasing trust in financial reporting. Additionally, automation reduces regulatory burdens, simplifying compliance with international standards. Overall, the transition to digital auditing enhances efficiency, improves financial security, and contributes to the expansion of the audit market.

AI is significantly changing the nature of international auditing by introducing automation and intelligent functions into various aspects of auditing. This contribution of AI is expressed primarily in the automation of routine tasks such as data collection, document classification and fact-checking, which frees auditors from monotonous duties and provides them with the opportunity to take a more strategic approach to auditing. AI systems are used to effectively implement everyday tasks, which allows auditors to focus on more important and analytical aspects of their work. Machine learning algorithms integrated into these systems efficiently process vast amounts of data and identify unusual patterns and potential risks (Seethamraju & Hecimovic, 2023). They can be used, for example, to analyse financial transactions, identifying irregular

transactions or suspicious changes in the expenditure pattern. Such intelligent data analysis significantly improves the accuracy and efficiency of audits.

In the modern auditing environment, big data analysis is becoming an integral part of practice, playing a key role in improving the quality and depth of understanding of companies' financial statements. This technology provides auditors with the tools to more thoroughly investigate the vast amounts of information contained in the financial data of enterprises. One of the outstanding aspects of using big data analysis in auditing is the ability to identify hidden trends (Furmanchuk, 2023). Auditors can use algorithms and analysis techniques to process data arrays and identify entities that might go unnoticed with conventional methods (Appelbaum *et al.*, 2017). This opens up new perspectives for understanding the long-term dynamics and changes in the financial situation of the company. In addition, big data analysis is becoming a reliable tool for detecting anomalies in financial statements. This technology is able to automatically detect unusual patterns or inconsistencies, which can serve as a signal to auditors about possible problems or errors.

Modern auditing practice is undergoing significant transformations, introducing new technologies to improve efficiency, accuracy, and strategic analysis. In this context, a number of successful examples demonstrate how audit companies are actively implementing modern technologies to improve their operations. KPMG has demonstrated the successful use of AI to automate audit routines. AI systems were trained to recognise and classify financial documents, which significantly reduced the time previously spent by auditors on data collection and analysis (Ranjith *et al.*, 2021). This approach not only increased efficiency, but also allowed auditors to shift their attention to more strategic analysis. AI has acted as a reliable tool that provides fast and efficient processing of large amounts of information, freeing auditors from monotonous tasks and improving the quality of inspections.

Deloitte has successfully integrated big data analysis into its practice to detect fraud in customer financial statements. Machine learning algorithms were configured to detect anomalies in financial transactions, which significantly improved the ability of auditors to quickly identify potential violations and fraudulent schemes (Chien, 2020). This technological innovation has become an additional means of ensuring the security of audits, helping to maintain customer trust and enhance the company's reputation.

PwC has applied data analytics to pre-identify potential risks in clients' financial activities. Data analysis algorithms were set up to quickly identify unusual trends and changes in data, which ultimately improved the quality of advice and recommendations provided (Earley, 2015). This practice has allowed PwC auditors to be proactive in preventing potential problems, strengthening customer relationships and improving the overall effectiveness of consultations. All these examples highlight how innovations in technologies such as AI and big data analysis improve the

work of auditors, making them more efficient, responsible and able to respond quickly to changes in the financial environment of clients.

Auditing activities face increased challenges in the field of cybersecurity, in the context of rapid digital development. Protecting the confidentiality and integrity of customer data is becoming a priority, and auditors are actively applying strategies to minimise risks and maintain customer trust. First of all, employee training and awareness play a key role in ensuring cybersecurity. A real-world example includes Equifax, which in 2017 faced a major data security breach in which the personal information of more than 147 million people was compromised (Barrett, 2023). This incident highlights the need for strict cybersecurity standards, regular audits and continuous improvement of security systems to prevent such incidents. An auditing company such as KPMG implements cybersecurity training, including phishing and basic security measures. This creates a culture of security, reduces the level of social engineering and increases employee awareness of possible cyber threats. The successful experience is provided by Deloitte, which actively applies advanced security tools, including antivirus programmes, intrusion detection systems and multi-factor authentication. The use of modern technologies provides auditors with effective means of protection against a variety of cyber threats, preventing attacks and ensuring data integrity.

The digitalisation of audit has a significant impact on the international economy, financial stability and the audit services market, contributing to increased efficiency, reduced costs and increased confidence in financial statements. The introduction of modern technologies, such as AI, blockchain and big data analysis, allows us to optimise audit processes, reducing the time of audits and minimising the risk of human error. This increases the transparency of financial transactions and facilitates the detection of financial abuse, which has a positive impact on the international economy by strengthening financial regulatory institutions and increasing the investment attractiveness of markets. Financial stability depends to a large extent on the reliability and accuracy of audit reports, and digital technologies help reduce the risks of fraud, manipulation, and misrepresentation of financial information. Thanks to automation and the use of AI algorithms, auditors can analyse large amounts of data faster and more efficiently, which allows them to identify financial anomalies and predict possible threats to the business. This strengthens the credibility of audit reports and provides greater financial predictability, which is critical to the stability of the global economy.

The audit services market is also undergoing significant changes as a result of digitalisation, as traditional audit methods are giving way to automated processes, which reduces operating costs and makes auditing more affordable for small and medium-sized businesses. This contributes to the expansion of the audit services market, increasing competition and encouraging companies to implement the latest technologies to improve their efficiency. At the same time, digitalisation is changing the requirements for

the competencies of auditors, who are required not only to be proficient in financial analysis but also to have in-depth knowledge of cybersecurity, data analysis, and digital risk management. This contributes to the formation of a new level of professional standards, which ensures a better and more reliable audit in the digital economy.

The digitalisation of audit has a positive impact on the international economy, contributing to financial stability, increasing control efficiency and reducing risks. At the same time, it is transforming the audit services market, forcing companies to adapt to new conditions and invest in technological development. This is creating new opportunities for audit firms and financial regulators, while also requiring a strategic rethinking of the role of audit in the digital age.

Regular audits and penetration testing are a strategic element in ensuring cybersecurity. Conducting systematic audits helps identify and eliminate vulnerabilities at an early stage, ensuring that auditors' systems remain reliable and resilient to modern cyber threats (Zhurakovska & Sydorenko, 2023). Data encryption is also an important element of security. The implementation of encryption

during data transmission and storage provides an additional level of protection, preventing unauthorised access to confidential information. Access control and the creation of strict control policies is a strategy that allows regulating and monitoring employee access to data. Identity and access management (IAM) provides privilege control, minimising the risks of unauthorised access. Compliance with standards and regulations such as GDPR (2016) and ISO 27001 (2019) ensures universal safety standards. Compliance with these standards helps auditors build reliable security systems that meet global requirements and standards.

In general, ensuring cybersecurity in auditing requires not only the use of technological tools, but also the development of a safety culture among staff. The combined efforts of training, the use of modern tools, systematic inspections and compliance with standards provide a comprehensive approach to data protection and create a reliable environment for auditors in the era of digital transformation. In the context of these changes, Table 2 identifies key technologies that are being actively implemented in the audit environment.

Table 2. Technological innovations in auditing practice

Technology	Role in the audit	Advantages of implementation
Blockchain	Ensuring data security and transparency, preventing falsification, continuous transaction history	Improved data reliability, reduced fraud risk, increased trust
Artificial intelligence	Automation of routine tasks, rapid analysis of extensive data, identification of irregular patterns and potential risks	Efficiency, freeing up time for strategic analysis, improved accuracy
Big data analytics	Detection of hidden trends, identification of anomalies, preliminary identification of potential risks	Deep understanding of financial statements, enhanced analytical capabilities
Digital platforms for sharing experiences	Collaboration, exchange of knowledge and experience, coordination of efforts between audit specialists	Increased efficiency, improved coordination, quick access to expert information
Cybersecurity	Data protection from cyber-attacks, ensuring confidentiality and integrity of information	Preventing data leaks, maintaining customer trust, and complying with security standards

Source: compiled by the authors based on D. Barr-Pulliam *et al.* (2022)

Each of these technologies plays an important role in improving audit processes, providing higher security, more efficient data analysis and increased customer trust. The detailed study and successful implementation of these technologies reflect the auditors' commitment to a modern and innovative approach in the digital age.

In the context of the active introduction of digital technologies into the economy, international auditing in Azerbaijan is also undergoing significant changes and is developing, adapting to the challenges of the digital era. Azerbaijani firms in the audit sector can implement programs for automatic analysis of financial data, which will shorten the time frame and increase the accuracy of inspections. The transition from paper documentation to electronic formats will simplify the collection and exchange of data between clients and auditors. This will improve communication efficiency, reduce time costs, and facilitate more expeditious audits. Auditors in Azerbaijan can implement blockchain technologies for a more reliable

and impartial audit of financial transactions. With the increase in digital processes, attention to cybersecurity is also growing. Azerbaijani auditors are actively implementing strategies and tools to protect the confidentiality and integrity of their clients' data. Companies also make efforts to comply with international standards in auditing. This is important to maintain the trust of international clients and investors (Agamamed *et al.*, 2023). In general, the level of digitalisation of international auditing in Azerbaijan can be described as gradually developing. Auditors strive to use modern technologies to improve the efficiency and accuracy of their work, and the country as a whole is demonstrating readiness for digital transformation in the field of financial auditing.

As already mentioned, in order to effectively adapt to changes, active research and integration of advanced technologies are necessary. It is proposed to develop recommendations that consider these technological trends and encourage their active implementation by audit firms in

order to improve the efficiency and accuracy of the audit. It is recommended that cybersecurity standards be systematically strengthened, including regular audits of security systems and continuous improvement of security measures. New approaches to detecting and preventing cyber-attacks may include the use of AI and big data analysis to identify anomalies and prematurely detect potential threats. The next important aspect is the standardisation of the use of blockchain technology. The development of innovative standards should ensure the security, transparency, and authenticity of data in the audit process. Updating educational programmes for auditors involves the introduction of new topics related to the use of blockchain technologies in auditing, and an emphasis on the practical application of this knowledge. To promote new standards and methods of international auditing, it is necessary to introduce advanced technologies such as data analytics, machine learning, and deep learning algorithms. The active use of digital platforms and tools for sharing experiences and coordinating efforts also gives an innovative character to this process.

In order to maintain the focus on ethics and responsibility in a digital environment, it is recommended to specifically implement standards highlighting the importance of ethical principles and responsible use of technology in the audit process. This can be ensured by setting up advisory groups where various experts can share their experiences and develop specific recommendations for improving standards. The development of flexible and adaptive standards in a rapidly changing digital environment involves new methods of regulation and management, including the use of digital transformation technologies to ensure prompt response to changes. This may include the introduction of innovative risk assessment and change management methods. These recommendations are intended to specifically create a balanced and innovative approach to international auditing in the digital age, ensuring a high level of efficiency, reliability, and ethics in the audit process.

Discussion

The findings of this study highlight the significant impact of digital transformation on international auditing practices. The convergence of advanced technologies, the process of globalisation and the evolution of regulation are reshaping the traditional audit landscape. The integration of technologies such as blockchain, AI, and big data analysis is a paradigm shift in auditing methods. The role of blockchain in ensuring data security and transparency is key, introducing a level of trust and reliability previously unavailable. The immutable nature of the blockchain facilitates the creation of a continuous transaction history, providing auditors with unprecedented research opportunities in the operations of financial companies. AI, with its automation capabilities, frees auditors from routine tasks, allowing a more strategic approach to complex analyses. The use of machine learning algorithms improves audit efficiency and accuracy by quickly identifying unusual patterns and potential risks. Big data analysis is becoming a

key tool, uncovering hidden trends and anomalies in vast datasets, providing auditors with a deeper understanding of financial statements (Llazo *et al.*, 2024).

The globalisation of auditing standards highlights the need to unify approaches in diverse cultural and regulatory environments. Auditors face the challenge of navigating intriguing cultural and regulatory intricacies while ensuring consistency and comparability of financial statements at the global level. This requires a deeper understanding of international ethical standards, which is key in maintaining the trust of stakeholders in conditions of increased public scrutiny. As digital technologies penetrate audit practice, the urgency of strengthening cybersecurity measures increases. The examples of Equifax and KPMG highlight the critical need for strict cybersecurity standards, regular audits, and continuous system improvements to prevent data leaks. The proactive approach of audit firms such as KPMG and Deloitte in employee training, penetration testing and encryption reflects the desire to ensure the security of customer data and maintain industry confidence. The fusion of technology, ethics, and global collaboration guides international auditing practices into a new era. Successful examples of firms actively implementing digital technologies highlight the transformational potential of these innovations (Gulaliyev *et al.*, 2023).

Scientists C. Cheng & Q. Huang (2020) provided an extensive analysis of blockchain's role in international auditing, emphasising its capability to prevent financial data manipulation and enhance transparency. Their research particularly focused on continuous auditor access to complete transaction histories, facilitated by blockchain's decentralised and immutable nature. This aspect is consistent with the present study, which also identifies blockchain as a critical technology for ensuring data reliability. However, while C. Cheng & Q. Huang (2020) concentrated on the accessibility of financial transaction records, the present study extends this discussion by emphasising blockchain's role in strengthening fraud detection mechanisms and enhancing trust in financial reporting. The additional focus on how blockchain minimises audit risks and reinforces investor confidence adds a new dimension to the analysis, suggesting that blockchain's application in auditing is not limited to transaction verification but extends to broader financial risk management (Berisha & Rexhepi, 2022).

Researchers I. Munoko *et al.* (2020) conducted a thorough analysis of the impact of AI on international auditing practices. Special attention was paid to the consequences of the introduction of AI, identifying significant improvements in the efficiency and accuracy of audit processes. The researchers examined in detail how machine learning algorithms are used to perform routine operations such as data collection, document classification, and fact-checking. This allows significantly reducing the time that auditors previously spent on monotonous duties, and free up resources for a more strategic and analytical approach to auditing activities. Getting rid of routine tasks gives specialists the opportunity to study financial statements more

thoroughly, identify trends and risks, which, in turn, increases the quality and value of auditing activities. These results correlate with the findings of this study, highlighting the significant impact of AI on improving the efficiency and accuracy of audit processes. The findings of I. Munoko *et al.* (2020) align with this study in emphasising the transformative impact of AI on international auditing practices. Both studies highlight how AI enhances efficiency and accuracy by automating routine tasks such as data collection, document classification, and fact-checking. By significantly reducing the time spent on manual processes, AI enables auditors to focus on more strategic, analytical aspects of auditing, leading to improved financial statement evaluations and risk identification.

A key similarity between authors and this study is the emphasis on machine learning algorithms as a central tool for detecting financial anomalies. AI-driven systems analyse large datasets to identify irregular patterns that might indicate fraud, errors, or financial misstatements (Aizenberh, 2024). This aligns with the present study's findings, which demonstrate that AI not only automates auditing processes but also strengthens fraud detection and financial risk assessment. The results of both studies suggest that AI-driven audits enhance financial transparency and help prevent fraudulent activities by quickly analysing vast amounts of financial data that would be impossible for human auditors to process manually.

The findings of G. Salijeni *et al.* (2019) align with the conclusions of this study, emphasising the transformative role of big data analysis in international auditing. Both studies highlight the ability of large-scale data analysis to enhance the depth and accuracy of financial investigations, enabling auditors to identify explicit and hidden trends within corporate financial data. The use of algorithms and advanced data analysis techniques significantly improves audit efficiency, allowing for a more comprehensive assessment of a company's financial position. A key aspect emphasised in G. Salijeni *et al.* (2019) is the ability of big data analytics to detect financial anomalies and emerging risks, a conclusion also supported by this study. By leveraging advanced analytical tools, auditors can recognise unusual patterns in financial statements, thereby improving fraud detection and risk assessment. The present study extends this discussion by examining how predictive analytics and real-time data processing enhance proactive risk management, providing auditors with the ability to anticipate financial instabilities before they materialise. This predictive capability is particularly crucial in a rapidly evolving global economic landscape, where financial uncertainties require continuous monitoring. Authors highlight how rapid anomaly detection enables auditors to act promptly when irregularities arise. This aligns with the findings of this study, which emphasize that big data allows auditors to conduct more dynamic audits, shifting from traditional retrospective analysis to real-time financial oversight. The shift towards continuous auditing enhances transparency and strengthens

financial governance by reducing the lag between financial reporting and anomaly detection.

A. Eltweri *et al.* (2021) focused on the problems of globalisation and ethical standards related to the practice of international auditing. Their study highlights several key aspects reflecting current trends in the auditing field. The main focus of the study is the need to develop common approaches to auditing in different countries. The researchers emphasise the importance of agreed standards to ensure consistency and comparability of financial statements of companies at the global level. This emphasis offers a perspective on how global aspects influence methods and approaches in auditing activities. Another significant element of the study is the emphasis on the development of ethical standards as an integral part of a successful international audit. Ethical principles are becoming increasingly important in light of increasing public pressure and demands for accountability.

A significant contribution of A. Eltweri *et al.* (2021) is the emphasis on ethical principles as a cornerstone of successful international auditing. Their study highlights that increasing public scrutiny and demands for corporate accountability necessitate stronger ethical guidelines in auditing. This perspective complements the present research, which also underscores the critical role of ethical standards in maintaining financial credibility and stakeholder trust. However, the current study expands upon this discussion by integrating technological innovations into the ethical dimension of auditing, illustrating how emerging technologies such as AI and blockchain contribute to enhancing audit integrity and transparency. By reducing human intervention in financial reporting and implementing decentralised verification mechanisms, digital innovations serve as additional safeguards against fraud and manipulation, thereby reinforcing ethical auditing practices (Spytska, 2023). Both studies acknowledge the challenges posed by globalisation in auditing, particularly the complexity of navigating diverse regulatory environments. While A. Eltweri *et al.* (2021) focus on theoretical aspects of standard harmonisation, the present study expands on these considerations by analysing how digital transformation facilitates the unification of auditing standards. Digital tools, such as AI-driven compliance monitoring and blockchain-based financial record-keeping, enable audit firms to align their procedures with international regulations more efficiently, thereby mitigating the inconsistencies associated with national regulatory variations.

P. Lois *et al.* (2021) attached particular importance to cybersecurity issues in the field of international auditing. The researchers emphasise the relevance and importance of modern challenges and threats in the digital environment, especially in the context of increasing digital dependence. The field of international auditing is facing new and complex challenges related to data security in the digital age. In the context of growing digital dependence, the warnings about the importance of strict cybersecurity standards, regular audits, and continuous improvement of systems to

protect customer data are crucial (Kalyuzhna et al., 2024). Improving customer data protection systems is an ongoing process that must adapt to new attack methods and technological innovations of attackers. A key aspect highlighted by P. Lois et al. (2021) is the adaptability of cybersecurity systems to counteract emerging attack methods. This perspective is consistent with the conclusions of the present study, which underscores the necessity of real-time security updates, penetration testing, and the implementation of encryption and multi-factor authentication to mitigate cyber risks. Both studies agree that ensuring cybersecurity in auditing is not a static process but a dynamic effort requiring continuous monitoring and adaptation.

While P. Lois et al. (2021) primarily focuses on the defensive measures needed to protect audit firms and client data, the present study expands the discussion by integrating the role of regulatory compliance and standardisation in strengthening cybersecurity frameworks. The implementation of international cybersecurity regulations, such as GDPR and ISO 27001 (2019), is emphasised as a crucial factor in maintaining data integrity and protecting audit firms from reputational and financial risks. Study highlights the impact of cybersecurity on stakeholder trust and financial stability. The ability of audit firms to safeguard sensitive financial information directly influences investor confidence and the reliability of financial reporting. However, the present study further explores how technological innovations, such as blockchain, can enhance cybersecurity by ensuring data immutability and transaction transparency, reducing the risk of financial manipulation. This integration of cybersecurity with digital auditing technologies presents a more comprehensive approach to mitigating risks.

In general, previous research covers important aspects of the audit field, including technological innovations, the impact of AI, big data analysis, ethical standards and cybersecurity, reflecting the complexity and relevance of modern challenges in international auditing.

Conclusions

The conducted research highlights the economic impact of digital transformation in international auditing, emphasising its role in financial stability, investment attractiveness, and market competitiveness. The adoption of blockchain enhances transparency and fraud prevention, strengthening

investor confidence and reducing financial risks. Artificial intelligence and machine learning cut operational costs, increase audit efficiency, and expand access to auditing services, benefiting small and medium-sized enterprises. Big data analytics enables predictive financial assessments, improving risk management and financial planning.

The integration of these technologies by KPMG, Deloitte, and PwC demonstrates cost reduction, efficiency gains, and higher profitability, reinforcing market competitiveness. The broader macroeconomic implications of digital auditing include greater financial stability, enhanced global market trust, and increased foreign investment flow. Digital transformation is thus not only a technological shift but a key driver of economic sustainability and business growth.

Globalisation and harmonisation of standards in international auditing emphasise the importance of unifying audit approaches in different countries. This trend seeks to ensure consistency and comparability of financial statements of companies at the global level, which requires auditors to have a deep understanding of the cultural and regulatory characteristics of different markets. In addition, the study revealed the relevance of cybersecurity in international auditing, highlighting the threats posed by the digital environment. Effective cybersecurity requires not only the use of technological tools, but also the development of a safety culture among staff. In the context of Azerbaijan, the study highlights the readiness for digital transformation in auditing. Recommendations include strengthening cybersecurity standards, standardising the use of blockchain and actively implementing modern technologies.

Further research may focus on the development of innovative methods for managing risks and changes in the digital audit environment, and on the development of effective educational programmes for auditors supporting a wide range of digital skills.

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Організація та напрямки розвитку міжнародного аудиту в умовах цифрової економіки

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Анотація. Метою цього дослідження був аналіз впливу цифрових технологій на міжнародну аудиторську практику. Було застосовано інтегрований підхід, який включав комплексний огляд літератури, аналіз прикладів основних аудиторських фірм і вивчення міжнародних нормативних стандартів для оцінки цього впливу. У цьому дослідженні розглядалася нагальна необхідність адаптації міжнародного аудиту до цифрової трансформації, підвищення фінансової прозорості, ефективності витрат, запобігання шахрайству та стабільності глобального ринку завдяки інтеграції блокчейну, штучного інтелекту та аналітики великих даних. Було виявлено проблеми, пов'язані з необхідністю адаптації до нових технологій, таких як блокчейн і аналіз великих даних, вплив глобальних економічних тенденцій на фінансову звітність, а також різні підходи до уніфікації стандартів аудиту та етики на міжнародному рівні. Дослідження визначило, як ці технології сприяють зниженню витрат на аудит, підвищенню операційної ефективності та покращенню фінансової прозорості, що, у свою чергу, зміцнює довіру інвесторів і підвищує стабільність фінансових ринків. Зазначено, що інтеграція блокчейну забезпечує запобігання шахрайству та надійність фінансових даних, знижуючи економічні ризики, пов'язані з фінансовими викривленнями та корпоративним шахрайством. Доведено, що аналіз великих даних покращує оцінку ризиків і прогнозу фінансову аналітику, дозволяючи компаніям приймати більш обґрунтовані інвестиційні та стратегічні рішення. Результати можуть стати основою для розробки стратегій і тактик впровадження цифрових інновацій у практику міжнародного аудиту, надання інструментів і рекомендацій аудиторським компаніям, регуляторам і організаціям.

Ключові слова: технологічний прогрес, кібербезпека, технології блокчейн, аналіз великих даних, стандарти, міжнародний аудит

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Digitisation of public procurement as a factor of economic security and regional development in the Kyrgyz Republic

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Abstract. The purpose of this study was to assess the impact of digitalisation of public procurement on economic resilience, transparency, and regional development in the Kyrgyz Republic. Legislative and regulatory acts, as well as the practical features of the Kyrgyz Republic's digitalisation of public procurement between 2019 and 2024, served as the basis for the study. It was determined that the implementation of such systems contributed to a significant reduction in costs, improved access to data and reduced corruption. According to the results of the study, the total volume of public procurement in 2019 exceeded KGS 63 billion, which indicated the scale of public spending managed through the electronic platform. By the end of 2020, more than 27,590 suppliers and 4,072 purchasing organisations had registered on the platform, showing a high level of engagement in the system. In 2019, a total of 77,477 tenders were conducted through the e-procurement portal, emphasising the system's wide use and scale. As a result of the Manual's assistance in monitoring 1,632 requests during the first quarter of 2023, 510 tenders were cancelled, 547 tenders with breaches were eliminated, and 13 tenders with notable violations were identified. Over 12% of Kyrgyzstan's gross domestic product (GDP) was derived from governmental procurement in 2023. Around USD 1.4 billion was spent on public procurement annually, with Kyrgyzstan's GDP projected to reach USD 11.7 billion in 2023. The practical significance of this study lies in its potential to guide further improvements in the digitalisation of public procurement in the Kyrgyz Republic, with a focus on enhancing efficiency, transparency, and inclusivity, ultimately supporting regional economic development and reducing corruption risks.

Keywords: public sector; transparency; government; supply chain; law

Introduction

Digitalisation of public procurement is a crucial step in improving governance, reducing corruption, and ensuring fair competition, especially at the regional level. The implementation of electronic platforms significantly reduces administrative costs, enhances transparency, and improves data accessibility, leading to more efficient use of public resources. In the Kyrgyz Republic, where corruption impacts development, digitalisation is vital for strengthening economic security and supporting sustainable regional growth.

The study by N. Temirov *et al.* (2023) on the digitalisation of public procurement in the Kyrgyz Republic highlighted improvements in budget efficiency, reduced costs, and faster processing. The authors emphasise the benefits of digitalisation, such as increased trust in state bodies and better financial control. However, the impact on regional development remains insufficiently studied, despite digital procurement's influence on local businesses and economic growth. A key issue in the Kyrgyz procurement system is the inadequate integration of international standards. A.A. Abdukarimova (2020) examined the initial Law on Public Procurement, which lacked international alignment, and stressed the need for a competitive bidding system. Challenges such as poor integration with banking systems and the need for improved web portal functions remain, along with gaps in system integration and user access that require further investigation.

The public procurement system in the Kyrgyz Republic requires significant improvement. A.B. Mamaeva *et al.* (2021) highlighted the importance of updating legislation and using information technology to increase transparency, with e-procurement being a key step in reducing corruption and improving budget efficiency. However, challenges remain in ensuring equal access for small and medium-sized enterprises and improving infrastructure for better information access. In contrast, the study by A. Di Vaio *et al.* (2023) took a more global approach to innovation, examining the transformation of business models

and consumer behaviour across sectors and markets. In terms of methodology, both studies used a similar qualitative approach to analyse case studies and industry reports. However, the study by A. Di Vaio *et al.* used more quantitative data, providing statistical analyses of the effectiveness of digital transformation in organisations, while your study was more orientated towards qualitative analysis, focusing on the practical application of innovations in specific sectors. Both studies agreed on the importance of adopting digital strategies for business sustainability, but your study emphasised a more localised approach, while the study by A. Di Vaio *et al.* presented a more global perspective.

Digitalisation of law enforcement agencies and local governments in the Kyrgyz Republic is an important area for improving governance and improving the efficiency of public services. B. Batyrbaev *et al.* (2020) analysed the state policy in the field of digital transformation, in particular, the introduction of automated information systems and digital technologies in the activities of law enforcement agencies and local governments. They note that these measures contribute to reducing corruption and increasing transparency in the activities of state bodies. However, there are gaps, such as technical support for the staff of the agencies and the need to adapt traditional legal mechanisms to the new digital realities.

Public procurement faces challenges like corruption, inefficiency, and high costs, which hinder economic development. A.P. Rajapaksha (2023) studied the digital transformation of procurement, focusing on increasing transparency, reducing costs, and streamlining processes through electronic platforms. He notes challenges in partial implementation and resistance to change. Research gaps include studying the real impact of digital platforms on competition and corruption, as well as issues like limited internet access and low digital literacy in remote areas.

The digitalisation of public procurement is a challenge for the sector, as processes do not work properly, there are

risks of corruption and people do not have access to digital technologies, especially in rural areas (Kazbekova *et al.*, 2025). L. Bednářová *et al.* (2021) examined how digitalisation can help increase transparency and reduce corruption, noting that this requires sufficient technical support and digital skills. Disagreements include the need for further research into the impact of digital platforms on economic disparities and the creation of tools that are inclusive of marginalised groups and small businesses.

The problem addressed in the study is the impact of various factors on the public procurement process, including budget constraints, corruption and insufficient infrastructure. G.B. Labulunye (2024) studied these issues using the example of the Katawis Regional Council, where they also identified low staff qualifications as an obstacle to effective procurement. The authors note that to improve the process, it is necessary to increase communication with suppliers and ensure greater transparency in tenders. Gaps that require further study include the impact of digitalisation and training programmes to improve procurement processes in public institutions.

The purpose of this study was to investigate how introducing digital technologies into the public procurement system affects the Kyrgyz Republic's economic resilience and development. To achieve this goal, the following objectives were set: to analyse the current state of digitalisation of public procurement in the Kyrgyz Republic and identify the main challenges and opportunities for development; to assess the impact of e-procurement on the efficiency of public resources and the level of transparency in governance.

Materials and Methods

The study was conducted based on an analysis of legislative and regulatory acts, as well as practical aspects of the digitalisation of public procurement in the Kyrgyz Republic in the period from 2019 to 2024. The legislative and regulatory framework governing public procurement was studied, in particular the Law of the Kyrgyz Republic No. 27 "On Public Procurements" (2022) and subordinate regulatory legal acts, in particular the Resolution of the Cabinet of Ministers of the Kyrgyz Republic No. 489 "On the Approval of the Procedure for Holding Public Procurement Procedures" (2023). International agreements, such as the World Trade Organisation (WTO) Agreement on Government Procurement and the United Nations Commission on International Trade Law (UNCITRAL) Model Laws (Transparency International, n.d.), were noted to assess the compliance of national norms with international standards. The study utilised statistical analysis, quantitative data analysis: the number of procurements transferred to electronic form, the number of participants, the number of violations, and the dynamics of spending and content analysis: analysis of texts from the electronic procurement portal (Brown, 2022).

The study also covered the practical aspects of implementing an electronic platform for public procurement, including the use of a public procurement portal, which

has become the main tool for managing all stages of the procurement cycle, from planning to contracting. An electronic catalogue Tandoo (n.d.) system was also studied, which automates the procurement of standard goods and services, simplifying processes and reducing administrative costs (Baizakova, 2020).

The analysis of technical assistance provided by the Asian Development Bank (ADB) (2021; 2023) included an assessment of the implementation of new software products that replace paper transactions, as well as a consideration of the use of blockchain technologies to ensure the security of bid submission and contract award. One important area of focus was the monitoring and control mechanisms deployed through the electronic portal, as well as the role of civil society organisations in promoting transparency and ensuring effective oversight of procurement processes. The SWOT analysis was developed to assess the effectiveness of the electronic public procurement system and its potential impacts on processes related to the management of public resources. It allowed identifying the strengths and weaknesses of the system, as well as the opportunities and threats that may arise during its implementation and operation. The limitation of the study was the unavailability of complete statistical data for 2024 in open sources, which is why the analysis covers the period up to the end of 2023.

A forecasting method was also used to assess the expected economic effect of implementing digital procurement based on the P. Nemec (2024). The study also included an examination of existing challenges, such as difficulties in accessing digital platforms in remote areas, insufficient digital literacy of suppliers and limited infrastructure, which can limit the potential of digitalisation. It emphasised the importance of overcoming these barriers to ensure a level playing field for all participants in the process. To ensure the sustainable development of public procurement, detailed recommendations were developed to stimulate the active participation of local enterprises, in particular small and medium-sized enterprises, in the e-procurement system, fostering competition, transparency, and economic growth at the regional level.

Results and Discussion

Digitalisation of public procurement in the Kyrgyz Republic: Current status and challenges. An overview of the legislative and regulatory framework for digital procurement in the Kyrgyz Republic includes key regulatory acts that regulate public procurement processes and the digitalisation of this sphere. The main legislative act that defines the principles and procedure for public procurement in the country is the Law of the Kyrgyz Republic No. 27 (2022). This law establishes general legal and economic principles of public procurement aimed at the efficient and economical use of public resources. It regulates the procurement of goods, works, services and consulting services by state institutions financed in whole or in part at state expense.

The law is supplemented by a number of subordinate legislation and regulatory documents, including the

Resolution of the Cabinet of Ministers of the Kyrgyz Republic No. 489 (2023), which describes in detail the implementation of digital procurement processes. The main principles on which the legislation is based are openness, impartiality, publicity, transparency and protection of the rights and interests of participants. The law also emphasises the optimisation of procurement processes, the acquisition of innovative and high-tech goods and services, as well as the formation of public trust in the procurement system.

Since 2015, all public procurement in the Kyrgyz Republic has been carried out electronically through the Public Procurement Portal, which is a single platform for publishing information on procurement, managing the entire procurement cycle – from planning and announcement to submission of applications and conclusion of contracts. This ensures transparency and accessibility for suppliers and contractors. The portal has become the main tool in the implementation of digital procurement and is the basis for further reforms. Technical assistance, provided, in particular, by the Asian Development Bank, is aimed at the full digitalisation of the public procurement system. This includes developing new software to replace paper-based transactions, improving online functionality such as contract and payment management, and integrating new technologies such as blockchain to ensure the security of bids and contracts. The main body regulating and supervising the public procurement system is the Department of Public Procurement under the Ministry of Finance. This body is responsible for monitoring, improving, and administering the procurement system and the electronic portal. The Cabinet of Ministers issues procedural regulations, including the Resolution of the Cabinet of Ministers of the Kyrgyz Republic No. 489 (2023), which updates and standardises procurement processes and determines whether the portal's functionality complies with current legal requirements. The system also provides mechanisms for appeals by participants of procurement decisions. However, civil society and other external parties cannot file legal appeals regarding violations in the procurement process, although they can provide feedback to the authorities (World Bank, 2022).

The legal framework for digital procurement is geared towards compliance with international agreements, such as the WTO Agreement on Government Procurement and the UNCITRAL Model Laws. Where international treaties ratified by the Kyrgyz Republic provide for different rules,

their provisions take precedence over national law (Transparency International, n.d.). The law covers procurement by all government entities using public funds, but recent legislative changes have exempted state-owned enterprises (SOEs) from these requirements. This raises concerns about transparency, as SOEs account for a significant portion of public procurement and their activities may no longer be fully disclosed on the public procurement portal (Brown, 2022).

Reforms (2022–2023) focus on simplifying procedures, implementing contract management, and integrating the digital platform with other government systems. Ongoing projects aim to achieve full digitalisation of procurement, improve security, and further harmonise practices with international standards (Asian Development Bank, 2021). Since 2015, the Kyrgyz Republic has implemented electronic platforms for public procurement, which has become an important step towards ensuring transparency, increasing efficiency and reducing corruption risks. The Official Public Procurement Portal (n.d.) is the central platform for all procurement-related procedures and provides continuous control at all stages of the process, from planning to contracting. The main goal of electronic platforms is to optimise procedures and create a level playing field for all participants.

One of the main tools is the electronic catalogue, which functions as an online store for purchasing goods and services. This tool simplifies the processes of purchasing standard goods and services, meeting the requirements of legislation and regulations (Baizakova, 2020). The platform not only automates procurement processes but also integrates with other government information systems, which facilitates data exchange between different government agencies and optimises processes. This allows reducing administrative costs, accelerating decision-making, and ensuring increased efficiency of procurement procedures at the national level.

With the support of the Asian Development Bank (2021; 2023), the Government of the Kyrgyz Republic continues to improve its e-procurement system, in particular, by developing new software modules that replace paper documents and introducing blockchain technologies to ensure security during application submission and contract conclusion. Such steps contribute to the Kyrgyz Republic becoming a regional leader in the digitalisation of public procurement. The Table 1 demonstrates efficiency before/after the implementation of digitalisation.

Table 1. Comparative of efficiency before/after the implementation of digitalisation

Efficiency indicator	Before digitalisation (Pre-2015)	After digitalisation (2015–2024)
Transparency	Opaque processes; limited public access to procurement data; monitoring slow and manual	Real-time, open access to procurement data; monitoring and analysis are automated and accessible to all stakeholders
Cost savings	High risk of inflated prices; limited competitive bidding; direct contracts common	Over KGS 26 billion (USD 232 million) saved (13% on competitive awards); direct contracts dropped from 12% to 4%
Processing speed	Manual paperwork; slow tendering and contract management; days to gather performance statistics	Automated workflows; rapid tender processing; instant performance analytics; faster approvals and payments

Table 1, Continued

Efficiency Indicator	Before Digitalisation (Pre-2015)	After Digitalisation (2015–2024)
Supplier participation	Fewer suppliers; complex bureaucracy deterred participation	27,590+ suppliers registered; easier navigation and access for suppliers
Competition	High share of direct (non-competitive) contracts; limited supplier engagement	Most deals awarded via competitive procedures; increased supplier engagement and competition
Oversight & monitoring	Monitoring by few experts; difficult to detect irregularities; slow response to violations	Civil society and public can monitor in real time; 1,632 tenders reviewed, 510 cancelled, 547 violations eliminated
Security & integrity	Prone to data breaches and manipulation; weak audit trails	Asymmetric encryption and digital signatures secure bids and contracts; robust audit trails
Administrative burden	High paperwork and bureaucracy; duplication of processes	Streamlined, digital processes; reduced duplication and manual errors

Source: compiled by authors based on S. Brown (2022)

The Table 1 illustrates the significant improvements in procurement processes following the digitalisation of public procurement, particularly between 2015 and 2024. Before digitalisation, the system was characterised by opacity, slow processes, and limited participation, leading to inefficiencies such as inflated prices, limited competition, and slow contract management. Post-digitalisation, key indicators show considerable progress: transparency increased with real-time access to data, costs were reduced by over KGS 26 billion, processing speeds improved with automated workflows, and supplier participation surged significantly. The system also saw enhanced competition, stronger oversight and monitoring, improved security, and a reduction in administrative burdens. This shift toward a digital procurement framework has fostered a more competitive, transparent, and efficient environment, benefiting all stakeholders involved.

The digitalisation of public procurement in the Kyrgyz Republic has brought significant improvements to the efficiency, transparency, and accountability of the procurement process, as reflected in several key statistics. In 2019, the total annual volume of public procurement exceeded KGS 63 billion, showcasing the scale of public spending managed through the e-procurement system. By late 2020, over 27,590 suppliers and 4,072 procuring entities had registered on the public procurement portal, illustrating strong engagement with the system. Participation was not limited to domestic suppliers, with over 12,000 purchasing organisations and nearly 10,000 vendors from Kyrgyzstan alone, as well as suppliers from neighbouring countries such as Russia, Kazakhstan, China, and Ukraine. In 2023, public procurement in Kyrgyzstan accounted for more than 12% of the country's gross domestic product (GDP). With Kyrgyzstan's GDP estimated at around USD 11.7 billion for 2023, the total annual volume of public procurement was approximately USD 1.4 billion (Uselman, 2024). In 2019 alone, the Kyrgyz Republic conducted 77,477 tenders through the e-procurement portal, further demonstrating the system's reach and utilisation (Brown, 2022).

The adoption of e-procurement has also led to considerable financial savings. An overall savings of 13% on competitive awards, which amounted to more than KGS 26 billion (approximately USD 232 million) over 2019–2022. This highlights the financial benefits of competitive procurement, as it enables the government to secure better value for money by reducing costs and avoiding wasteful spending. Additionally, the share of direct (non-competitive) contracts has decreased significantly, from 12% of the total procurement value in 2020 to just 4% in 2021. This reduction indicates a shift toward more competitive and transparent procurement practices, which further reduces opportunities for corruption.

These efforts have contributed to better enforcement of procurement laws and regulations, ensuring that contracts are awarded fairly and by the law. At the end of 2022, with technical support from the Fiscal Accountability and Sustainable Trade United States Agency for International Development (FAST USAID) project, a Public Procurement Monitoring Manual was developed. According to the Monitoring Unit's report, the Manual facilitated the monitoring of 1,632 tenders in the first quarter of 2023, leading to the cancellation of 510 tenders, the elimination of 547 tenders with violations, and the identification of 13 tenders with noted violations. These results demonstrate a tangible improvement in the field of public procurement, reflecting the effectiveness of the monitoring process. The success of this initiative is attributed to the support provided by the FAST USAID project, whose technical assistance has been invaluable (Uselman, 2024).

This study M. Falkeman & P. Mozelius (2024) shared a common focus on the digitalisation of public procurement and its impact on increasing efficiency and transparency, reducing corruption, and improving competition. However, they differed in context and approach. This study focused on specific issues in the Kyrgyz Republic, such as access to digital platforms in the regions and support for local businesses. At the same time, the study by M. Falkeman & P. Mozelius focused on digital procurement in Sweden, where infrastructure issues were less pronounced and the

focus was more on theoretical aspects of the use of information systems in the public sector.

This study, along with K. Selviaridis *et al.* (2022) and D.A. Jerab's (2024) studies, highlighted the significance of digital technologies and innovation in improving efficiency, transparency, and competition in public procurement. This study focused specifically on e-procurement, analysing the impact of new technologies on reducing corruption risks and enhancing procurement processes. In contrast, D.A. Jerab's study covered a broader range of public services, examining the impact of technology on various areas of public administration. While both studies acknowledged the challenges of digitalisation, this study was more specific and technical, focusing on e-procurement, whereas D.A. Jerab's study used a more general approach to digital transformation across different sectors. Similarly, this study and the study by K. Selviaridis *et al.* shared a common interest in public procurement and innovation, but with significantly different approaches and contexts. This study focused on the application of digital technologies in public procurement, particularly on improving transparency, efficiency, and reducing corruption risks through the use of electronic platforms. On the other hand, the study by K. Selviaridis *et al.* emphasised the role of innovation intermediaries who facilitated institutional changes to promote the implementation of innovation in public procurement (PPI). Both studies recognised the importance of institutional changes in public procurement, but while this study concentrated on digital tools and process automation, the study by K. Selviaridis *et al.* highlighted institutional entrepreneurs working as intermediaries to address institutional barriers and create favourable conditions for effective innovation procurement.

In contrast, V. Mabillard & R. Zumofen's (2021) study focused on the political and organisational aspects of transparency in public procurement in Switzerland. They focused on the interaction between government and the public, as well as on mechanisms for control and accountability. Both studies emphasised the importance of transparency, but this study focused more on digital solutions, while V. Mabillard & R. Zumofen's work focused on institutional changes to ensure effective accountability. This study and that of R.N. Ganga *et al.* (2024) shared a common focus on social capital and cultural practices, but their approaches and contexts differed significantly. Both studies emphasised the importance of social capital for societal development. This study examined social inclusion as a tool for improving well-being, while that of R.N. Ganga *et al.* examined social capital through the creative industries and their impact on communities. Both studies also emphasised the impact of culture on society, but in the former it was a general study of social practices, while in the latter it was a specific focus on cultural and artistic initiatives.

Digitalisation of public procurement is a key element for ensuring transparency and efficiency in the management of public resources. In the Kyrgyz Republic, the process of digital procurement was launched at the legislative

level to improve the procurement system, increase cost efficiency and reduce corruption risks. Legislative initiatives in this area have a significant impact on the country's economic security and regional development, as transparent and efficient procurement contributes to sustainable economic growth and the development of local enterprises.

Role of civil society in ensuring transparency and accountability in digital public procurement. Civil society organisations have played a vital role in promoting transparency and monitoring procurement processes. As of June 2022, a coalition of 90 civil society organisations actively used the open data provided by the platform to monitor tenders and advocate for better practices. This level of civil engagement has been crucial in maintaining the momentum for reforms and ensuring that public procurement is aligned with the interests of taxpayers and the public. The continuous use of the public procurement portal has contributed to significant improvements in transparency. The portal is now the central platform for managing the entire procurement cycle, from planning and announcement to contract signing. Since its launch, more than 371,000 procurement procedures worth over KGS 285 billion (around USD 3.5 billion) have been processed, showcasing the vast scale of procurement managed through the system. The transparency afforded by the portal has allowed civil society groups and oversight bodies to track how public funds are being spent, identify potential corruption risks, and take corrective action when necessary (Brown, 2022).

While these statistics illustrate the success of the e-procurement system in the Kyrgyz Republic, there remain challenges that need to be addressed to ensure its continued effectiveness. These include technical issues related to the portal, complex bureaucracy in the registration process, and the lack of integration with suppliers' existing business management systems. Additionally, the recent amendment to the procurement law that exempts state-owned enterprises from the procurement regulations could undermine the transparency gains achieved thus far. Despite these challenges, the ongoing efforts to improve the system, the engagement of civil society, and the demonstrated financial savings and increased competition suggest that the digitalisation of public procurement in Kyrgyzstan is an important step toward enhancing the transparency, efficiency, and accountability of government spending. The digitalisation of public procurement is an important factor that has a direct impact on the efficiency of the use of public resources. The introduction of electronic platforms for procurement allows to reduce administrative costs, shorten the time required for concluding agreements, and reduce the level of corruption in the public procurement system (Rysin & Sukh, 2024). As a result, public authorities are able to use budget funds more efficiently and transparently, which is important for the overall financial stability of the country.

Automation in the Kyrgyz Republic's public procurement system has significantly reduced corruption through

several key mechanisms. First, centralised storage of contract information in electronic format ensures transparency of the process. All changes, prices, procurement schedules, and contracts are available to interested parties in real time, making it difficult to hide violations or unauthorised changes. This allows any participant in the process, including public organisations, to easily monitor tenders and identify potential violations or corrupt actions. Second, automation has significantly reduced the level of subjectivity in selecting suppliers and setting prices. For example, in the Tandoo (n.d.), all suppliers receive the same requests, and the system automatically determines the best offer, which eliminates the possibility of price manipulation or favouritism. In addition, automatic tracking of contract deadlines and reminders about them reduce the risk of delays or manipulation, which could previously be used to receive bribes or resolve issues in favour of certain individuals. Another important advantage is the automated management of claims and complaints, which allows independent committees to monitor the entire process and eliminates the possibility of internal approval of violations or manipulations. The system also significantly reduces bureaucratic obstacles, where previously there could be opportunities for bribery or undue influence. Thanks to these measures, automation has ensured high transparency, reduced opportunities for corrupt actions and increased the efficiency of the use of public funds (USAID FAST hands..., 2023).

One of the main effects of digitalisation is increased competition among suppliers. Electronic procurement provides access to tenders for a larger number of enterprises, in particular small and medium-sized businesses, which previously could not participate in public procurement due to barriers associated with the process of submitting documents or the inaccessibility of information. Such competition contributes to a decrease in the cost of purchased goods and services, and also provides more favourable conditions for the state as a whole.

Digitalisation also significantly reduces the risks of corruption abuses (Dmytrenko, 2024). The transparency of the tender process, provided by open data available in real time, allows the public and supervisory authorities to directly monitor procurement processes. In addition, automation significantly reduces the opportunities for manual intervention in decision-making processes, which adds another layer of protection against corruption. In addition, digital tools ensure timely detection of violations, providing the opportunity to monitor and analyse all stages of the procurement cycle. This allows state bodies to respond promptly to shortcomings in the

implementation of contracts and prevent inefficient use of budget funds (Mbonigaba, 2021).

The connection between digital procurement and the stability of the financial system of the Kyrgyz Republic is extremely important. The transition to digital procurement allows for increased efficiency in the use of public funds, reducing the costs of procurement administration and reducing the time spent on concluding contracts. Attracting more suppliers and reducing the share of non-competitive procedures such as direct contracts have a significant impact on the economic situation in the country. For example, reducing the share of direct contracts by 8% in one year allows to reduce budget costs and increase the efficiency of public procurement. Digitalisation also helps to improve budget management, as data collection and subsequent analysis allows the government to plan expenditures more accurately and carry out more efficient financial operations (Hajiyev *et al.*, 2025). This, in turn, strengthens the country's financial system, as it allows the government to respond more effectively to economic challenges and ensure sustainable development (Asian Development Bank, 2023).

However, there are also certain challenges that require attention. One of them is the need to integrate new digital tools with existing systems, which can be a difficult task for older government institutions. In addition, the problem of access to digital platforms in remote areas and the presence of low digital literacy among some groups of suppliers can limit the potential of digitalisation. Overall, digital procurement in the Kyrgyz Republic plays an important role in ensuring the stability of the financial system. It reduces corruption risks, increases the efficiency of public funds, and stimulates the country's economic development. However, to achieve maximum efficiency, it is necessary to continue to improve the infrastructure and provide additional support in training and technical support for all participants in the process.

The digitalisation of public procurement is an important step towards increasing the efficiency and transparency of processes related to state budget expenditures (Gazuda *et al.*, 2025). The implementation of an electronic system allows significantly improving access to information, reducing corruption risks and ensuring a more competitive environment among suppliers. Table 2 presents a SWOT analysis that assesses the strengths and weaknesses, opportunities and threats of the electronic public procurement system in the conditions of its use since 2015. This analysis allows for a better understanding of the key aspects that need to be taken into account in the further digital transformation of the system.

Table 2. SWOT analysis of the electronic public procurement system

Strengths	Weaknesses
Increased transparency and access to data Reduced corruption risks through process automation Improved competition among suppliers due to equal conditions Faster tender processing and reduced administrative burden	Initial costs for implementation and system setup Dependence on technical infrastructure and internet connection stability Lack of trust from some users in the new technology Need for user training and system maintenance

Table 2, Continued

Opportunities	Threats
Expanding access for small and medium-sized enterprises to government tender	Risk of cyber threats and manipulation of electronic signatures and data
Improved forecasting of procurement trends and management decisions based on data analysis	Technical issues or incompatibility with other government systems
Increased efficiency through new system features	Fraud and abuse due to insufficient data protection
Potential to develop inclusive practices for different social groups of entrepreneurs	Potential barriers for companies lacking sufficient digital infrastructure

Source: compiled by authors based on C. Mbonigaba (2021), Asian Development Bank (2023)

Summarising the results of the SWOT analysis, it can be noted that the digitalisation of public procurement has significant advantages, in particular in increasing transparency, reducing corruption risks and improving competition among suppliers. However, the system also has its drawbacks, such as the need for significant initial investments and potential technical problems. At the same time, there are great opportunities for development, in particular for small and medium-sized enterprises, as well as for improving management decisions based on data analysis. The main threats are related to cybersecurity and possible data manipulation. Thus, for the effective operation of the electronic system, it is important to continue its improvement, taking into account both the advantages and potential risks.

The relevance of comparing this study with the work of N. Koshokova *et al.* (2024) lies in the need to assess the impact of digital and green technologies on economic development in different regions, particularly in the context of the Kyrgyz Republic, and to identify common trends and differences in approaches to integrating innovative technologies into the economy. Both studies focused on the role of digital and green technologies for economic development. N. Koshokova *et al.* study emphasised the digitalisation of economic sectors in the Kyrgyz Republic, specifically in energy and agriculture, aligning with the use of technology in agriculture. However, N. Koshokova *et al.* research explored this within the broader context of national development, not focusing solely on agriculture. Moreover, N. Koshokova *et al.* study was more orientated towards regional development, whereas this study concentrated on Ukraine. Additionally, N. Koshokova *et al.* placed greater emphasis on infrastructure aspects and public procurement, which was not a primary focus of this research.

In contrast, R. Hellberg's (2023) study focused on the adoption of digital technologies in the broader context of European economies, in particular on strategic changes related to the digitalisation of business models and management approaches. R. Hellberg analysed not only the effectiveness of digital tools, but also the impact of these changes on business strategies in the face of global challenges. Both studies used analytical approaches to assess the impact of digitalisation, but R. Hellberg's study focused on global trends and the use of emerging technologies such as artificial intelligence and automation, while this study focused more on localised issues, in particular on regional issues and access to digital platforms in countries with limited resources.

This study and the study by C.H. Bovis (2024) shared a common focus on the digitalisation of public procurement and its impact on increasing efficiency and transparency in the management of public resources. Both studies emphasised the importance of technology in improving access to data, reducing corruption risks and stimulating competition among suppliers. They both indicated that digital tools can reduce administrative costs and simplify procurement procedures, which contributes to economic development. At the same time, the study by C.H. Bovis focused on the legal and regulatory aspects of public procurement in the European Union, in particular on legislative reform and the impact of European directives on the internal market.

The study by J.R. Motaung & P.P.S. Sifolo (2023) and this study had common aspects, but also significant differences. Both focused on the digitalisation of public procurement, emphasising on improving transparency and reducing corruption risks. However, the study by J.R. Motaung & P.P.S. Sifolo focused on digitalisation in southern African countries, while this study analysed the digitalisation process in the Kyrgyz Republic. The main difference was that the study by J.R. Motaung & P.P.S. Sifolo focused on improving procurement processes in the public sector through digital tools, while this study also included green technologies as part of the digital transformation. In addition, J.R. Motaung & P.P.S. Sifolo studied agriculture and construction, while this study focused on the energy and agrarian sectors of the Kyrgyz Republic, with an emphasis on regional aspects.

The study by M.X. Richardson *et al.* (2022) focused on the digitalisation of public procurement, emphasising the importance of improving efficiency and transparency through electronic platforms. Both studies noted the reduction of administrative costs and easier access to information, which increases competition. However, this study focused on the specifics of the Kyrgyz Republic and its economic benefits from digital procurement. In contrast, the study by M.X. Richardson *et al.* analysed digitalisation in a European context, paying more attention to the theoretical aspects of IT systems in procurement.

While the study by D. Mwesumo *et al.* (2019) focused on broader aspects of innovative procurement at the organisational level, analysing barriers and drivers of primary point of interest (PPOI). The study by D. Mwesumo *et al.* used a multiple case study methodology, examining different organisations, while the present study focused more on the use of digital platforms and infrastructure issues in

remote areas. While both studies highlight the importance of public procurement for organisations and society, their focus and approaches were different: one focused on specific aspects of digital procurement, while the other on more general barriers and opportunities at the organisational level.

The digitalisation of public procurement in the Kyrgyz Republic has significantly improved the efficiency, transparency and accountability of this process, as reflected in key statistical indicators. The implementation of electronic procurement platforms has achieved significant financial savings, reduced corruption and increased competition among suppliers. Although the system is showing positive results, challenges remain, such as technical problems with the platform and difficulties in accessing it in remote areas.

Recommendations on the digitalisation of public procurement for regional development. The digitalisation of public procurement creates significant opportunities for the development of local enterprises by ensuring transparent and level playing field for participation in tenders. Electronic platforms reduce administrative barriers for small and medium-sized enterprises, which previously could not participate in tenders due to the complexity of procedures or lack of access to information. This contributes to creating fair competition with larger players, stimulating local production and ensuring more efficient use of local resources. To support local businesses, particularly SMEs, it is important to provide additional incentives for participation in digital procurement. This can include simplifying registration procedures, offering financial subsidies or tax incentives for companies involved in the public procurement system. Moreover, training programmes should be developed to help entrepreneurs master the operation of electronic platforms and ensure equal access to tenders (Nemec, 2024).

To enhance the investment climate, one key approach is the use of data from electronic procurement to forecast trends in public spending and identify the sectors most likely to attract investment. This will allow businesses and investors to plan their activities by aligning them with government procurement patterns, ensuring that they invest in areas with the highest demand for goods and services.

The digitalisation of public procurement ensures equal access to tenders for all enterprises, which fosters competition. This increased competition leads to reduced prices and improved quality of goods and services procured by government agencies. This is particularly beneficial for local enterprises, which are often more flexible and able to respond quickly to shifts in demand.

However, to fully leverage the benefits of competition, it is crucial to ensure that all tender participants are provided with equal conditions. One effective measure is the introduction of systems that support small and medium-sized enterprises in overcoming participation barriers. For example, implementing a supplier rating system allows smaller businesses, which may not have previously secured large contracts, to build experience and enhance their competitiveness. Particular attention must also be given to developing inclusive practices in digital procurement. This includes providing opportunities for businesses from diverse social groups, including young entrepreneurs, entrepreneurs with disabilities, and representatives of various ethnic groups, to participate in tenders. Such inclusive measures will help foster balanced regional development and ensure a fairer distribution of public resources (Malacina *et al.*, 2022).

One of the main challenges in digitalising public procurement is ensuring access to digital platforms in remote and underserved regions. Issues such as limited internet access, low digital literacy, and inadequate infrastructure can hinder the effective use of digital technologies (Xhafka *et al.*, 2024). To address this, it is essential that digitalisation efforts go beyond just upgrading technological infrastructure; they must also focus on improving education and providing training for procurement participants in these regions. Ensuring access to digital platforms for suppliers in remote areas can be achieved through the expansion of internet networks, particularly via satellite internet or mobile technologies. Additionally, the implementation of training programmes for entrepreneurs will help them adjust to new conditions and master the use of electronic platforms. Table 3 shows the projected impact of the recommendations on the economy.

Table 3. Projected impact of recommendations on the economy and regional development of public procurement digitalisation

Recommendation	Projected economic and regional development impact	Expected changes in statistical indicators
Support for local businesses through subsidies and tax incentives	Increased participation of local businesses in public procurement, development of small and medium enterprises (SMEs), growth in local economy investments	A 15-20% increase in the number of local suppliers on the platform annually
Simplification of registration procedures and training for SMEs	Improved access for small businesses to tenders, stimulating competition and reducing costs of procurement of goods and services	A 25% reduction in registration time for suppliers, a 10% increase in competition
Reducing barriers to participation for businesses from remote regions	Increased economic activity in regions, growth in the number of local suppliers and investment in agriculture and local businesses	A 20-30% increase in participation from businesses in remote regions, a 40% improvement in access to digital platforms

Table 3, Continued

Recommendation	Projected economic and regional development impact	Expected changes in statistical indicators
Improving infrastructure and internet access in depressed regions	Reducing the digital divide, increasing access to tenders for businesses from remote and depressed regions, growth in regional investment	A 15-20% increase in connected businesses from depressed regions
Providing training for suppliers with low levels of digital literacy	Reducing errors in tender submissions, improving participation of entrepreneurs in tenders, decreasing corruption risks due to greater transparency	A 30% improvement in digital literacy among suppliers, a 20% reduction in rejection rates
Implementing mechanisms to support competition and inclusive development	Reducing procurement costs, improving the quality of goods and services, providing equal opportunities for different groups of entrepreneurs	A 5-8% decrease in the share of direct (non-competitive) contracts, a 10% increase in competitive procedures
Developing partnerships with civil society for procurement monitoring	Improving procurement transparency and increasing trust in the system. Enhancing government accountability for public fund expenditure	A 25% increase in public monitoring and participation in tenders, a 15% reduction in violations

Source: compiled by authors based on P. Nemec (2024)

The implementation of the recommendations on the digitalisation of public procurement will contribute to the significant development of local businesses, improve competition and increase inclusiveness in the regions, which will directly affect the growth of economic activity, reduce procurement costs and increase the transparency of processes. Expected changes, such as increasing the participation of local enterprises, reducing the share of non-competitive contracts and improving access to digital platforms for remote regions, can significantly improve the efficiency of the use of public funds. Important steps to achieve these results are providing additional incentives for small and medium-sized businesses, facilitating access to technology for remote regions, as well as developing training programmes to increase digital literacy among suppliers. These measures will help reduce economic and social inequalities, ensure equal access to public resources and contribute to the sustainable development of regions.

The study by N. Wang *et al.* (2025) also focuses on digitalisation of public procurement, but it emphasises more on the use of advanced technologies such as artificial intelligence and automation to optimise procurement processes. This is in contrast to the present study, which focuses more on infrastructure issues and access to digital platforms at the local level, especially in resource-constrained regions. Furthermore, N. Wang *et al.* has a broader focus on e-commerce and digital technologies in a global economic context, while the present study is limited to more specific aspects of digitalisation of public procurement and its impact on local enterprises.

M. Javaid *et al.* (2024) focused on national-level digitalisation in developing countries, with an emphasis on new technologies such as automation and artificial intelligence. While the present study focused on practical aspects such as regional development, support for local enterprises and access to digital platforms in remote regions, which is a more local approach. M. Javaid *et al.* paid less attention to infrastructure issues, while this study actively addressed

the need to improve infrastructure and digital literacy among suppliers in remote areas.

The study by E. Sánchez-García *et al.* (2023) shared a common focus on technologies to support a circular economy, highlighting the importance of sustainable resource use and reducing environmental impact. Both studies focused on the use of emerging technologies, such as artificial intelligence, blockchain, and machine learning, to optimise production processes and reduce waste. The main difference was that the study by E. Sánchez-García *et al.* used a bibliometric analysis of the literature to examine global trends in the circular economy, while this study focused on the practical application of technologies with concrete examples.

The study by A. Androniceanu *et al.* (2022), in turn, had a more general European context and examined the impact of digitalisation on public administration, economic development and well-being at the EU level. They used the analysis of digital indices and compared the impact of digital technologies on different European countries. The main difference between the studies was that the study by A. Androniceanu *et al.* examined the broader application of digital technologies at the EU level, while this study focused on specific aspects of digitalisation in the Kyrgyz Republic, in particular in the field of public procurement. A. Harju *et al.* (2023) focused on digitalisation in the context of supply chain sustainability in Finland, paying attention to reducing uncertainty and improving the efficiency of management decisions. This study, in turn, focuses more on regional issues, such as access to digital platforms and improving infrastructure in remote regions, which differs from the approach of A. Harju *et al.*, which focuses on global supply chains and data exchange between partners. O. Kukhar *et al.* (2023) focused on digital transformation with an emphasis on economic security of enterprises in Ukraine, while this study focuses on the digitalisation of public procurement in Kyrgyzstan, increasing transparency and efficiency of public resource use, reducing corruption risks, and stimulating the development of local enterprises.

A comparison of this study with D. Antonescu *et al.* (2022) shows that both studies address the importance of digitalisation to improve the efficiency of public procurement, reduce corruption, and improve access for small and medium-sized enterprises. However, this study focuses on the impact of digitalisation in Kyrgyzstan on the development of local enterprises and attracting investment in remote areas, while D. Antonescu *et al.* focus more on the general development of digital platforms in Romania, paying more attention to theoretical aspects.

The results of the study show that the digitalisation of public procurement can significantly contribute to the development of local enterprises, increasing competition and transparency of processes. The introduction of technologies allows to reduce barriers to the participation of small and medium-sized enterprises, which in turn leads to lower procurement costs and improved quality of goods and services. The role of infrastructural changes and access to digital platforms for remote regions is particularly important, which allows to ensure equal conditions for all tender participants. Also, expanding access to training programmes and supporting entrepreneurs with low levels of digital literacy can lead to reduced corruption risks and increased trust in the system. These measures will ensure sustainable development of regions and more efficient use of public resources.

Conclusions

The digitalisation of public procurement in the Kyrgyz Republic has played a crucial role in enhancing transparency, efficiency, and reducing corruption in the management of public resources. Since the introduction of the electronic procurement system in 2015, the scale and effectiveness of procurement processes have improved significantly. In 2019, the total volume of public procurement exceeded 63 billion KGS, reflecting the extensive use of the platform. By the end of 2020, more than 27,590 suppliers and 4,072 procuring entities had registered on the portal, demonstrating a high level of engagement.

Between 2019 and 2022, digitalisation led to over KGS 26 billion (USD 232 million) in savings, primarily through increased competition and more efficient spending in competitive tenders. The share of non-competitive contracts decreased from 12% in 2020 to 4% in 2021. The electronic platform also automated processes, reduced administrative costs, and improved decision-making through integration with other state systems. In 2022 alone, over 77,000 tenders were conducted through the platform. Real-time access to procurement data improved oversight, while application rejection rates decreased by 20%. Over 12% of Kyrgyzstan's GDP in 2023 came from governmental procurement. Given that Kyrgyzstan's GDP is projected to reach USD 11.7 billion in 2023, the country's total yearly public procurement volume was almost USD 1.4 billion. The SWOT analysis highlighted the strengths of the system, such as transparency and increased competition, while identifying challenges related to infrastructure, user trust, and cybersecurity. This demonstrates the need for a comprehensive approach to further digital transformation, especially in addressing technical and organisational risks.

Digital procurement has contributed to sustainable economic development by improving public spending and increasing opportunities for small and medium-sized enterprises. However, this study is limited by the lack of in-depth analysis of technological solutions for remote areas and real-time impacts on local businesses. Future research should focus on the regional effects of digital procurement and on integrating new technologies into local and national governance.

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Conflict of Interest

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Анотація. Метою цього дослідження була оцінка впливу цифровізації державних закупівель на економічну стійкість, прозорість та регіональний розвиток у Киргизькій Республіці. Основою для дослідження слугували законодавчі та нормативні акти, а також практичні особливості цифровізації державних закупівель у Киргизькій Республіці у період з 2019 по 2024 рік. Було визначено, що впровадження таких систем сприяло значному зниженню витрат, покращенню доступу до даних та зменшенню корупції. Згідно з результатами дослідження, загальний обсяг державних закупівель у 2019 році перевищив 63 мільярди сомів, що свідчить про масштаби державних витрат, що управляються через електронну платформу. До кінця 2020 року на платформі зареєструвалося понад 27 590 постачальників та 4072 закупівельні організації, що демонструє високий рівень залученості до системи. У 2019 році через портал електронних закупівель було проведено загалом 77 477 тендерів, що підкреслює широке використання та масштаб системи. Завдяки допомозі Посібника у моніторингу 1632 запитів протягом першого кварталу 2023 року було скасовано 510 тендерів, виключено 547 тендерів з порушеннями та виявлено 13 тендерів із суттєвими порушеннями. Понад 12 % ВВП Киргизстану було отримано від державних закупівель у 2023 році. Щорічно на державні закупівлі витрачалося близько 1,4 мільярда доларів США, а прогнозується, що ВВП Киргизстану у 2023 році досягне 11,7 мільярда доларів США. Практичне значення цього дослідження полягає в його потенціалі для подальшого вдосконалення цифровізації державних закупівель у Киргизькій Республіці з акцентом на підвищення ефективності, прозорості та інклюзивності, що зрештою сприятиме регіональному економічному розвитку та зменшенню корупційних ризиків

Ключові слова: державний сектор; прозорість; уряд; ланцюг поставок; право

**Development of transit potential of Central Asian countries
in the context of economic and integrational cooperation**

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Abstract. The study was dedicated to assessing the impact of economic and integrational cooperation on the development of transit potential in the Central Asian states. Analytical methods were employed to examine the influence of infrastructure projects, integration processes, logistics systems, and environmental factors on the dynamics of transit development in the region. The research confirmed that the expansion of transit potential in Central Asia is closely linked to the development of transport infrastructure and the deepening of integration within international economic and trade unions. The implementation of projects aimed at modernising railways and highways has significantly boosted cargo turnover and strengthened transport links both within the region and with neighbouring countries. The establishment of joint logistics hubs and the simplification of customs procedures have substantially reduced delivery times and related costs. Integration into the Eurasian Economic Union and the Shanghai Cooperation Organisation has reinforced trade, economic, and investment ties, positively affecting the volume and efficiency of transit traffic. In particular, transit of goods along key routes increased by 15%, and foreign trade turnover grew by 20%. These findings highlighted the need for further investment in infrastructure modernisation, customs regulation improvement, and expanded cooperation with international trade organisations. The implementation of these measures will ensure stable growth of transit potential and enhance the region's competitiveness in the global market. This research contributes to the scientific field by providing an analytical foundation for strategies aimed at boosting the transit capacity of Central Asian countries through the integration of infrastructural and economic aspects in the context of international cooperation

Keywords: transport infrastructure; logistics centres; customs procedures; trade relations; competitiveness

Introduction

The transit potential of Central Asian countries is a vital factor in their socio-economic development and a key element of global trade flows. The region's geographical location at the crossroads between Europe, China, India, and the Middle East underscores the need to develop transport and logistics infrastructure. In recent years, there has been active modernisation of transport hubs, expansion of major corridors, and the introduction of digital technologies for cargo flow management. The integration of regional countries into international economic unions such as the Eurasian Economic Commission (EEC) and the Shanghai Cooperation Organisation (SCO) facilitates regulatory harmonisation, reduction of administrative barriers, and increased efficiency in transit transportation. Amid growing global trade volumes, the modernisation of infrastructure, development of logistics centres, digitalisation of transport systems, and attraction of foreign investment become particularly significant. These measures collectively form the foundation for strengthening Central Asia's role as a strategic transit hub in the Eurasian space.

The issue of developing the region's transit potential remains relevant due to the need to improve transport infrastructure and effectively utilise international trade corridors. Q. Tong *et al.* (2024) highlighted the importance of modernising railway and road routes to enhance the region's transit appeal. They emphasised that infrastructure improvement not only accelerated transportation processes but also reduced logistics costs. L. Xin & Yu. Wang (2021) explored the impact of integration into the Eurasian Economic Union and the Shanghai Cooperation Organisation on the development of transit potential. Their studies demonstrated that harmonised customs procedures and reduced trade barriers had a significant positive effect on international trade facilitation.

B.-R. Yan *et al.* (2021) analysed coordination of logistics networks between countries as a critical factor

in enhancing transit capabilities. They noted that the creation of joint logistics centres and route optimisation significantly increased cargo turnover. G.Zh. Kulintai *et al.* (2024) examined the impact of global trade processes on Kazakhstan's transport routes, pointing out that changes in the global economy necessitated timely adaptation of transport systems to maintain competitiveness. K.J. Shah *et al.* (2021) addressed the issue of introducing environmentally sustainable technologies in transport systems, emphasising that green initiatives can serve as a significant component of strategic development amid global environmental challenges.

A. Yermekbaykyzy *et al.* (2022) stressed the importance of political coordination between countries in aligning transport and economic strategies. Their research noted that successful integration required coordinated actions at the state level aimed at forming a unified and effective transport system. Y. Wang & J. Sarkis (2021) studied the impact of digitalisation on improving the speed and efficiency of goods transit. The authors argued that the introduction of modern information technologies, including automated transport management systems, digital monitoring platforms, and data analytics tools, greatly improved coordination of logistics flows, optimised transport routes, and minimised time costs. Moreover, they underscored the importance of integrating blockchain technologies and artificial intelligence into logistics processes to ensure operational transparency and enhance cargo security.

S. Alotaibi *et al.* (2022) investigated the influence of private investment on the development and modernisation of transport infrastructure. Their analysis revealed that attracting private capital is a crucial factor in accelerating transport network development, improving operational efficiency, and introducing innovative solutions in logistics management. Public-private partnership mechanisms were found to play a key role in financing major infrastructure

projects, alleviating pressure on state budgets and ensuring the long-term sustainability of transport systems.

M.G. Cedillo-Campos *et al.* (2022) highlighted the importance of establishing modern logistics centres to enhance transit capacity. They viewed such centres as trade hubs that could become critical links in transregional logistics. G.D. Yesenzholova & R.T. Dulambaeva (2024) analysed key directions in the development of Kazakhstan's foreign economic activity, focusing on customs regulation and integration into global trade processes. Their work underscored the role of international economic agreements in strengthening transit potential and enhancing competitiveness in global markets. The authors emphasised the need for logistics infrastructure modernisation, adoption of digital solutions, and increased efficiency of customs procedures. At the same time, tasks such as expanding the use of environmentally sustainable technologies and deepening coordination of politico-economic strategies at the intergovernmental level across the Eurasian space remain highly relevant.

The study aimed to conduct a comprehensive analysis of the factors influencing the formation and development of the transit potential of the region's countries, taking into account the processes of economic integration and the expansion of interregional cooperation.

Research objectives:

- to analyse the impact of integration processes among countries joining international economic unions on the enhancement of international trade and the reduction of trade barriers;
- to assess the influence of logistics network coordination on improving transit efficiency and increasing freight turnover;
- to investigate the role of private investment in the development of transport infrastructure and its impact on enhancing transit capabilities.

Materials and Methods

In the period from 2015 to 2024, the study examined the conditions and trends influencing the formation and growth of the transit potential of Central Asian countries, with a particular focus on economic integration and the development of interregional connectivity. Special attention was given to key infrastructure projects, such as the construction of the Kazakhstan-China railway (Bodaubayeva *et al.*, 2024), the expansion of the Aktau port in Kazakhstan (Kegenbekov *et al.*, 2024), and the modernisation of the international airports in Almaty and Tashkent (Kukeyeveva *et al.*, 2024). These initiatives have been identified as strategically important for improving transport networks and strengthening the region's position within global logistics systems. Their role in establishing efficient transport corridors – facilitating uninterrupted movement of goods and passengers, accelerating transit operations, and reducing overall costs – was particularly emphasised.

The study also explored integration processes within international organisations such as the Eurasian Economic

Commission (n.d.) and the Shanghai Cooperation Organisation (n.d.). These processes were analysed in terms of their impact on trade facilitation and the harmonisation of transport infrastructure standards in the region. Special emphasis was placed on the alignment of economic and customs procedures as key factors in accelerating trade and enhancing the transit potential of Central Asian countries, as well as their influence on infrastructure development.

A central aspect of the study was the comprehensive analysis of the region's logistics and customs systems. Current logistical challenges were identified, and possible optimisation pathways were outlined through the adoption of advanced technological solutions. The research discussed directions for improving the performance of logistics centres and the use of cutting-edge customs technologies that can accelerate the movement of goods, reduce costs, and improve the overall efficiency of transit operations. The potential for establishing new logistics hubs and strengthening Central Asia's role as a key transit node was also considered.

The influence of economic policy on attracting both public and private investment into transport infrastructure development was also examined. The study highlighted the main mechanisms of public-private cooperation that facilitate the timely implementation of infrastructure projects. International best practices and various economic strategy models aimed at mobilising financial resources for the expansion of the regional transport network were reviewed, showing their direct influence on strengthening transit capacity.

Environmental considerations were also integrated into the scope of the research. The planning of transport infrastructure projects was assessed in terms of their impact on the environment, particularly in the context of global climate change. The extent to which Central Asian countries incorporate environmental risks into the design of new routes and facilities was analysed, along with the application of sustainable approaches to minimise environmental harm.

The final section of the study focused on evaluating the impact of logistics and customs infrastructure development on the transit capabilities of Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, and Turkmenistan. It examined the functioning of existing logistics centres and customs procedures, as well as the implementation of digital solutions aimed at improving transport operations. It was stressed that optimising these components accelerates transit, reduces logistical costs, and enhances trade connectivity, thereby strengthening Central Asia's competitive position in global markets.

Results

Infrastructure projects form the foundation for sustainable development and enhanced regional competitiveness. Beyond their material contribution, they create favourable conditions for effective interstate cooperation, expanded trade relations, increased investment inflows, and improved quality of life. In the context of Central Asia – where

transport infrastructure plays a pivotal role in successful integration into the global economy – the development of

modern transport networks emerges as a cornerstone of the region's economic strategy (Table 1).

Table 1. Infrastructure projects as a foundation for enhancing the competitiveness of the Central Asian region

Project	Cost (USD million)	Length/area	Expected increase in trade turnover (million tonnes)	Increase in throughput capacity (million people/cargo)	Delivery time reduction (hours)	Start year	Completion year	Funding
Kazakhstan-China Railway	6,000	1,300 km	15%	10 million tonnes/year	48 hours	2015	2025	Kazakhstan (50%), China (50%)
Aktau Port	1,500	2,000,000 m ²	20%	5 million tonnes/year	36 hours	2013	2023	Kazakhstan (100%)
Almaty International Airport	1,200	100,000 m ²	10%	4 million passengers/year	20% faster	2010	2020	Kazakhstan (100%)
Tashkent International Airport	800	90,000 m ²	12%	3.5 million passengers/year	25% faster	2012	2022	Uzbekistan (100%)
Turkmenistan-Iran Railway	620	677 km	10%	3 million tonnes/year	30 hours	2017	2024	Turkmenistan (70%), Iran (30%)

Source: compiled by the authors based on M. Augan & A. Alipbayev (2023), A. Beifert & A. Moldabekova (2024), C. Wu *et al.* (2024)

According to Table 1, the implementation of the Kazakhstan-China railway project has reduced cargo delivery time by 48 hours compared to the previous route through Russia, which relied on a combination of rail and road transport and involved prolonged border delays and transshipments. The new route provides direct rail connectivity, significantly accelerating the movement of goods (Augan & Alipbayev, 2023). The modernisation of airports in Kazakhstan and Uzbekistan has led to a 25% reduction in passenger and cargo handling time. This improvement was achieved through the adoption of digital solutions, upgrades to runways, and the enhancement of security and processing procedures. Compared with pre-modernisation figures, the average time savings per flight amount to approximately two hours. The Turkmenistan-Iran railway project has cut transportation time by 30 hours compared to the earlier route, which traversed Uzbekistan, Kazakhstan, and the Caspian Sea, involving a multimodal combination of road and maritime transport. The new railway offers a direct connection between Ashgabat and Bandar Abbas. This development creates new opportunities for Kazakhstan as a key transit hub, strengthening its position within global trade routes. The railway's construction enables deeper integration into international transport networks and facilitates the strategic use of the region's location to develop new logistics corridors, which contributes to the economic advancement of both Kazakhstan and its neighbouring countries.

In addition to rail infrastructure, port facilities have been actively developed, exemplified by the modernisation of the Aktau Port in Kazakhstan. Situated on the Caspian Sea, this maritime hub plays a pivotal role in facilitating trade flows between Central Asia, the Caucasus, Iran,

Turkey, and Europe. The port has undergone significant upgrades to optimise logistical operations. As a result, cargo delivery time has been reduced by 36 hours compared to routes via Bandar Abbas (Iran) and Alat (Azerbaijan), which previously required additional transshipment and administrative procedures, such as document clearance and vessel waiting times. The development of Aktau Port enhances Kazakhstan's ability to increase transit volumes and solidify its role as a vital component of international transport corridors (Beifert & Moldabekova, 2024; Kegenbekov *et al.*, 2024). Improvements at the Aktau Port include the expansion of port infrastructure, the modernisation of berths, the construction of new terminals, and enhancements to container handling capabilities. These upgrades have increased cargo throughput and service quality, thereby reduced business costs and improved overall logistics efficiency. Moreover, port expansion creates new opportunities for the development of transport and economic ties with neighbouring regions and countries, fostering trade and investment. The upgraded infrastructure also supports the development of multimodal transport. Alongside railways and ports, roads and airports remain crucial to the region's internal and external mobility of passengers and goods. Major highways and international airports – such as Almaty International Airport and Tashkent International Airport – are undergoing continuous expansion as part of large-scale infrastructure modernisation projects. These initiatives aim to boost capacity, improve passenger and cargo service quality, and strengthen international connectivity. Notably, the international terminal in Almaty has been renovated, and a new passenger terminal has been constructed in Tashkent, further integrating the region into global logistics networks. Such projects play a central role

in ensuring an efficient transport system, accelerating the movement of goods and people, and thereby enhancing the region's competitiveness on the international stage (Wu *et al.*, 2024; Kukeyeva *et al.*, 2024).

Infrastructure projects, such as the Kazakhstan-China railway and the development of the Aktau Port, form the backbone of Kazakhstan's competitiveness. These initiatives not only enhance transport networks but also create new opportunities for business development, logistics improvements, and the strengthening of trade positions. Advancing transport infrastructure contributes not only to regional economic growth but also to greater geopolitical

influence, allowing the region to assume a more prominent role in the international arena.

Integration processes are particularly significant in today's globalised world, where intergovernmental cooperation is a key driver of economic development and stability. For Central Asia, participation in organisations such as the Eurasian Economic Commission (EEC) and the Shanghai Cooperation Organisation (SCO) presents new opportunities for regional growth, improved trade relations, enhanced political and economic cooperation with neighbouring countries, and higher standards in transport infrastructure (Table 2).

Table 2. Impact of integration processes on trade and transport in Central Asia

Organisation	Member countries	Expected outcomes	Impact on goods transit (% increase)	Impact on trade relations (% growth in turnover)
Eurasian Economic Commission	Kazakhstan, Russia, Belarus, Armenia, Kyrgyzstan	Simplification of customs procedures, increase in trade turnover	10	15
Shanghai Cooperation Organisation	China, Russia, India, Kazakhstan, Uzbekistan, Tajikistan, Pakistan, Mongolia (observer status), Iran (observer status since 2021)	Enhanced competitiveness, creation of free economic zones	12	20
China-Central Asia Transport Corridor	China, Kazakhstan, Kyrgyzstan, Uzbekistan	Faster delivery of goods, development of new logistics routes	15	18

Source: compiled by the authors based on T. Kenderdine & P. Bucsky (2021), P. De Lombaerde *et al.* (2024), H. Mubarak & S. Akhtar (2024)

According to the data presented in Table 2, integration frameworks in Asia involving China deliver a higher growth rate in transit and trade relations compared to the Eurasian Economic Commission (EEC). The China-Central Asia transport corridor has the greatest impact on accelerating cargo flows, with an increase of 15%, underscoring its key role in the region's logistics development. The participation of Central Asian countries in the EEC holds strategic significance, as it facilitates the expansion of trade ties with the region's largest economies, improves business conditions and investment attraction, and optimises the internal transport network. Within the framework of the Eurasian Economic Union, substantial infrastructure projects are being implemented, aimed at enhancing industrial capacity and strengthening economic ties among member states. For instance, Kazakhstan is undertaking the construction of a polyethylene production plant in the Atyrau region, with an investment volume of 486.2 billion tenge, equivalent to approximately USD 1.1 billion (Performance under investment..., n.d.).

The Shanghai Cooperation Organisation (SCO) focuses on political, economic, and cultural integration among its members, establishing a foundation for cooperation in security, trade, energy, and infrastructure sectors. For Central Asia, the SCO represents a crucial mechanism to reinforce regional cooperation and expand economic linkages, especially with major economies such as China and India. Key cooperation priorities within the SCO include

the improvement of transport infrastructure, development of transit routes, and simplification of trade processes. SCO member states have agreed to cooperate based on principles of mutual benefit, harmonisation of transport standards, simplification of customs procedures, and the creation of favourable conditions for investment projects. In particular, agreements have been developed to support joint infrastructure initiatives, such as the construction and modernisation of roads, railways, and ports, alongside the introduction of new logistics technologies. These measures contribute to enhancing the region's attractiveness for foreign investors and improving the business environment in SCO countries (Mubarak & Akhtar, 2024).

A key element of integration within both organisations is the establishment of a unified transport network, which strengthens economic links and improves logistics. Notably, the development of transport corridors such as China-Kazakhstan-Europe, along with projects focused on modernising ports and railways, plays an essential role in reducing delivery times and lowering logistics costs. Integration of transport systems enhances access to global markets and consolidates Central Asia's position as a vital transit hub (Kenderdine & Bucsky, 2021).

The participation of Central Asian countries in organisations like the EEC and SCO is crucial for ensuring economic stability and growth in the region. Integration processes within these frameworks promote the enhancement of trade relations, the creation of a unified transport space,

standardisation, and increased competitiveness. Deepening cooperation with neighbouring countries opens up opportunities for Central Asia to strengthen its global standing and improve the quality of life for its population through infrastructure development and better economic indicators. In the context of globalisation, where the speed and efficiency of goods delivery are decisive for the growth of

international trade, the improvement of logistics and customs systems becomes essential for boosting regional competitiveness. Of particular importance are the development of logistics centres and the implementation of modern technologies in customs procedures. These advancements not only accelerate the movement of goods but also reduce costs, thereby ensuring higher overall transit efficiency (Table 3).

Table 3. Impact of EEC and SCO on logistics and customs systems in Central Asia

Country	Implementation of new logistics technologies (year)	Implementation of digital customs systems (year)	Reduction in logistics costs (%)	Reduction in customs processing time (days)	Notes
Kazakhstan	2021 (digitalisation of transport and warehouse systems, introduction of monitoring systems and process automation)	2022 (implementation of automatic declaration system, integration with international platforms)	8	3	In Kazakhstan, the implementation of technologies includes real-time monitoring systems, automated cargo handling, and new platforms for integration with global markets, accelerating cargo processing.
Kyrgyzstan	2020 (introduction of GPS tracking for goods, warehouse operation automation)	2021 (digitalisation of customs clearance, electronic declaration systems)	10	2	In Kyrgyzstan, technologies such as GPS tracking and warehouse automation are used to increase transparency in freight transport, alongside electronic declarations to speed up customs procedures.
Uzbekistan	2023 (digitalisation of logistics chains, introduction of unmanned delivery vehicles)	2024 (implementation of electronic customs clearance system, integration with the European Union (EU))	7	4	Uzbekistan is developing innovations in unmanned technologies and digital logistics platforms, as well as implementing electronic declaration systems and automated customs control to improve transit speed.
Tajikistan	2022 (innovations in transport and warehousing, introduction of new cargo management methods)	2023 (development of digital platforms for customs clearance)	6	3	Tajikistan is introducing new technologies for logistics flow management and digitalising customs procedures to accelerate the movement of goods across borders and enhance transparency.

Source: compiled by the authors based on K. Kim *et al.* (2022)

According to Table 3, the greatest reduction in logistics costs (10%) resulting from the influence of the EEC and SCO was achieved in Kyrgyzstan, thanks to the early implementation of GPS monitoring and electronic declarations. Meanwhile, Uzbekistan demonstrates more innovative technological solutions, particularly the use of unmanned transport and integration with the EU, indicating the country's strategy for modernising logistics and customs. Kazakhstan has become one of the regional leaders in adopting digital solutions in logistics. In 2021, the "Digital Transport Corridor" system was launched, encompassing the automation of warehouse processes as well as real-time cargo monitoring through the Kazakh Transporters' Union platform, KazLogistics. This has significantly increased the transparency of logistics operations and reduced delivery times (JSC KTZ Express..., 2024). These measures have strengthened Kazakhstan's position as a key transit hub on the China-Europe and North-South routes.

In 2020, Kyrgyzstan implemented GPS cargo monitoring as part of the TIR-EPD project within the framework of the International Road Transport Union (IRU) (The TIR-EPD system..., 2024). The automation of warehouse operations has enhanced the efficiency of distribution centres, especially in Bishkek and Osh. These steps, carried out to comply with EEC requirements, reduced logistics costs by 10% and improved delivery predictability, positively impacting the country's appeal as a transit route between China and Russia. Tajikistan began an active upgrade of its transport and warehouse infrastructure in 2022, including the implementation of digital freight flow management systems under the CAREC Corridors project, sponsored by the Asian Development Bank (Hussain *et al.*, 2024). In 2023, an electronic customs clearance system based on the Automated System for Customs Data (ASYCUDA) Lite version was introduced, accelerating data exchange between customs authorities and businesses. These initiatives reduced logistics costs by 6% and customs procedure times

to under three days, particularly on routes through the land borders with China and Uzbekistan. Increased transparency and predictability of deliveries position the country as an important transit element within SCO corridors.

Despite its non-aligned neutral status, Turkmenistan has shown interest in developing partnerships with regional integration bodies such as the EEC and SCO. The country is gradually strengthening cooperation with these organisations in logistics and digitalisation. The focus is primarily on transport-logistics and digital sectors, driven by Turkmenistan's advantageous geographical location. The country is actively modernising transport infrastructure, including high-speed highways and multimodal hubs, potentially laying the foundation for integration into international transport corridors supported by EEC and SCO member states. In 2022, the modernisation of Turkmenistan's transport corridors began with the introduction of high-speed rail systems and automated control points (Malakhov *et al.*, 2023). In 2023, pilot projects for digital customs control based on the "single window" principle were launched jointly with Iran and Kazakhstan. Future cooperation prospects include the exchange of customs data, the introduction of electronic platforms, and the standardisation of technical logistics norms. Thus, in each Central Asian country, the implementation of new logistics and customs technologies has had a significant impact on reducing costs and accelerating trade turnover. In most cases, these projects have been carried out in collaboration with international organisations or within the framework of regional initiatives under the EEC and SCO, enhancing transit potential and making the region increasingly attractive for international trade.

Logistics hubs have been equipped with new technological solutions that improve the efficiency of warehouses and transport nodes. The introduction of automated sorting systems has minimised the impact of human error and reduced mistakes in cargo handling. Kazakhstan – Logistics Centre in Almaty, a key transport hub in the country. In 2020, the centre implemented warehouse process automation, including automated sorting systems (Izteleuova & Izteleuova, 2022). This significantly sped up goods processing and decreased errors related to human factors. The centre actively utilises technologies for tracking and monitoring cargo.

The Port of Aktau, located on the Caspian Sea coast, is also undergoing rapid development. Since 2019, the port's infrastructure has been modernised, with new digital systems introduced to improve logistics and container handling (Malakhov *et al.*, 2023). Uzbekistan's logistics centre is situated in Tashkent, where logistics hubs are actively developing. One major project is the Tashkent International Airport, which has introduced automation systems to simplify cargo handling procedures, though these are primarily airport-focused. The country is also pursuing projects to establish automated warehouse complexes to improve goods processing (Eronen, 2001). Kyrgyzstan is also seeing growth in its logistics infrastructure

(notably the Trade and Logistics Centre in Bishkek), particularly through cooperation within the EEC framework. However, detailed data on specific warehouse automation and sorting projects in Bishkek is more limited and less extensively documented than in other regional countries (Zalesky, 2023).

Moreover, the digitalisation of warehouse operations has ensured the accuracy of logistics processes, reducing costs and accelerating order processing. This approach is exemplified by major European logistics centres such as the Port of Rotterdam, DHL's logistics centre in Leipzig, Amazon's fulfilment centre in Manchester, Kuehne + Nagel's logistics centre in Switzerland, and XPO's centre in Villefranche-sur-Saône, where robotic cargo flow management systems are employed. Enhancements in logistics and customs systems also help reduce costs associated with goods movement. Optimising logistics routes, improving infrastructure, and reducing customs clearance times substantially lower transportation costs, making products more accessible and competitive in international markets.

The reduction of logistics costs positively affects both small and medium enterprises and large corporations by lowering expenses and increasing overall business efficiency. Additionally, lower transport costs contribute to reduced final product prices, enhancing the region's economic attractiveness for foreign investors. In this context, Central Asia actively attracts investments from both external countries and EEC and SCO member states, thanks to integration processes within these organisations. Specifically, Kazakhstan attracts significant investments from China – especially in energy and infrastructure – and from Russia, which actively invests in agriculture and the oil and gas industry.

Furthermore, EU countries represent an important source of investment in extractive and processing industries (Barpybaev, 2024). In Kyrgyzstan, key investors include China and Turkey, primarily in infrastructure construction and the textile industry, as well as Russian companies engaged in energy and mining. Uzbekistan, in turn, actively attracts investments from China and South Korea, particularly in textiles and agriculture, as well as from Russia in construction and transport. European companies also show interest in investing in the extractive and processing sectors. Tajikistan, despite a smaller scale of investments, attracts capital from China, Russia, and Iran – especially in construction and energy – as well as from EU countries for small and medium-sized projects.

Optimising logistics centres and introducing new technologies in customs procedures are crucial factors for improving the efficiency of goods transit. Notably, the implementation of high-speed and automated systems such as ASKOD (Automated Document Control System) in Kazakhstan and the Automatic Goods Declaration System (AGDS) is actively employed to speed up border clearance and control processes. Since 2018, Kazakhstan has been rolling out ASKOD, also known as the "ASTANA-1" Information System (ASYCUDA), covering more than 15

customs procedures including export, import, and transit. This system enables entrepreneurs to submit declarations remotely, significantly accelerating processes and reducing corruption risks (Adylkanova, 2018). Turkmenistan introduced the electronic customs declaration system “ASYCUDA World” on 1 January 2020 in cooperation with the United Nations Conference on Trade and Development (UNCTAD). This system covers all customs regimes and is actively used to expedite clearance and control at the border (Business Turkmenistan, 2020). These systems significantly reduce processing times and minimise errors in cargo handling. For example, the implementation of GPS cargo tracking in Kyrgyzstan and unmanned delivery technologies in Uzbekistan further improves logistics processes by cutting transport costs and accelerating transit. The introduction of such technologies at customs checkpoints and logistics hubs enhances the transparency and efficiency of foreign trade, facilitating interaction with international platforms. These measures contribute to faster delivery processes, cost reduction, and improved service quality, positively impacting the region’s economy by boosting its competitiveness and appeal for international trade. Enhancing logistics infrastructure and automating customs procedures are becoming vital factors for sustainable growth and integration into global economic systems.

The Trans-Caspian International Transport Route (TMTM) represents a key transport corridor system connecting China with Europe via Kazakhstan, Turkmenistan, Azerbaijan, and the Black Sea. This route actively develops the transit capabilities of Central Asia, ensuring efficient transportation of goods and reducing delivery times between Asia and Europe. Within the framework of the TMTM, railway and port infrastructures are undergoing active modernisation, which contributes to improved logistical connections, reduced transit costs, and increased trade volumes in the region. One of the most important areas for improving logistical infrastructure in Central Asia, the EEC, and the SCO has been the implementation of digital technologies in customs procedures. In particular, Kazakhstan and Kyrgyzstan have introduced electronic declaration systems, such as the “Electronic Customs”, which automates the declaration submission and verification process, thereby shortening customs clearance times. Kazakhstan also actively employs the Automated Goods Declaration System (AGDS), integrated with international platforms, which significantly accelerates cargo processing and enhances transit transparency. Within the cooperation of EEC and SCO countries – for example, the Electronic Declaration System (EDS) of the EEC countries – all participants operate via shared digital platforms, enabling efficient real-time information exchange on transit cargo. This cooperation aims to simplify procedures, reduce the number of inspections, and speed up customs clearance within the single economic space.

In Uzbekistan, since 2024, an electronic customs clearance system has been introduced, integrated with European and international platforms (Bodaubayeva *et al.*, 2024).

This system facilitates faster processes and minimises human error, improving interaction with external markets. Thus, the use of digital monitoring platforms and electronic declaration systems within the EEC and SCO enables countries to collaborate effectively, accelerating goods transit and reducing costs, which significantly enhances the region’s competitiveness in international markets.

Under the “One Belt, One Road” initiative, China has actively developed electronic customs systems in partnership with Central Asian countries, simplifying goods transit and promoting increased bilateral trade volumes (Cao, 2019). To date, such systems operate in close cooperation with Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan. This particularly pertains to improved customs clearance procedures for rail, road, and air transport. For Kazakhstan, for example, an electronic declaration system was implemented, which speeds up cargo clearance processes at the border. The “Astana-1” platform operates actively in Kazakhstan, enabling data exchange between EEC countries and China, substantially reducing customs clearance times. Uzbekistan has implemented a similar system at key rail and road checkpoints, facilitating goods transit, especially within cross-border trade with China. Moreover, in major transport hubs such as the Khorgos port in Kazakhstan, electronic systems are actively used to manage cargo flows, and in some cases, these systems cover not only rail routes but also ports. Electronic customs systems are also well integrated into airport infrastructure, helping to accelerate air cargo processing.

These measures aim to ensure the uninterrupted movement of goods through key transport corridors, enhancing transit efficiency and reducing costs at various stages of the logistics chain. State economic policy plays a crucial role in creating conditions for developing the region’s transit potential. In particular, devising an effective strategy that supports both private and public investments in transport infrastructure is a vital factor for further strengthening the region’s international standing. In today’s globalised world, where fast and efficient goods movement is a competitive advantage, government support and investment incentives in infrastructure are essential tools for accelerating economic growth (Ayyildiz *et al.*, 2018).

A key aspect of economic policy is creating conditions conducive to attracting private investment into transport infrastructure development. Private capital can significantly expedite modernisation and construction of transport facilities such as roads, railways, ports, and airports. This requires introducing mechanisms to mitigate investor risks, such as tax incentives, subsidies, and provision of long-term, stable investment conditions. A prominent example of the effective implementation of such policy is the attraction of private investments in infrastructure development in some Asian countries, where public and private partners jointly design and manage transport projects, contributing not only to the renewal of facilities but also to increased transit volumes through these regions (Mukhamedova *et al.*, 2025).

Equally important is the support for public investment in transport infrastructure. State funding ensures the creation of essential foundational facilities such as main transport corridors, bridges, and port structures, which lay the groundwork for further private investment. It is crucial that state economic policy focuses on establishing efficient project management mechanisms, ensuring transparency and long-term planning. An example of successful public investment policy implementation is Kazakhstan's transport infrastructure renewal programme. Within the "Nurly Zhol" programme, aimed at modernising Kazakhstan's transport infrastructure, substantial public investments were allocated to building and expanding railway routes, as well as developing port facilities. The programme covers the period from 2015 to 2019, and its implementation has significantly enhanced the country's transit potential by ensuring more efficient connections with neighbouring states and reinforcing Kazakhstan's position as a key transit hub between China and Europe. One of the programme's main directions was constructing new railway lines, such as the "Khorgos–Almaty" line, which greatly increased capacity for goods transportation along international corridors. Additionally, the "Astana–Shchuchinsk" railway line was modernised, and improvements were made to existing railway sections, contributing not only to better internal transport communication but also to a significant reduction in transit times between major regions and neighbouring countries. Regarding port infrastructure, the "Nurly Zhol" programme also included a project to modernise the Aktau seaport, which significantly increased capacity for container and general cargo shipments across the Caspian Sea. The construction and expansion of the Kuryk port were completed within the programme, further improving infrastructure for goods transportation through this key Caspian region. The total amount of public investment in infrastructure projects under the programme reached approximately 4.1 trillion tenge (about USD 10 billion), a significant portion of which was directed towards developing transport corridors, railways, and port facilities. This, in turn, attracted private investments, positively impacting the economic development of related sectors such as construction, logistics, and cargo processing (Office of the Leading Group for Promoting the Belt and Road Initiative, 2019).

State economic policy has had a substantial impact on the development of transit potential in these countries. Creating favourable conditions for attracting private investment into transport infrastructure played a significant role in modernising logistical facilities. China and Kazakhstan (Khorgos–Almaty railway). Within the "One Belt, One Road" initiative, a project was implemented to modernise and construct the Khorgos (border with China) – Almaty railway line. Building this new railway route increased capacity and accelerated goods transit between China and Central Asia. The project was completed in 2015. The total Chinese investment in this project amounted to approximately USD 1.4 billion. China and Uzbekistan (railway infrastructure). Under the "One Belt, One Road"

initiative, China also invested in modernising Uzbekistan's railway infrastructure, including a railway construction project linking Uzbekistan with China. In particular, in 2017, a railway project heading towards China through Uzbekistan was completed. Chinese investment amounted to approximately USD 250 million. Turkmenbashi Port (Turkmenistan). China invested in developing the Turkmenbashi port, modernising infrastructure and expanding capacity to increase container transportation volumes. Chinese investments in developing the Turkmenbashi port infrastructure were estimated at 500 million US dollars. The project was carried out within the framework of the "One Belt, One Road" initiative cooperation, contributing to expanding Turkmenistan's transit capabilities. Aktau Port (Kazakhstan). Investments were made in reconstructing and modernising Aktau port infrastructure, including improving cargo turnover and expanding berths. The approximate investment amount was 300 million US dollars. Chinese companies participated in projects to reconstruct the port and upgrade its capacity to increase transit volumes as part of the "One Belt, One Road" cooperation (How projects are..., n.d.).

Specifically, Chinese investments in constructing terminals at the Lianyungang port significantly expanded export capabilities via maritime routes. One effective mechanism for financing logistics projects has been public-private partnerships (PPPs), which combine state and business resources. PPPs are important mechanisms for financing infrastructure projects aimed at logistics development and improving transit accessibility in Central Asia. Kazakhstan and Uzbekistan have actively applied the PPP model to implement several major infrastructure projects, which have contributed to improving logistical accessibility and increasing the efficiency of transit routes. In Kazakhstan, one of the key PPP projects in the logistics sphere is the construction and modernisation of transit roads and infrastructure based on the International Logistics Centre at Khorgos. This project was implemented within the "Nurly Zhol" programme, aiming to increase capacity and improve access to trade routes between China and Europe. Private investors were attracted to build warehouse facilities, railway terminals, and modernise port facilities. The total project cost was 3.4 billion US dollars, with the main stages of work scheduled for completion in 2019–2020. This project significantly improves Kazakhstan's transit infrastructure, increasing throughput, reducing transport costs, and shortening the time required for goods transit. In Uzbekistan, an important PPP project is the development of a transport and logistics centre in the Fergana Valley, realised in 2018. The project included building railway terminals, upgrading warehouse capacities, and implementing new digital technologies for faster cargo processing. Private investors provided a substantial portion of the financing, with total investments amounting to about 200 million US dollars. This project improved Uzbekistan's logistical accessibility for exports and imports, especially for transit goods passing through neighbouring countries.

Furthermore, the international logistics centre “Tashkent” has also become a significant PPP project in Uzbekistan. This involved constructing transport terminals and modernising railway and road networks, considerably accelerating cargo transportation processes. The project involved local companies and international investors from China and Russia. The total project cost is estimated at around 400 million US dollars (Ameh, 2024).

These public-private partnership (PPP) projects in Kazakhstan and Uzbekistan are aimed at developing transit infrastructure, improving logistical accessibility, and creating efficient transport corridors, thereby contributing to increased trade volumes and attracting investment into the economies of these countries. In particular, the development of the China-Kazakhstan-Europe transport corridor has played a key role in enhancing logistical connectivity and reducing delivery times. This corridor constitutes a vital component of the Silk Road, traversing China, Kazakhstan, and onwards to Europe, including transit through Russia, Ukraine, or other Central and Eastern European countries. The implementation of this transport corridor in Kazakhstan included the modernisation of railway infrastructure, construction and enhancement of port facilities (e.g., in Khorgos), as well as the development of road and aviation infrastructure, which significantly reduced cargo delivery times. Through PPP arrangements, private investors were engaged in the construction of terminals, logistics centres, and the modernisation of transport facilities. The reduction in transit time for goods along this corridor has led to increased trade turnover between China and Europe, while also significantly enhancing Kazakhstan's appeal as a transit hub within global trade routes (Nguyen *et al.*, 2021).

In Central Asian countries, the consideration of environmental factors during the construction and modernisation of transport infrastructure has become a crucial aspect of the long-term development of logistics. The introduction of sustainable technologies, such as energy-efficient systems and environmentally friendly transport, has contributed not only to the reduction of the carbon footprint but also to the enhancement of transport services (Wang *et al.*, 2024). The adoption of digital cargo flow management platforms has improved logistics efficiency by streamlining processes and expediting the transit of goods. For Central Asian countries such as Kazakhstan and Uzbekistan, environmentally sustainable projects have also attracted foreign investment, as adherence to environmental standards has become a key criterion for many international partners. For instance, the introduction of electric vehicles and renewable energy sources at transport hubs has helped reduce pollution and improve the overall transit environment, thereby increasing the region's competitiveness in international markets (Raimbekov & Syzdykbayeva, 2021).

A key element in improving the logistics infrastructure in Central Asian countries is the development of policies aimed at encouraging private sector participation. This includes reducing administrative barriers, simplifying the process of obtaining permits and licences, and providing

tax and financial incentives for private companies. One of the most effective tools in this area is PPP, which enables the pooling of public and private sector efforts to implement infrastructure projects. Within the PPP framework, private investors gain the opportunity to participate in high-return projects, which helps reduce risks and maintain the sustainability of transport infrastructure in the long term (Yang *et al.*, 2023).

Under China's Belt and Road Initiative, several multimodal transport hubs have been established to integrate different modes of transport and improve international transit. One such key hub is the Port of Lianyungang, located on the eastern coast of China. This port links maritime routes with rail corridors connecting China with Europe and Central Asia. Container trains passing through Lianyungang significantly reduce the time required to deliver goods from China to Europe – from several months to just a few weeks. Another significant multimodal hub is Khorgos, located on the border between Kazakhstan and China, which connects rail and road networks. Khorgos serves as a major transit point for goods bound for Russia, Europe, and the Middle East and is a key component of the transport corridor linking China with Europe via Kazakhstan. Another important facility is Dostyk, a rail hub on the Kazakh-Chinese border that plays a vital role in transporting goods to Europe through Central Asia. The Port of Piraeus in Greece is also a significant multimodal hub that links maritime and railway routes and is actively used for the transit of goods from Asia to Europe. The Port of Chennai in India and the city of Urumqi in Xinjiang, China, also serve crucial functions in multimodal transportation, facilitating the transit of goods between Asian, Middle Eastern, and European countries. These hubs are vital links in the international transport network, reducing both delivery times and logistics costs, while also fostering deeper cooperation among participating countries. The adoption of innovative logistics and transport planning solutions has helped to enhance the region's economic attractiveness and minimise environmental impact in line with the principles of sustainable development. An effective economic policy aimed at attracting both private and public investment in transport infrastructure is a key instrument for developing the transit potential of the region (Abdullayev *et al.*, 2024). The adoption of new financing methods and the creation of a favourable business environment not only support infrastructure expansion but also promote the region's long-term sustainable development. This contributes to improved competitiveness, enhanced economic conditions, and stronger positions in the global marketplace.

Global climate change has become one of the most pressing contemporary issues, significantly affecting ecosystems worldwide through rising temperatures, altered precipitation patterns, and sea level rise (Buribayev *et al.*, 2020). In such circumstances, it is crucial to consider environmental factors during the planning and implementation of transport projects. In Central Asian countries, the integration of sustainable development principles into

transport infrastructure is gradually gaining traction, with measures being taken to account for carbon footprints. Kazakhstan is actively advancing environmentally friendly technologies, including electric and hybrid vehicles, as part of its strategy to reduce emissions and improve air quality. A key aspect of modernisation is the development of energy-efficient rail systems and the use of renewable energy sources. Uzbekistan also considers environmental aspects in its transport infrastructure upgrades, implementing energy efficiency projects in rail transport and exploring initiatives to develop infrastructure for electric and hybrid vehicles. In Kyrgyzstan, steps are being taken to use alternative energy sources in transport, including the introduction of electric buses in cities, which helps reduce carbon emissions from public transport. Tajikistan is also working to improve the environmental sustainability of its transport infrastructure, although projects specifically aimed at reducing the carbon footprint remain limited. However, future plans include the development of energy-efficient and environmentally friendly transport facilities. Thus, Central Asian countries are gradually introducing sustainable technologies in the transport sector, with a focus on clean transport and the modernisation of existing infrastructure (Ibrayeva, 2023).

One of the main environmental considerations in transport project planning is the assessment of ecological impacts. Transport infrastructure – including roads, rail networks, airports, and seaports – can significantly damage ecosystems, such as by disrupting natural landscapes, obstructing wildlife migration routes, and polluting air and water resources. To prevent such consequences, comprehensive environmental assessments are required at all stages of project development. These assessments include analyses of biodiversity, and air, water and soil quality, as well as evaluations of potential risks to public health and ecosystems. It is essential that planners and developers take these factors into account and implement measures to minimise potential harm. Modern approaches to environmentally sustainable transport infrastructure design include the use of clean technologies and solutions that can significantly reduce negative environmental impacts (Gutarevych *et al.*, 2020). For example, the planning and construction of roads and railways should involve materials and technologies that minimise air and water pollution. Another critical step is the introduction of environmentally neutral vehicles, such as electric buses and cars, which substantially reduce emissions of carbon dioxide and other pollutants. In this way, sustainable technologies help to improve quality of life while protecting nature and ecosystems. In the design of port and airport facilities, it is necessary to consider not only their impact on land and water resources but also the potential for integrating alternative energy sources, such as solar panels and wind turbines. Such solutions can significantly reduce the carbon footprint and make transport infrastructure more environmentally friendly. Furthermore, it is important to establish waste collection and recycling systems, minimise noise pollution, and improve conditions for flora and fauna in surrounding areas.

The consideration of environmental factors in transport projects is becoming increasingly important against the backdrop of global climate change. Modern solutions can have a lasting impact on the state of the environment, making it essential to take proactive measures to minimise ecological harm. The application of sustainable design principles in transport infrastructure not only helps protect the natural environment but also enhances quality of life, creating a safe and comfortable environment for future generations. Thus, environmental issues are becoming an integral part of the planning process for transport infrastructure. In the context of climate change, it is crucial to implement environmentally safe and sustainable solutions that minimise the impact on nature and ensure long-term development. A key step in this process is the use of modern technologies that account for environmental risks, along with the integration of sustainability principles at every stage of design and construction.

Discussion

The study examined how the development of the transit potential of Central Asian countries is linked to their economic and integration cooperation. The findings indicate that active participation in integration initiatives – such as the Eurasian Economic Union and the Shanghai Cooperation Organisation – is a crucial factor in improving transit infrastructure. Engagement in these organisations has significantly enhanced transport communications and optimised trade routes, which, in turn, has positively influenced the economic performance of the region's countries. Integration processes have also accelerated the harmonisation of customs procedures and the reduction of trade barriers, making Central Asia more attractive to international investors.

A.K. Górecka *et al.* (2021) concluded that international economic unions contribute to the modernisation of transport infrastructure by creating favourable conditions for logistics flows. Joint investment projects are aimed at developing key transport hubs, ensuring uninterrupted movement of goods. The coordination of transport policy within unions enables route optimisation and reduces transportation costs. Y. Liang *et al.* (2021) found that integration agreements support the development of new transport corridors, increasing their throughput capacity and reducing delivery times. Simplified customs procedures and harmonised regulatory requirements lower trade barriers between countries. As a result, companies gain access to broader markets, and consumers benefit from a more diverse and affordable range of goods. The conclusions of Y. Liang *et al.* (2021) and A.K. Górecka *et al.* (2021) confirm the results of this study, as the improvement of transport infrastructure within economic unions indeed helps to reduce logistics costs. The analysis shows that integration agreements accelerate the modernisation of key transport corridors, which positively affects trade volumes and the speed of goods turnover. In addition, the harmonisation of customs procedures and the simplification of regulatory

requirements help minimise delays at borders, making international trade more efficient.

One of the key aspects of this study is the focus on infrastructure projects such as the construction of the railway between Kazakhstan and China and the development of the Port of Aktau. These projects have played a crucial role in strengthening transport links between Central Asia and other regions. The construction of the railway significantly improved logistics, speeding up delivery and reducing transport costs. Such initiatives enhance the region's competitiveness by providing Central Asian countries with vital transport corridors connecting them to European and Chinese markets. The study by J. Zhao *et al.* (2021) also highlighted that large-scale infrastructure projects play a key role in economic integration by lowering barriers to trade and investment. Modern transport hubs and logistics centres enable efficient regional interaction, strengthening their competitive advantages. As a result, the attractiveness of these areas to businesses increases, which stimulates economic growth and creates new jobs. Similarly, Z. Raimbekov *et al.* (2022) concluded that the development of strategic transport corridors ensures faster and more cost-effective goods movement, reducing logistics costs. Improvements in the transport network contribute to market expansion, which is particularly important for export-oriented industries. In the long term, such projects increase economic resilience by ensuring stable supply chains for raw materials and finished products.

These findings are consistent with the core arguments of this study, demonstrating the link between infrastructure development and increased regional competitiveness. The analysis shows that the modernisation of transport corridors contributes to trade growth and reduced logistics costs. The establishment of modern logistics hubs also facilitates access to international markets, highlighting the importance of infrastructure projects in stimulating economic development. Special attention was paid to the improvement of logistics and customs systems, which played a significant role in increasing the transit potential of the region. The implementation of modern technologies in customs procedures has accelerated goods movement and reduced processing costs. The development of logistics centres has also improved transport efficiency by ensuring prompt cargo handling and simplifying documentation processes. All these changes have made transit through Central Asia more competitive, contributing to trade growth and the expansion of international commerce. I. Meidutė-Kavaliauskienė & R. Činčikaitė (2023) also conducted a study confirming that the optimisation of logistics centres and the introduction of automated customs systems significantly reduce transit times. Modern distribution hubs enable more efficient storage and cargo handling, reducing business costs. The automation of customs control simplifies border crossing procedures, minimising delays and enhancing the transparency of trade operations. C. Dong *et al.* (2021) similarly found that new technologies and digitalisation accelerate international transport through the use of intelligent freight flow management systems. The

integration of blockchain and artificial intelligence in logistics processes increases data security and reduces the risk of fraud. As a result, companies benefit from more reliable and predictable supply chains, which positively affects the entire delivery process.

A comparative analysis of the research data reveals a clear trend towards increased efficiency of logistics processes through automation and digital technologies. The findings show that the implementation of intelligent freight management systems helps reduce transit times and logistics costs. Furthermore, the digitalisation of customs procedures enhances the transparency and security of international transport, underlining the key role of technological solutions in the development of global trade. In terms of economic policy, the research shows that stimulating private investment in transport infrastructure has become a vital element in developing the region's transit potential. Successful projects – such as the modernisation of ports and the construction of transport networks – have attracted substantial funding and enhanced the overall investment appeal of Central Asia. Investment in infrastructure projects has strengthened the region's position on the international stage, raising its status as an important transit hub for global trade (Stoian, 2024). Economic policies supporting such initiatives have yielded positive outcomes by encouraging investment and improving infrastructure quality. M. Celestin *et al.* (2024) found that both public and private investments are essential for the modernisation of transport and logistics systems, contributing to their efficiency and stability. Public-private partnerships offer the opportunity to attract additional funding and accelerate the implementation of infrastructure projects. This reduces the fiscal burden and creates more favourable conditions for entrepreneurship, thereby enhancing economic competitiveness. W. Jiang *et al.* (2021) identified economic policy as an important tool for attracting foreign investment in infrastructure projects by providing stable legal and financial frameworks. Tax incentives, guarantees, and subsidies increase the investment appeal of the transport sector. As a result, international cooperation is strengthened, and the modernised infrastructure fosters trade growth and economic development.

The analysis of research results shows that attracting private investment into infrastructure supports the rapid development of transport and logistics networks. The findings confirm that public-private partnerships help minimise budgetary costs and increase the efficiency of major projects. Moreover, a well-designed economic policy aimed at creating a favourable investment climate contributes to an increased inflow of foreign capital into the infrastructure sector. Despite considerable achievements, certain gaps have been identified that require further attention and research. One such area is the need for further development of environmentally sustainable technologies in the transport sector. In the context of global climate change and stricter environmental regulations, the region must adapt its transport systems to meet these challenges. The development of clean and energy-efficient

technologies in the transport sector has become a key priority for Central Asian countries. This will not only improve the environmental situation but also enhance the region's attractiveness to international partners. This issue has also been explored by A. Roy & S. Pramanik (2024), whose findings indicate that the integration of environmentally friendly technologies into transport projects is an important step in combating global climate change. The use of electric and hydrogen-powered vehicles and the establishment of infrastructure for alternative fuels help reduce CO₂ emissions. These efforts not only lessen the environmental impact but also improve the energy efficiency of transport systems. According to the study by G. Bodaubayeva *et al.* (2024), environmental standards are a key driver in modernising transport infrastructure, promoting the shift towards sustainable logistics models. The introduction of strict regulations on emissions and energy efficiency encourages the adoption of innovative solutions and the improvement of transport operations. This fosters the development of a more sustainable and cost-effective logistics system, supporting long-term economic growth.

It is important to emphasise that the introduction of clean technologies into transport systems requires significant investment and a comprehensive approach. The analysis shows that successful infrastructure modernisation is achievable through a combination of government support, private investment, and international cooperation. Moreover, compliance with environmental standards not only reduces ecological damage but also enhances the competitiveness of transport companies amid tightening sustainability requirements. Overall, the studies have confirmed that the development of Central Asia's transit potential in the context of economic and integration cooperation plays a significant role in ensuring sustainable economic growth and enhancing the region's competitiveness. Participation in international economic associations, the development of transport and logistics infrastructure, the improvement of customs procedures, and the stimulation of private investment are key elements contributing to the region's integration into the global economy. At the same time, it is essential to continue taking environmental factors into account and to strengthen measures aimed at improving the environmental sustainability of transport systems.

Conclusions

The study established that the development of the transit potential of Central Asian countries was directly dependent on the level of economic integration and the modernisation of transport infrastructure. The expansion and improvement of strategically important transport corridors had a significant impact on the region's competitiveness. Infrastructure projects such as the construction of the Kazakhstan-China railway, the modernisation of the Aktau port, and the development of the Trans-Caspian International Transport Route contributed to reduced delivery times, lower logistics costs, and the strengthening of Central Asia's position as a key transit hub between Europe and Asia.

The research also confirmed that the integration of the region's countries into international frameworks, including the EEC, SCO, and the Belt and Road Initiative, contributed to the enhancement of transit capacity. Participation in these structures facilitated the harmonisation of transport and customs procedures, the reduction of bureaucratic barriers, and the standardisation of logistics infrastructure. As a result, this reinforced trade relations, simplified cross-border goods movement, and improved the countries' positions in global markets.

Improving logistics and customs systems played a crucial role in increasing transit efficiency. The introduction of digital technologies, the development of logistics hubs, and the implementation of automated cargo flow management systems accelerated cargo processing, optimised delivery routes, and reduced operational costs. A significant contribution to the efficiency of transport corridors came from customs digitalisation projects, including electronic declaration systems and automated checkpoints introduced in several countries in the region. These measures also supported the attraction of private investment necessary for further expansion of transit potential. Participation in the China-Central Asia transport corridor resulted in the highest increase in transit freight – by 15% – and an 18% rise in trade turnover among the participating countries. Meanwhile, integration into the SCO contributed to a 12% growth in transit and a 20% increase in trade relations, indicating the organisation's high potential for strengthening regional economic ties.

An important factor in the sustainable development of the region's logistics infrastructure was compliance with environmental standards in the design and operation of transport facilities. In the context of growing climate challenges, the implementation of environmentally friendly technologies – such as low-carbon transport, energy-efficient logistics centres, and emission monitoring systems – has become increasingly relevant. These solutions help to minimise the environmental footprint of the transport sector while improving infrastructure quality and creating better conditions for sustainable economic growth.

Overall, the findings confirmed that the successful development of the transit potential of Central Asian countries requires a comprehensive approach that includes the modernisation of transport networks, active participation in international economic and logistics initiatives, the implementation of digital technologies in logistics and customs processes, and the consideration of environmental factors. All these elements are essential for enhancing the region's competitiveness and its integration into the global economic system. Further research is needed to examine the impact of digital technologies, artificial intelligence, and automated transport systems on increasing the efficiency of transit flows and reducing operational costs in the region.

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Анотація. Дослідження присвячене оцінці впливу економічної та інтеграційної співпраці на розвиток транзитного потенціалу держав Центральної Азії. В рамках дослідження застосовувалися аналітичні методи вивчення впливу інфраструктурних проектів, інтеграційних процесів, логістичних систем та екологічних факторів на динаміку розвитку транзитного потенціалу регіону. Результати дослідження підтвердили, що розширення транзитного потенціалу країн Центральної Азії тісно пов'язане з розвитком транспортної інфраструктури та поглибленням інтеграційних процесів у рамках міжнародних економічних та торгових об'єднань. Встановлено, що реалізація проектів із модернізації залізничних та автомобільних магістралей сприяла значному зростанню вантажообігу, а також зміцненню транспортних зв'язків як усередині регіону, так і з сусідніми державами. Створення спільних логістичних хабів та спрощення митних процедур значно сприяли скороченню термінів доставки товарів та зниженню супутніх витрат. Інтеграція до Євразійського економічного союзу та Шанхайської організації співробітництва сприяли зміцненню торговельно-економічних та інвестиційних зв'язків, що позитивно відбивається на масштабах та ефективності транзитних перевезень. Зокрема, збільшення транзиту товарів ключовими маршрутами склало 15 %, а зростання обороту зовнішньої торгівлі – 20 %. Отримані результати свідчать про необхідність подальших інвестицій у модернізацію інфраструктури, удосконалення митного регулювання та розширення співробітництва з міжнародними органами торгівлі. Реалізація цих заходів забезпечить стабільне зростання транзитного потенціалу та підвищення конкурентоспроможності регіону на світовому ринку. Проведене дослідження робить внесок у наукову сферу, формуючи аналітичну основу для розробки стратегій підвищення транзитного потенціалу країн Центральної Азії за рахунок інтеграції інфраструктурних та економічних аспектів в умовах міжнародної взаємодії

Ключові слова: транспортна інфраструктура; логістичні центри; митні процедури; торговельні відносини; конкурентоспроможність

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The influence of demographic processes on the formation and effective use of human capital in the context of regional economy

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Abstract. The purpose of this study was to identify existing problems in the utilisation of human capital in urban and rural regions of Azerbaijan. For this purpose, demographic data for 2000-2024 were analysed, and experts in the field of human resource management and human capital development were interviewed. As part of the research, a comprehensive analysis of human capital and demographic processes in Azerbaijan was carried out. Concepts related to demographic transition and human capital accumulation were considered, which made it possible to reveal the importance of quality educational programmes, decent pay and attractive conditions in periods of change in the age structure of the population. According to the survey data, 30% of respondents from rural areas pointed to the shortage of skilled labour, which might have affected technological innovation and economic growth rates in the regions. Urban respondents also confirmed this trend, with 35% noting difficulties in finding specialists with the required skills. In addition, it was revealed that the share of elderly people (over 60 years old) in the population structure tended to reach 15%, which posed new challenges for the social protection system. To overcome the negative consequences of population ageing, the need to develop mechanisms to engage the older generation in economic activity was justified. It was analysed how infrastructure constraints, public policies and urbanisation affected the professional mobility and competitiveness of workers; the results showed that with proper support from public institutions and employers, as well as the involvement of educational institutions in the constant updating of curricula, it was possible to mitigate the negative effects of population ageing and the shortage of qualified specialists. The research showed that maximising the economic potential of regions in the conditions of accelerated population ageing and migration processes required the interaction of state institutions, business and educational organisations

Keywords: population ageing; migration; public policy; infrastructure constraints; advanced training; urbanisation

Introduction

Demographic processes are increasingly influencing the socio-economic development of countries and regions: changes in the age structure of the population, migration flows, and declining birth rates are creating new challenges for labour markets, education, and social protection systems. These processes exacerbate the need to rethink strategies for the utilisation of human capital, which is a key factor of sustainable economic growth and social stability. From a regional economic perspective, factors such as educational attainment, access to health services and vocational training can be seen as determinants of human capital formation. For developing countries (Azerbaijan included), it is important to take into account the specificity of regions, as differences in the level of development of urban and rural areas have a significant impact on the dynamics and quality of human capital.

Studies on the impact of demographic and economic changes on human capital and the labour market in Azerbaijan have identified existing challenges and directions for development. H. Baghirov *et al.* (2022) showed that the Russian-Ukrainian war has changed trade flows, increased migration and required adaptation of labour resources, which at the same time opened new opportunities in the energy sector of Azerbaijan. According to K.V. Abdurakhmanov (2023), ageing population and migration led to the outflow of skilled labour from Azerbaijan. The author recommended a systematic approach to labour market adaptation through retraining programmes and support for older workers, and pursuant to S. Pürhani *et al.* (2022), investments in education and health can stimulate economic growth and reduce social inequality.

The problem of using human capital to realise demographic potential and fight poverty is also relevant. M. Idrees *et al.* (2022), in a study, revealed that demographic dividend can only contribute to economic growth

if human potential is effectively utilised through education and training, while S. Harnani (2023) stated that economic growth does not guarantee poverty alleviation with unresolved problems of high unemployment and inadequate quality of human capital. Although the reviewed studies have revealed significant interrelationships between demographic processes and the economy, the long-term impact of investments in human capital on poverty reduction remains understudied, especially in view of digitalisation and employment transformation.

The relationship between human capital development, innovation and economic productivity has been studied by a number of scholars. F. Rezaei *et al.* (2021) found that effective knowledge management has a positive impact on the productivity of organisations only if attention is paid to human capital development. That is, competent employees and knowledge sharing culture within the company play a crucial role in enhancing competitiveness. D.J. Deming (2022) noted that human capital forms the basis for sustainable growth if investments in education and skills start early in the life cycle and continue throughout life, and X. Zhang & X. Wang (2021) confirmed that the key indicators of the impact of human capital on the economy are education level, skills, and health.

Longevity and its impact on demographic and social sustainability are significant elements of sustainable development of society. Population ageing and declining fertility form new economic realities and, according to E. Gagnon *et al.* (2021), increase the pressure on labour markets and social systems. The authors conclude that solutions such as digitalisation and automation can compensate for labour shortages and increase the efficiency of the economy. J.W. Vaupel *et al.* (2021) also noted that increasing longevity increases pressure on health and pension systems, but also offers opportunities for the elderly population to

engage in economic and social life through retraining and flexible working conditions.

Despite the extensive body of research on human capital, the long-term impact of demographic change on the quality of the labour force and labour market adaptation to an ageing population remains understudied. The aim of this study was to examine regional differences in the formation and utilisation of human capital in different regions of Azerbaijan. To achieve this goal, the following objectives were set: to identify the main demographic trends affecting the labour market; to survey experts to identify regional differences in the formation of human capital; to identify the key problems and barriers faced by the regions.

Materials and Methods

Modern approaches to the theory of human capital, the role in the context of population ageing and the declining share of the working-age population were analysed. The concepts of the impact of investment in education, training, and health on sustainable economic growth were also considered, and statistical data on the demography of Azerbaijan

from the resources of the State Statistical Committee of the Republic of Azerbaijan (2012) and the President of Azerbaijan (Population of the..., 2025) were studied. Additionally, adaptation mechanisms, such as retraining and continuing education, aimed at activating older age groups were investigated, which revealed the need to integrate human capital theory with regional economic models.

The total number of respondents was 382, of which 257 were male (67.28%) and 125 were female (32.72%). The average age of the participants was 39.6 years. The sample was formed non-randomly from experts directly related to human resource management and human capital development. The sample included human resource managers, recruitment specialists, trainers, and consultants in the field of professional development of employees, as well as analysts engaged in strategic planning of human resources. This choice was driven by the need to obtain a professional assessment of the state of human resource capacity and to identify key issues and challenges associated with demographic change. Figure 1 showed the distribution of survey respondents by region of Azerbaijan and the location of the organisations.

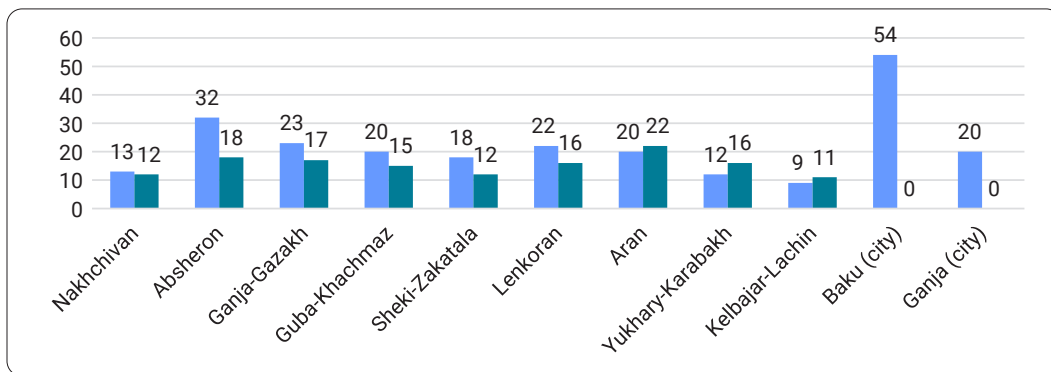


Figure 1. Distribution of respondents by type of locality

Source: compiled by the authors

The study was conducted in the second quarter of 2024 in compliance with the ethical standards specified in the Code of Ethics (American Sociological Association, 1997): respondents' participation was completely voluntary and informed; the respondents were also

guaranteed anonymity, and the information was used exclusively for scientific purposes. Study participants were sent questionnaires created in Google Forms format to the email accounts (Table 1). The questionnaire included the following questions:

Table 1. Questionnaire

No.	Question	Variance of answers
Block 1: Regional affiliation of the respondents		
1	In which region/city do you work?	a) Nakhchivan; b) Absheron; c) Ganja-Gazakh; d) Guba-Khachmaz; e) Sheki-Zakatala; f) Lenkoran; g) Aran; h) Yukhary-Karabakh; i) Kelbajar-Lachin; j) Baku (city); k) Ganja (city).

Table 1, Continued

No.	Question	Variance of answers
Block 1: Regional affiliation of the respondents		
2	Where is your company/organisation located?	a) city; b) rural area.
3	What personnel problem do you face most often?	a) lack of qualified specialists; b) high level of migration from the region; c) limited access to education and training; d) lack of vacancies for young people; e) other.
Block 2: General questions about demographic processes		
1	How do you assess the demographic situation in your region? (Assess on a scale from 1 to 5, where 1 – the situation is very bad, 5 – the situation is good)	open answer
2	What changes in the population of the region do you consider the most important?	a) decrease in the birth rate; b) increase in the number of the elderly; c) migration of young specialists; d) movement of population from villages to cities; e) other.
Block 3: Formation of human capital		
1	What problems with human resources do you observe in your organisation?	a) there are not enough young workers; b) there are not enough qualified specialists; c) there are many vacancies but no suitable candidates; d) the level of staff training is below the required level; e) there are not enough financial opportunities to offer decent salaries and attractive working conditions to specialists; f) other.
2	What role does education in your region play in personnel training? (Assess on a scale from 1 to 5, where 1 – does not help at all, 5 – plays a key role)	open answer
Block 4: Efficiency of human capital utilisation		
1	Which groups of employees in your organisation are experiencing the greatest difficulties?	a) young people (under 30 years old); b) middle-aged employees (30–50 years old); c) older employees (50+ years).
2	What, in your opinion, prevents the effective utilisation of human capital?	a) lack of human resources; b) poor infrastructure; c) low wages; d) lack of investment; e) other.
Block 5: Recommendations and perspectives		
1	What measures could improve the situation with human resources?	a) improvement of labour conditions; b) increasing salaries; c) development of professional training; d) programmes to attract young specialists; e) development of infrastructure; f) other.
2	What would help older employees to work better?	a) flexible working hours; b) retraining opportunities; c) improved working conditions; d) other.
3	How do you assess the support of the state in solving personnel problems? (Score on a scale from 1 to 5, where 1 – no support, 5 – support at a high level)	open answer
Block 6: Consideration of regional peculiarities		
1	To what extent does the specifics of your region influence the personnel situation? (Assess on a scale from 1 to 5, where 1 – does not influence at all, 5 – influences very strongly)	open answer
2	What features of the region do you consider important for the development of personnel policy?	a) economic conditions; b) the level of migration; c) infrastructure development; d) social policy; e) other.

Source: compiled by the authors

The collected data from the questionnaires were exported to Microsoft Excel for further processing; systematisation of responses, frequency distribution analysis, calculation of % age and arithmetic mean values were carried out. The results were visualised using charts and tables for visual presentation of the survey results. Student's t-test was used to test the differences in responses between urban and rural respondents. The analysis confirmed that the differences between the groups were statistically significant ($p < 0.05$).

Results

Theoretical analysis of the influence of demographic processes on human capital

Human capital theories developed in the 21st century suggest that investments in education, professional development and health are valid methods for sustainable economic growth (Qamruzzaman *et al.*, 2021; Sarwar *et al.*, 2021; Almutairi, 2024). However, in the context of demographic change, these theories require revision and adaptation to adequately respond to the challenges facing regions with declining populations. Classical approaches to human capital link its quality to the level of education, professional skills and health status of the working-age population. Nevertheless, the processes of natural population decline and ageing of society are transforming the age structure of the labour force, which has a direct impact on labour productivity. The increase in the proportion of older workers is accompanied by the need to find new methods for adopting new technologies, rising costs of maintaining employee health and an increased need for measures to adapt the work environment (Pang *et al.*, 2021; World Health Organization, 2021; Gong *et al.*, 2022). This necessitates a reorientation of investments: the focus is shifting from training young professionals to supporting the professional activity of older age groups.

One of the most significant areas of adaptation of the concept of human capital is the inclusion of approaches that consider the return on investment in the context of the demographic crisis. In a situation where the share of young working-age people is declining, the economic return on investment in older workers is increasing. Retraining and continuing education programmes for such workers are strategically important mechanisms for reducing the burden on the economy and maintaining gross domestic product growth. A related consequence of natural population decline is increased competition for limited resources of able-bodied labour. This is especially true in regions where migration processes intensify the problem: the most mobile and qualified personnel choose to move to economically more developed centres. In such conditions, human capital theory should be integrated with regional economic models that aim to create attractive working and living conditions for the retention and development of local human resources.

Population ageing, which is an integral part of natural attrition, has introduced an additional challenge for human capital management. Older workers have considerable accumulated experience but often face labour market constraints and lack of opportunities for professional growth, which requires the development of institutional mechanisms to encourage the participation in economic life. Such mechanisms could include tax incentives for employers to offer jobs to older employees or the introduction of flexible work schedules. Some scholars also believe that population attrition can increase the degradation of human capital (Adeleye *et al.*, 2022; Jones, 2022; Goldin, 2024). The integration of human capital theory with regional development concepts points to the need to invest in infrastructure, education, and health to maintain the socio-economic potential. A decline in the country's fertility rate can have a significant impact on the formation and reproduction of human capital (Fig. 2).

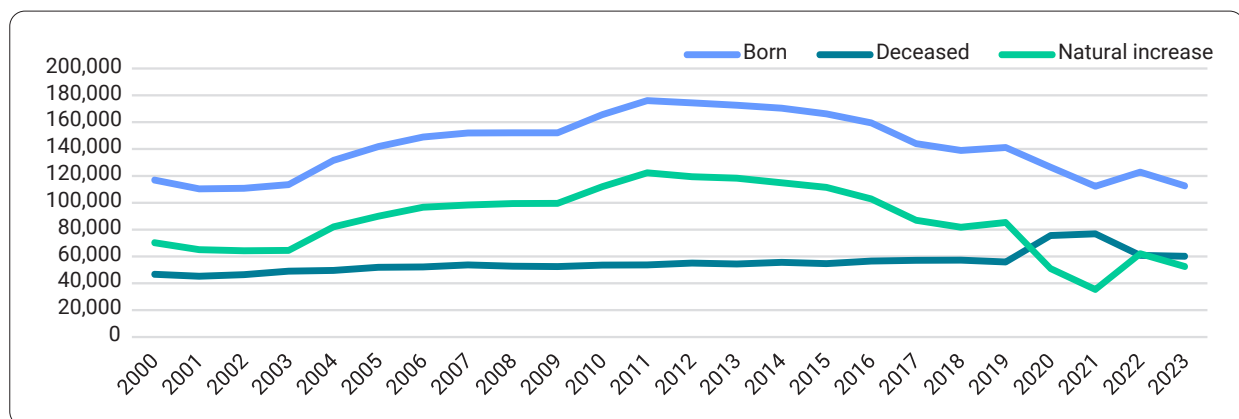


Figure 2. Dynamics of births, deaths and natural increase in Azerbaijan, 2000-2023

Source: compiled by the authors based on Population of the Republic of Azerbaijan (2025)

A decline in the number of children and young people can lead to a reduction in the base for the future working-age population, which weakens the economic potential

of regions and the country as a whole, and also creates the threat of untimely replacement of losses caused by the retirement of older generations (Table 2).

Table 2. Population of Azerbaijan by age groups

Age groups	Thousands of people						%					
	2019	2020	2021	2022	2023	2024	2019	2020	2021	2022	2023	2024
0-4	771.8	687.1	663	637.2	635.7	608.8	7.7	6.9	6.6	6.3	6.3	6
5-9	829.7	825.5	809.9	777	738	709	8.3	8.3	8.1	7.7	7.3	6.9
10-14	637.6	798.7	818.1	838.7	843.2	843.2	6.4	8	8.2	8.4	8.3	8.3
15-19	646.8	651.3	673.7	698.7	729.2	762.2	6.5	6.5	6.7	6.9	7.2	7.5
20-24	760.6	692	661.1	644.5	640.2	637.4	7.6	6.9	6.6	6.4	6.3	6.3
25-29	916.8	879.7	844.9	801.4	759.8	721.1	9.2	8.8	8.4	8	7.5	7.1
30-34	919.8	927.9	936.3	941	930.6	912.8	9.2	9.3	9.3	9.4	9.2	9
35-39	787.8	793.2	819.7	847.5	873.8	899.1	7.9	7.9	8.2	8.4	8.6	8.8
40-44	651.3	665.9	690.1	715.5	742.6	769.1	6.5	6.7	6.9	7.1	7.3	7.5
45-49	622.6	579.2	582.6	587.9	603.2	625.4	6.2	5.8	5.8	5.8	6	6.1
50-54	648.6	618.2	611.1	605	589.9	579.2	6.5	6.2	6.1	6	5.8	5.7
55-59	643.7	618.2	612.9	603.6	600.7	597.4	6.5	6.2	6.1	6	5.9	5.9
60-64	466.1	514.9	540	562	580.8	585.8	4.7	5.2	5.4	5.6	5.8	5.8
65-69	277.3	316.1	342	364.6	396.7	429.4	2.8	3.2	3.4	3.6	3.9	4.2
70+	401	406.1	420.7	438.7	462.7	500.9	4	4.1	4.2	4.4	4.6	4.9

Source: compiled by the authors based on Population of the Republic of Azerbaijan (2025)

The presented data showed significant changes in the structure of the age groups of the population. The decline in the number of infants and children was particularly noticeable: in the 0-4 years age group, the increase decreased by more than 20 % over the five years from 2019 to 2024, indicating a decline in fertility. The 5-9 years group has also shown a declining trend, due to the same reasons. The increase in the number in the 10-14 and 15-19 age categories is maintained by those born between 2000 and 2010, when fertility dynamics were increasing, but it can be assumed that these groups will also soon decline as less numerous generations follow.

The number of young people aged 20-24 and 25-29 is also declining. This situation may be related to the fact that fertility rates have been falling between 1990 and 2005, as well as to the outflow of young people in search of better opportunities abroad. At the same time, the group of 30-34 years old showed insignificant reduction (0.76% for the period under consideration) and stable leadership as the most numerous age group of the population of Azerbaijan.

At the same time, it should be noted that the decrease in the number of young people is not accompanied by a decrease in the requirements to the quality of education. On the contrary, according to scholars, the need to improve educational programmes is increasing as each unit of human capital becomes critical for economic growth (Abdelnabi, 2022; Rothomi & Rafid, 2023). Employers may face a shortage of young professionals, leading to changes in the labour market, including increased demand for automation and technology that can compensate for labour shortages. These changes transform the labour market and have social consequences that weaken the role of youth in social life and innovative development.

As for the following age categories, the situation is opposite: in five years, the 35-40 and 40-44 age groups have shown growth of 14% and 18% respectively, which can be

explained by the peculiarities of the demographic wave caused by the increase in birth rates in the 70s-80s of the 20th century, whose representatives are now moving into older age categories (State Statistical Committee of the Republic of Azerbaijan, 2012).

The increasing share of older people in the total working-age population creates new challenges for employment and training systems: maintaining the employment of older people requires the introduction of flexible working conditions, which entails additional costs for employers. At the same time, older workers need to update the skills, especially in the face of rapid technological change, but existing training programmes are often not tailored to the needs, creating additional barriers to the integration into modern labour markets.

It is important to note that the 60-64, 65-69 and 70+ age groups are steadily increasing, although the 50-54 and 55-59 groups are decreasing. Such dynamics may be related to the effect of natural attrition in the 50-59 age groups, which may indicate problems in the health system, working conditions or living standards in earlier periods. Thus, not all members of these generations reach older age groups. However, increasing the proportion of the older population is an opportunity for the State: through the implementation of appropriate policies, the inclusion of this group of citizens in social and economic life can be achieved.

Demographic ageing is changing the structure of the economy, with health care, social protection and care for older persons becoming important sectors. The development of these areas requires the training of personnel to work in these areas. The increasing number of older persons in the population also increases the costs of health and social care systems, and the additional costs can strain the economy and limit investment in other important areas (e.g., education and infrastructure).

At the same time, older generations, despite the extensive professional experience, have limited opportunities to

participate in the creation and implementation of innovations. This requires the introduction of programmes that promote intergenerational cooperation in order to harness the experience of older workers together with the creative potential of young people.

The demographic structure of Azerbaijan's regions is characterised by differences between urban and rural

areas (Fig. 3). The urban population of the country continues to increase due to internal migration, which leads to concentration of economic activity in large cities (Baku, Ganja and Sumgait). Urbanisation is accompanied by improved access to educational, health and vocational opportunities, but increases demographic and socio-economic disparities between regions.

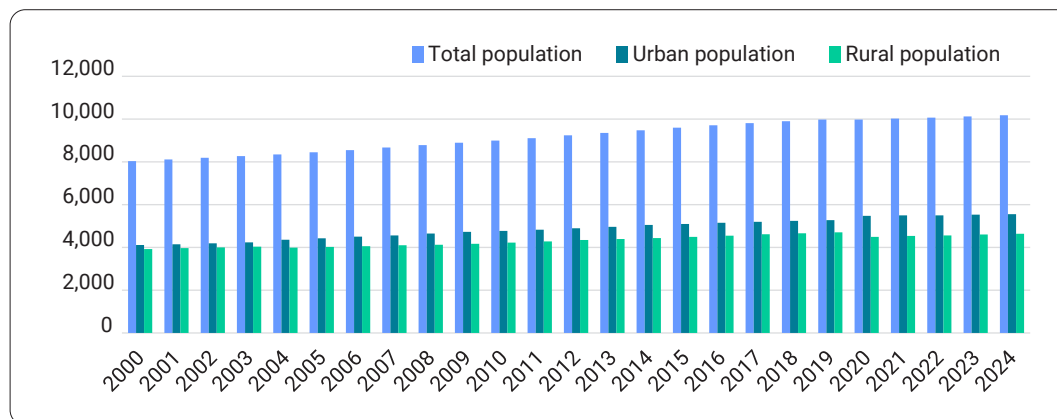


Figure 3. Population of Azerbaijan in 2000-2024

Source: compiled by the authors based on Population of the Republic of Azerbaijan (2025)

The 3.4% decrease in the population in rural areas can be explained by low-income levels, limited access to quality services and infrastructure, and reduced employment opportunities. This problem most often affects young people, resulting in an ageing rural population and a decline in the economic activity. The loss of the labour force in rural areas can create a vicious cycle: population decline undermines opportunities for local economic development, which in turn accelerates migration.

Differences in the level of development between urban and rural areas may be related to the insufficient involvement of rural areas in national economic processes. In the context of Azerbaijan, this problem is particularly relevant, as rural areas play an important role in ensuring the country's food security and preserving cultural traditions. The current situation requires a systematic approach aimed at gradually increasing the attractiveness of rural areas. By investing in infrastructure, developing local labour markets and creating opportunities for entrepreneurial activity, it is possible to help reduce migration and create more sustainable conditions for long-term economic growth in rural areas, strengthening the contribution to the overall development of the country.

Emigration of highly qualified specialists remains an important demographic and economic challenge for Azerbaijan. The desire of professionals to find more favourable conditions for professional fulfilment and life abroad leads to a drain of significant human capital, which hampers national development. Reduction of innovation potential becomes one of the consequences of such an outflow: it is known that when specialists with high competences in various fields (e.g., information technology, health care, science,

and education) become unavailable to the country's economy, this limits the possibility of introducing advanced technologies and reduces the state's competitive position in the international arena (Hermele, 2021; Elsner, 2022).

Public resources invested in education and training often yield returns outside the country, leaving a gap between the investment in human capital and its contribution to the national economy. This imbalance has long-term implications for economic sustainability. Furthermore, the emigration of skilled workers creates additional social challenges: skills shortages, especially in health and education, can lead to a decline in the quality of services, which exacerbates social inequalities as access to high-quality services becomes difficult for a large part of the population.

To mitigate the negative consequences of the departure of the educated population, it is necessary to focus on creating more favourable conditions for professionals within the country through competitive remuneration, prospects for professional growth and improvement of the overall quality of life. At the same time, it is important to develop repatriation programmes that will help those who have previously left the country to return and effectively integrate these programmes into the national economy. Such initiatives can significantly strengthen Azerbaijan's human capital and create a sustainable basis for its economic development.

Empirical analysis: Results of a survey of specialists in the field of human capital management

Representatives of all regions of Azerbaijan took part in the survey, which made it possible to cover the diversity of opinions and assess the peculiarities of human capital in different parts of the country (Fig. 4).

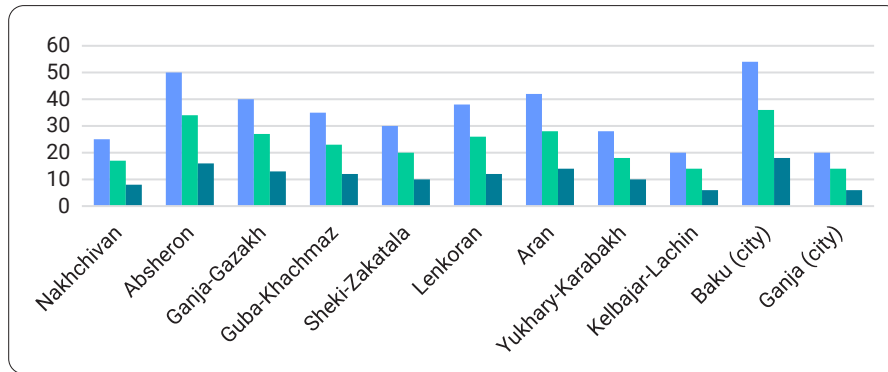


Figure 4. Regional affiliation of survey participants

Source: compiled by the authors

The distribution of respondents from urban and rural areas reflected the urbanisation trend: two thirds of

respondents were from cities. Data on the most widespread personnel problems in the regions are presented in Figure 5.

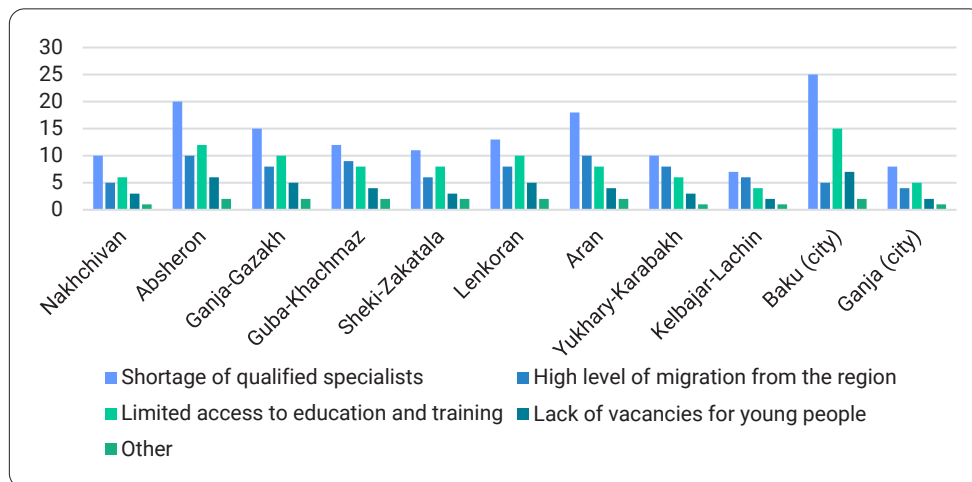


Figure 5. Distribution of experts' responses to the question about the personnel problems being encountered most often
Source: compiled by the authors

The answers received indicated that the most common problem faced by respondents is the lack of qualified specialists – it was reported by 39% of survey participants. This problem is most pronounced in Baku (25 respondents or 46%) and Absheron region (20 respondents or 40%), which indicates high competition for qualified personnel in economically more developed zones.

The second most significant problem was limited access to education and training, noted by 24% of respondents (92 out of 382). It should be noted that although the capital city, with its developed educational infrastructure, might show lower rates of this problem, 28% of respondents indicated the problem of limited access to education and training, which is high for a region with such resources. One possible explanation is competition for quality education: the capital may have a shortage of places in leading educational institutions or a lack of educational programmes that meet the demands of the labour market. In addition, limited access to retraining and additional training for working professionals may have affected respondents' perceptions.

Another factor could be the overload of educational infrastructure due to high population concentration.

At the same time, the high indicator in Baku may indicate specific requests of employers who expect higher qualifications from candidates than in the regions. Thus, the problem may be related not so much to the objective availability of education as to the high level of requirements in the labour market. A high level of migration from the region was mentioned by 21% of survey participants. This problem is most acute for such regions as Aran (24%) and Guba-Khachmaz (26%), which may be related to the lack of sufficient number of jobs and low level of salaries in these regions.

The results of answers to the question about demographic situation showed significant differences in assessment between the regions of Azerbaijan. The highest average scores were observed in Baku (4) and Absheron (3.8), reflecting the relatively favourable situation in these regions. In particular, 40% of respondents in Baku (22 people) gave a score of 5, the highest %age among all regions. On the other hand, the lowest average scores were recorded

in Yukhary Karabakh (2.8) and Kelbajar-Lachin (2.9). The overall average score for the country was 3.4, indicating a moderate assessment of the demographic situation. However, the high polarisation between regions suggests the

need for a differentiated approach to solving demographic problems depending on territorial specifics. The most important demographic changes in the opinion of respondents are shown in Figure 6.

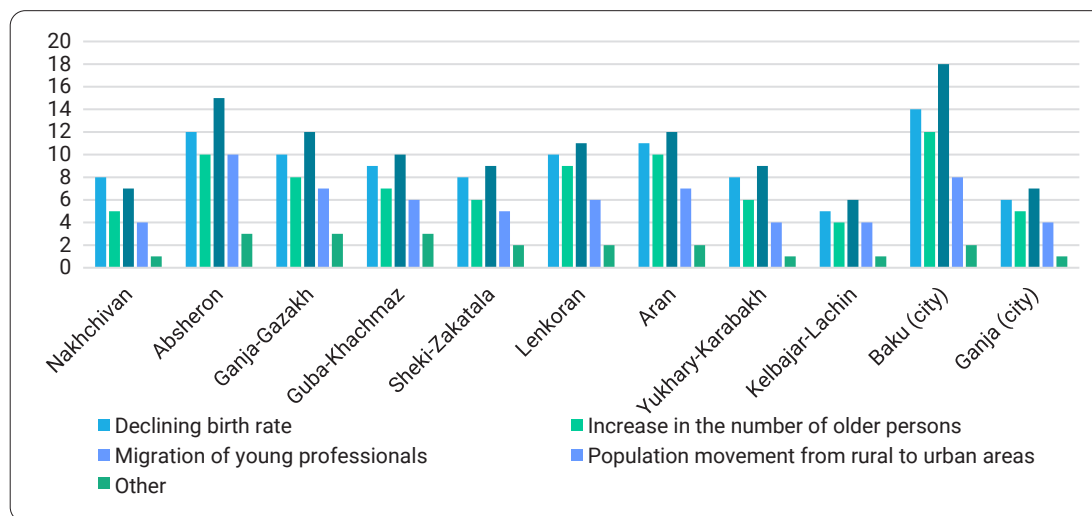


Figure 6. Distribution of experts' responses to the question about the most important demographic changes

Source: compiled by the authors

The survey results demonstrate that the most frequently mentioned change in the population of the regions is the migration of young professionals. This option was chosen by 30% of respondents (116 out of 382), and the highest %age of references to migration was observed in Baku – 33% (18 out of 54 respondents) despite the fact that when asked about staffing problems, respondents from Baku assessed migration as less significant. Since Baku, as an economic and cultural centre of the country, attracts specialists from other regions, the negative impact of migration on the local labour market remains low, emigration is perceived more as a general process affecting young people rather than a direct threat to the capital's staffing. High estimates of migration in Baku may also reflect concerns about brain

drain outside the country: the capital's companies and organisations often compete for talent internationally, which may reinforce the perception of this problem in the context of the global labour market.

In addition, a significant proportion of respondents from Absheron (30%) and Ganja-Gazakh (30%) also mentioned the migration of young professionals, indicating the need to create conditions for retention in these regions. It is worth noting that the decline in birth rate and increase in the number of elderly were the most relevant for the regions of Lankaran and Aran, where the share of responses was 26% and 24% respectively, indicating the challenges associated with ageing and changing population structure in these regions. The most worrying problems with labour resources for respondents are presented in Figure 7.

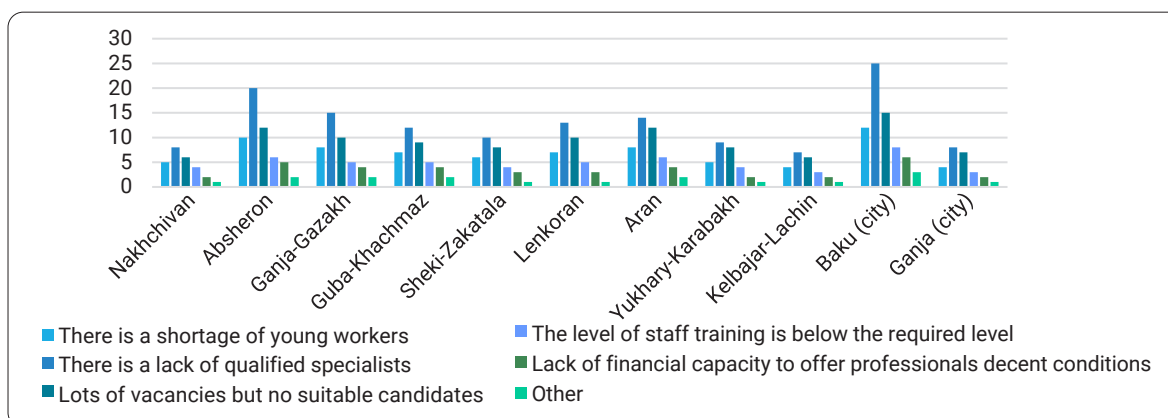


Figure 7. Distribution of experts' responses to the question about labour force problems

Source: compiled by the author

The data analysis confirmed that the distribution of answers to the question about problems with labour resources showed a stable pattern in all regions: in all cases, the most frequent answer was the lack of qualified specialists – this option was chosen by 42% of respondents (161 out of 382), followed by the answers about numerous vacancies without suitable candidates (27%) and insufficient level of employee training (14%). Financial constraints preventing from offering competitive labour conditions (10%) and lack of young employees (20%) remain important problems.

When asked about the role of education in staff training, the following data were obtained: the highest average score (4) was given by respondents from Baku, indicating the high level of educational infrastructure and its

importance for staff training. Absheron (3.8) and Ganja (3.7) also showed high results, which confirms the importance of these regions as centres of professional development. The lowest scores were given by respondents from Yukhara-Karabakh (2.8) and Kelbajar-Lachine (2.9). These data may indicate a lack of educational institutions or resources, which creates serious obstacles to the training of qualified personnel in these regions. The overall national mean score was 3.4, indicating a moderate perception of the role of education in addressing training challenges. Regional differences indicated the need to strengthen educational infrastructure in remote and post-conflict zones. The groups of staff experiencing the greatest difficulties in the work are summarised in Figure 8.

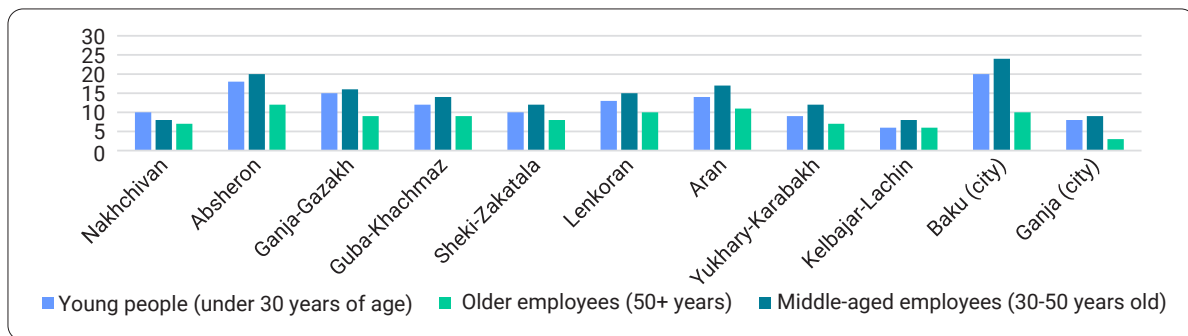


Figure 8. Distribution of experts' responses to the question about the category of employees experiencing the greatest difficulties in the company

Source: compiled by the authors

The survey revealed that difficulties in organisations are most often experienced by middle-aged employees (30-50 years old) – these difficulties were mentioned by 40% of respondents (155 out of 382). This group faces high demands both for professional qualifications and adaptation to the use of new technologies. Young people under 30 (35%, 135 out of 382) ranked second, which may

indicate a lack of experience or problems with adaptation in the working environment. Older employees (50+ years) were mentioned less frequently (24%, 92 out of 382), which may reflect the smaller size of this group in organisations or the less involvement in processes that require rapid adaptation. Barriers to the effective utilisation of human resources are revealed in Figure 9.

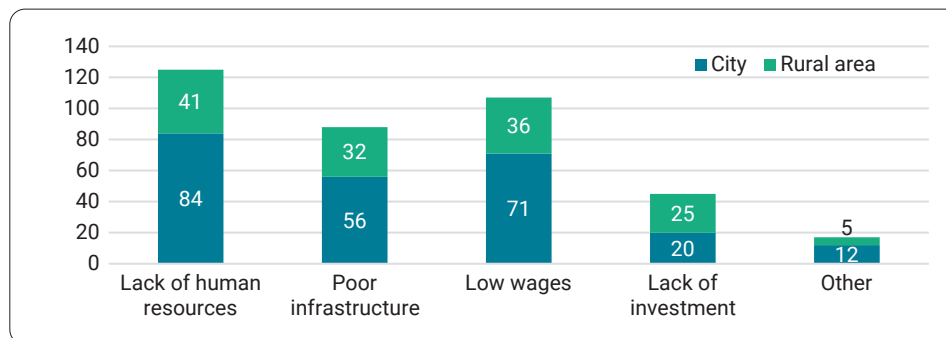


Figure 9. Distribution of experts' responses to the question about barriers to the effective use of human capital in cities and rural areas

Source: compiled by the authors

The most frequently mentioned problem for respondents from all regions was the lack of personnel, but this problem is more common in urban areas (35%) than in rural areas (30%), which may be due to high competition

for qualified specialists in cities, as well as migration of labour force abroad.

Poor infrastructure is a problem in both rural and urban areas (23% each), indicating the need for modernisation

throughout the country. Low wages are also a common problem in rural areas (26%) and cities (29%); respondents identified this problem as the main obstacle to the effective use of human resources, as restrictions in economic activity

reduce the ability to offer competitive labour conditions. Lack of investment affects villages (18%) more than cities (8%). The measures that respondents consider most effective to overcome the existing problems are presented in Figure 10.

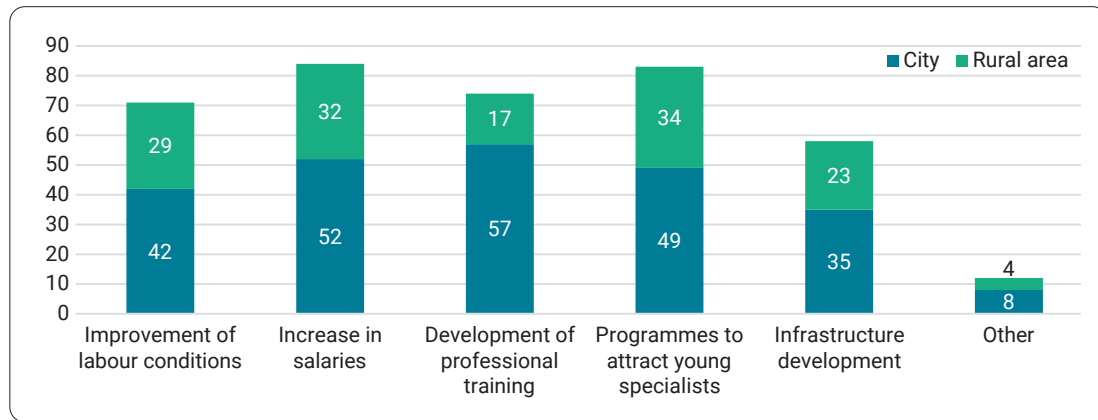


Figure 10. Distribution of experts' responses to the question about measures to improve the personnel situation in cities and rural areas

Source: compiled by the authors

The most popular measure, which, according to respondents, could improve the situation with human resources, was an increase in salaries. This option was chosen by 21% of respondents from urban areas and 23% of respondents from rural areas. The importance of financial motivation for increasing the attractiveness of work is the same in both urban and rural organisations. The prospect of using programmes to attract young professionals was assessed almost identically. The programmes were mentioned by 20% of urban respondents and 24% of respondents from rural areas, which indicates that the respondents understand the importance of creating conditions for professional growth and stability for young personnel, especially in rural areas. The development of professional

training was particularly relevant for urban respondents (23%), indicating a high demand for advanced training in the context of high competition for skilled labour. Infrastructure development was seen as more important for rural areas (17%) than for urban areas (14%), which is expected given the differences in access to basic services and working conditions in these regions.

Improving working conditions was supported by 17% of urban respondents and 21% of rural respondents, indicating the need for a better working climate to improve overall employee productivity. The measures that respondents considered most effective to integrate older workers into the ageing population of Azerbaijan are summarised in Figure 11.

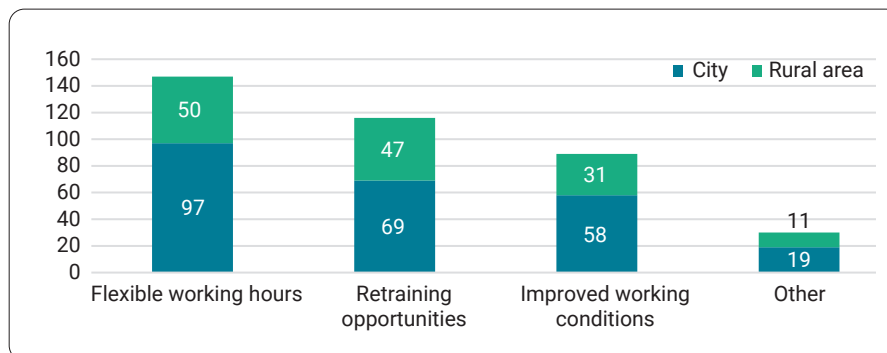


Figure 11. Distribution of experts' responses to the question on measures to improve the performance of older workers in cities and rural areas

Source: compiled by the authors

The most popular measure that respondents thought could help older employees work better was flexible working hours: this option was chosen by 40% of respondents

from urban areas and 36% of respondents from rural areas. Thus, it was found that the understanding of the need to adapt working hours to the capabilities and needs of older

employees is present among representatives of all regions of the state, which, however, may not always correspond to reality due to limited resources for training more employees or overloading the HR system.

The option of providing retraining opportunities was supported by 28% of urban respondents and 34% of rural respondents. The problem of training older employees in new skills to improve the performance is more acute in rural areas, which is a response to the trend of young people moving to cities and abroad and an attempt to preserve economic potential.

Evaluations of state support in solving personnel problems demonstrated respondents' perception of the level of this assistance: in urban areas, the largest number

of participants (29%) rated the support at 2 points, indicating low satisfaction with state support measures; a similar situation was observed in rural areas: 25% of respondents also gave a rating of 2, i.e., current state support measures are perceived as insufficient and do not meet expectations. State support was rated 1 by 25% of urban respondents and 29% of rural respondents, while only 7% of urban respondents and 6% of rural respondents gave a score of 5. Positive perception of state support is episodic and not mass. The average score for the country was 2.5, which indicates insufficient efforts of the state in the context of solving personnel problems. The impact of regional specifics on the personnel situation is disclosed in Figure 12.

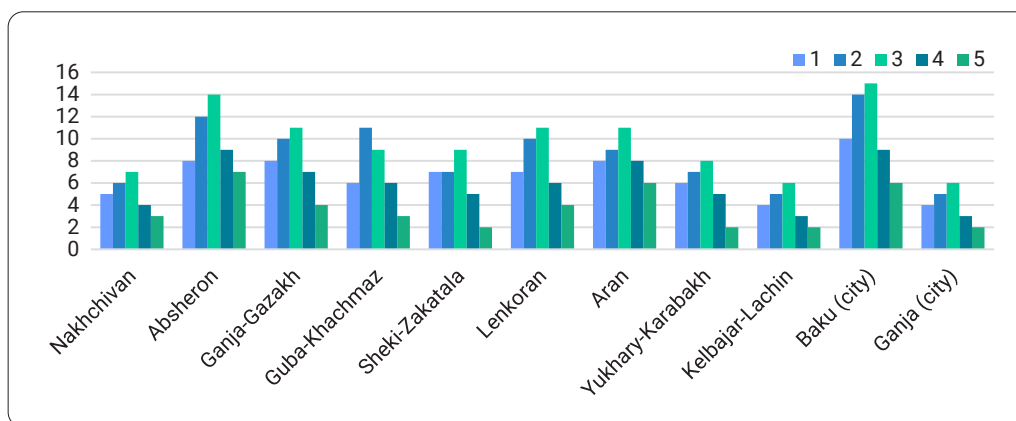


Figure 12. Distribution of experts' answers to the question about the influence of the specifics of the region on the personnel situation

Source: compiled by the authors

Assessment of the influence of regional specifics on the personnel situation showed that the majority of respondents perceive these specifics as a significant factor. The most frequent assessments (2 and 3 points) indicate a below average degree of influence. The greatest difficulties were identified in Sheki-Zakatala and Yukhary-Karabakh:

respondents from these regions indicated significant difficulties related to lack of infrastructure and limited opportunities for professional development. The highest scores were given by respondents from Absheron and Aran. The impact of regional characteristics on HR policy is illustrated in Figure 13.

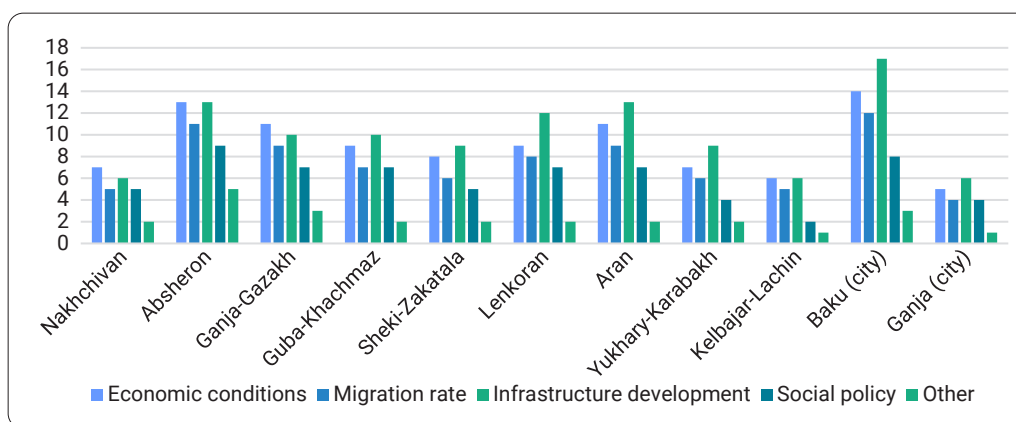


Figure 13. Distribution of expert responses to the question about the promising features of regions in the context of developing personnel policy

Source: compiled by the authors

Economic conditions, infrastructure development and migration level were the priority features that respondents consider important for the development of human resources policy. Economic conditions turned out to be the most significant for most regions, which confirmed the dependence of HR policy on the level of economic activity.

Demographic changes in Azerbaijan had a significant impact on the state of human capital in the regional economy: the reduction in the number of young people and the increase in the share of the elderly population transformed the structure of the able-bodied population, which created new challenges for the labour market. In developed regions, such as Baku and Absheron, growing competition for skilled labour has led to higher requirements for education and training, forcing employers to reconsider the approaches to human resource management.

Migration processes both within and outside the country have increased the imbalance between urban and rural areas. The study has shown that limited employment opportunities, low level of infrastructure and uneven distribution of educational resources contribute to the outflow of able-bodied population from rural areas. As a result of these processes, the economic potential of rural areas continues to decline, which aggravates the problems of population ageing and lack of qualified personnel.

To overcome these challenges, respondents pointed to the need to modernise approaches to human capital management by adapting jobs for older employees, developing infrastructure in rural areas and introducing educational programmes that could meet the current demands of the labour market. These measures can be considered as a basis for reducing the negative impact of the demographic crisis and increasing the efficiency of labour resources use in the future.

The analysis of answers also revealed that the level of state support in solving personnel issues remains insufficient. The survey participants noted that the existing measures do not meet the needs of the regions, especially in rural areas, which indicates the need to revise state policy to create equal opportunities in the development of human capital throughout the country.

Discussion

The study analysed the current situation of human capital and demographic processes affecting different age groups, and assessed the role of infrastructural and economic factors in the formation of human resources in Azerbaijan. The analysis of structural changes in the labour market and the barriers that hinder the effective use of workers' potential and reduce the attractiveness of certain regions has shown that if the current trends persist, without comprehensive measures to improve the level of qualifications and working conditions, the uneven distribution of human resources and the burden on the social sphere may increase.

The situation with human capital in rural areas of Azerbaijan can be characterised as follows: the lack of qualified labour force here is closely linked to low wages, poor infrastructure and limited opportunities for training and

professional development (Ismayilov *et al.*, 2024a). As a result, young people prefer to leave for cities or abroad, while the remaining population faces difficulties in adapting to the changing requirements of the labour market. Such dynamics leads to an unsolvable situation when the shortage of personnel complicates the economic development of rural regions, and the lack of effective mechanisms of state support makes it difficult to overcome this outflow (Rexhepi & Murtezaj, 2024). This imbalance leads not only to the decline of traditionally "rural" industries, but also to limited prospects for innovative endeavours. The low attractiveness of rural life has led to an outflow of young people, resulting in demographic shifts and a growing proportion of the elderly population requiring special adaptation programmes (Hasani *et al.*, 2023). The cumulative impact of these problems hinders the formation of a sustainable model of economic growth, as rural areas lose the development potential and cannot compete effectively with cities for investment and human resources. A comparison with the study by K.R. Schneider *et al.* (2024) on rural transformation in sub-Saharan Africa under conditions of climatic, demographic and social change showed a similar need to strengthen rural economies through education, infrastructure upgrading and social programmes. However, in the context of Africa, the authors of the reviewed study revealed the role of climate challenges and the need to balance traditional economy and innovation, while for Azerbaijan, it is socio-economic aspects that are crucial: insufficient state support, low wages and limited opportunities for vocational training hinder the effective use of human capital in rural areas.

Due to the fact that the most mobile and educated part of the youth leaves for the cities, rural areas remain without the necessary share of qualified labour force (Adilov, 2025). The reduction in the number of specialists is also aggravated by the fact that older generations have difficulties in mastering new technologies, and the labour market itself does not provide sufficient incentives for upgrading qualifications. The result can be an imbalance in which some local enterprises cannot find the right skills and potential employees do not see the point in investing in the own education, which undermines the economic sustainability of peripheral areas, preventing greater innovation and regional competitiveness. According to N. Sitohang (2022), successfully overcoming demographic challenges is possible if companies realise the value of human capital and invest in its development, including through corporate training programmes. Similarly, in the work of S. Bawono (2021) on how human capital and technological development affect economic growth in Indonesia, the author pointed out the importance of combining new technologies with a skilled labour force to strengthen the economy in the long term. For rural areas in Azerbaijan, conditions should also be created where education and professional development become accessible and in demand, and the development and application of innovative solutions are not limited to cities and large private enterprises.

In conformity with the results of the survey, there is heterogeneity in the quality of human capital in cities: despite a higher level of educational infrastructure compared to rural areas, a gap was found between necessary skills and actual competences. In particular, respondents pointed to the lack of practical training for young professionals and the lack of technology skills among older workers. At the same time, respondents noted low satisfaction with continuous learning opportunities: retraining and professional development programmes are not adapted to the rapidly changing requirements of the labour market in large cities. A study of the long-term impact of human capital on innovative development and economic growth in Europe by C. Diebolt & R. Hippe (2022) showed that sustainable economic growth is largely determined by the ability of regions to accumulate quality human capital that promotes innovation. In the context of Azerbaijani cities, this means that with proper investment in education and practice-oriented training programmes, it is possible to increase innovation and reduce skill imbalances. In turn, A. Grigorescu *et al.* (2021) studied the development of the digital economy in Central and Eastern European countries that are part of the European Union and found that in these countries, advanced IT competences and developed infrastructure are key success factors. Thus, increasing access to quality educational resources and improving digital learning practices will improve the adaptation of employees to technological change and enable the competitiveness and economic development of urban regions.

Over the period 2019-2024, the share of older people (60+) in the total population structure of Azerbaijan increased from 11.5% to 14.9%, which may lead to a rebalancing of the labour market as the number in the most economically active age groups decreases and the burden on the social services system increases (Ismayilov *et al.*, 2024b). That is, under conditions of limited financial and infrastructural resources, this may lead to a shortage of staff in the spheres of health care and social support. At the same time, some older citizens with valuable knowledge and experience could potentially remain economically active, but face a lack of retraining programmes and flexible employment options. Thus, the growing number of older people not only affects the social and economic situation, but also raises the question of the need to develop new mechanisms for integrating age groups into the economic life of society. N. Bairoliya & R. Miller (2021) studied the demographic transition in China and noted that declining fertility and an ageing society have turned the initial demographic dividend (an increase in the proportion of the working-age population) into potential ballast for the economy. The impact of this process is largely determined by the level of human capital: the higher the quality of education and training, the easier it is to overcome the negative effects of ageing and maintain sustainable economic growth. Similar results were shown by the study of S. Purohit (2023). The author studied demographic change in India and concluded that without proper investment in

human capital and job creation, the demographic transition can lead to unemployment and increased social inequality. In the context of the data presented on the growing number of older people in Azerbaijan, it can be concluded that comprehensive policies are needed to mitigate demographic risks: investing in lifelong learning programmes, promoting flexible employment and creating incentives to keep older age groups healthy. This approach will increase the economic activity of older people and retain the expertise in production and services.

The role of government support in the development and management of human capital, including by funding educational programmes and skills development initiatives, should be aimed at ensuring access to training for different population groups and adapting training courses to the changing needs of the labour market. Some respondents in the survey pointed to the possibility of closer coordination between different agencies and educational structures in order to strengthen the practice-oriented approach to training. The findings suggest that expanding the range of educational opportunities and further strengthening the links between government and employers can contribute to improving the quality of human capital. M. O'Neill & S. Bagchi-Sen (2023) revealed how public educational institutions in the United States have a significant impact on human capital formation by making education more accessible to the general population. The results of the study showed that stable funding and support of universities contribute to the training of in-demand specialists and reduce social inequality. Thus, the interaction of public educational institutions with real sectors of the economy, as well as regular updating of educational programmes will help graduates to adapt more quickly to the requirements of the labour market in Azerbaijan and contribute to the overall economic and social development of the country.

The reviewed studies have highlighted general trends in the formation of human capital and the impact of demographic changes on economic development. The authors agreed that it is difficult to ensure long-term growth and innovation activity without expanding educational programmes, improving the retraining system and considering regional specifics. At the same time, there are still gaps related to the mechanisms of retaining qualified specialists in remote areas, the formation of flexible forms of employment for the elderly population and overcoming the digital divide. These aspects require further research and more detailed analysis in order to improve the effectiveness of practical measures and strengthen socio-economic stability.

Conclusions

The study revealed the impact of demographic processes on human capital in Azerbaijan, its trends and challenges, considered changes in the age structure of the population, migration processes, as well as the impact of these factors on the economic and social stability of the regions. The revealed reduction in the number of infants and

young children in the 0-4 and 5-9 age groups against the background of an increase in the share of the elderly population has demonstrated a tendency towards population ageing, which in the future may lead to a decrease in the number of able-bodied population and create additional pressure on economically active age groups.

It was also revealed that internal migration from rural areas and emigration of qualified specialists abroad have significantly exacerbated the problem of economic instability of the state: the decline in the population of rural areas has undermined its economic activity, while the outflow of young people and skilled workers has limited the opportunities for innovation and competitiveness in the international arena.

The survey of experts in the field of human resources allowed drawing conclusions about the current situation with human resources and the impact of demographic changes on the regional economy of Azerbaijan. According to the results, 39% of all respondents named lack of qualified personnel as the most widespread problem. Respondents from Baku (46%) and Absheron region (40%) were most affected by this problem. Limited access to educational and professional resources was mentioned by 24% of respondents, and in rural areas this problem is aggravated by poor infrastructure and insufficient support from government programmes.

When asked about problems with labour resources, 42% of all respondents noted an acute shortage of qualified specialists. The lack of modern retraining and professional development programmes was noted by 14%, while 28% of respondents from urban areas and 34% from rural areas highlighted the need to create conditions for retraining

and adaptation of older age groups, due to the increasing proportion of the elderly population and the need for integration into the labour market.

The state policy aimed at supporting human capital, according to the survey participants, does not meet the current challenges. Insufficient efforts to develop infrastructure, launch targeted educational initiatives and stimulate the attraction of personnel to rural areas limit the effectiveness of labour resource management, which has a particularly acute impact on rural areas against the background of population ageing.

This study has highlighted the need to revise human capital management strategies in Azerbaijan through a comprehensive approach that includes adapting educational programmes to demographic changes, expanding state support measures, stimulating rural development and creating conditions for retaining qualified specialists.

It is recommended that further research should be devoted to studying the relationship between digital skills and the level of professional mobility of workers of different generations, which in the future will allow developing strategies to adapt human resources to technological changes and increase the sustainability of the regional economy.

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Conflict of Interest

None.

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Вплив демографічних процесів на формування та ефективне використання людського капіталу в умовах регіональної економіки

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Анотація. Метою цього дослідження стало виявлення наявних проблем у використанні людського капіталу в міських і сільських регіонах Азербайджану. Для цього було проаналізовано демографічні дані за 2000-2024 роки та проведено опитування експертів у сфері управління людськими ресурсами та розвитку людського капіталу. У рамках проведеного дослідження було здійснено комплексний аналіз людського капіталу і демографічних процесів в Азербайджані. Було розглянуто концепції, пов'язані з демографічним переходом і накопиченням людського капіталу, що дало змогу розкрити значущість якісних освітніх програм, гідної оплати та привабливих умов у періоди зміни вікової структури населення. Згідно з даними проведеного опитування, 30 % респондентів із сільської місцевості вказали на брак кваліфікованої робочої сили, що може позначитися на технологічному оновленні та темпах економічного зростання регіонів. Опитані з міст також підтвердили цю тенденцію: 35 % зазначили труднощі в пошуку фахівців, які повною мірою володіють необхідними навичками. Крім того, було виявлено, що частка літніх людей (старше 60 років) у структурі населення прагне до 15 %, що ставить нові завдання перед системою соціального захисту. Для подолання негативних наслідків старіння населення було обґрунтовано необхідність розроблення механізмів, що дають змогу залучати старше покоління до економічної активності. Було проаналізовано, яким чином інфраструктурні обмеження, державна політика та урбанізація впливають на професійну мобільність і конкурентоспроможність працівників; результати засвідчили, що за умови грамотної підтримки з боку державних інституцій і роботодавців, а також за умови залучення освітніх закладів до постійного оновлення навчальних планів, можна пом'якшити негативні ефекти старіння населення та нестачі кваліфікованих фахівців. Проведене дослідження засвідчило, що максимізація економічного потенціалу регіонів в умовах прискореного старіння населення та міграційних процесів потребує взаємодії державних інститутів, бізнесу та освітніх організацій

Ключові слова: старіння населення; міграція; державна політика; інфраструктурні обмеження; підвищення кваліфікації; урбанізація

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Food security as a basis for socio-economic sustainability in war conditions

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Abstract. In times of war, access to food affects the humanitarian situation, economic stability, and national security. The purpose of the study was to analyse the main challenges of ensuring food security in war conditions and identify key principles and priorities for its support. Methods of statistical data analysis, comparative analysis, and generalisation of theoretical approaches were used to develop recommendations for improving the sustainability of food systems in Ukraine. As a result of the study, it was found that due to a full-scale invasion in 2022, wheat production in Ukraine decreased by more than 30%, and sunflower oil exports decreased by more than 1 million tonnes compared to pre-war levels. The world grain price index rose 17.9% in 2022, confirming the significant impact of the war on global food security. The study highlighted the main challenges of ensuring food security in Ukraine caused by military aggression: destruction of infrastructure, reduction of production capacity, land pollution, lack of resources for farmers, and reduction of export potential. The impact of the armed conflict on the agricultural sector, global food markets, and the availability of food products for the population was assessed. The results of the study confirmed that to ensure food security of Ukraine, it is necessary to implement comprehensive measures: modernisation of logistics and production infrastructure, stimulation of innovations in the agricultural sector, strengthening state support for farmers, and reducing dependence on imports. Recommendations have been developed for strengthening socio-economic sustainability through effective management of food systems. The proposed solutions are aimed at minimising the impact of war, stabilising food systems, and creating conditions for economic recovery. The results of the study can be used to develop food security strategies, adapt agricultural and economic policies in war conditions, and develop programmes to support producers and consumers

Keywords: armed conflict; rural economy; economic stability; infrastructure; export potential; sustainability of food systems

Introduction

Food security is a fundamental factor in ensuring socio-economic stability and the well-being of society. In the current context of global challenges, in particular armed conflicts, the problem of ensuring food security has become particularly important. Wars and other crises pose serious threats to the functioning of food systems, limiting the availability, stability, and use of food. However, food security is not only a matter of physical access to food, but also an important element of social cohesion, economic sustainability, and national security.

Armed conflicts cause large-scale disruptions in agricultural production, destruction of infrastructure, economic decline, and forced displacement of the population. As a result, the risks of hunger, malnutrition, and social instability are increasing, which exacerbates inequality between different regions and segments of the population. During military operations, access to food resources becomes significantly more difficult, dependence on external aid increases, and the vulnerability of food systems to external shocks increases. M.F. Asghar *et al.* (2022) highlighted the deep global consequences of the conflict, in particular, its violation of international governance, sovereignty, and the balance of power. The study discussed how the invasion destabilised Ukraine politically, economically, and socially, and highlighted its implications for global food security, energy supplies, and transnational mobility.

H.S. Grantham (2024) analysed the relationship between human conflict, food security, and biodiversity. The study reported that military action and socio-economic instability in conflict zones lead not only to food shortages, but also to ecosystem degradation, which threatens wildlife conservation. The researcher stressed the importance of developing sustainable policies that reduce pressure on natural ecosystems while ensuring food security for vulnerable communities. He proposed a model of sustainable

resource use that includes the introduction of regulated wild animal catches and measures to support local agriculture, which can reduce dependence on natural ecosystems. O. Zghurska *et al.* (2024) examined the importance of sustainable development of Ukraine's agrosocial system after the war. The researchers emphasised the need to combine economic growth, social responsibility, and environmental sustainability to ensure food security and sustainable economic development. They proposed innovative approaches to the restoration of the agro-industrial sector, including the introduction of modern technologies, environmentally friendly production, and the development of social infrastructure in rural areas. The importance of ensuring food security during and after military crises is relevant not only for Ukraine, but also for many other countries of the world.

F.G.M. Yar & N. Karimi (2024) conducted a study of food security in rural Afghanistan, which is suffering from economic difficulties, armed conflicts, and weak infrastructure. The researchers analysed possible strategies for improving food supply, drawing on the experience of other countries with similar socio-economic conditions, such as Ethiopia, India, and Bangladesh. The researchers emphasised that the success of these strategies depends on adapting to the social, cultural and economic context of Afghanistan. This study highlighted the importance of an integrated approach to food security that combines increased agricultural productivity, income, and infrastructure. Using successful models from other countries can be an effective solution for Afghanistan, but they need to be adapted to the specific conditions of the region. R. Su *et al.* (2024) examined the impact of socio-economic and environmental policies on land conflicts and food security in China. The researchers have shown that effective land management in the face of increasing urbanisation pressures is critical to ensuring food security and environmental stability. The

most effective approach is a combination of economic and environmental strategies that ensure a balance between the conservation of natural resources and the development of urban and agricultural areas.

E. Halmaghi *et al.* (2023) examined the impact of armed conflict on food security, focusing on global impacts. The researchers noted that armed conflicts directly destroy key elements of the food system: the production, storage, and transportation of food in war zones. This makes it impossible to deliver the necessary resources to the local population, which exacerbates the humanitarian crisis.

The relevance of the study of food security in war conditions is conditioned by the need to find effective solutions to reduce the impact of armed conflicts on the agro-industrial sector, increase agricultural productivity, and ensure stable nutrition of the population. This is a key element in achieving economic sustainability, social peace, and the restoration of territories affected by military operations.

The purpose of the study was to analyse the main challenges of ensuring food security in war conditions, identify key principles and priorities for its support, and develop recommendations for strengthening socio-economic sustainability through effective management of food systems.

Materials and Methods

The study covered the period 2014–2024, which allowed tracking the impact of the military conflict on Ukraine's food security from the beginning of Russian aggression in 2014 and its escalation in 2022 to current challenges. The analysis included an assessment of the dynamics of changes in agriculture, export policies, infrastructure destruction, and changes in the economic availability of food.

To analyse the impact of war on food security, the following statistical and econometric methods were used: descriptive statistics – to assess major changes in food systems (production volumes, export indicators, price dynamics); regression analysis – to model the relationship between military operations and key indicators of the agricultural sector (for example, the impact of infrastructure destruction on grain production); correlation analysis – to assess the interdependence between changes in food prices, economic availability of products and risk factors (for example, inflation, logistics restrictions); trend analysis – to predict changes in production and exports time series analysis (ARIMA-modelling) – to assess the dynamics of food prices and export products; SWOT analysis – to identify the strengths and weaknesses of Ukraine's food security in war conditions.

The assessment of food security risks was carried out using a combined approach, which included: methods of multi-factor risk analysis – assessment of the impact of military operations, inflation, changes in the exchange rate, changes in the availability of fertilisers and fuel on the food sector; scenario analysis (What – if Analysis) – used to predict the possible consequences of various scenarios of war development (for example, the continuation of the blockade of Black Sea ports, the expansion of international assistance); modelling of the economic stability

of the agricultural sector – assessment of the stability of farms to economic shocks.

The following software tools were used to analyse statistical and econometric data: SPSS – for regression and correlation analysis of the relationship between war and food security indicators; Stata – for modelling time series and evaluating the dynamics of food prices; Excel – for data visualisation and calculation of basic statistical indicators.

Official statistical and analytical data were used for the study: State Statistics Service of Ukraine (n.d.a; n.d.b) – data on food production, export and import; Food and Agriculture Organisation of the United Nations (FAO) (n.d.) – information on the availability of access to food in Ukraine; World Food Programme (WFP) (n.d.) – assessment of the humanitarian impact of war on food security; World Bank (n.d.) – macroeconomic indicators and forecast assessments of the economic situation in Ukraine; Ministry of Agrarian Policy and Food of Ukraine (n.d.) – official data on losses of the agricultural sector due to the war.

Results and Discussion

Food security is a comprehensive system for ensuring the availability, sufficiency, safety, and quality of food for all people at all times. Rome Declaration World Food Security (1996) defines food security as a guarantee of providing high-quality, safe food and drinking water necessary for a healthy life and social development of every person. The definition covered two fundamental components of food security – nutrition and drinking water, recognising their critical role in maintaining a healthy life. Quality and safety are emphasised, which go beyond the mere availability of resources, highlighting their compliance with the standards necessary for health. The link between food security and socio-economic development is also emphasised. This is important because sustainable access to quality food and water is the foundation for social cohesion, economic growth, and reducing inequality.

The issue of food security in the context of socio-economic stability attracts considerable attention of foreign researchers. In particular, A. Sen (2000) noted that true development is determined not only by economic growth, but also by the expansion of human freedoms. He saw food security as one of the key components of freedom, which is the foundation for achieving other forms of freedom and general well-being. The researcher considered food security as the consumption of food by an individual, family, or social group, depending on their ability to acquire the necessary resources to meet their nutritional needs. The focus was on the economic availability of food and the ability of an individual, family, or social group to meet their nutritional needs through the acquisition of resources. A. Sen highlighted social and economic inequality, which can be a major barrier to nutrition even in countries with sufficient food supplies. This is especially true in times of crisis, when food prices are rising and incomes are declining. While the definition indicates dependence on economic opportunities, it does not sufficiently consider the impact of global

factors such as armed conflicts, climate disasters, or political instability that can completely destroy food systems.

American researcher L. Brown (2011) analysed the current state of the global economic system and the natural environment, focusing on the relationship between socio-economic stability and food security. S. Maxwell (1996) proposed an expanded approach to understanding food security. He stressed that food security covers not only the provision of food, but also socio-economic aspects that affect the availability and possibility of obtaining food. Its concept demonstrates the link between food security and broader development issues such as poverty, inequality, and sustainability. Maxwell emphasised the need to consider various dimensions of food security, including production, economic availability, use, and supply stability.

A more comprehensive definition of the concept of food security was proposed by P. Pinstrup-Andersen (2009). The researcher considered food security at several levels: global, national, regional, and household levels. It was noted that effective strategies should consider the challenges of each of these levels to ensure sustainable development. It treats food security as a condition in which all people at all times have physical, social, and economic access to a sufficient amount of safe and nutritious food that meets their nutritional needs and preferences for an active and healthy life. The definition contains such important components of this concept as the availability, safety, and quality of food, and also emphasises the need to meet both physical, social, and economic needs. However, in the context of today's global challenges, it is important to consider not only access to food, but also the control of communities and states over their own food systems.

The issue of food security was also explored by a number of international institutions that deal with this issue from various aspects: economic, social, environmental, and political. Food and Agriculture Organisation of the United Nations (FAO) (n.d.) is a key organisation that investigates issues of global food security, developing agriculture, fisheries, and forestry. The annual report of the State of Food Security and Nutrition in the World, which is being prepared jointly with the World Food Programme (WFP) (n.d.), the International Fund for Agricultural Development (IFAD), the United Nations International Children's Emergency Fund (UNICEF), and the World Health Organisation (WHO) monitors progress towards achieving Goal 2 of Sustainable Development of the United Nations – "Overcoming famine" (United Nations Development Programme, n.d.) and also analyses the challenges and risks that affect food security in the world.

Food and Agriculture Organisation of the United Nations (FAO) (n.d.) defines food security as a condition in which all people at all times have physical, social, and economic access to a sufficient amount of safe and nutritious food that meets their needs and preferences for a healthy life. The FAO definition covers all four dimensions of food security: physical accessibility (availability of sufficient food); economic accessibility (ability to purchase food from income or other resources); social access (consideration of

social conditions that may affect access to food); food safety and quality (ensuring that food meets nutritional and safety standards). It is important to note that the definition pays attention to individual nutritional needs and preferences. This makes it more human-centred and adaptable to different cultural contexts. M. Zakhodym (2022) revealed food security as a state of the economy that ensures stable physical, economic, and social availability of food products, their safety and high quality. This situation guarantees a sufficient level of food supply under normal conditions and a minimum level in emergency situations, while maintaining the country's food sovereignty.

Law of Ukraine No. 1877-IV (2004) defines food security as the protection of human vital interests, which is expressed in ensuring unhindered economic access to food for maintaining normal life. The law proposes a definition of food security that focuses on the economic aspect of access to food. This definition emphasises the role of the state in ensuring the basic needs of the population by creating conditions for economic access to food. The definition emphasises that food security is a basic human right necessary for the maintenance of its normal life. This is an important socially oriented approach that corresponds to modern concepts of human rights and highlights state guarantees as a key mechanism for ensuring food security. This reflects the government's commitment to creating an enabling environment for economic access to food through price regulation, support for the agricultural sector, and social protection for vulnerable segments of the population. Emphasis on economic access to food, which is critical, especially in times of economic crises, when rising food prices can endanger the nutrition of the most vulnerable categories of the population. The Law of Ukraine "On state support for agriculture of Ukraine" offers a basic definition of food security, focused on economic access. However, to fully reflect the current concept of food security, it is necessary to include aspects of stability, food quality, and consider global challenges.

Order of the Cabinet of Ministers of Ukraine No. 684-r (2024) offers a definition of food security that reflects the current understanding of this concept, with an emphasis on the physical and economic availability of food products, and their safety and compliance with human needs. It is emphasised that food security is "...a component of national security and defence of Ukraine. ...is a system that clearly functions to provide all segments of the population with food products in accordance with accepted physiological norms at the expense of domestic production and necessary imports of those food products for which there are no domestic conditions". It is noted that armed aggression has become a global test for food security not only for Ukraine, but also for the whole world and can cause political instability in dozens of countries around the world. The main problems that are critical for ensuring food security in Ukraine and whose solution requires a comprehensive approach involving cooperation between government agencies, international partners and the agricultural sector are the following (Table 1).

Table 1. Problems of food security of Ukraine in the conditions of war

Problem	Content of the problem
Disruption of logistics chains	Armed aggression has led to significant destruction of transport infrastructure, which is critical for the delivery of agricultural products and food products to consumers. The blockade of seaports, through which the main export of agricultural products was carried out, significantly limited Ukraine's opportunities on world markets.
Reduction of production capacity	As a result of the fighting, many agricultural facilities were destroyed or damaged, including farms, food processing enterprises, grain elevators, and irrigation systems. This led to a decrease in agricultural production.
Land pollution	About 30% of agricultural land has become unusable due to mining or chemical contamination as a result of military operations. This creates additional difficulties for sowing campaigns and reduces the area suitable for growing crops.
Lack of resources for farmers	Agricultural sector faces a significant shortage of fuel, fertilisers, seeds, and plant protection products. In addition, high global prices for these resources limit the access of Ukrainian farmers to the necessary materials for production.
Insufficient government support	The lack of systematic state support programmes aimed at restoring destroyed enterprises and adapting to EU requirements significantly complicates the possibility of effective restoration of the agro-industrial complex.
Deterioration of food availability	The decline in the consumer capacity of the population caused by the economic consequences of the war makes it difficult to access food. Rising food prices are exacerbating the problem, especially in the regions that have suffered the greatest losses.
Reduced export potential	Due to the loss of stable export channels, the volume of deliveries of grain and other agricultural products to international markets has significantly decreased. This has a negative impact on both Ukraine's economy and global food security.
Lack of state food reserves	There is virtually no effective system of strategic food reserves in Ukraine, which creates additional risks under martial law.
Changing the consumption structure	Migration of the population, in particular, internal and external, has led to a reduction in the fund of domestic food consumption, which creates an uneven distribution of food resources between regions.
Destruction of the irrigation system	In the southern regions, a significant part of the irrigation system has been destroyed, which makes it difficult to grow crops, especially in arid conditions.
Deterioration of the humanitarian situation	In regions affected by significant destruction, there is a shortage of basic food, which causes a humanitarian crisis and poses risks to the most vulnerable segments of the population.
Growing dependence on imports	Restrictions on the production of certain categories of food products increase Ukraine's dependence on imports, which creates additional economic risks in an unstable geopolitical situation.
Environmental consequences of war	Water pollution, destruction of natural ecosystems, and the spread of explosive objects on agricultural land pose long-term risks to Ukraine's food security.

Source: compiled by the authors based on data from the Order of the Cabinet of Ministers of Ukraine No. 684-r (2024)

Food security problems caused by the war seriously undermine Ukraine's socio-economic sustainability, creating multi-level threats. The destruction of logistics and production chains, land pollution, reduced export potential and rising food prices lead to a decrease in the standard of living of the population, increased unemployment and economic inequality. The lack of resources and insufficient state support complicate the recovery of the agricultural

sector, which is a key driver of the economy. These challenges exacerbate the humanitarian crisis, reduce the purchasing power of the population, and increase the country's dependence on external aid, jeopardising both national security and sustainable development prospects. However, these are not the only challenges that are associated with the violation of food security in Ukraine. Table 2 summarises the risks to food security.

Table 2. Risks to Ukraine's food security

Risks	Content of risks
Economic risks	Armed aggression leads to significant challenges for the Ukrainian economy, including limited access of farmers to credit resources, high prices for raw materials, fertilisers, and fuel, and an increase in the tax burden. These factors complicate the functioning of the agricultural sector and reduce its competitiveness in the global market.
Military risks	The fighting caused the destruction of infrastructure, enterprises, and agricultural land. Mining of territories, damage to irrigation systems, and destruction of agricultural facilities significantly affect the ability to grow and process food.
Environmental risks	Chemical pollution of land, destruction of water resources, excessive use of fertilisers and soil degradation pose a serious threat to the environmental stability of agricultural territories. In addition, climate change increases the negative impact on the agro-industrial complex.

Table 2, Continued

Risks	Content of risks
Technological risks	The lack of innovation and the destruction of research infrastructure make it difficult to introduce new technologies in the production and processing of agricultural products. However, the lag behind global trends in technological progress deepens dependence on external technology supplies.
Social risks	Deterioration of the humanitarian situation, rising unemployment, and declining incomes significantly reduce the availability of food for vulnerable groups. In addition, internal and external population migration causes an uneven distribution of food resources.
Infrastructure risks	Destruction of transport, logistics, and storage infrastructure (grain elevators, refrigeration units) limits the ability to store and transport agricultural products. Imperfect infrastructure also complicates the development of the agricultural sector and reduces its efficiency.
Import dependency	Due to the loss of part of its production capacity, Ukraine is forced to partially rely on the import of certain food products. This creates additional economic risks in an unstable geopolitical situation.

Source: compiled by the authors based on data from the Order of the Cabinet of Ministers of Ukraine No. 684-r (2024)

Each of these risks requires a comprehensive approach to overcoming, in particular infrastructure development, stimulating innovation, environmental monitoring, and active support of the agricultural sector at the state level.

Russian aggression has profoundly affected Ukraine's ability to ensure food security and maintain stable agricultural exports, creating new challenges for both the Ukrainian economy and the global food system (Fig. 1).

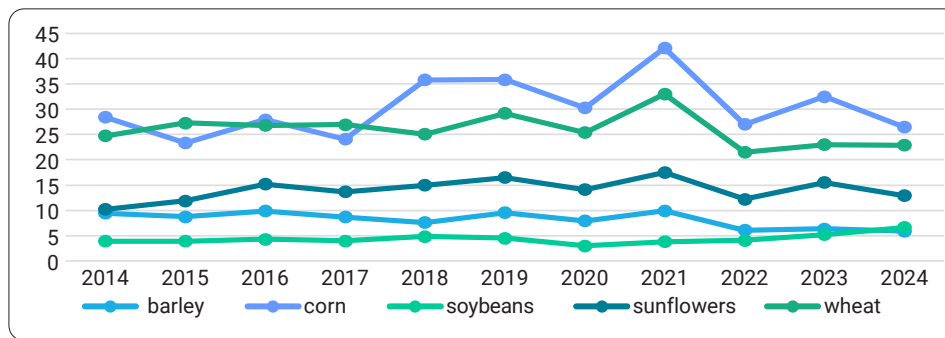


Figure 1. Production volume of barley, corn, soybeans, sunflowers, and wheat in Ukraine, thousand tonnes

Source: compiled by the authors based on data from United States Department of Agriculture (USDA) (n.d.)

According to N. Havrylenko *et al.* (2022), when assessing the importance of the Ukrainian agricultural sector for global food security, statistics clearly prove its significance. Statistics show that Ukraine is a leading producer of sunflower (more than 60% in the world production of sunflower seeds), wheat (about 40%) and corn (about 30%), which makes it an important player in the global agricultural sector. The global importance of Ukraine and Russia in these categories reinforces their role in ensuring global food

security, and highlights the risks to the global market in the context of conflict or other destabilising factors.

The war significantly affected global markets for wheat, corn, and barley. Together, Ukraine and Russia are among the largest grain exporters, and export disruptions due to port blockades and infrastructure destruction have caused a shortage of products on world markets. This, in turn, led to a sharp increase in prices. For example, wheat prices rose particularly strongly in 2021-2022 (Fig. 2).

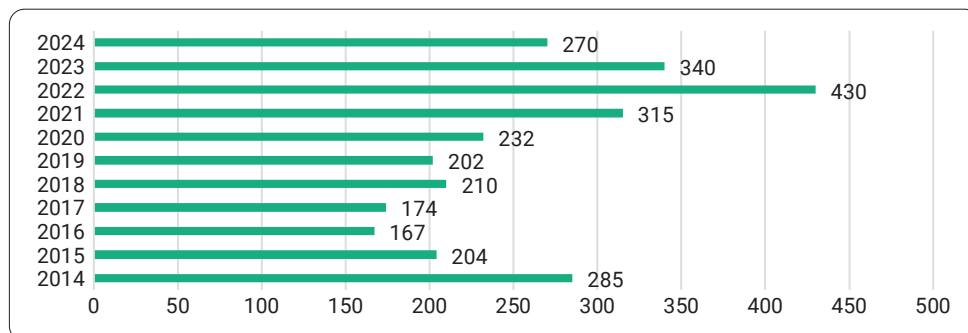


Figure 2. Average prices for US wheat

Note: HRW from 2014 to 2024 (in nominal USD per tonne)

Source: compiled by the authors based on data from Statista (2024)

Sunflower oil prices also rose to record levels due to a reduction in exports from Ukraine, which is the world's largest exporter of sunflower oil. In 2022, the price of sunflower oil reached USD 1,427.4 per tonne, which is significantly higher than in previous years (Fig. 3).

Higher prices for cereals and oils have led to higher costs in the food industry, which has led to higher prices for

other food products such as meat, dairy products, and eggs. High prices for agricultural products have led to a decrease in food availability for many countries, especially in regions that depend on Ukrainian grain imports. The war has led to volatility in global agricultural markets. Fear of a prolonged deficit due to the ongoing conflict forced importers to accumulate inventory, which further stimulated price increases.

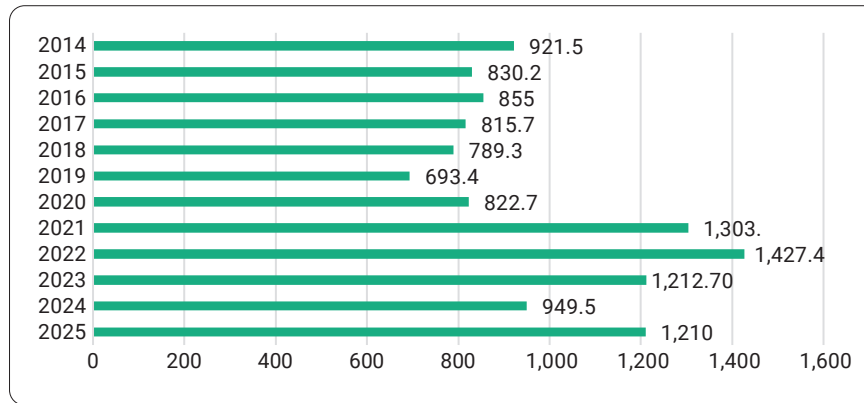


Figure 3. International prices for sunflower oil

Note: FOB Rotterdam (in USD per tonne)

Source: compiled by the authors based on data from INSEE (2025)

J.W. Glauber (2023) noted that Russia's invasion of Ukraine has created serious risks to global food security, which has required a number of responses from governments and international organisations. The situation remains very volatile today and introduces significant uncertainties in the already tough global market. Of immediate concern is the vulnerability of net food importing countries, which are highly dependent on Ukraine for supplies, such as the Middle East region. After peaking in May 2022, prices for agricultural products in general fell to pre-war levels, and price volatility also fell. While some may conclude that the global food crisis is over, concerns remain.

B. Rice *et al.* (2023) noted that the war significantly exacerbated the instability of global food prices, especially for wheat, corn, soybeans, and rice. Military actions disrupted the export chains of Ukraine, one of the world's leading grain suppliers, and also led to higher prices for energy resources and fertilisers, which increased the cost of agricultural production. The introduction of export restrictions in various countries (in particular, in Russia and Kazakhstan) also contributed to higher prices, and changes in demand for alternative products, such as rice, only increased overall market volatility. The researchers noted that in the short term, the situation will remain unstable, and international monitoring of export policies and prices is necessary to stabilise the market.

Russia uses food shortages in low-and middle-income countries as an instrument of influence in two ways: first, it tries to eliminate Ukraine as a competitor in the supply of food to these countries, which reduces the influence of Ukraine; second, it increases the dependence of these states on Russian food exports, strengthening its own

geopolitical influence. C. Welsh & J. Glauber (2024) and N. Kutsmus *et al.* (2024) noted that since the start of a full-scale war in 2022, the volume of food exports from Russia has increased, while Ukrainian exports have declined. Wheat exports from Ukraine to Europe increased from 2% to 50%, and corn – from 36% to 64%. Although most of this grain is then sent to other countries through European intermediaries, a sharp increase in supplies to neighbouring countries has led to market imbalances, in particular, in Poland, Romania, Hungary, Slovakia, and Bulgaria. This has caused trade conflicts between Ukraine and these states, and disputes within the EU over how to support Ukrainian farmers without harming local farmers at the same time. These difficulties have resulted in political consequences, including the impact on elections in individual countries and increased tensions both in the region and in the European community itself.

M. Dorosh-Kizym *et al.* (2024) argued that the war seriously affected Ukraine's food security, in particular, through the destruction of infrastructure, disruption of logistics chains, and reduced food production. Agricultural enterprises have demonstrated significant resilience due to the ability to move farms to safer regions. This contributed to the growth of the number of cattle in such oblasts as Zakarpattia, Kharkiv, and Lviv. Such positive changes demonstrate the ability of the agricultural sector to adapt to the new realities of war, although the overall demographic situation in the industry remains difficult. V. Vytoptova (2024) noted that small farmers, in particular those engaged in growing seasonal crops, were most affected, because this sector provided jobs and a stable income for a significant part of the rural population.

According to the Ukrainian food security and livelihood cluster, about 7.3 million Ukrainians, which is 20% of the population (excluding the occupied territories), face moderate or serious food shortages. Among them are 1.2 million children and 2 million elderly people. These data are also confirmed by the United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA) and the World Food Programme (WFP) (IFPRI, 2023).

According to the FAO (n.d.), the war affected more than 150 thousand farmers and workers of the food system, who either suffered significant losses or were forced to emigrate. Almost 90% of small crop producers reported a decline in income, and more than 70% of them recorded a significant or sharp decline – more than 25%. Small producers of livestock products were less affected, but more than 60% of them reported a decline in income, including 46% – a significant or sharp decline (Mykhailo, 2023).

The rise in the price of agricultural products requires special attention in the context of ensuring food security. Rising prices have a significant impact on food security, as it affects all of its key components:

1. *Physical availability of food products.* Rising prices can reduce production volumes, especially if

producers face high costs for resources (fuel, fertilisers, logistics). This affects the availability of basic food products for the population, especially in regions that depend on domestic supplies.

2. *Economic accessibility.* High prices for agricultural products increase costs for end users. Most of all, this affects low-income groups of the population, who may lose the opportunity to buy enough quality food. As a result, this leads to increased hunger, poor nutrition and health.

3. *Stability of the food system.* Sharp price fluctuations create instability for food markets. This can lead to a shortage of goods, speculation, and additional logistical problems. The war in Ukraine, for example, caused disruptions in global supply chains, which affected the prices of cereals and oils, which are key for many countries.

4. *Social consequences.* Rising food prices can lead to social tension, protests, or even political instability. This is especially true for countries that depend on food imports from regions such as Ukraine, where the war has severely restricted exports.

Figure 4 shows the average prices for agricultural products sold by enterprises in Ukraine for the period 2014-2023 (UAH/tonne).

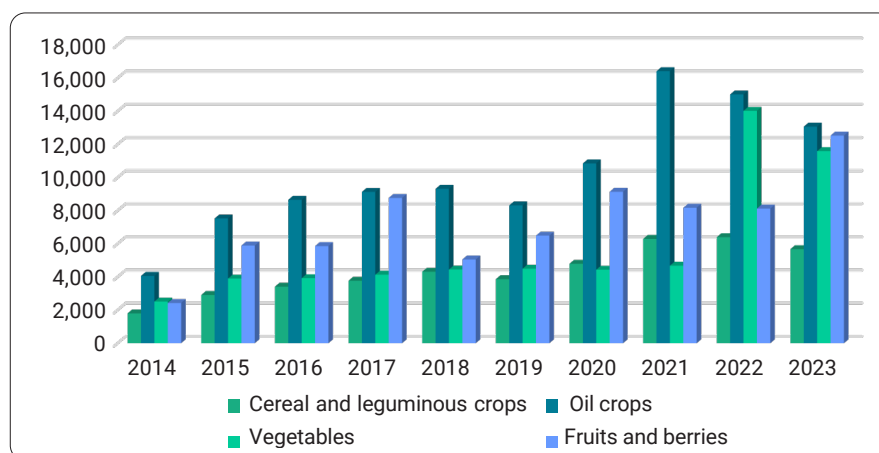


Figure 4. Average prices for agricultural products sold by enterprises in Ukraine for the period 2014-2023 (UAH/tonne)
Source: compiled by the authors based on data from State Statistics Service of Ukraine (n.d.C)

According to the FAO (n.d.) disruptions caused by the war in Ukraine have raised the average food price index to the highest level in history. The FAO grain price index rose 17.9% in 2022 due to factors such as significant market disruptions, rising energy and resource prices, adverse weather conditions, and the continued high level of global food security (Filho *et al.*, 2023). In this context, the analysis of the Ukrainian price environment allows making several generalisations. First of all, the most pronounced increase in prices is observed in the segment of livestock products (in particular, farm animals in live weight) and oilseeds. This indicates both increased domestic and external demand for the relevant products, and increasing production costs, including energy resources, feed, and logistics. A more moderate increase in prices for grain and

vegetable crops may be associated with relatively stable domestic demand, less dependence on foreign markets, and constant yields of these categories during the analysed period. Special attention is drawn to the sharp increase in prices after 2015, which coincides with a period of macroeconomic instability, currency fluctuations, and global growth in inflationary pressures. This, in turn, affected the cost of production and transportation of agricultural products. In addition, the rapid rise in the price of products with high export potential, such as oilseeds and meat, is of particular importance. This confirms the strategic importance of foreign trade activity for the Ukrainian agricultural sector, since these categories provide foreign exchange earnings and increase the competitiveness of agricultural producers on world markets. Thus, the analysis of price

dynamics over the past decade allows tracing not only economic patterns, but also the impact of global challenges, including war, climate change, and fluctuations in energy markets, which shape the modern environment of functioning of the agro-industrial complex of Ukraine.

Conclusions

The risks to Ukraine's food security during the war are multifaceted and include economic, military, environmental, technological, social, and infrastructure threats. These include the destruction of logistics and production infrastructure, land pollution, limited access of farmers to resources and financing, reduced export potential, and dependence on imports. In addition, technological lag, climate change, rising unemployment, humanitarian crisis, and limited government support exacerbate the vulnerability of the agricultural sector and reduce the sustainability of food systems, jeopardising the physical and economic availability of food for the population.

The assessment of the impact of the war in Ukraine on food security showed the scale and depth of the consequences for the agro-industrial complex both at the national and global levels. In the period 2014-2024, the production of major crops, such as wheat, barley, corn, sunflower, and soybeans, fluctuated significantly. For example, in 2021, Ukraine produced more than 42 million tonnes of corn and 33 million tonnes of wheat, but as a result of a full-scale invasion in 2022, these volumes decreased by more than 30%. In 2023, sunflower oil exports decreased to 5.7 million tonnes compared to 6.8 million tonnes in 2020, which indicates limited logistics and loss of sales markets.

Prices for agricultural products have increased significantly: the average price of US wheat (HRW) in 2022

reached USD 468 per tonne, which is almost twice as high as in 2020. The FAO grain price index rose 17.9% in 2022, while the price of FOB Rotterdam sunflower oil rose to USD 1,427.4 per tonne, a record high. In domestic terms, average prices for agricultural products in Ukraine in 2023 were two and sometimes three times higher than in 2014. The data also show that more than 7.3 million Ukrainians are facing food shortages, including 1.2 million children and 2 million elderly people. About 30% of Ukraine's agricultural land became unusable due to mining or destruction, and 90% of small farmers reported a decrease in income.

Consequently, the war in Ukraine not only disrupted the internal food system, but also destabilised world markets. To overcome these challenges, it is necessary to systematically reform agriculture, build sustainable supply chains, restore logistics infrastructure, and increase international assistance. Without comprehensive solutions, food security will remain at risk in the face of prolonged conflict. Further research will focus on developing strategies and policies aimed at strengthening the sustainability of food systems, ensuring sustainable access to resources for farmers, and mitigating the negative effects of war and global crises on food security.

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Conflict of Interest

None.

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Продовольча безпека як основа соціально-економічної стійкості в умовах війни

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Анотація. В умовах війни забезпечення доступу до продовольства впливає на гуманітарну ситуацію, економічну стабільність та національну безпеку. Метою дослідження був аналіз основних викликів забезпечення продовольчої безпеки в умовах війни та визначення ключових принципів та пріоритетів її підтримки. Використано методи аналізу статистичних даних, порівняльний аналіз і узагальнення теоретичних підходів для формування рекомендацій із підвищення стійкості продовольчих систем України. У результаті дослідження встановлено, що через повномасштабне вторгнення у 2022 році виробництво пшениці в Україні зменшилось на понад 30 %, а експорт соняшникової олії скоротився на понад 1 мільйон тонн порівняно з довоєнним рівнем. Індекс світових цін на зернові у 2022 році зріс на 17,9 %, що підтверджує суттєвий вплив війни на глобальну продовольчу безпеку. Дослідження висвітлює основні виклики забезпечення продовольчої безпеки України, спричинені військовою агресією: руйнування інфраструктури, скорочення виробничих потужностей, забруднення земель, дефіцит ресурсів для аграріїв та зниження експортного потенціалу. Оцінено вплив збройного конфлікту на сільськогосподарський сектор, глобальні ринки продовольства та доступність харчових продуктів для населення. Результати дослідження підтвердили, що для забезпечення продовольчої безпеки України необхідно впровадити комплексні заходи: модернізацію логістичної та виробничої інфраструктури, стимулювання інновацій у аграрному секторі, посилення державної підтримки фермерів і зниження залежності від імпорту. Розроблено рекомендації для зміцнення соціально-економічної стійкості через ефективне управління продовольчими системами. Запропоновані рішення спрямовані на мінімізацію впливу війни, стабілізацію продовольчих систем і створення умов для економічного відновлення. Результати дослідження можуть бути використані для розробки стратегій продовольчої безпеки, адаптації аграрної та економічної політики в умовах війни, формування програм підтримки виробників та споживачів

Ключові слова: збройний конфлікт; сільське господарство; економічна стабільність; інфраструктура; експортний потенціал; стійкість продовольчих систем

**Role of corporate social responsibility in strengthening
the economic sustainability of agricultural business in the context
of sustainable development**

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Abstract. The study aimed to identify the impact of corporate social responsibility (CSR) on improving the economic sustainability of enterprises in the agricultural sector based on the stakeholder theory. The development of the recommendations and the analysis was based on a study of the non-financial statements of Ukrainian agricultural holdings. The study determined that social responsibility measures have a direct impact on the economic sustainability of agricultural businesses through actions aimed mainly at different groups of stakeholders. The study found that eight out of 10 leading agricultural holdings in the Ukrainian market publish non-financial information, of which 50% publish information in an arbitrary form rather than in the format of internationally and nationally defined reports. The study determined that out of seven possible dimensions of corporate social responsibility (competitors, suppliers, consumers, producers, employees, community and environment), Ukrainian agroholdings focus their efforts mainly on consumers (23.33%), community (20%) and employees (20%), neglecting the opportunity to diversify social responsibility measures and ensure economic sustainability in the near future. The most appropriate changes in corporate social responsibility for Ukrainian agricultural holdings are to increase efforts to implement environmental measures, namely, to reduce carbon emissions, and improve resource efficiency and energy saving. The study determined that enterprises with a higher level of social responsibility demonstrate higher economic sustainability and the ability to adapt to the challenges of sustainable development. The analysis of empirical data confirmed the positive impact of socially responsible approaches on financial stability, innovation and competitiveness. The results of the study can be used to increase the economic sustainability of agricultural businesses by implementing socially and environmentally responsible solutions that reduce risks and increase partner trust and long-term development of the enterprise

Keywords: non-financial reporting; areas of social responsibility; stakeholders, resource efficiency; energy saving

Introduction

The public, politicians, entrepreneurs and academics are increasingly interested in sustainable development and corporate social responsibility (CSR). The operating environment of the agricultural sector is becoming more focused on the responsible behaviour of entrepreneurs towards society and the environment. International norms and agreements, interaction with stakeholders and competition in the market require agribusinesses to implement CSR principles in operations. In the context of the Russian-Ukrainian war, it is especially necessary for Ukrainian agricultural enterprises not only to implement CSR in their operations but also to adapt CSR principles to new conditions and challenges to ensure economic security and further operation. Corporate social responsibility has become a concept that has given rise to many different definitions: corporate citizenship, philanthropy, social responsibility of business, triple bottom line, etc. (Chang *et al.*, 2023). This diversity has formulated an abstract definition of the concept and made it impossible to compare the social responsibility of one company with another.

As of 2025, various studies were conducted by the international scientific community on the impact of CSR on the economic sustainability of agricultural businesses, but the results of previous studies are not unambiguous. Most researchers point to a positive relationship between CSR practices at agricultural enterprises and various economic indicators of functioning within the framework of sustainable development. Studying the effects of CSR implementation on the financial performance of the enterprise, T. Yasinska (2024) determined that social responsibility measures affect the increase in the market value of the enterprise and financial performance. The study noted that the benefits of implementing CSR measures are much greater than their costs. O. Chorna *et al.* (2023) analysed

the impact of CSR on the economic security of Ukrainian agricultural holdings and determined a direct correlation. First, the effectiveness of social responsibility depends on the interaction with the stakeholders of agroholdings, both internal and external.

In a study of the structural relationship between CSR of Chinese agricultural enterprises and performance, Z. Zhou *et al.* (2022) concluded that CSR positively affects the performance of agricultural enterprises. At the same time, CSR also positively affects the social capital of the company. On the example of Pakistani agricultural firms H. Ayub & H. Nawaz (2022) proved that by investing part of their profits in CSR, agricultural firms improve productivity in the short term. For CSR to have a long-term impact on business performance, agricultural firms need to raise additional debt, which is something that companies are reluctant to do. However, some studies do not prove the impact of CSR on the economic sustainability of agricultural businesses or prove its indirect impact. For example, by studying the impact of CSR on the economic efficiency of Spanish agricultural companies in the dairy and fruit and vegetable industries, A. Coppola *et al.* (2020) empirically determined that the higher the CSR orientation of enterprises, the higher the profitability. This applies to the focus on the needs of consumers and employees. However, there is no correlation between CSR and innovative development, which affects the efficiency of enterprises.

Focusing on small businesses in Chinese agriculture, F. Fan (2023) noted that CSR can be a burden for this type of enterprise or have a negative impact on financial performance. However, the implementation of CSR, together with the implementation of quality and brand management measures, achieves high-performance indicators. Analysing the impact of CSR on the value of assets of Czech

agricultural enterprises, M.Š. Pechrová & O. Šimpach (2024) identified an indirect relationship between these indicators. Using cluster analysis, the researchers found that those enterprises that emphasised legal and ethical responsibility had the highest asset value. As a result of analysing the reports of Hungarian agricultural enterprises, K. Biró & M.S. Csete (2020) concluded that CSR primarily affects non-financial indicators: the image of agricultural enterprises and leadership among competitors in sustainable development.

The results of previous studies indicate that the views of researchers on CSR in the agricultural sector vary from positive or negative impact to indirect or no impact. A possible explanation for the divergence of researchers' views may be the formulation of the CSR concept (stakeholder theory, three-dimensional model of sustainable development) and the methodology for studying the relationship between the aspects under investigation.

The study aimed to determine how agricultural enterprises can improve their own economic sustainability by implementing CSR practices, while simultaneously improving the satisfaction of stakeholders in the framework of sustainable development. To achieve the research objective, the following tasks were performed: to identify the main characteristics and features of the multidimensional concept of CSR in the context of sustainable development; to identify the direction of CSR of Ukrainian agricultural enterprises through seven dimensions (partners, consumers, competitors, producers, employees, community and environment); to substantiate the appropriate changes in the directions of CSR of Ukrainian agricultural business to improve the economic stability of enterprises.

Materials and Methods

At the beginning of the study, the concept of "sustainable development" and the features of the three-component model of sustainable development for enterprises were analysed. Such an analysis determined how enterprises can implement economic, environmental and social measures to function within the framework of sustainable development. In addition, CSR was identified as one of the ways to implement sustainable development. To study possible implementation measures among enterprises, the stakeholder theory was chosen. The choice of this theory is determined by the frequency of its use in practice among enterprises and the expedient study of indirect indicators of CSR impact on economic sustainability. Since the focus of this study is sustainable development, CSR and economic sustainability, the main factors of CSR impact on the economic sustainability of agricultural enterprises are identified based on the international experience of previous studies in the agricultural sector (Martos-Pedrero *et al.*, 2019).

The study of the Ukrainian agrarian market was created to determine the implementation of CSR measures in seven main aspects that can affect the economic sustainability of agricultural business: competitors, suppliers,

consumers, producers, employees, community and environment. With the acceleration of globalisation and integration processes in the world, agricultural enterprises have grown and consolidated across the globe, leading to the creation of agricultural holdings and an annual increase in the concentration of land holdings in the hands of such companies. Therefore, 10 leading agricultural holdings of Ukraine according to the Ukrainian Business Award (2024) were selected for consideration based on the land bank, number of employees and experience in the Ukrainian agricultural market: Kernel Holding LLC (2024), Myronivsky Hliboproduct PJSC (MHP, 2021), Nibulon JV LLC (2021), LZN Group PJSC (n.d.), UkrLandFarming PLC (2024), Firm Astarta Holding PLC (2024), APG Agroprosperis (n.d.), EpicentrAGRO LLC (2025), Continental Farmers Group LLC (2025), Agrovista LLC (2021).

To identify the areas of CSR activities among Ukrainian agriholdings, a qualitative content analysis of the materials on the official websites of the companies was conducted to determine the disclosure of non-financial information and reporting, as well as forms of reports on social responsibility and sustainable development. As a result of the analysis, priority areas of CSR of Ukrainian agriholdings were identified following the seven dimensions of the stakeholder theory. Such agriholdings as Agrovista LLC and APG Agroprosperis were not included in the further qualitative content analysis, as these companies do not disclose information on CSR or sustainable development.

The information on most agricultural holdings on CSR activities has been changing, but some companies did not periodically publish non-financial reports, so the period of 2021-2024 was chosen for the assessment. The statistics presented in this paper are already retrospective for such companies as Continental Farmers Group LLC, EpicentrAGRO LLC, Astarta Holding LLC, PLC UkrLandFarming, PJSC LZN Group, LLC JV Nibulon, PJSC Myronivsky Hliboproduct, and LLC Kernel Holding. Based on the data obtained from the reports and information on the official websites of agricultural entrepreneurs, the study has developed recommendations for improving the economic stability of agricultural businesses in Ukraine as part of further sustainable development.

Results

Modern society is developing following the Sustainable Development Goals adopted by the United Nations (UN) (n.d.b). One of the Sustainable Development Goals for global society, Goal 12, is to ensure sustainable consumption and production patterns (United Nations, 2024). As part of this global development goal, production processes should operate based on sustainable development by 2030. This is due, on the one hand, to population growth and, on the other hand, to the constant depletion of available resources (Shrivastava *et al.*, 2020; Galan, 2025). In such circumstances, in the modern economy, especially among growing companies in the agricultural sector, there is often a lack of clear understanding and conscious acceptance

that sustainable CSR is not something exceptional that arises due to special circumstances, but a norm that stems from the way of doing business, from corporate philosophy and is one of the ways to achieve sustainable development (Geursen, 2022). CSR is not just an option that any company can choose to do business with, but a globally recognised concept that defines the basic ideas and forms of corporate activity in modern conditions at all levels of management – tactical, operational and strategic. However, the term became widely used in the business environment only after 1990, along with the development of the concept of sustainable development (Fet & Knudson, 2023).

At the same time, the different uses of the terms “sustainability” and “sustainable development” mean that their meaning is becoming increasingly imprecise and blurred. After analysing numerous definitions of these categorical terms, the United Nations (n.d.a.) definition was chosen. In this study, the term “sustainability” refers to meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. Accordingly, “sustainable development” should be defined as a process of change in which the use of resources, the targeting of investments, the direction of technological development, and institutional changes are aligned to improve both the present and future capacity to meet human needs and aspirations (Brenner & Hartl, 2021).

Until the second half of the 20th century, sustainable management meant an economic approach in which consumed resources were returned to the system in the same quantity as they were used. For example, forests, water resources, raw materials, etc. This is the opinion for strong sustainability. However, strong sustainability has been replaced by the weak sustainability approach, in which the used resources can be consumed without complete replacement, but with the help of different technologies and with the preservation of human capital (Braun, 2020; Singh *et al.*, 2021). Therefore, sustainable development is nowadays presented as a three-pillar model to emphasise that sustainable development can only be achieved through the simultaneous achievement of environmental, social and economic goals (Younis & Chaudhary, 2017). In other words, the “three pillar model” is intended to emphasise that the satisfaction of one factor is less important than all aspects together. As natural resources are finite, environmental sustainability is still relevant. Environmental sustainability means the efficient use of limited natural resources. However, economic sustainability is also important – the ability of an enterprise to maintain a certain level of productivity over a long period.

Before environmental awareness went global, the environment and sustainability were perceived by companies and organisations as problems and risk factors. However, the gradual development of general global environmental awareness has led to these issues being seen as opportunities for growth and efficiency. Therefore, the three-pillar model of sustainable development is central to achieving effective business performance (Carvalho *et al.*, 2016).

Until 2015, only the largest and most powerful companies could afford CSR-related costs. Every year, modern organisations are constantly looking for ways to gain a competitive advantage to adapt to changing conditions within the framework of sustainable development (Bruch & Walter, 2005; Diaz-Iglesias *et al.*, 2021). One such framework is the United Nations Global Compact, the world's largest corporate sustainability initiative, which describes the basic principles of CSR in ten principles related to human rights, labour, environment, and anti-corruption. Companies can sign up to the Global Compact and thereby commit to upholding these principles throughout their operations and value chains. The Global Compact is an accessible guide for all companies, regardless of their size or maturity level. The Organisation for Economic Co-operation and Development (OECD) (2023) has also launched a broad CSR initiative. “The Guidelines for Multinational Enterprises on Responsible Business Conduct” were developed by OECD member governments for the implementation of CSR. It encourages organisations to implement a strategic CSR model not only for economic efficiency but also to maintain a positive corporate image and increase the company's competitiveness.

The European Commission (2022) defines CSR as a concept whereby companies integrate social and environmental issues into their business activities and stakeholder engagement voluntarily. In practice, this concept is regulated by ISO 26000:2010 (2010). Notably, E. Geursen (2022) defined CSR as situations in which a company goes beyond compliance and takes actions that contribute to the public good, which exceeds the company's interests and legal requirements. Some emphasise the environment, others on society or human rights. In addition, some view CSR as an ethical issue, while others promote CSR as a proactive approach to meeting stakeholder needs (Fet & Knudson, 2023).

From this, it is possible to conclude that the responsible topics within the strategic management of CSR that companies can focus on are legal, ethical, philanthropic and economic (Fet & Knudson, 2023). From a theoretical point of view, at the strategic level, all social obligations are imposed on each company by society at a certain point in time. This means that the basis for all levels of social responsibility is economic security (making a profit, increasing profitability). Legal responsibility obliges companies to comply with the current legislation of the country. Ethical responsibility is manifested in harmlessness towards the environment, stakeholders and society. Philanthropic responsibility is manifested in additional responsibility that benefits society, stakeholders and the environment using additional resources. Meeting these expectations ensures that the organisation operates effectively from a strategic point of view and improves its competitive position in the market and financial performance. Based on the experience of Italian agribusinesses, A. Martos-Pedrero *et al.* (2019) empirically proved that CSR has a direct impact on financial performance and, consequently, on economic

sustainability. However, enterprises implement CSR in most cases out of obligations to different stakeholder groups.

In a modern business environment, a company interacts with various stakeholders as part of its market activities, regardless of industry, size or ownership. Stakeholders are individuals or groups of individuals who depend on the organisation to achieve its goals and on whom the organisation depends in turn (Geursen, 2022). A company's stakeholder groups are often divided into internal and external according to their influence on the company. Internal stakeholders are those who are directly related to and involved in the activities of the agricultural enterprise. They include employees, company owners, directors, shareholders, etc. External stakeholders are those who can influence performance but are not directly related to the company. This group of stakeholders includes competitors, the community, etc. Stakeholder relationships are the most important assets that managers must manage, and they are the main source of an organisation's wealth in strategic management.

Accordingly, to analyse the possible impact of CSR on the economic sustainability of agricultural enterprises, the so-called "stakeholder theory" was selected as a basis (Mahajan *et al.*, 2023). The main assumption of the theory is that stakeholders have different views on the development and functioning of the same company, which does not remain without an impact on its efficiency. In other words, in strategic management, CSR can be defined as a concept that concerns only stakeholders. It should be noted that all company resources are determined by stakeholders and, in the long run, by relations with them (consumers, suppliers, investors, employees, competitors, etc.) (Freeman, 2023). Hence, it is possible to conclude that the balance of a rational distribution of stakeholder relationships is the most important part. This approach differs significantly from the resource-based and organisational approaches, as they focus on the company or industry rather than on the stakeholders. However, a company must develop in-house resources for its development in the short term, both financial and human, technological and innovative, which determine the improvement of the company's overall competitiveness. In other words, the concept of resources is consolidated in this aspect. As the company operates in a competitive market, it also adapts to the work of those involved in it. In other words, the organisational concept is manifested in this aspect. However, the company also exists in a political and social environment, i.e., it forms a system that not only encompasses the two models mentioned above but also complements them (Geursen, 2022).

A modern company defines its activities in response to the expectations of its stakeholders. This system helps to ensure the company's competitiveness and development potential. At the same time, the development of "relationship values" is a key aspect of strategic management or, in other words, the main tool for achieving long-term sustainable development of the company. Thus, it can be

concluded that CSR can be viewed as a rational response of a company to conflicting expectations of stakeholders regarding sustainable development, as well as an element of competitive strategy through the prism of the industry concept, but also as an independent concept of strategic management. This concept is largely complementary to all the previously proposed concepts (resources and industry).

The agricultural market is one of the largest and most capacious markets with the highest possible level of competition at all levels: local, regional, national, and international (Falcicola *et al.*, 2020). The highest possible level of competition requires agricultural producers to be as efficient as possible in production, management, marketing, financial and human resources management. The industry under study, as a certain system of elements, interacts with the external environment: the external environment affects the Ukrainian agriculture sector in general and the performance of Ukrainian agroholding companies in particular. The agriculture sector, alongside leading enterprises, depends on the external environment (Xuan *et al.*, 2019). Various determinants, such as government, market, and competitive determinants, as well as factors such as political, economic, social, environmental, technological, and international factors, which directly and indirectly affect the activities of companies in this sector in Ukraine, are noteworthy. Various stakeholder groups are increasingly demanding from agricultural producers not only quality products but also responsibility at all stages of their creation and sale, as well as social responsibility that does not directly depend on the production process. Therefore, the main task for enterprises in this agro-industrial economy is to adjust the functionality of the enterprise in such a way as to ensure their own economic sustainability and sustainable development through effective interaction with all stakeholders (Martos-Pedrero *et al.*, 2019). This situation requires agroholdings to ensure, maintain and manage internal economic security (stable economic and financial development based on the identification, localisation and elimination of the impact of negative internal and external determinants). Therefore, to analyse the impact of CSR on the economic sustainability of agricultural enterprises, seven main dimensions were selected based on the stakeholder theory: competitors, suppliers, consumers, producers, employees, community and environment.

The largest enterprises in the Ukrainian agricultural market are agricultural holdings. The main characteristics of the largest Ukrainian agriholdings in 2024 are shown in Table 1. From the data presented in Table 1, it is possible to conclude that the top 10 agriholdings in Ukraine own a land bank of about 2.5 million hectares, which proves a significant influence on the national agro-industrial complex. Agriholdings also have an impact on employment in the agricultural sector, as the companies in the Table provide jobs for more than 90,000 people. Out of the top 10 agriholdings, only 90% publish non-financial information on sustainable development and CSR in the public domain.

Table 1. Key performance indicators of leading agricultural holdings in the Ukrainian market, 2024

Name	Land bank, million hectares	Number of employees, thousand people	Duration of operation, year	Type of CSR and sustainability reporting
Kernel Holding	0.51	11	29	A separate section in the annual report
MHP	0.36	28	26	Sustainability report
Nibulon	0.07	4	32	Sustainability report
LZN Group	0.09	3.50	10	Information on the website
UkrLandFarming	0.48	25	17	Information on the website
Astarta Holding	0.22	7	31	Sustainability report
Agroprosperis	0.30	4	17	No information available
EpicentrAGRO	0.17	4.2	9	Information on the website
Continental Farmers Group	0.19	2.4	32	CSR report as an online map on the website
Agrovista	0.08	1	24	No information available

Source: compiled by the authors based on Agrovista LLC (2021), MHP (2021), Nibulon JV LLC (2021), Kernel Holding LLC (2024), UkrLandFarming PLC (2024), Firm Astarta Holding PLC (2024), EpicentrAGRO LLC (2025), Continental Farmers Group LLC (2025), LZN Group PJSC (n.d.), APG Agroprosperis (n.d.)

The analysis of the data presented in Table 1 demonstrated a significant variation between the leading agriholdings in terms of land bank size, number of employees and duration of operation. The largest employer among the companies represented is PJSC Myronivsky Hliboproduct with 28 thousand employees, while Agrovista LLC has the lowest number of employees (1 thousand). This indicates differences in the scale of operations and, probably, in the resource potential for implementing socially responsible practices. In turn, Kernel Holding LLC is the leader in terms of land bank area (0.51 million hectares), which may indicate a wide geography of operations and increased environmental responsibility. However, despite the significant scale of its operations, this company is limited to the sustainability section of its annual report, which does not provide sufficient transparency.

It is worth noting that the oldest companies in terms of the duration of operation are Nibulon JV LLC and Continental Farmers Group LLC (32 years), and both companies publish CSR information through a standardised sustainability report, and the latter through an online map. This indicates a well-established management tradition that

includes the institutionalisation of responsible business principles. At the same time, the presence of companies that have been operating for more than ten years and are among the Top 10, but do not have any public information on CSR (APG Agroprosperis, Agrovista LLC) is an indicator of the low level of integration of sustainable development principles into the strategies of some market players.

Overall, among the top 10 agricultural holdings, 80% of companies declare some form of CSR reporting, but only 37.5% of them use internationally recognised practices in the form of a full-fledged sustainability report. Another 50% are limited to fragmentary information on their websites, which significantly reduces the comparability and reliability of the data provided. The picture demonstrated a declarative approach to social responsibility, which requires deeper standardisation and reporting as a factor in increasing trust from investors, partners and society. The main problem of Ukrainian agriholdings is the narrow and non-diversified focus of CSR activities, which are repeated among companies. In general, Ukrainian agriholdings prioritise the implementation of social responsibility measures towards employees, consumers and the community (Table 2).

Table 2. Priority areas of CSR of Ukrainian agricultural holdings according to the stakeholder theory

Area	Share of the total amount, %
Consumers	23.33
Community	20
Employees	20
Competitors	16.67
Environment	13.33
Producers	3.33
Suppliers	3.33

Source: compiled by the authors based on Agrovista LLC (2021), MHP (2021), Nibulon JV LLC (2021), Kernel Holding LLC (2024), UkrLandFarming PLC (2024), Firm Astarta Holding PLC (2024), EpicentrAGRO LLC (2025), Continental Farmers Group LLC (2025), LZN Group PJSC (n.d.), APG Agroprosperis (n.d.)

As shown in Table 2, CSR prioritises consumers (23.33%), the community (20%) and employees (20%),

which together account for 63.33% of all identified socially responsible initiatives. This concentration indicates that

companies focus mainly on those groups that provide direct reputational benefits and prompt feedback, through public opinion and the internal climate of the team. At the same time, actions in relation to such important groups as competitors (16.67%) and the environment (13.33%), although important for sustainable development, remain less covered. This creates strategic risks, in the context of compliance with international environmental standards and adaptation to the global challenges of the green transition. The low level of attention to producers and suppliers (3.33% each) is particularly critical, despite their role in building sustainable supply chains and reducing overall operational risk. Insufficient involvement of suppliers in CSR strategies can make it difficult to integrate environmentally friendly practices into supply chains, which in turn limits the achievement of targeted environmental performance at all stages of production. Similarly, neglecting producers as a distinct stakeholder group can lead to a gap in vertical cooperation and a loss of potential for innovation in primary agricultural production. Given the current political and economic instability and the growing demand for sustainable development, this asymmetry in the distribution of CSR initiatives needs to be reviewed and balanced. Thus, the identified predominance of short-term profitable social responsibility strategies over a comprehensive systemic approach reduces the adaptive potential of Ukrainian agribusiness and limits its ability to grow in the long term. A promising area for improvement is to shift the focus from reactive social support to proactive development of partnerships and environmental management, which will not only strengthen the economic sustainability of enterprises but also enhance their competitiveness in the global market. These results are counterintuitive, as the main goal of stakeholder management theory is to achieve a mutually beneficial outcome, preferably in the medium to long term (Mahajan *et al.*, 2023). Stakeholder management aims to align resources with the outcomes of planned scenarios, focusing on meeting the needs of all key stakeholder groups (Freeman, 2023).

In addition to consumers, one of the most popular areas of CSR implementation by Ukrainian agriholdings is local community development, which refers to social programmes and activities undertaken by the company to support socially vulnerable groups in a particular community, including aspects such as poverty alleviation, disease control, rural development and education. Community-related activities also include assistance to the Armed Forces of Ukraine (AFU). The trend is determined by the full-scale invasion of Ukraine. Employees are an important stakeholder, accounting for 1/5 of CSR activities among Ukrainian agriholdings. Human resource development among Ukrainian agriholdings focuses on attracting and retaining talented employees, motivating them, social packages, recreation and leisure facilities, diversity and equal opportunities. This also includes health and safety, sanitary and hygienic working conditions, and medical care. Socially responsible restructuring remains an important aspect of

increasing labour productivity by cutting inefficient jobs and changing the corporate structure (Alishli *et al.*, 2024). This means that companies are actively implementing corporate education programmes on sustainable development. On the one hand, employees who personally behave sustainably can bring these views and values to the company and thus create a culture of sustainability within the company. On the other hand, corporate sustainability management becomes particularly convincing when it is complemented by activities that not only serve organisational goals but also express a shared interest in sustainability. This can improve corporate image, employee motivation and the quality of the work environment (Muster & Schrader, 2009).

Since the beginning of the Russian-Ukrainian war, the priority areas of CSR activities of Ukrainian agricultural holdings have changed. For the most part, agriholdings' CSR activities are now focused on helping internally displaced persons (IDPs), the Armed Forces of Ukraine and the territories where they operate. Efforts to protect the environment have fallen by the wayside. Of efforts, 13.33% of the leading Ukrainian agricultural holdings emphasise environmental responsibility, including water and air conservation, renewable energy, waste management, material recycling, biodiversity, soil protection and animal welfare.

At the same time, agriholdings aim to achieve sustainable development for consumers, employees and communities by prioritising products or services and neglecting the interests of other stakeholders. Consumers, shareholders and partners are the three key stakeholder groups for agricultural businesses. Focusing CSR on these three groups can bring agricultural enterprises the greatest opportunities to improve their financial performance (Martos-Pedrero *et al.*, 2019). In Ukrainian agriholdings out of the seven groups studied, apart from consumers, who account for more than 23% of CSR efforts, shareholders (producers) and suppliers are the stakeholder groups on which enterprises focus minimal efforts, along with environmental improvement measures.

For instance, shareholders, as one of the stakeholders, have all the legal rights to regulate the goals of the organisation. The main goal of shareholders is to maximise the profitability and capital of the company, which they entrust to the managers and directors of the company. At the same time, managers may not accept the high transaction costs associated with integrating CSR into the strategic plan, labour turnover and the added value that can be attributed to each employee. In such cases, CSR is often implemented in the form of labour practices, i.e. ensuring proper working conditions, continuous professional development of employees, and providing safe working conditions and social packages for employees. This aspect can be an obstacle to the active implementation of CSR in the company's strategic management plan and has numerous consequences. In addition, it is shareholders who can influence the diversification of investments, reduce risks and costs of enterprises, while improving the economic security of agriholdings. Of the analysed Ukrainian

companies, only Kernel Holding LLC, PLC UkrLand-Farming and Firm Astarta Holding LLC actively implement CSR measures concerning this stakeholder group.

To ensure long-term economic security, in 2025 Ukrainian agriholdings should not only focus CSR activities on consumers, communities and employees but also on other stakeholder groups that are equally important for ensuring economic sustainability within the framework of sustainable development, namely shareholders and suppliers, by improving the environment. Firstly, Ukrainian agriholdings should improve the form of reporting on CSR and sustainability activities in the form of integrated reporting following international standards, gradually moving away from CSR, GRI and Global Compact formats. This will enable Ukrainian agriholdings to attract additional investments and improve their economic security by engaging more different stakeholder groups. Furthermore, accurate process knowledge and proper environmental impact assessment of a particular process or industry can help a company optimise costs and reduce risks to avoid liability for environmental damage in the future. Ukrainian agricultural holdings can set goals to reduce or mitigate their environmental impact and inform the public about the results. Reducing environmental impact can be achieved by improving processes, installing new equipment, etc. This means that one of the most important aspects is the need to reduce the negative environmental footprint left by the agricultural business.

The challenges faced by businesses in the agricultural sector in Ukraine to operate in an environmentally and economically sustainable manner, while being fully socially responsible, are an important area of the modern economy. In the context of growing environmental awareness and the realisation that natural resources are finite, resource efficiency and energy conservation are of particular importance. In the current context for Ukrainian agriholdings, energy efficiency is a key resource for economic and social development and can bring significant benefits to various stakeholders, from organisations developing energy efficiency measures to all members of society. Energy efficiency strategies should encompass all changes that will reduce the amount of energy required to produce a unit of economic output. As energy efficiency is a “green” innovation product for agriholdings, more energy-efficient production can lead to long-term reductions in production costs and thus affect economic performance. In addition, policymakers are considering energy efficiency improvements at the plant and company level as an important approach to reducing national and global carbon emissions. In addition to cost savings, numerous benefits can be achieved through better alignment of energy issues with strategic corporate priorities, such as increased competitiveness, profitability, quality, etc. Thus, energy efficiency can be a strategic advantage, not just an afterthought, for Ukrainian agriholdings in the context of sustainable development.

Another prerequisite for the sustainable development of companies is the aspect of resource efficiency, i.e.

material efficiency, which is aimed at reducing the use of resources and/or materials per unit of output. Resource-saving strategies are among the methods used to prevent environmental pollution. Such strategies may include re-engineering production processes to optimise the use of raw materials and energy, as well as developing innovative waste management methods. They can not only reduce the negative impact of a company's operations on the environment but also lead to lower procurement and waste disposal costs and overall cost savings. Lastly, it should be emphasised that resource-saving strategies can not only help reduce a company's environmental footprint but also create a more sustainable and profitable business model. This approach contributes to the transition to a circular economy, in which resources are maximised, and waste minimised through recycling and reuse. This is important because resource conservation is at the heart of the concept of sustainable corporate development (Geursen, 2022).

It is also important that companies not only use implicit resources efficiently as part of their sustainable management but also integrate renewable resources into their production and operations. The integration of renewable resources will also help to reduce the negative impact on the environment. On the other hand, the development and implementation of new technologies for the efficient use of renewable resources requires research and development, which can contribute to the development of new competencies and open new market opportunities.

Discussion

The analysis of Ukrainian agriholdings' CSR reporting has revealed that the forms of reporting to stakeholders differ between agriholdings. Most companies publish information on their official websites (50%) and publish sustainability reports (37.5%). These findings are consistent with those of I. Zamula & A. Ishchenko (2021), who analysed the non-financial reporting of Ukrainian agricultural enterprises. The study determined that in 2019, 70% of the largest agroholdings in Ukraine published information on CSR activities in an arbitrary form on their official website. Only three agriholdings, namely Monsanto LLC, PJSC Myronivsky Hliboproduct and Astarta Holding LLC, published a sustainability report. Comparing these results with those obtained in this study, a positive trend in the period 2019-2024 towards improving the forms of disclosure of information on social responsibility and sustainable development is notable. At the same time, one (Agroprosperis APG) of the ten companies analysed in this study does not publish information on CSR activities at all. Incorporating the results of the analysis of I. Zamula & A. Ishchenko, it is worth noting that this trend has been continuing since 2019. By not publishing reports on CSR activities, Agroprosperis APG limits the ability of stakeholders to influence the economic sustainability of the agricultural holding.

The analysis demonstrated that out of the seven main dimensions of CSR according to the stakeholder theory (competitors, suppliers, consumers, producers, employees,

community and environment), consumers, shareholders and partners are the most important for the agricultural sector. However, among agricultural holdings in Ukraine, the largest number of CSR activities are aimed not only at consumers but also at the community and employees. These areas of CSR activities are related to the military conditions in which enterprises operate. The main problem that is common to all analysed Ukrainian agriholdings is the lack of diversification of activities in different CSR dimensions according to the stakeholder theory. This is especially true for shareholders and environmental protection measures that can be supported by shareholders.

In 2022, a global survey of 32,000 respondents was conducted to determine attitudes towards CSR activities among businesses. The study determined that 53% of respondents believed that companies were not doing enough to combat climate change. At the same time, 50% of respondents said that companies are not doing enough to address economic inequality and energy shortages. Only 9% of consumers globally said that companies are doing too little to provide them with reliable information (Statista, 2024). The results of this study underline the veracity and trend of the research, as in 2024, in the Ukrainian agro-industrial market, 10% of the national largest agricultural holdings do not publish information on CSR activities, and the environment as a priority area of CSR occupies about 13% of the total focus of social responsibility actions.

The study highlights the importance of environmental CSR activities for Ukrainian agriholdings in practice, as Ukrainian agribusinesses focus mainly on CSR aimed at social aspects. It is the diversification of CSR activities to include not only social aspects but also environmental ones that will help Ukrainian businesses in the agricultural sector achieve economic sustainability. Similar conclusions were reached by M. Cristea *et al.* (2022), who studied the focus of CSR on economic, environmental and social aspects among agricultural enterprises. As a result of statistical calculations, the researchers found a direct impact of CSR measures aimed at the environment on the size of the enterprise. Although this study did not find a direct correlation between CSR and company size, it proved the impact of CSR aimed at the environment on the sustainable development of agricultural businesses. Company size also affects economic security and the ability to diversify further CSR activities (Konstantynovskiy & Zmicerevska, 2023).

The economic arguments for doing business sustainably are manifold. The most obvious is increased sales, as consumers respond positively to companies that they perceive to be ethically correct (Li *et al.*, 2022). However, as modern production theory shows, the implementation of sustainable business practices can also bring significant benefits in terms of increased productivity and reduced costs. It is also possible that the behaviour of employees has a significant impact on the behaviour of the company, which in turn affects the prosperity of the company. In addition, the introduction of sustainable practices in the operation of enterprises in the agricultural sector

can lead to a significant reduction in financial risks (Bekpayeva *et al.*, 2025). There is also a certain synergy between these factors, which in general can lead to higher revenues, lower costs and lower financial risk for sustainability companies. Such results of previous research by R.N. Mefford (2011) fully confirm the validity of the results obtained in this study.

In particular, the study found that reducing the negative environmental footprint of activities, resource efficiency and energy saving are the main priority measures for Ukrainian agriholdings. These results partially confirm the findings of previous studies, such as S. Fortunati *et al.* (2020), analysing the CSR of Italian agro-industrial enterprises. As a result of the analysis, the researchers concluded that agricultural activities are becoming less environmentally friendly, so it is advisable for enterprises to introduce a circular economy by implementing such a system in the operation of the enterprise. For enterprises to develop within the framework of sustainable development, the combination of circular economy and CSR is an alternative to improving the business process. Other studies, such as A. Muscio & R. Sisto (2020), in the analysis of the agro-industrial complex, concluded that the implementation of the circular economy is not an urgent task. The circular economy can help agricultural enterprises increase revenues by innovating production processes, improving environmental impact, and keeping prices for consumers at the same level (Khumarova & Mahats, 2023). However, most companies face numerous challenges and, in some cases, even rejection when it comes to effectively implementing energy efficiency measures. The biggest obstacle is access to capital. Agribusinesses face problems with state funding for circular economy measures in the agricultural sector. Such factors make it impossible and reduce the willingness of entrepreneurs in the agricultural sector to implement the circular economy.

However, when achieving sustainable development goals, market competition should also be considered. In the current conditions of digitalisation of society, the use of digital technologies for agricultural business can also be attributed to economic sustainability. The study found that by modernising fixed assets, implementing resource efficiency and energy saving, Ukrainian agriholdings can ensure not only economic sustainability but also improve their competitive position in the market. These results are also confirmed by the findings of an earlier study by E. Fosu *et al.* (2023) on the impact of CSR on the performance of enterprises in the Ghanaian agri-food sector. As a result of the empirical study, the researchers identified the direct impact of CSR on corporate image and, accordingly, on the competitive position in the agricultural market. Therefore, the implementation of the developed recommendations in the practice of Ukrainian agriholdings will not only have a positive impact on improving the economic sustainability and reputation of Ukrainian agriholdings but will also be part of the investment in the future growth of the country's agricultural business.

Conclusions

Possible specifications of the rules of economic sustainability of agriholdings have been discussed in economic science for a long time, but there is still no consensus. Therefore, there are no concepts that can be used without undue doubt. In this study, the focus was on the CSR of agricultural holdings. The stakeholder theory was chosen to analyse the impact of CSR on economic sustainability and to project this theory onto the Ukrainian agriholding market. It is the CSR activities aimed at different stakeholder groups that can ensure the economic sustainability of the agricultural business. That is, the priority is the company's responsibility to all parts of society (including partners, consumers, employees, etc.). The analysis shows that the implementation of the CSR strategy is voluntary and goes beyond legal and regulatory requirements, and externalities, i.e. side effects of business activities, are controlled and internalised by the company. In addition, the needs and interests of many stakeholders are considered, and social and economic responsibility are harmonised. Environmental and social values are embedded in the CSR strategy, and CSR should take priority over philanthropy.

According to the stakeholder theory, consumers, shareholders and partners are critical and the main ones among all CSR directions for agricultural enterprises. The analysis of the CSR focus areas of nine leading agricultural holdings in the Ukrainian market determined that the main efforts are directed at consumers (23.33%), while CSR aimed at shareholders and partners is hardly mentioned in the reports on non-financial activities. Along with consumers, Ukrainian agribusinesses implement many measures to meet the needs of communities (20%) and employees (20%). This is mainly determined by the military conditions in which companies operate and attempts to help IDPs and the Armed Forces, as well

as the areas where agricultural holdings operate. However, such a narrow focus and lack of diversification of CSR activities limits the long-term economic sustainability of the enterprise. Therefore, to improve the situation, recommendations have been developed to focus more efforts on improving the environment: reducing carbon emissions, ensuring resource efficiency and energy saving in core production. Such actions will not only provide a short-term improvement in financial performance but will also enable long-term economic sustainability and market competitiveness. Notably, there is no non-financial reporting on the CSR of agricultural enterprises in Ukraine. The information used in this study was collected from open sources (official websites of agriholdings) and therefore is rather fragmentary than complete. This is a limitation of this study, as the analysed information can be used to identify only the main trends in CSR activities of agribusiness in Ukraine.

Further research is needed to develop more specific recommendations for each of the ten agricultural holdings in Ukraine. One of the important areas for further research is to analyse the impact of CSR not only on the economic sustainability of each of the ten agriholdings but also on the competitiveness indicator. The prospects for such further research lie in the possibility of improving the recommendations developed as a result of this study.

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Роль корпоративної соціальної відповідальності у зміцненні економічної стійкості аграрного бізнесу в умовах сталого розвитку

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Анотація. Метою даного дослідження було виявлення впливу корпоративної соціальної відповідальності (КСВ) на покращення економічної стійкості підприємств в аграрній галузі на основі теорії зацікавлених сторін. Розробка рекомендацій та їх аналіз було засновано на дослідженні нефінансової звітності українських агрохолдингів. В результаті дослідження визначено, що заходи соціальної відповідальності прямо впливають на економічну стійкість аграрного бізнесу через дії, спрямовані здебільшого на різні групи зацікавлених сторін., що вісім із 10 агрохолдингів-лідерів на українському ринку публікують нефінансову інформацію, із яких 50 % публікують інформацію у довільній формі, а не у форматі міжнародно- та національно визначених звітів. Визначено, що із семи можливих вимірів спрямування дій корпоративної соціальної відповідальності (конкуренти, постачальники, споживачі, виробники, працівники, громада та довкілля), українські агрохолдинги спрямовують свої зусилля здебільшого на споживачів (23,33 %), громаду (20 %) та працівників (20 %), нехтуючи можливістю диверсифікувати заходи соціальної відповідальності та забезпечити економічну стійкість в найближчому майбутньому. Доцільними змінами корпоративної соціальної відповідальності для агрохолдингів України є збільшення зусиль щодо реалізації заходів, які стосуються довкілля, а саме впровадження зниження викидів вуглецю, покращення ресурсоефективності та енергозбереження. У ході дослідження виявлено, що підприємства з вищим рівнем соціальної відповідальності демонструють вищу економічну стійкість та здатність адаптуватися до викликів сталого розвитку. Проведений аналіз емпіричних даних підтвердив позитивний вплив соціально відповідальних підходів на фінансову стабільність, інноваційність та конкурентоспроможність. Результати дослідження можуть бути використані для підвищення економічної стійкості аграрного бізнесу шляхом впровадження соціально та екологічно відповідальних рішень, що сприяють зменшенню ризиків, зростанню довіри партнерів і довгостроковому розвитку підприємства

Ключові слова: нефінансова звітність; напрямки соціальної відповідальності; зацікавлені сторони, ресурсоефективність; енергозбереження

**Modelling economic productivity of Ukraine
in the context of military challenges**

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Abstract. Military challenges have transformed the economy of Ukraine, stipulating the necessity of reevaluating the sources of its productivity. An attempt was made to model the impact of these factors on Ukraine's GDP using the Cobb-Douglas production function and the Solow residual. Statistical data for 2014-2024 were analysed, regression analysis was performed to determine the relationship between the main economic variables and the elasticity of capital and labour was estimated. The Solow residual was used to estimate the technological level of the economy and identify exogenous factors affecting productivity. The results of the study suggest that spending on scientific and technical activities had a negative impact in the short term due to insufficient funding and macroeconomic instability. Military expenditures failed to provide a significant increase in productivity due to their unproductive focus. In contrast, international aid contributed to macroeconomic stability, although failed to stimulate long-term growth. The partial contribution of factors to the formation of the Solow residual made up 27.92% for innovation, 25.95% for military spending and 20.99% for international aid. The model indicated a high R^2 value (0.96), suggesting its validity in explaining changes in TFP. Recommendations were developed to improve economic productivity of Ukraine, which include improving scientific and technical activity through improved funding for scientific research, rationalising defence spending by integrating military investments into the overall economic strategy, as well as effectively attracting international aid for structural reforms and human capital development. The obtained results can serve as the foundation for shaping economic policies aimed at the country's post-war recovery

Keywords: Cobb-Douglas production function; employment; international aid; expenditures on scientific and technical activities; Solow residual

Introduction

Economic growth and productivity remain central issues in economics, as they determine the nation's well-being and its place in the global economy. The study of productivity and key factors of its growth is particularly relevant for Ukraine, being in the process of profound economic transformation. In the context of modern challenges, such as a full-scale Russian invasion, post-war recovery and integration into the European market, the analysis of economic productivity is becoming an important tool for developing effective economic strategies.

The signing of the Association Agreement with the European Union has created new opportunities for Ukrainian companies to expand access to EU markets, while at the same time emphasising the need to assess resource efficiency and the contribution of technological innovation to increasing economic productivity. According to the State Statistics Service of Ukraine, foreign investment in the technology sector grew steadily until 2021 and decreased by 28% in 2022 due to the full-scale Russian invasion (Minfin, n.d.a; n.d.b). These data emphasise the urgency of adaptation of the economy to the crisis and the need to innovate. Infrastructure destruction and instability have had a significant impact on the level of employment and domestic demand. Thus, the level of employment has fallen from an average of 91.64 million people in 2014-2021 to 84.65 million in 2022-2023 (OECD, 2023). At the same time, Ukraine's level of innovation, as recorded in the Global Innovation Index (GII), continues to grow even in the face of military challenges, suggesting the country's technological potential. According to this index, Ukraine maintains positive trends and ranks 60th in the world (Global Innovation Index 2024, 2024).

In response to the challenges, caused by the full-scale Russian invasion, as well as the tasks of post-war recovery and integration into the European market, scholars

are increasingly focusing on exploring ways to improve economic productivity of Ukraine in the globalised world. Authors M. Bril & I. Pyvavar (2022), L. Deineko *et al.* (2022) studied the impact of economic factors on the country's innovation level, using the instrumental approach to assess the influence of investments, scientific research and technological projects. Their findings emphasised the role of innovation as a key element of the overall factor productivity. L. Bielousova *et al.* (2022) drew attention to the need of integrating international standards and technologies to ensure economic growth in the post-war period. The authors emphasised that strategic planning is a key factor for restoring infrastructure and reintegration of production processes.

O. Mykolenko (2025) studied the importance of supporting high-value-added industries in the post-war recovery. A special emphasis was placed on stimulating the export of technological products as one of the directions of economic growth and directing international aid to strategic projects, such as the modernisation of energy systems and the development of transport. V. Zakharchenko *et al.* (2021) pointed out in their paper that the overall economic growth of the country cannot be offset solely by the increase in labour and total capital, whereas modern scientific and technological progress is of particular importance. P. Makarenko *et al.* (2023) and I. Babets (2023) examined the dependence of gross domestic product (GDP) on the volume of capital, labour, and financing of the scientific and technical sphere. Their findings confirmed the idea of insufficient financing of science and technology hampering long-term economic growth.

Summarising the findings of scientific research, it can be argued that the recovery of the Ukrainian economy provides for the introduction of innovations, attracting investments in high-tech industries and adaptation to

global economic conditions. A special emphasis is placed on the use of economic analysis tools to assess the role of production factors and technological progress. In this respect, the Cobb-Douglas function, combined with the Solow residual, provides a powerful analytical approach for modelling economic productivity. This methodology provides for both assessing the impact of major factors of production, such as labour and capital and identifying the contribution of technological progress and other external factors, such as scientific and technical activity, military spending or international aid. This is extremely important for Ukraine, since its economy is concurrently experiencing the influence of destructive military actions and stimulating technological changes.

Given the complexity of the problem, for modelling the economic productivity of the Ukrainian economy in the context of military challenges, it is advisable to use the Cobb-Douglas function, as a well-known mathematical model for determining economic productivity, which makes it possible to estimate the contribution of capital and labour to the GDP dynamics. The aim of the present paper is to model the economic productivity of Ukraine using the Cobb-Douglas production function and the Solow residual to determine the impact of major factors of production, estimate the role of technological innovations and external factors in the context of military challenges.

Materials and Methods

Assessing Ukraine's economic productivity using Cobb-Douglas and Solow residual modelling is an important stage in the analysis of structural changes in the economy, as these methods allow for a deeper understanding of the main factors determining the current state of the economy and its growth, which in turn contributes to the development of recommendations for increasing Ukraine's economic productivity. The methodology for analysing technological shifts and structural changes in the Ukrainian economy in the context of military challenges included such stages as data collection, estimation of the parameters of the Cobb-Douglas production function and Solow residual, comparative analysis and interpretation of the results for 2014–2023. The analysis was conducted based on official statistical indicators of the Ministry of Finance of Ukraine (Minfin, n.d.a; n.d.b), the Ministry of Economy of Ukraine (Ministry of Economy of Ukraine, 2024), the National Bank of Ukraine (2023) and scientific and analytical reports of UkrISTEI (Pysarenko *et al.*, 2021; 2024). The Excel spreadsheet was used to determine the unknown parameters of the model and to check its adequacy.

At the first stage, a comparison of structural changes in the economy of Ukraine before and after the start of full-scale military operations was made. The main data for comparison include the following indicators: Gross domestic product (n.d.); the volume of capital investments in the economy of Ukraine (Minfin, n.d.a); data on the number of people employed in the national economy of Ukraine (Ukrstat, n.d.; State Employment Service, 2023); the indicator of

the technological level of Ukraine – the GII index for the period of 2014–2024 (Global Innovation Index 2024, 2024); the volume of spending on scientific and technical activities to the GDP (Pysarenko *et al.*, 2021; 2024); the volume of funds from foreign countries and international organisations, the share of military spending in the defence budget of Ukraine (Minfin, n.d.b). The given set of data allowed for an accurate assessment of structural changes in the economy of Ukraine, taking into account the impact of military challenges on investment, employment and the shift in production to innovative industries and sectors with high added value, as well as identifying key aspects for further modelling of economic productivity using the Cobb-Douglas function and the Solow residual.

A comparative analysis method was used to assess changes in the structure of the Ukrainian economy before and during martial law. Thus, major structural changes, resulting from military actions, were presented, in particular, the shift towards strategic and innovative sectors of the economy, and employment decline trends and investment activity under martial law were identified. This approach contributed towards identifying consequences of the full-scale Russian invasion for the Ukrainian economy, as well as made it possible to assess the opportunities for its recovery and development through adaptation to new conditions.

At the second stage, the Cobb-Douglas production function modelling was used to analyse Ukraine's economic productivity. This function allowed for assessing the relationship between capital, labour and technological progress, and determining the elasticity of capital and labour. The calculations were performed using the following formula (1):

$$Y = a^0 K^{\alpha_1} L^{\alpha_2}, \quad (1)$$

where Y is the volume of production (GDP); L is the amount of labour; K is the amount of capital; a^0 is the technological level (efficiency parameter); α_1 and α_2 are labour and capital elasticity. At the third stage, the Cobb-Douglas function was linearised using logarithmic transformation and calculation of the corresponding differentials. As a result, the following linear function was obtained (2):

$$\ln Y = Y'; \ln a^0 = a'; \ln L = L'; Y' = a'_0 + \alpha_1 K' + \alpha_2 L' \quad (2)$$

where Y' is the volume of nominal GDP of Ukraine; K' is the volume of capital investments in the economy of Ukraine; L' is the number of those employed in the national economy of Ukraine; α_1 is capital elasticity, a parameter that characterises the quantitative impact of the volume of capital investments in the economy of Ukraine on the dynamics of its economic growth; α_2 is labour elasticity, a parameter that characterises the quantitative impact of the number of employees in the national economy of Ukraine on the dynamics of its economic growth; a'_0 is a free term of the equation.

The methodology for estimating capital and labour elasticity is based on regression analysis of logarithmic

values, which allowed for a more accurate assessment of the impact of each factor on the GDP. The calculations were performed using the regression analysis tools of the Excel 2020 software package ("Service" – "Data Analysis" – "Regression"), as well as using other software tools, such as Stata. Logarithmic transformation of data and the use of regression analysis made it possible to calculate capital and labour elasticity, which is an indicator of their relative importance in production. This approach allowed for discovering that under martial law, the role of labour and capital is changing, while the importance of technological development is concurrently increasing.

At the fourth stage, the Solow residual (TFP) was applied to gain a deeper understanding of the impact of exogenous factors, which traditional indicators of capital and labour fail to explain. This residual represents the part of economic growth resulting from external changes, such as innovations, support from international partners and adaptation to external shocks. The calculation was carried out according to the following formula (3):

$$TFP = \frac{Y}{K^{\alpha_1}(L \cdot N)^{1-\alpha_1}}, \quad (3)$$

where N is the indicator of the technological level of the Global Innovation Index (GII)

At the fifth stage, a regression analysis was applied, in which the Solow residual was the dependent variable, and the actual data for the specified factors were independent. It made it possible to estimate the share of influence of each factor on the total Solow residual. The calculations were performed according to the following formula (4):

$$TFR = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon, \quad (4)$$

where α_0 is the Solow residual; β_0 is a free term (constant), determining the initial value of the Solow residual when all independent variables are equal to zero; $\beta_1, \beta_2, \beta_3$ are regression coefficients, showing the influence of each

independent variable on the Solow residual; X_1 is expenditures on scientific and technical activities to the GDP; X_2 is military expenditures; X_3 is funds from foreign countries and international organisations; ε is the residual error.

At the sixth stage, the shares of influence of each factor on the dependent variable were identified, using the coefficients of the regression model, expressed in percentages, according to the corresponding formulas (5; 6):

$$Sa.k = |\beta_0| + |\beta_1| + |\beta_2| + |\beta_3|, \quad (5)$$

$$Share_i = \frac{|\beta_i|}{Sa.k} * 100, \quad (6)$$

where $Sa.k$ is the sum of absolute values of the coefficients; β_i is the coefficient for each variable in the regression model.

Data normalisation for calculations was performed using the minimum-maximum method, reducing all variables to a scale from 0 to 1. For each value of the variable x , the following formula was used (7):

$$x_{norm} = \frac{x - x_{min}}{x_{max} - x_{min}}, \quad (7)$$

where is the normalised value; x is the original value; x_{min} is the minimum value of the variable; x_{max} is the maximum value of the variable.

Based on the results of the research, recommendations were made regarding Ukraine's current economic policy, with the focus on such key priorities as stimulating innovation, optimising defence spending and strategic planning of international aid.

Results

The study began with a quantitative assessment of the impact of main factors of production on the economic productivity of Ukraine under martial law. A comparison of structural changes in the Ukrainian economy before and after the start of the full-scale Russian invasion, presented in Figure 1, revealed differences in the economic dynamics of both periods in terms of the GDP and human capital.

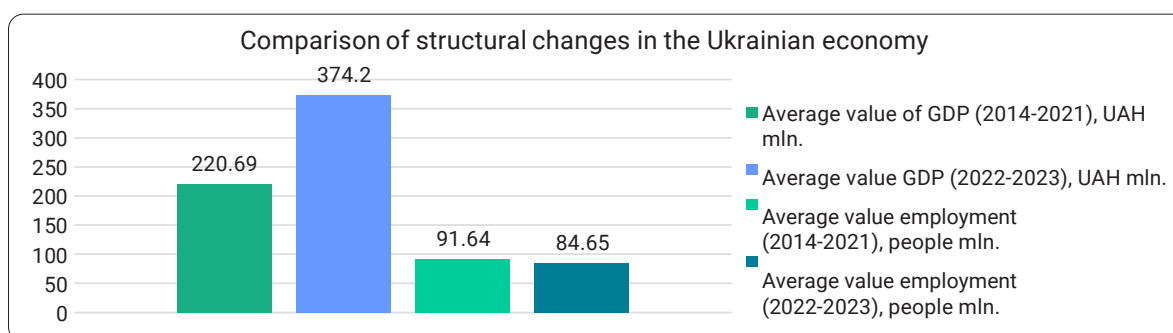


Figure 1. A comparison of structural changes in the Ukrainian economy (average GDP and employment) for the periods (2014-2021) and during full-scale military operations (2022-2024)

Source: calculated by the authors, based on Minfin (n.d.a; n.d.b)

As Figure 1 suggests, the average GDP value increased, indicating a certain revival of economic activity, despite the challenges of wartime. This suggests the ability of the

economy to adapt to crisis, as well as a possible reallocation of resources to more productive sectors, in particular, the defence and innovation industries. At the same time,

the average employment level decreased during this period, which may indicate a reduction in the labour force caused by both the direct impact of hostilities and general economic instability. The decrease in the employment level may also result from structural changes, when significant spending on the defence sector and other priority areas requires significant human resources, causing a redistribution of labour. The analysis of these structural changes contributes to better understanding of key trends in the national economy, in particular, the peculiarities of

the redistribution of labour resources and the dynamics of economic activity in certain sectors. This lays the foundation for a deeper study of the factors of economic growth, clarification of reasons for the increase in the GDP and assessment of the impact of various factors on its dynamics. Based on statistical data on the GDP, capital investment and employment level in the economy, the parameters of the Cobb-Douglas production function were calculated. The obtained data are summarised, logarithmised and presented in Table 1.

Table 1. Calculation of parameters of the Cobb-Douglas production function based on statistical data on the GDP, capital investment and employment level in the Ukrainian economy

Years	Ukraine's GDP, million UAH. (Y_i)	$Ln_{(Y)}$	Volume of capital investments in the economy of Ukraine, million UAH (K)	$Ln_{(K)}$	Number of those employed in the national economy of Ukraine, million people (L)	$Ln_{(L)}$
2014	1566728	14.3	219419.9	12.3	18.1	2.89
2015	1979548	14.5	273116.4	12.5	16.44	2.799
2016	2383182	14.7	359216.1	12.8	16.28	2.78
2017	2982920	14.9	448461.5	13.0	16.16	2.78
2018	3558706	15.0	578726.4	13.3	16.36	2.79
2019	3974564	15.2	623978.9	13.3	16.58	2.80
2020	4194102	15.2	508217	13.1	15.92	2.76
2021	5459574	15.5	673899.3	13.4	15.61	2.74
2022	5191028	15.5	409660	12.9	15.36	2.73
2023	6537825	15.7	425060	12.9	15.23	2.72

Note: $Ln_{(Y)}$, $Ln_{(K)}$, $Ln_{(L)}$ – natural logarithms of the GDP, capital investment and those employed. The data does not include the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and part of the temporarily occupied territories in Donetsk and Luhansk regions

Source: calculated by the authors on the basis of statistical Minfin (n.d.a; n.d.b)

Further, the calculation of capital and labour elasticity was carried out by constructing a linear regression on logarithmic data. The obtained coefficients had the following values: capital elasticity (α_1) was 0.511; labour elasticity (α_2) was -6.145. These parameters were non-standard, since (α_2) is a positive value as a rule. Negative labour elasticity may indicate certain economic or methodological peculiarities, in particular, that an increase in the volume of labour may have a decreasing effect on total production due to oversaturation of the

labour force or inefficient use of labour resources. This result indicated the need for further analysis or revision of the economic model to clarify the impact of labour on economic productivity, in particular, under conditions of an unstable economic situation. The obtained calculated parameters made it possible to compare the real and estimated values of Ukraine's GDP (Table 2). A graphical interpretation of the dynamics comparison of GDP dependence on capital and labour, both before and during hostilities, is presented in Figure 2.

Table 2. Calculated data for comparing the actual and estimated GDP of Ukraine

Years	Ukraine's GDP, million UAH (Y_i)	Estimated GDP volume (Y')
2014	1566728	1245553.3
2015	1979548	2492748.4
2016	2383182	3045010.2
2017	2982920	3569234.7
2018	3558706	3769967.2
2019	3974564	3609072.8
2020	4194102	4171243.9
2021	5459574	5437044.2
2022	5191028	4655784
2023	6537825	4998795.6

Source: calculated by the authors on the basis of Minfin (n.d.a; n.d.b), Ukrstat (n.d.)

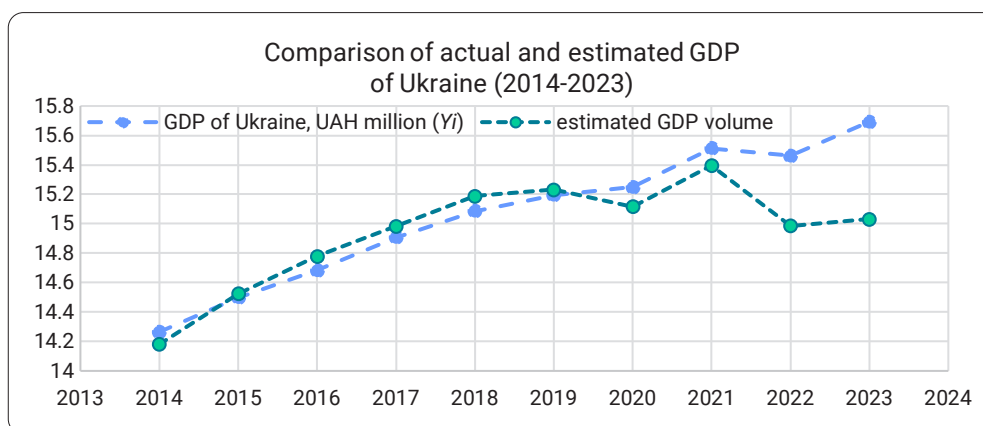


Figure 2. Comparison of actual and estimated GDP of Ukraine (2014-2023)

Source: calculated by the authors

The graph shows the dynamics of the actual and estimated GDP of Ukraine for the period of 2014-2023. Both lines demonstrate the growth of the GDP from 2014 to 2023, which indicates the overall positive dynamics of the country's economic development during this period, despite economic difficulties. The period of 2014-2019 is characterised by a stable Cobb-Douglas model, which almost completely corresponds to the actual GDP indicators and already in the period of 2019-2020 a certain lag of the actual GDP from the calculated by the model can be traced. This can be explained by the effect of COVID-19 pandemic, which disrupted economic cycles. In the period of 2021-2023, the Cobb-Douglas model demonstrates greater volatility. In particular, in 2022, the actual indicators are significantly lower than the estimated ones. This situation reflects the impact of martial law on the economy of Ukraine. Reduced investment, infrastructure destruction and unstable employment have significantly affected the country's economic performance. The actual GDP shows growth, unlike estimated values, which may indicate the impact of factors not depending on the values of capital and employment of the population, as well as unforeseen adjustment factors or external assistance that supported the economy more than expected.

Since 2022, there has been an increase in the negative impact of employment in the national economy, as well as a deterioration in the investment climate. However, it should

be mentioned that significant deviations of the model in recent years indicate that the standard Cobb-Douglas production function fails to take into account the impact of external shocks, such as military challenges and global crises. Economic reality is becoming much more complex and traditional models can generate significant errors. Therefore, it can be concluded that the Cobb-Douglas Production Function model operates well in more stable periods, whereas its accuracy is significantly reduced during periods of military operations, significant economic changes and other possible stressful conditions.

Based on the obtained results, the Solow residual (TFP) was calculated using expression (3). According to the characterisation provided by W. Kenton (2023), the Solow residual is the growth of output, taking place beyond the simple growth of costs. Thus, the Solow residual is described as an indicator of productivity growth due to technological innovation. It is proposed to adopt the Global Innovation Index (GII) as the TFP indicator, which is a comprehensive indicator, according to the methodology of the World Intellectual Property Organisation (WIPO) (Global Innovation Index 2024, 2024). The GII is based on more than 80 indicators of innovation potential, including investment in research and development, education spending and high-tech products (see Table 3). The calculation results are graphically presented in Figure 3.

Table 3. Statistical values for determining the Solow residual

Years	Ukraine's GDP, million UAH (Yt)	Volume of capital investments in the economy of Ukraine, million UAH (K)	Number of those employed in the national economy of Ukraine, million people (L)	Technological level indicator of GII (N)
2014	1566728	219419.9	18.1	63
2015	1979548	273116.4	16.44	64
2016	2383182	359216.1	16.28	56
2017	2982920	448461.5	16.16	50
2018	3558706	578726.4	16.36	43
2019	3974564	623978.9	16.58	47

Table 3, Continued

Years	Ukraine's GDP, million UAH (Yi)	Volume of capital investments in the economy of Ukraine, million UAH (K)	Number of those employed in the national economy of Ukraine, million people (L)	Technological level indicator of GII (N)
2020	4194102	508217	15.92	45
2021	5459574	673899.3	15.61	49
2022	5191028	409660	15.36	57
2023	6537825	425060	15.23	55

Source: developed by the authors based on statistical data from the Ministry of Finance (n.d.a; n.d.b), Scientific, scientific-technical and innovative activity in Ukraine in 2023 (Pysarenko *et al.* 2021; 2024), Ministry of Finance (Financing of the state budget of Ukraine, 2025)

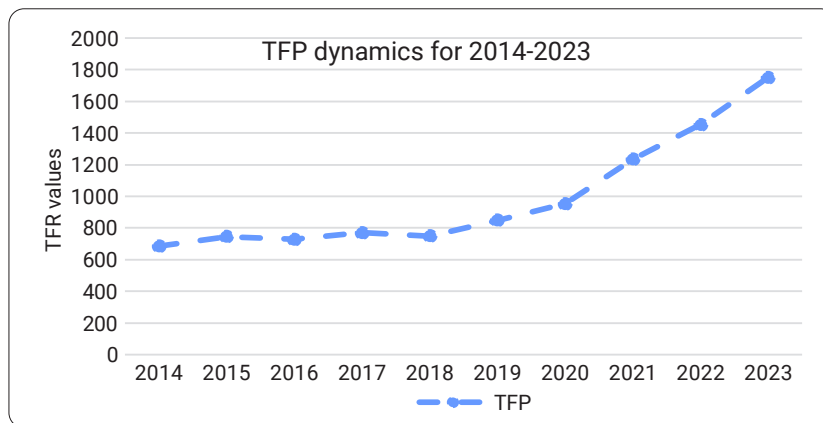


Figure 3. TFP dynamics (technological factor or productivity that cannot be attributed to labour and capital indicators)
Source: calculated by the authors

As it can be seen from Figure 3, TFP changes over time and in recent years the indicators have been gradually increasing, which indicates an increase in indicators that do not depend on the magnitude of the values of capital (K) and labour (L). Observations suggest that the technological level or productivity, which do not depend on changes in labour and capital indicators, are of great importance for explaining economic shifts in Ukraine. Since standard capital and labour factors fail to explain the GDP growth, the Solow residual indicates a significant impact of technology and other factors and the authors suggest that this may be innovative development, military spending or international aid. Therefore, it is proposed

to consider the Solow residual as a set of components such as innovation, military spending and international aid.

Further, a regression analysis is carried out, where the Solow residual is the dependent variable and the actual data for the specified factors are independent. This will allow for assessing the share of impact of each factor on the total Solow residual. The data representing innovation, military spending and international aid over the years are summarised in Table 4. The data is indexed in order to clearly see how spending on scientific and technical activities, military spending and international aid have changed over the years, comparing them in relative values.

Table 4. Statistical values for determining the components of the Solow residual (TFP)

Years	GDP, million UAH		Expenditures on scientific and technical activities to GDP		Ukraine Military Spending/ Defence Budget		Funds from foreign countries and international organisations, UAH million	
	GDP	(Yi)	(X1)	(X1i)	(X2)	(X2i)	(X3i)	
2014	1566728	0	0.60	1	0.023	0	5383.0	0.009
2015	1979548	0.083	0.55	0.815	0.033	0.025	1800.3	0.002
2016	2383182	0.164	0.48	0.556	0.032	0.022	4109.4	0.006
2017	2982920	0.285	0.45	0.444	0.029	0.015	1607.4	0.001
2018	3558706	0.401	0.47	0.519	0.032	0.022	1464.8	0.001
2019	3974564	0.484	0.43	0.37	0.035	0.029	1139.9	0

Table 3, Continued

Years	GDP, million UAH		Expenditures on scientific and technical activities to GDP		Ukraine Military Spending/ Defence Budget		Funds from foreign countries and international organisations, UAH million	
	GDP	(Yi)	(X1)	(X1i)	(X2)	(X2i)	(X3i)	
2020	4194102	0.529	0.41	0.296	0.038	0.037	1029.7	0
2021	5459574	0.783	0.38	0.185	0.032	0.022	1289.9	0.001
2022	5191028	0.729	0.33	0	0.33	0.754	481090.7	1
2023	6537825	1	0.33	0	0.43	1	433404.5	0.901

Source: developed by the authors based on statistical data from the Ministry of Finance (n.d.a; n.d.b), Scientific, scientific-technical and innovative activity in Ukraine in 2023 (Pysarenko et al. 2021; 2024), Ukraine military spending/defence budget 1992-2025 (n.d.)

The dynamics of the components (X1, X2, X3) according to the data presented in Table 4 reflects the main trends in the specified indicators. There is a gradual decrease in spending on scientific and technical activities, which indicates their significant reduction. Defence spending (X2) demonstrates a sharp increase, especially in 2022 (33% of GDP) and 2023 (43% of GDP). The volumes of

funds provided by foreign countries and international organisations have changed significantly, in particular, in recent years their significant growth has been observed. This suggests the increased international support for Ukraine, as well as an increase in dependence on foreign aid. After calculations, the following main parameters of the TFP function (4) were obtained, which are summarised in Table 5.

Table 5. Main parameters of the TFP function

TFP function parameters	TFP function parameter value
R-squared	0.962212405
Multiple coefficient	0.925852713
Normalised R-squared	0.888779069
Standard error of approximation of 1	0.108183523

Source: created by the authors

Main parameters of the TFP function demonstrated a high R-squared value, which suggests that the model explains accurately the dependence of the Solow residual (TFP) on the variables X1, X2, X3. Approximation of 1 means a high correspondence of the actual and estimated values. The multiple coefficient revealed a strong correlation between the dependent variable (TFP) and the

independent variables. The obtained value of the normalised R-squared proved that the model retains high accuracy even after correction. The standard error of approximation testified a low level of dispersion of the residuals, which highlighted the reliability of the model. The estimated values of the basic level of TFP and the coefficients are summarised in Table 5.

Table 6. Results of values of the Solow residual components with coefficients

Indicators	Coefficient	Standard Error	t-Statistic	P-Value	Confidence Interval (95%)
Y-intercept	0.777	0.090	8.592	0.00014	[0.556, 0.999]
β_1	-0.864	0.153	-5.664	0.0013	[-1.237, -0.491]
β_2	0.803	0.458	1.754	0.1300	[-0.317, 1.923]
β_3	-0.649	0.413	-1.572	0.1671	[-1.660, 0.362]

Source: created by the authors

The coefficient characterising the impact of expenditures on scientific and technical activity is statistically significant, despite having a negative value. This suggests that contrary to expectations, this component has a negative impact on economic productivity in the model. At the same time, the coefficient reflecting the impact of military spending is not statistically significant, which indicates the absence of a considerable impact of this factor on economic activity. Similarly, the

coefficient characterising international aid is also statistically insignificant, which indicates the minimal impact of this indicator within the analyzed model. Then, the share of impact of each factor on the dependent variable was found using the coefficients of the regression model. The share of impact of each factor is determined by the ratio of its coefficient to the sum of the absolute values of all coefficients (including the constant) according to equation (5) (see Table 6).

Table 7. Results of the analysis of the share of impact of factors on the dependent variable (Solow residual)

TFP function parameter name	TFP parameter value, %
Share of basic productivity level of Yp	25.13
Share of X1	27.92
Share of X2	25.95
Share of X3	20.99

Source: created by the authors

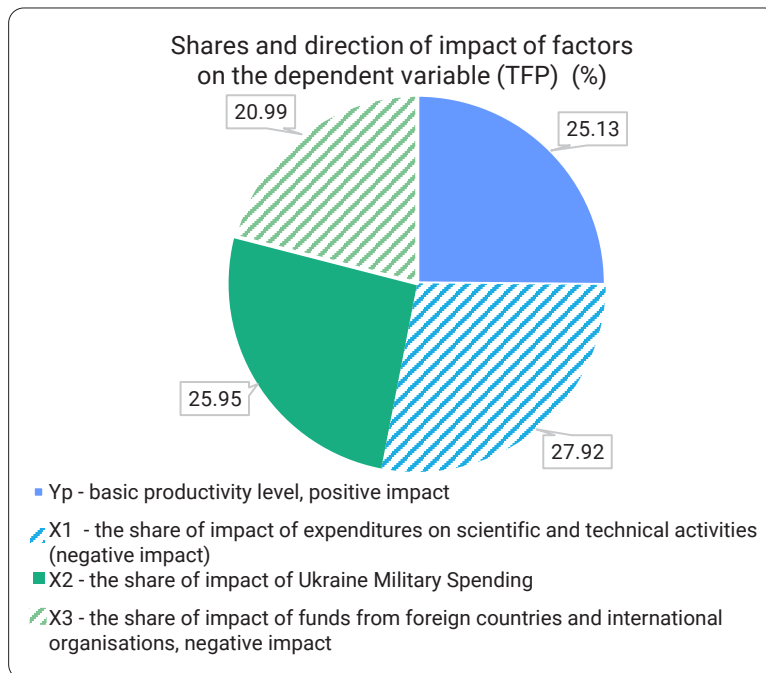
The sum of the absolute values of the coefficients is as follows:

$$Sa.k = 0.777 + 0.864 + 0.803 + 0.649 = 3.093476$$

The obtained results of the shares of impact of factors on the Solow residual demonstrated a balanced distribution between components. The basic productivity level provides a quarter of the impact on the total Solow residual. This level reflects the basic productivity, which does not depend on changes in factors and indicates a significant contribution to internal stability due to factors ignored by the variables. For example, adaptive capacity, infrastructure reforms or other non-economic factors that are of a significant impact. Expenditures on scientific and technical activities (variable X1) play a considerable role in the model, although this impact is negative, which suggests that insufficient funding for scientific and technical activities complicates their positive

effect. The value of variable X2 indicates its significant, although balanced impact on the economy productivity. At the same time, the results suggest that high spending is not compensated by productivity growth in other sectors, which may negatively affect the overall economic dynamics.

The value of variable X3 reflects a significant impact of international aid, which highlights its important role in maintaining economic stability. However, the aid is mainly directed towards humanitarian purposes, its impact on economic productivity is significant due to its support of infrastructure projects and satisfaction of basic needs, which indirectly contributes to economic stability. Thus, the obtained values indicate a relative uniformity of the impact of factors on the Solow residual. Expenditures on scientific and technological activities (X1) remain a key driver of productivity, validating its importance for long-term development. A visual representation of the impact of factors on overall productivity is given in Figure 4.

**Figure 4.** Shares of impact of each factor on the dependent variable (TFP)

Source: calculated by the authors

Reduction in spending on scientific and technical activities decreases the positive potential of innovation, which explains the negative impact of X1. Increased military spending and international aid do not lead to a significant increase in the basic level of productivity, since these

funds are aimed at ensuring stability and security, rather than supporting economic growth. Thus, it can be concluded that under conditions of military challenges and crises, innovative investments can have an unexpected negative impact and military spending and international

aid do not have a significant impact on economic productivity in the short term.

Based on the conducted analysis and considering the current conditions of economic instability in Ukraine, a number of recommendations are proposed aimed at increasing innovative activity, optimising defence spending, effectively using international aid and solving the problem of returning the working population:

1. It is necessary to develop a long-term strategy for integrating defence spending into general economic policy, in particular, in the field of developing the latest defence technologies that can become competitive export goods. An important task is to create a system for assessing the effectiveness of defence spending, which will ensure their maximum economic return. Moreover, it is worth attracting private investment in the defence industry through public-private partnership mechanisms.

2. International aid should be directed to the restoration of critical infrastructure, in particular, energy and transport, as well as to support the population affected by the war. It is also advisable to use international aid for the development of innovation and production infrastructure, including the creation of new industrial zones and technological clusters. It is important to ensure transparent reporting to donors on the targeted use of funds and demonstrate the effectiveness of implemented projects, which will help strengthen the trust of international partners.

3. To encourage the return of migrant workers, it is necessary to implement programs that provide decent working conditions, competitive wages and new jobs. A special attention should be paid to investing in programs to improve the skills of workers, particularly in technological and strategic sectors. Moreover, ensuring access to quality medical, social and educational infrastructure will contribute to the reduction of the outflow of skilled personnel abroad.

4. To stimulate investment in the Ukrainian economy, it is necessary to guarantee transparency, efficiency and accountability of economic policy. Important steps include strengthening the protection of investors' rights, reducing administrative barriers and minimising corruption risks, which will create favorable conditions for attracting domestic and foreign investments.

This study analyzes Ukraine's economic productivity using the Cobb-Douglas model and the Solow residual. The main attention is paid to the impact of scientific and technological activity, military spending and international aid on economic growth under martial law. The conducted analysis demonstrates both consistency with previous studies and certain specifics related to technological and structural changes in the Ukrainian economy. The level of GDP growth is defined as one of the key factors of economic development. This is consistent K. Redko's *et al.* (2024), also T. Stahl *et al.* (2019) findings, suggesting that the real GDP is a critical indicator for assessing economic growth. Similar results were obtained by T. Cherkashyna (2019), estimating the dynamics of Ukraine's economic development. The results of the current research prove that the GDP is

an important factor, although its growth does not always correlate with productivity in other sectors.

The results of the calculations suggest that, contrary to expectations, scientific and technical activity has a negative impact on the economic productivity of Ukraine in the model. This can be explained by the deferred effect of innovations that require a long-term payback period, suboptimal financing of innovative projects under conditions of economic instability and the outflow of qualified personnel due to the war. This is consistent with W. Kenton's assertion (2023) that the Solow residual reflects both technological changes and resource efficiency, which may be reduced under unstable conditions. As W. Kenton (2023) points out, the Solow residual is a key indicator of the overall factor productivity, which provides for assessing the contribution of technological progress regardless of changes in capital and labour. The results of the current study suggest that expenditures on scientific and technical activities, which in a stable economy usually contribute to increasing productivity, may not have an immediate positive effect during a crisis.

The results of the study also support J. Brusuelas & T. Nguyen's findings (Solow residual..., n.d.), suggesting that in the economies of developed countries, the Solow residual remains stable even under crisis conditions, since significant investments in technology and efficient resource management support productivity. However, in the case of Ukraine, the results of the current study demonstrate that the impact of innovative investments is negative, which may result from their insufficiency, inappropriate distribution or lack of proper institutional support. The analysis of military spending revealed their statistical insignificance in the model. This implies that they do not have a direct impact on economic productivity. At the same time, military spending can contribute to the development of the defence industry, although under war conditions, the main funds are directed to current operational needs, rather than to technological developments.

Despite significant external support, international aid failed to demonstrate a statistically significant impact on economic productivity. This may result from insufficient integration of external financial resources into strategic sectors, the use of aid mainly for social benefits rather than development programs, as well as the lack of an effective resource allocation mechanism.

The above findings partially overlap with the recommendations of the OECD (2023) on the need to restore Ukraine's innovation ecosystem and develop digital infrastructure. At the same time, the CSIS (2023) emphasises that international assistance should be accompanied by structural reforms to maximise its impact.

The results of the current analysis correlate with O. Sokolova' (2022), V. Momot & O. Lytvynenko's findings (2023), V. Ivanchenkov *et al.* (2024) studying the modelling of macrosystem economic stability, emphasising the importance of the stable functioning of main economic sectors. They emphasised that under instability conditions, the adaptive potential of the economy depends on the

efficiency of resource management and investment allocation. Similar conclusion was made by A. Ostapenko & D. Zalevska (2024), claiming that short-term innovative investments do not always have a positive effect due to unpredictable changes in the economic environment. The results of the current study, giving evidence for the limited effectiveness of innovative investments during martial law, are consistent with the findings of the above-mentioned authors about the need for a comprehensive approach to economic development, particularly under crisis conditions.

O. Suncova's (2022) and I. Pidorycheva's (2022) studies focused on the impact of financial technologies and virtual assets on economic growth. The authors studied the ability of new financial instruments to contribute to increasing the overall productivity, despite the fact that their impact largely depends on the effectiveness of regulation and the level of integration into the financial system. The current results suggest that ineffective management of innovation costs can reduce their positive role in the model of economic productivity. It is consistent with O. Suncova's (2022) and I. Pidorycheva's (2022) findings, suggesting that the role of technological changes in economic development is determined both by their availability and the ability of the system to adapt them to current conditions, therefore Ukraine should insist on a post-war development scenario aimed at creating an innovative industrial economy, having developed a comprehensive plan for the post-war reconstruction of the country based on new technological foundations.

The use of the Cobb-Douglas function and the Solow residual in this study proves their effectiveness in modelling economic productivity, which is consistent with S. Shumskaya's (2007), V. Volkova's *et al.* (2024) findings. V. Kapustian *et al.* (2022) and S. Turlakova (2022) also emphasise the need to adapt classical economic models to the realities of Ukraine and O. Hirina *et al.* (2024) emphasised the role of technological innovations in adjusting traditional approaches to economic analysis.

Thus, the results of the study are consistent with Ukrainian scientists' findings on the complexity of the impact of scientific and technical activities and economic factors on economic productivity under conditions of military challenges. They emphasise the need to improve innovation management mechanisms, optimise resource allocation and increase the effectiveness of state policy on economic stability

Conclusions

The use of the Cobb-Douglas production function revealed a change in the role of capital, labour, and innovation in the formation of Ukraine's GDP, especially under martial law. It has been discovered that traditional factors, such as labour, in some cases have a negative impact, which can be explained by a decrease in the efficiency of their use. The Solow residual indicates the significant role of technological progress, which, although not immediately affecting productivity, is a key to long-term development. Innovation remains a significant factor, although in the short term

its impact may be negative due to insufficient funding and economic instability. Defence spending and international aid have a minimal impact on productivity in the short term, which highlights the need for strategic planning of their use. Based on the results of the research, a number of recommendations are proposed to increase Ukraine's economic productivity. First of all, it is necessary to increase the share of investments in scientific developments, as well as actively stimulate international cooperation in the field of innovation. An important step is the integration of defence spending into the economic strategy in order to promote the development of a high-tech defence complex, which provides for the introduction of a mechanism for monitoring the effectiveness of defence investments, as well as directing part of the costs to the development of dual technologies that can be used in civilian industries.

Moreover, international aid should be focused on strategic projects, in particular, the modernisation of energy systems, the development of transport infrastructure and ensuring the livelihoods of the affected territories. Another important aspect is increasing the transparency of the use of international aid, which will help strengthen the trust of donors. Taking into account the problem of inefficient use of labour resources, it is advisable to create favourable conditions for returning labour migrants. It is also worth implementing state programs aimed at attracting young people to scientific and technical specialties, which will become the basis for long-term strengthening of the country's human capital. The results of the study suggest that innovation remains a key factor in productivity, even despite the negative impact in the short term, which proves the need to stimulate innovative development for economic recovery. The introduction of innovative technologies and the implementation of structural reforms will ensure sustainable economic growth. In the context of military challenges, the Ukrainian economy is undergoing significant changes in the structure of production, which can be traced in changes in capital and labour elasticity. The identified increase in the technological level, which is not connected with the growth of traditional factors, indicates the significant role of innovation processes and adaptation to external challenges.

As far as the impact of defence spending on productivity is concerned, based on the research results the need is emphasised to implement a system for monitoring the effectiveness of these expenditures. The research results indicate the need to integrate military investments into the overall economic strategy, particularly in the field of defence technologies, as well as the need for strategic planning of aid use, focusing it on long-term investments in infrastructure, technology, and human capital. Further research should include adapting models to unstable conditions by integrating additional factors, such as global shocks and socio-economic changes.

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Conflict of Interest

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Моделювання економічної продуктивності України в умовах воєнних викликів

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Анотація. Воєнні виклики трансформували економіку України, що актуалізувало потребу у переоцінці джерел її продуктивності. Метою було змодельовати вплив цих факторів на ВВП України за допомогою виробничої функції Кобба-Дугласа та залишку Солоу. Проаналізовано статистичні дані за 2014-2024 роки, виконано регресійний аналіз для визначення взаємозв'язку між основними економічними змінними, а також оцінено еластичність капіталу та праці. Залишок Солоу використовувався для оцінки технологічного рівня економіки та ідентифікації екзогенних факторів, що впливають на продуктивність. Результати дослідження показали, що витрати на науково-технічну діяльність мали негативний вплив у короткостроковій перспективі, що пов'язано з недостатнім рівнем фінансування та макроекономічною нестабільністю. Військові витрати не забезпечили значного приросту продуктивності через їхню непродуктивну спрямованість. Натомість міжнародна допомога сприяла макроекономічній стабільності, однак не стимулювала довгострокове зростання. Частковий внесок факторів у формування залишку Солоу склав 27,92 % для інновацій, 25,95 % для військових витрат та 20,99 % для міжнародної допомоги. Модель показала високе значення R^2 (0,96), що свідчить про її надійність у поясненні змін ТФР. Було розроблено рекомендації для підвищення економічної продуктивності України, які передбачають покращення науково-технічної діяльності через покращення фінансування наукових досліджень, раціоналізацію оборонних витрат завдяки інтеграції військових інвестицій у загальну економічну стратегію, а також ефективне залучення міжнародної допомоги для проведення структурних реформ і розвитку людського капіталу. Отримані результати можуть слугувати основою для формування економічної політики, спрямованої на післявоєнне відновлення країни

Ключові слова: виробнича функція Кобба-Дугласа; залишок Солоу; зайнятість населення; витрати на науково-технічну діяльність; міжнародна допомога

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Social entrepreneurship in the Republic of Kazakhstan as a tool for increasing employment among socially vulnerable population groups

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Abstract. The purpose of the study was to examine social entrepreneurship as a means of employment for socially vulnerable population groups in the Republic of Kazakhstan. A contextual analysis of the national labour market was conducted using the PEST framework and statistical data from the Bureau of National Statistics, the Asia Pacific Career Development Association, and the World Bank Group. The cases of three social enterprises in Kazakhstan, Green TAL, Garbar Group, and Kunde, were also analysed. The contextual analysis demonstrated that despite a relatively low average annual unemployment rate of 3.3-3.6%, certain categories of the working-age population remain the least competitive in terms of receiving job offers, earning competitive wages, or achieving career advancement. These categories include graduates of vocational and higher education institutions without work experience, women, and persons with physical disabilities. The case studies demonstrated the high potential of socially oriented enterprises in addressing systemic social issues, including job creation, training and retraining of specialists, elevating the status of specific professions, and reducing property inequality. Several strategy groups were developed to enhance the effectiveness of social enterprises in employing vulnerable population groups: expansion of state support and regulatory frameworks for social entrepreneurship; development of a financial and investment support system for socially oriented enterprises; educational and advisory initiatives aimed at increasing awareness of the prospects of social entrepreneurship; and the development of partnerships and infrastructure in the field of social enterprise. The findings may be used to improve the performance of socially oriented enterprises, the activities of which have only been legally regulated since 2021

Keywords: social entrepreneurship; employment; inclusive labour market; working-age population; income inequality; legislative regulation

Introduction

Being a driving force behind economic development, entrepreneurship also contributes to addressing socially important challenges such as the stigmatisation and isolation of specific groups. Vulnerable population groups, for instance, single parents, individuals with chronic illnesses, former prisoners, and others, require targeted support, which can be provided by social enterprises. Based on this statement, the analysis of the prospects and development trends of this form of entrepreneurship remains a highly relevant subject. The concept of social entrepreneurship is relatively recent. According to Y. Agarwal (2024), the core philosophical aspects of the phenomenon were first discussed by Milton Friedman in 1970. In the cited paper, social entrepreneurship was presented as a counterpoint to conventional entrepreneurship, which prioritised profit generation at any cost, including the violation of ethical standards. A. Ualiyeva (2024) indicated that in the Republic of Kazakhstan, the legal recognition of social entrepreneurship was only formalised in 2021. B. Tursynova *et al.* (2024) argued that the relatively short history of social entrepreneurship in the country explains the lack of comprehensive support for its development.

A.M. Yerzhanova *et al.* (2024) emphasised that social entrepreneurship emerged as a response to the government's inability to resolve pressing social issues, including rising unemployment and the associated social tensions. M.H. Sohel & M. Shamsuddoha (2020) noted that the empirically confirmed ability of social entrepreneurship to address systemic issues led to its growing popularity across many countries. J. George & K.A. Kumar (2024) highlighted the absence of a universally accepted definition of social entrepreneurship, identifying it as a potential source of strategic disagreement. In an effort to avoid such discrepancies, the cited researchers proposed that social entrepreneurship should be defined by its core feature: a

focus on addressing social issues and generating positive societal change through entrepreneurial activity. A similar approach was uncovered by L. Glasbeek *et al.* (2024), who underlined that the primary objective of social entrepreneurship is to create social value rather than to pursue personal or shareholder enrichment.

The advantages of social entrepreneurship were explored in numerous studies, including that of S.T. Okutayeva *et al.* (2021), who argued that this form of entrepreneurship contributes to the expansion of economic opportunities, particularly for marginalised groups, by providing employment, introducing innovative business models, and supporting initiatives aimed at enhancing innovation capacity. Similar conclusions were drawn in the study by S. Kumar & S.K. Yadav (2023), who applied their proprietary managed cooperation network model to demonstrate that the positive local-level impact of social entrepreneurship can be scaled to address global challenges. Studies conducted in various countries confirm that social entrepreneurship is consistently effective in tackling the global issue of unemployment, regardless of the prevailing economic context. One such study, by A.P. Mukherjee *et al.* (2023), focused on the development of social entrepreneurship in India. According to the authors, the growth of social enterprises in rural areas of the country supports the empowerment of women, thereby helping to mitigate the economic repercussions of the COVID-19 pandemic.

Examining the experiences of 20 entrepreneurs in Uganda, P. Turyakira *et al.* (2025) concluded that, despite certain challenges, social entrepreneurship serves as an effective mechanism for achieving the seventeen Sustainable Development Goals (SDGs) outlined by the United Nations. Drawing on the African context, P. Turyakira *et al.* argued that social entrepreneurship is particularly effective in advancing Goals 1, 4, 5, 8, and 10, which relate to poverty

reduction, quality education, gender equality, decent work and economic growth, and the reduction of inequality. Analysis of data from a sample of 208 South Korean social enterprises between 2017 and 2019 enabled C.Y. Kim (2024) to establish a statistically significant positive correlation between the level of social entrepreneurship and the growth rates of overall employment, employment among vulnerable workers, and enterprises' financial performance. In summarising the experience of Malaysia, H. Halid *et al.* (2023) confirmed the role of social entrepreneurship in expanding employment opportunities, highlighting its particular relevance for addressing youth unemployment.

Although the unemployment rate in the Republic of Kazakhstan remains relatively low, significant disparities persist in access to employment and the socio-economic benefits it entails. A. Ismagulova & S. Massakova (2024) stated in their study that wealth inequality continues to represent one of the most pressing systemic issues in the country. External shocks, including the effects of the COVID-19 pandemic, further exacerbated inequalities that have existed for decades. Social stratification, in turn, not only increases the likelihood of conflict between different social groups but also hampers the nation's economic development.

The development of social entrepreneurship could serve as a viable solution to the issue, yet its specific features within Kazakhstani society remain insufficiently explored. In light of these gaps, the study set out to examine social entrepreneurship as a means of increasing employment, a subject of clear contemporary relevance. The objectives of the study are as follows:

- to analyse selected case studies of social entrepreneurship in the Republic of Kazakhstan;
- to explore the potential for scaling the accumulated experience.

Materials and Methods

The material for this study consisted of statistical data obtained from the official website of the Ministry of Labour and Social Protection of the Population of the Republic of Kazakhstan (n.d.). These statistics were employed to assess employment trends, including among socially vulnerable groups such as women and young people. Supporting materials included papers by G.Zh. Doskeyeva (2021), A. Bekenova (2022), and L.A. Kuanova & A. Anessova (2024). These sources were analysed to identify the population categories most affected by inequality in employment and investigate the underlying causes of such disparities.

The study was based on a combination of methods, including content analysis, contextual analysis, and case study methodology. Content analysis was applied to the industry reports and academic sources mentioned above. Sources were selected based on credibility and relevance, and preference was given to those published from 2020 onwards to enhance the currency of the findings. Contextual analysis was conducted to investigate the factors that shaped the development of the labour market in the Republic of Kazakhstan and the emergence of socially disadvantaged

groups within it. This analysis employed two tools: a framework for identifying key labour market indicators and the Political, Economic, Social, Technological, Environmental and Legal (PESTEL) model. The former was developed using data from the Bureau of National Statistics (2024) and served to highlight and examine the principal characteristics of the labour market of Kazakhstan. PESTEL was used to analyse the external factors – political, economic, social, technological, environmental, and legal – that influence labour market development in Kazakhstan.

A case study methodology was used to explore the operations of specific socially oriented enterprises in the Republic of Kazakhstan in detail. Three enterprises were selected as case studies: Green TAL (n.d.), Garbar Group (n.d.), and Kunde (Video case..., n.d.). These organisations were chosen because their activities aim to achieve socially beneficial goals and address pressing societal issues. Socially oriented projects that failed to submit activity reports for the 2023-2024 reporting period were excluded from the sample. A standardised analysis was conducted by examining the following elements of each selected case: the history and focus of the enterprise's socially oriented activity, employment statistics for the most vulnerable population groups, and the outcomes of the most significant projects. The data extracted from these cases were used to develop recommendations for the planning and management of social enterprises to enhance employment opportunities for socially vulnerable groups.

Results

Development of the labour market in the Republic of Kazakhstan

The national labour market encompasses all citizens of the country who are capable of performing certain types of work. The Bureau of National Statistics (2024) applies a set of criteria to provide a comprehensive profile of the labour market of Kazakhstan. One of the key indicators is age, as the labour force includes individuals aged 15 and older. As of 2024, the working-age population between 15 and 64 years old accounted for 62% of the total population, equating to approximately 13 million people (Ministry of Labour..., n.d.). According to the Bureau of National Statistics' methodology, this group is further divided into those who are part of the labour force and those excluded from it for various reasons. Given that not all individuals aged 15-64 are engaged in the production of goods or services, it may be inferred that the actual size of the labour force in Kazakhstan is smaller than the aforementioned 13 million. This assumption is supported by experts from the Bureau of National Statistics, who report that the total labour force in the country stands at 9.664 million, of whom 9.214 million are employed. The employment rate among the working-age population, therefore, stands at 95.3%, a comparatively high figure. The same report indicates that employment levels are showing a slight but consistent increase: in the third quarter of 2024, the unemployment rate stood at 3.3%. The labour market of Kazakhstan is shaped

by a combination of external factors. The most influential among these are political, economic, social, technological, environmental, and legal factors. Their impact on the Kazakhstani labour market is presented in Table 1.

Table 1. Factors influencing the functioning of the labour market in the Republic of Kazakhstan

Factor	Explanation
Political	1. State employment policy – development of employment support programmes, including “Enbek” and other initiatives aimed at upskilling workers. 2. Investment in the economy – state support for industrialisation, digitalisation and business development affects the creation of new jobs. 3. Political stability – a crucial factor in attracting investors and ensuring labour market stability. 4. Government reforms – implementation of educational reforms, development of vocational and technical education, and attraction of foreign investment.
Economic	1. Growth in gross domestic product (GDP) – Kazakhstan demonstrates moderate economic growth, which is reflected in the labour market. 2. Unemployment rate – remains stable at 4.8-5.0%, though there is a mismatch between labour demand and supply. 3. Inflation and wage levels – high inflation reduces purchasing power and increases demand for higher wages. 4. Dependence on extractive industries – the mining sector remains a key employer, though there is a trend towards economic diversification. 5. Development of small and medium-sized enterprises (SMEs) – an increase in start-ups and SMEs is generating new job opportunities.
Social	1. Demographic changes – a growing youth population increases competition in the labour market. 2. Education level – the number of university graduates is rising, yet there remains a shortage of qualified technical specialists. 3. Labour migration – outflow of skilled workers abroad and inflow of migrants from neighbouring countries. 4. Gender issues – an increase in women in leadership positions is observed, although wage inequality remains a concern.
Technological	1. Automation and digitalisation – the introduction of artificial intelligence (AI), robotics, and automation is reducing employment in conventional sectors. 2. Development of the IT industry – active development of the IT sector is generating opportunities for highly qualified professionals. 3. Remote work – following the COVID-19 pandemic, many companies adopted remote working arrangements. 4. Professional training – growth in online education and upskilling platforms (Coursera, Stepik, university courses).
Environmental	1. Growth of the green economy – the emergence of jobs in the renewable energy sector. 2. Environmental standards – influence of international environmental, social, and governance (ESG) requirements on the labour market. 3. Industrial pollution – impact of environmental degradation on working conditions in mining and manufacturing industries.
Legal	1. Labour legislation – development of laws protecting workers’ rights, minimum wages, and working conditions. 2. Migration regulation – introduction of quotas for labour migrants and programmes aimed at attracting highly skilled specialists. 3. Taxation and incentives – tax benefits for businesses and start-ups contributing to job creation. 4. Workers’ rights protection – growing influence of trade unions and social initiatives on labour relations regulation. 5. Adoption of Law of the Republic of Kazakhstan No. 52-VII ZRK “On Amendments and Supplements to Certain Legislative Acts of the Republic of Kazakhstan on Entrepreneurship, Social Entrepreneurship and Compulsory Social Health Insurance” (2021).

Source: compiled by the authors based on Asia Pacific Career Development Association (n.d.), G.Zh. Doskeyeva (2021), A. Bekenova (2022), Bureau of National Statistics (2024), World Bank Group (2024a), L.A. Kuanova & A. Anessova (2024)

Table 1 demonstrates that the labour market in the Republic of Kazakhstan is developing under relatively favourable conditions shaped by government support for education and employment initiatives, stable economic growth, technological innovation, and legal advancements in the sector. Nonetheless, several external

factors influence the equitable distribution of employment opportunities, exacerbating challenges faced by socially vulnerable groups.

One such factor is uneven economic growth combined with rising inflation, which intensified income inequality within the country. According to the World Bank Group

(2024a, 2024b), the rapid economic expansion of Kazakhstan in the early 2000s brought the country close to attaining high-income status. However, the COVID-19 pandemic of 2019-2020 slowed annual economic growth, which fell to 1.4% in 2021-2022. Modest economic growth, coupled with an inflation rate of 8.6% in 2024, led to reduced purchasing power for segments of the population and further deepening of socio-economic disparities (Bureau of National Statistics, 2024). The World Bank Group states that the poorest 40% of the population are most vulnerable to economic shocks, during which their consumption growth may stagnate or even turn negative. Z. Chulanova *et al.* (2024) also highlight a higher unemployment rate among the poorest population segments, linked to systemic issues such as limited access to education and proximity to critical infrastructure. Based on this evidence, there is a clear need to ensure stable employment for the poorest social groups as a means of supporting sustainable development within Kazakhstani society.

Table 1 further shows that employment among young people aged 15 to 34 constitutes a challenge. According to the Bureau of National Statistics (2024), there has been a slight but steady increase in the population within this age group, contributing to heightened competition in the labour market. Evidence for this is encountered in the unemployment rate of 4.6-3.7% recorded in Kazakhstan in

2024, with 3.1-3.2% attributed to individuals under the age of 34. The relatively high unemployment rate among young people may result in systemic issues, including population outflow, the diminishing prestige of vocational and higher education, and increased social tension. Based on these statistical indicators, young people represent a socially vulnerable demographic whose employment should be treated as a national priority.

A high level of vulnerability is also characteristic of women, who face difficulties in securing employment and receiving competitive wages. Evidence of gender inequality was presented by L.A. Kuanova & A. Anessova (2024), who compared the unemployment rates among the working-age male and female populations in Kazakhstan between 2011 and 2021. According to the authors, the average labour force participation rate for women during this period was 64.96%, compared with 76.38% for men. The rate of informal employment among women was also 4.5% lower than that of their male counterparts. The cited researchers emphasised that, despite comparable levels of vocational and higher education among working-age men and women, the female unemployment rate is higher, standing at 5.71% compared with 4.36% for men. Attention should also be given to people with disabilities, who represent one of the largest socially vulnerable groups. Key statistical data for this demographic are presented in Table 2.

Table 2. Employment of persons with disabilities in the Republic of Kazakhstan, 2023-2024

Indicator	2023 (as of November 1)	2024 (as of November 1)
Total number of persons with disabilities	725,000	732,100
Number of working-age persons with disabilities	381,000	381,000
Number of employed persons with disabilities	148,000	148,700
Employment rate among working-age persons with disabilities	39%	39%

Source: compiled by the authors based on “More than 20.7 thousand persons with disabilities were provided with employment assistance measures” (2024), Ministry of Labour and Social Protection of Population of the Republic of Kazakhstan (n.d.)

The Table 2 shows that no substantial changes occurred in the employment figures for persons with disabilities between 2023 and 2024. As of 1 November 2024, 732,100 persons with disabilities were living in the country, approximately half of whom were of working age (More than 20.7..., 2024). Despite this sizeable working-age population, only 39% were officially employed. The presented statistics highlight the importance of social initiatives aimed at the active inclusion of persons with disabilities in the country's economic development.

Based on the analysis, employment opportunities in the Republic of Kazakhstan are unevenly distributed across different population groups, contributing to social inequality and generating a range of systemic issues. Socially vulnerable groups include individuals with low incomes, young people aged 15 to 34, and women. These categories of the population stand to benefit from the growth of socially oriented enterprises, which have seen increased development in the Republic of Kazakhstan.

Socially oriented enterprises in the Republic of Kazakhstan

As of 2025, several socially oriented enterprises operate in the Republic of Kazakhstan, including Green TAL (2025). Founded in 2015 in Astana by Emin Askerov, Green TAL serves as a notable example of successful social entrepreneurship in Kazakhstan. The enterprise focuses on employment and professional development for individuals from socially vulnerable groups, including persons with disabilities, single mothers, orphanage graduates, and former prisoners. The primary objective of Green TAL is to establish a sustainable infrastructure that enables “special employees” to reach their full potential and become integrated into society through work and education. The enterprise's mission lies in addressing social issues through entrepreneurial activity, ensuring financial stability and potential for expansion. Green TAL operates through a number of production workshops, including the following: a carpentry workshop producing furniture, educational eco-toys, and wooden

souvenirs; a sewing workshop specialising in garments such as hoodies, vests, eco-bags, and other textile items; a felt workshop dedicated to handmade products including carpets, scarves, bath sets, and children's creative kits; and a printing division focusing on applying logos to promotional items through sublimation, thermal flex, and laser engraving techniques. Employees without formal vocational qualifications have the opportunity to undergo in-house training and continually enhance their skills through various courses. Since its founding, Green TAL has trained over 700 individuals and employed more than 50 staff members with special needs. Special attention is given to individuals with mental health conditions such as schizophrenia, autism, and intellectual disabilities, for whom the enterprise creates adapted working environments (Social enterprise Green TAL, n.d.). Since 2021, Green TAL has been actively expanding its operations, establishing branches in various regions of Kazakhstan, including Pavlodar and Ekibastuz. These initiatives are conducted with the support of the Samruk-Kazyna Trust fund and local akimats, contributing to the creation of new employment opportunities for socially vulnerable population groups.

Another example of a socially oriented enterprise is Garbar Group (n.d.), based in Astana, Kazakhstan. The company specialises in the production of furniture, including tables and chairs, and offers comprehensive solutions for furnishing cafés and restaurants. Garbar Group actively applies principles of social entrepreneurship, aiming to establish a sustainable business model that benefits society. A key aspect of its operations is the employment and vocational training of individuals from socially vulnerable groups, including persons with disabilities. The company provides opportunities to acquire in-demand skills in furniture manufacturing, contributing to social integration and improving the quality of life for these individuals.

As of the first half of 2025, the social enterprise Green TAL (n.d.) had employed 62 individuals in Kazakhstan, 53 of whom belong to socially vulnerable groups. Similar statistical findings are presented in the study by S.T. Okutayeva *et al.* (2023), which emphasised that Green TAL continues to expand its operations by establishing branches

in various regions of Kazakhstan, including Pavlodar and Ekibastuz. This expansion facilitates the creation of new jobs and enhances employment opportunities for a larger number of socially vulnerable individuals. Garbar Group is also developing professional training programmes focused on practical skills in carpentry and furniture production. These initiatives enable participants not only to acquire a new profession but also to increase their competitiveness in the labour market. The company collaborates with a range of organisations and public institutions, including the Samruk-Kazyna Trust, ArcelorMittal Temirtau JSC, Eurasian Resources Group (ERG), and the Toraygirov University NAO, to expand training and employment opportunities. Such partnerships contribute to the development of an inclusive environment and support socially impactful projects.

Among other socially focused enterprises is Kunde, a social café in Kazakhstan founded by Maulen Akhmetov, a graduate of Nazarbayev University. The café provides employment to individuals with mental health conditions, supporting their social integration and professional development (Tadamon, n.d.). The primary goal of Kunde is the creation of an inclusive environment where people with mental differences can work on equal terms with others (Video case..., n.d.). The café aims to challenge stereotypes and demonstrate that every person is capable of making a contribution to society. According to publicly available sources, the café employs 18 individuals with mental health conditions, in addition to 7 professionals, including chefs and administrators. A defining feature of Kunde is its focus on sustainable growth and continuous expansion. In 2024, Kunde received a USD 30,000 grant from Tadamon, which selected the project from among 250 global applicants. Further support was provided by organisations such as AB Restaurants, which donated essential tableware and kitchen equipment (Saby Charitable Foundation, 2018). In 2020, Kunde was named a finalist in the international Shell LiveWIRE Top-10 Innovators competition, highlighting the project's international relevance and high standard.

A comparative analysis of the strategies employed by the aforementioned enterprises is presented in Table 3.

Table 3. Comparative analysis of strategies adopted by selected social enterprises in the Republic of Kazakhstan

Criterion	Green TAL	Garbar Group	Kunde
Target group	People with disabilities, single mothers, orphanage graduates, former convicts, individuals with mental health conditions	People with disabilities and other socially vulnerable groups	Individuals with mental health conditions
Social mission	Social integration through employment and training	Improving quality of life through skills development	Creating an inclusive environment and challenging stereotypes
Integration strategies	On-site training, continuous professional development, tailored conditions for mentally unstable employees	Vocational training, internships, employment in the hospitality sector	Vocational training, internships, employment in the hospitality sector
Partner support	Samruk-Kazyna Trust, akimats	Samruk-Kazyna Trust, ERG, ArcelorMittal Temirtau, Toraygirov University	AB Restaurants, Tadamon, Saby Charitable Foundation

Source: compiled by the authors based on Video case "Social enterprise Kunde" (n.d.), Garbar Group (n.d.), Green TAL (n.d.), Tadamon (n.d.)

Table 3 indicates that the development strategy of a social enterprise is influenced by several factors, including the target audience and the overarching social mission, which in turn shapes the goals and objectives related to integration. Among the most widely applied strategies for the inclusion of socially vulnerable groups are vocational training programmes, often delivered directly in the workplace. This type of training enhances the competitiveness of vulnerable groups and strengthens their participation in national economic development. Another commonly implemented approach involves forming partnerships with public institutions, international foundations, and other agents of social change. Such collaborations serve as a source of tangible and intangible resources required for improving employability and increasing the competitive standing of socially vulnerable populations (Istrefi *et al.*, 2025).

The Republic of Kazakhstan is thus witnessing the growth of socially oriented entrepreneurship, with a strong emphasis on the employment of disadvantaged groups. These groups include young professionals, women, individuals with disabilities, and others. The experience accumulated by enterprises such as Green TAL, Garbar Group, and Kunde can be expanded into various sectors of the national economy.

Strategies for the development of social entrepreneurship in Kazakhstan

Based on the case studies discussed above, a set of development strategies for social entrepreneurship in Kazakhstan can be devised, with a particular focus on improving employment opportunities for socially vulnerable populations. The key strategies and their core components are outlined in Table 4.

Table 4. Strategies for the development of socially-oriented entrepreneurship in the Republic of Kazakhstan

Strategy	Description
Government support and regulation	1. Development of a legal framework that encourages social entrepreneurship. 2. Grant programmes and tax incentives for social enterprises. 3. Establishment of state funds and support programmes (e.g., through DAMU, JSC "Baiterek"). 4. Inclusion of social entrepreneurship in national business development initiatives.
Financial and investment support	1. Development of social investment mechanisms (funds, grants, subsidies). 2. Creation of venture capital funds for social start-ups. 3. Crowdfunding and other forms of collective financing.
Educational and advisory programmes	1. Development of university and business school courses on social entrepreneurship. 2. Implementation of acceleration programmes, training sessions, and workshops. 3. Mentorship and guidance from experienced entrepreneurs.
Awareness and outreach	1. Organisation of forums, competitions, and events for social entrepreneurs. 2. Creation of platforms for knowledge sharing and collaboration. 3. Engagement of mass media in showcasing successful case studies.
Development of partnerships	1. Collaboration with international organisations (UN, World Bank, etc.). 2. Engagement with the private sector in joint social initiatives. 3. Expansion of corporate social responsibility (CSR) programmes.
Infrastructure development	1. Establishment of hubs and incubators for social start-ups. 2. Creation of a support ecosystem: legal assistance, accounting services, marketing support.

Source: compiled by the authors based on Saby Charitable Foundation (2018), Video case "Social enterprise Kunde" (n.d.), Garbar Group (n.d.), Single Platform of Volunteers (n.d.), Tadamon (n.d.)

Table 4 demonstrates that the development of social entrepreneurship aimed at improving employment opportunities for vulnerable population groups requires the application of several strategies, including government support. This is exemplified by the adoption of Law of the Republic of Kazakhstan No. 52-VII ZRK (2021), which formally establishes the legal status of social enterprises and defines their criteria, including population categories in need of additional support. Government backing for social entrepreneurship was also reinforced through the Order of the Minister of National Economy of the Republic of Kazakhstan No. 130 "On Approval of the Rules for the Implementation of Support for Social Entrepreneurship Development Initiatives by Government Agencies, National Holdings, National Development Institutions and Other Organisations" (2023). These policy documents confirm the state's recognition of the importance

and diversity of social entrepreneurship, and its commitment to providing comprehensive support for the sector. However, these legal instruments contain certain limitations and unresolved issues that, if addressed, would strengthen state support for social enterprises. One key concern is the absence of clearly defined mechanisms for tax incentives and state-backed support for social enterprises. It is therefore recommended that secondary legislation be developed to specify support measures in greater detail, thereby increasing the motivation of enterprises to employ individuals from socially vulnerable groups.

Based on the table, the development of social entrepreneurship in the Republic of Kazakhstan is not feasible without adequate financial and investment support. The fact that social entrepreneurship was only formally recognised at the state level in 2021 highlights the insufficient development of mechanisms for its investment support

(Adilov, 2025). As of 2024, the involvement of international institutions, such as the United Nations and the World Bank, in financing social entrepreneurship in Kazakhstan remained limited (Baltabayeva *et al.*, 2024; Suieubayeva *et al.*, 2025). Given this context, it is recommended that investment be increased through the creation of venture capital funds for social enterprises, the expansion of concessional lending systems for businesses employing socially vulnerable groups, and engagement with global financing programmes to attract international investors. On the national level, funding for social entrepreneurship may be facilitated through cooperation with the DAMU Fund, JSC “Baiterek”, and other relevant organisations.

In addition to the proposed strategies, the development of social entrepreneurship in Kazakhstan may progress through the implementation of appropriate educational initiatives. Limited access to educational materials on social entrepreneurship in the country may lead university graduates to develop a biased view of this type of activity. Several higher education institutions, including AlmaU, Astana International University, and Nazarbayev University, took steps to address this stigma by offering dedicated courses on social entrepreneurship. The experience of these institutions could be scaled across other educational establishments throughout the country to raise awareness among stakeholders regarding the potential and opportunities of social entrepreneurship, along with the tools available for its development in support of employment for socially vulnerable groups. Scaling successful practices would entail the integration of a “Social Entrepreneurship” course into the curricula of vocational and higher education institutions, the development of multilingual online courses to reach a wider audience, and the establishment of specialised training centres for the education and retraining of socially-oriented entrepreneurs.

The development of educational strategies may be implemented in parallel with broader efforts to raise public awareness regarding the prospects of social entrepreneurship (Al-Nuimat *et al.*, 2023). A central aim of such outreach is to increase public trust in this form of activity and to attract stakeholders involved in its advancement (Berisha & Rexhepi, 2022). These stakeholders include entrepreneurs, investors, representatives of socially vulnerable population groups, and public leaders. Tools for raising awareness and promoting social entrepreneurship include business festivals and forums such as “Atameken”. While participation in these events is common among representatives from various economic sectors, the presence of socially-oriented businesses remain limited. It is recommended that to increase the involvement of social enterprises, an annual national forum on social entrepreneurship be held, alongside competitions offering grants and investment for leading social start-ups, and thematic events hosted at universities and business incubators (Rexhepi & Murtezaj, 2024). Public outreach may be facilitated through popular social platforms, including YouTube, Instagram, and TikTok, which are accessible to a broad demographic. Social enterprises

can utilise these platforms to showcase their work, thereby attracting the interest of potential employees and investors.

Infrastructure development is also recommended as a means of enhancing the effectiveness of social enterprises and strengthening their collaboration with vulnerable population groups. As of 2025, the Republic of Kazakhstan is home to the Kazakhstan Association of the Universities Business Incubators and Accelerators (n.d.), which includes prominent institutions and organisations such as Ahmet Yassawi University, Deutsch-Kasachische Universität, StartUp Academy, and TAU University. A key advantage of this association lies in its promotion of knowledge and resource sharing, which supports entrepreneurial development. A substantial limitation, however, is the low participation of socially-oriented enterprises, which restricts employment opportunities for vulnerable social groups. A similar issue is evident in co-working spaces in Almaty and Astana, where few participants identify as social entrepreneurs. In light of these limitations, it is recommended that dedicated incubators and hubs be established for social enterprises, regional support centres be developed for socially-oriented entrepreneurs, and co-working spaces be created with preferential rental conditions for businesses employing members of marginalised communities.

Based on the analysis conducted, social entrepreneurship remains a relatively new phenomenon within the economy of the Republic of Kazakhstan, and several aspects of its functioning require further legal regulation. The development of social entrepreneurship necessitates increased public engagement, which would support more active efforts to employ socially vulnerable groups, including graduates, women, and persons with disabilities. Strategies are proposed to increase public and private sector involvement in advancing social entrepreneurship as a means of addressing systemic challenges.

Discussion

The central argument of this study asserts that social entrepreneurship serves as a key instrument for addressing systemic social challenges. This assertion is supported by previous research, including the study by T. Dedilova *et al.* (2024), who analysed the potential impact of social entrepreneurship on sustainable economic development in the aftermath of large-scale military conflict and other crises. According to the cited authors, sustainable development is achieved through the strategic mission of social entrepreneurship, which lies in balancing the pursuit of financial gain with the resolution of social problems. S. Ghosh *et al.* (2024) emphasised the importance of social entrepreneurship in achieving sustainable development, reducing poverty, and narrowing the wealth gap within society. J.N.A. Quaye *et al.* (2024) argued that social entrepreneurship is an effective mechanism for achieving the seventeen Sustainable Development Goals (SDGs) declared by the United Nations. Among these goals, particular emphasis was placed on addressing acute social issues, including the eradication of hunger, improvement of education quality, promotion of gender equality, and the

provision of fair wages. L. Kiladze *et al.* (2024) highlighted the contribution of social entrepreneurship to the creation of a more inclusive and, as a result, economically prosperous society. S. Kumar & S.K. Yadav (2023) further stressed the capacity of social entrepreneurship to address challenges on both national and international scales. Based on a bibliometric analysis of 461 academic sources, T. Miah *et al.* (2024) concluded that the effectiveness of social entrepreneurship stems from its dynamism, the resilience of its entrepreneurial ecosystem, and its integration of innovative solutions. Collectively, these studies support the view that social entrepreneurship holds significant potential in addressing a range of societal challenges, including the focus of this paper: overcoming inequality in employment.

While social issues are diverse, the present study concentrated specifically on examining the impact of social entrepreneurship on reducing employment inequality. The contribution of social entrepreneurship to resolving this issue was also confirmed in prior research, such as that of V. Ratten (2025), which argued that social entrepreneurship plays a particularly important role in tackling inequality within developing economies. The study by V. Ratten asserted that the development of social entrepreneurship is a strategic priority for the Republic of Kazakhstan, which has not yet attained the status of a developed economy due to the economic disruptions of the early 21st century. Drawing on the experience of South Korea, J. Jeon *et al.* (2024) concluded that social entrepreneurship is a driving force of national economic development, as it enables the integration of previously underutilised human capital. An analysis of 209 studies enabled A. Bonfanti *et al.* (2024) to conclude that the effectiveness of social entrepreneurship in employing marginalised groups is partly due to its capacity to adopt hybrid forms. Based on the cited study, the argument presented in this paper – that social entrepreneurship offers a viable solution to the employment challenges faced by vulnerable population groups – is both timely and well-substantiated.

This study emphasised, however, that the development of social entrepreneurship and the employment of vulnerable population groups in the Republic of Kazakhstan remains a challenging task due to the existence of several barriers. One such barrier identified in this study is the low level of public awareness regarding the potential and benefits of social entrepreneurship in addressing systemic issues, including unequal access to employment opportunities. This obstacle was also explored in earlier studies, including that of X. Lyu *et al.* (2024). Drawing on interviews with 684 university students and graduates from Southern China, X. Lyu *et al.* highlighted that a lack of comprehensive information about the specifics of managing social enterprises reduces engagement among the target audience. Similar conclusions were reached by M. Karim *et al.* (2024), who investigated the relationship between awareness and engagement in social entrepreneurship among a sample of 334 students from Bangladesh. These studies support the relevance of the recommendations presented in this paper, including the need to raise awareness and promote social

entrepreneurship among students and graduates of secondary vocational and higher education institutions, as well as among active entrepreneurs.

This study also underscored the importance of state support in advancing social entrepreneurship and proposed strategies for increasing such support within the context of a developing sector. The conclusion that legislative regulation of social enterprises and the introduction of additional support measures are warranted finds support in previous research, including that of S. Tišma *et al.* (2022). Using Croatia as a case study, the authors found a statistically significant positive correlation between state policies aimed at supporting social entrepreneurship and the increasing number and diversity of social enterprises. C.J. Fox *et al.* (2023) surveyed 577 working-age respondents in the United States and concluded that there is a direct correlation between the perception of social support and the intention to engage in social entrepreneurship. The cited researchers, however, noted the absence of a direct correlation between the perception of institutional support and the intention to pursue social entrepreneurship, which contrasts with the conclusions presented in this study. Given this discrepancy, further investigation into the potential relationship between perceptions of social and institutional support and their impact on engagement in social entrepreneurship is recommended.

In addition to the aforementioned recommendations, this study also presented the idea of fostering collaboration with national and international organisations to advance social entrepreneurship in the Republic of Kazakhstan and promote the employment of socially vulnerable population groups. It was concluded that insufficient cooperation with institutions such as the United Nations, the World Bank, and other alliances hinders the development of social entrepreneurship in Kazakhstan. The importance of collaboration in the context of social entrepreneurship was also supported by earlier research, including the study by S. Kovanen (2021), which emphasised that collaboration forms the foundation of social entrepreneurship. The study also highlighted the multi-dimensional nature of such cooperation, involving interactions between the community experiencing specific needs and the state responsible for addressing them; between the state and socially oriented businesses; and between socially oriented businesses and the community. The importance of collaboration was likewise stressed by D. Shelenko *et al.* (2024), who argued that the creation of a well-developed system of interaction enhances the value of the social service provided and diversifies risks, thereby stimulating socio-economic development and improving the welfare of specific economic sectors or regions. Collaboration was also emphasised by F.J. Santos *et al.* (2025), who compared the performance of two conventional enterprises with that of two worker cooperatives. According to the researchers, enterprises operating as worker cooperatives exhibited greater efficiency, including in the development and implementation of innovative solutions. Drawing on these studies, the conclusion presented in this paper, that collaboration at national and international

levels represents an effective strategy for developing social entrepreneurship and addressing systemic social challenges in the Republic of Kazakhstan, appears well-founded.

In summary, the findings of this study are consistent with existing research. The identified correlations suggest that the recommendations proposed are both relevant and viable. The experience of three socially oriented Kazakhstani enterprises may be scaled across specific segments of the economy to enhance employment opportunities and protection for socially vulnerable groups, such as young professionals, women, and persons with disabilities.

Conclusions

The study examined the potential of social entrepreneurship as a means of increasing employment among socially vulnerable groups in the Republic of Kazakhstan. Contextual analysis demonstrated that, despite the relatively low national unemployment rate, certain segments of the population continue to face barriers to accessing the labour market. These socially vulnerable groups include graduates of vocational and higher education institutions, women, former prisoners, and individuals with physical or mental disabilities. The challenges encountered by these groups include fewer job offers, poorer working conditions, or lower wages. Social enterprises, the activities of which aim to address systemic social issues, may provide significant benefits to these population categories. Although the demand for such enterprises is considerable, their presence in Kazakhstan remains limited, which may be attributed to the relatively recent development of the social entrepreneurship sector. Social entrepreneurship was formally regulated in Kazakhstan in 2021, with state initiatives aimed at its promotion and support introduced in 2003.

The study analysed the operations of three socially oriented enterprises: Green TAL, Garbar Group, and Kunde. The social focus of these enterprises is evident in their efforts to train and retrain individuals with limited competitiveness in the labour market, invest in social development, and address structural social problems, including social orphanhood and inequality. These enterprises support the employment of vulnerable populations by creating new jobs, offering grants and financial assistance, and promoting specific vocational activities.

The comparative analysis of the enterprises indicated that the choice of strategy depends on the target group and the social mission of the organisation. The most common strategies included training and retraining socially vulnerable individuals to enhance their competitiveness and integration into economic activity. Another widespread practice was collaboration with national institutions and international foundations, which serve as sources of material and non-material resources for implementing social initiatives. Based on the contextual analysis and the experiences of the referenced companies, several strategic groups were proposed to enhance the effectiveness of social entrepreneurship in employing vulnerable population groups. These strategies include: state support and regulation of socially oriented entrepreneurial activity; financial and investment assistance for enterprises that provide employment to vulnerable groups; educational and advisory programmes highlighting the prospects and advantages of managing social enterprises; development of national and international partnerships in the field of social entrepreneurship; and the expansion of infrastructure aimed at creating a network of social enterprises and connecting them with the most disadvantaged segments of the population.

This study is subject to several limitations, including the small number of socially oriented enterprises selected for analysis within the Republic of Kazakhstan. Future studies should consider expanding the number of enterprises under review and conducting a comparative analysis of social enterprise management practices in Kazakhstan and other Central Asian countries.

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Conflict of Interest

None.

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Соціальне підприємництво у Республіці Казахстан як інструмент підвищення зайнятості соціально вразливих груп населення

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Анотація. Метою дослідження було вивчення соціального підприємництва як засобу працевлаштування соціально вразливих груп населення в Республіці Казахстан. Контекстуальний аналіз національного ринку праці проводився з використанням структури PEST та статистичних даних Бюро національної статистики, Азіатсько-Тихоокеанської асоціації розвитку кар'єри та Групи Світового банку. Також аналізувалися випадки трьох соціальних підприємств у Казахстані: Green TAL, Garbar Group та Kunde. Контекстуальний аналіз продемонстрував, що, незважаючи на відносно низький середньорічний рівень безробіття 3,3-3,6 %, певні категорії населення працездатного віку залишаються найменш конкурентоспроможними з точки зору отримання пропозицій роботи, отримання конкурентної заробітної плати або досягнення кар'єрного зростання. До цих категорій належать випускники професійно-технічних та вищих навчальних закладів без досвіду роботи, жінки та особи з обмеженими фізичними можливостями. Тематичні дослідження продемонстрували високий потенціал соціально орієнтованих підприємств у вирішенні системних соціальних проблем, включаючи створення робочих місць, підготовку та перепідготовку спеціалістів, підвищення статусу певних професій та зменшення майнової нерівності. Розроблено кілька стратегічних груп для підвищення ефективності соціальних підприємств у працевлаштуванні вразливих груп населення: розширення державної підтримки та нормативно-правової бази для соціального підприємництва; розробка системи фінансової та інвестиційної підтримки соціально орієнтованих підприємств; освітні та консультаційні ініціативи, спрямовані на підвищення обізнаності про перспективи соціального підприємництва; та розвиток партнерських відносин та інфраструктури у

сфері соціального підприємництва. Результати дослідження можуть бути використані для покращення ефективності соціально орієнтованих підприємств, діяльність яких законодавчо регулюється лише з 2021 року

Ключові слова: соціальне підприємництво; зайнятість; інклюзивний ринок праці; населення працездатного віку; нерівність доходів; законодавче регулювання

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Development of strategic management of a corporation through the implementation of scenario analysis

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Abstract. This study was focused on investigating the impact of scenario analysis on the strategic management process of a corporation to enhance its adaptability and competitiveness. The research examined scenario analysis as a key strategic planning tool in conditions of uncertainty. It included a historical review of the development of the scenario approach, particularly its application within corporations. The main stages of scenario analysis were described: identification of key factors, determination of driving forces of change, formulation of alternative scenarios, their evaluation, and the development of strategic responses. The primary approaches to scenario construction were also discussed, including expert judgement methods, analysis of key factors and trends, stress testing, and system dynamics. As a practical case, the activities of the Ukrainian agricultural company Kernel, operating under high uncertainty caused by geopolitical and economic factors, were studied. The scenario analysis conducted outlines three possible development paths for the company over the next 3-5 years: optimistic (restoration of stability and growth), baseline (adaptation to wartime conditions), and pessimistic (crisis and contraction of operations). For each scenario, the impact of external factors was assessed, key financial indicators were forecast, and strategic recommendations were developed. The findings indicated that using scenario analysis helps companies increase the flexibility of managerial decisions, adapt to unstable environments, and reduce strategic risks. The recommendations proposed for Kernel include diversification of logistical routes, enhancement of operational efficiency, active cooperation with international financial institutions, and development of high value-added products. The practical recommendations developed from the Kernel case can be adapted by other agricultural holdings in Ukraine and worldwide to design scenarios in response to economic challenges

Keywords: risk analysis; forecasting; flexibility; entrepreneurial opportunities; technological trends

Introduction

In an unstable business environment, corporations are compelled to adapt their strategies to rapid market changes, technological breakthroughs, crises, and geopolitical challenges. Traditional strategic planning, based on linear forecasts, often proves ineffective under high uncertainty. Hence, the importance of scenario analysis grows, as it enables modelling alternative development paths, assessing risks, and developing flexible strategies. The application of this tool enhances business resilience and opens new avenues for growth amid globalisation and economic turbulence. The main challenge lies in the qualitative development of scenarios, their adaptation to the company's specifics, and integration into management processes. The question of evaluating the effectiveness of scenario analysis is also relevant. Research in this area holds both theoretical and practical value, contributing to the formation of adaptive strategies and strengthening the competitive positions of businesses.

In strategic management research, many authors have addressed the application of scenario analysis in corporate practice. For instance, D. Settembre-Blundo *et al.* (2021) emphasised the importance of scenarios as a tool for risk assessment and unforeseeable changes, enabling businesses to respond to external challenges. They noted that a clear scenario structure allows companies not only to adapt to future changes but also to proactively create development strategies that increase their flexibility. O. Bugrov *et al.* (2023) argued that scenario analysis helps avoid overreliance on forecasts, which may be inaccurate amid global changes. They stressed the necessity of incorporating unpredictable elements, such as political and social factors, into the scenario creation process. In the work of E. Bekkers & R.B. Koopman (2022), it was demonstrated that scenario analysis significantly reduces uncertainty by creating strategic plans based on alternative scenarios that

can be adjusted in real time. An analysis of the study by V.O. Kuzminykh *et al.* (2024) confirmed that scenario analysis not only enhances strategic precision but also strengthens organisational culture by involving top management in the strategic planning process. This, they claimed, enables companies to reduce risks through more effective uncertainty management.

G. Culot *et al.* (2020) noted that a primary advantage of scenario analysis is the ability to thoroughly examine potential consequences of strategic decisions over the short and long term. S. Andros *et al.* (2021) highlighted that implementing scenario analysis fosters increased innovation within corporations, allowing leaders to consider a broad spectrum of potential outcomes and focus on long-term growth. S. Melnychenko *et al.* (2020) viewed scenario analysis as a tool for assessing probable consequences of global economic and political changes, such as financial crises or geopolitical conflicts. They emphasised that proper use of this tool enables corporations to develop adaptive strategies. According to research by M. McMaster *et al.* (2020), scenario analysis has become a central element of risk management for many international companies. Their work demonstrated that scenario planning allows firms to better assess the impact of global trends on their activities, including demand changes, technological shifts, and regulatory factors. A. Nechyporenko (2024) stressed the enormous potential of scenario analysis in enhancing corporations' strategic flexibility. He pointed out that not only the scenarios themselves but also their integration into the company's overall management strategy are crucial. Research by M.A.K. Harahap *et al.* (2023) noted the significant role of scenario analysis in developing corporate strategy amid globalisation and technological change. Their study showed that the most effective application of scenario analysis occurs when it is integrated with other strategic planning tools.

Thus, the works of these authors demonstrate the importance of scenario analysis for contemporary corporate strategic management. Despite considerable scholarly interest in scenario analysis as a strategic management tool, some aspects require further investigation. Specifically, the practical integration of scenario analysis into management decision-making in large corporations remains underexplored, as do mechanisms for evaluating the effectiveness of its implementation. Additionally, there is limited attention to adapting this approach to the specifics of different industries and exploring potential barriers to its application.

The aim of this study was to determine the role of scenario analysis in corporate strategic management for its implementation. The objectives were: to analyse the conceptual foundations of scenario analysis and its place in strategic management; to identify the key benefits and challenges of implementing scenario analysis in corporate practice; and to develop practical recommendations to improve the effectiveness of strategic planning.

Materials and Methods

This study employed qualitative and quantitative analysis methods to evaluate possible development scenarios for the Ukrainian agricultural company Kernel amid an unstable environment. Kernel was selected for research due to its leading position among Ukrainian agricultural firms and its significant role in international grain and oilseed exports. The company possesses an extensive infrastructure, making it sensitive to changes in macroeconomic and geopolitical conditions. Financial indicator analysis covered the period from 2019 to 2024, allowing for tracking the dynamics of the company's activities before and during crises caused by both internal and external factors.

The primary materials comprised the financial reports of Kernel (2025), analytical reviews of Ukraine's agricultural sector by the Ministry of Agrarian Policy and Food of Ukraine (n.d.), and data from international organisations, notably the World Bank (n.d.) and the International Monetary Fund (n.d.). Geopolitical factors influencing business development were also taken into account, including the impact of military actions, sanctions, and changes in global supply chains. The methodological foundation of the study is based on scenario analysis as a tool for strategic planning. Initially, key factors affecting the company's operations were identified, including macroeconomic indicators (gross domestic product (GDP), inflation, exchange rates), internal business metrics (profitability, liquidity, cost structure), as well as sectoral trends (export dynamics, competition, regulatory changes). Subsequently, an analysis was conducted of the driving forces shaping the company's future development, such as technological innovations, climate change, shifts in trade relations, and access to financing.

The next stage involved developing alternative development scenarios. Three principal scenarios were formulated: optimistic, baseline, and pessimistic. The optimistic scenario envisaged economic stabilisation, recovery of export markets, attraction of foreign investment, and production

growth. The baseline scenario was based on maintaining current risk levels, gradual adaptation of the company to changes, and stabilisation of financial indicators at a moderate level. The pessimistic scenario accounted for a further deterioration of operating conditions, a decline in exports, rising operational costs, and the necessity for asset restructuring. For each scenario, an assessment was carried out of the potential impact of external and internal factors on the company's financial performance. Additionally, sensitivity analysis was applied to identify the most critical parameters influencing Kernel's financial stability. Financial modelling was utilised to quantitatively evaluate the scenarios' effectiveness, based on key indicators such as revenue, Earnings Before Interest, Taxes, Depreciation and Amortisation (EBITDA), net profit, assets, and equity. Extrapolation and regression analysis methods were employed to forecast possible financial outcomes within each scenario.

Thus, a comprehensive approach to scenario analysis, incorporating both qualitative and quantitative methods, enabled the formulation of well-founded recommendations for adapting Kernel's business strategy. The use of diverse analytical approaches enhances forecast accuracy and enables company management to prepare for potential changes in the external environment.

Results

In an environment characterised by rapid change and high uncertainty, corporations face constant challenges complicating strategic planning. The rapid development of technology, globalisation, economic crises, legislative changes, social transformations, and environmental challenges – all these factors render traditional forecasting methods less effective. Strategic management has often relied on extrapolating historical data; however, this approach is becoming increasingly irrelevant in a world where the future is unpredictable. Hence, scenario analysis is gaining importance as a tool that helps corporations not merely react to change but proactively prepare for various possible developments.

Scenario analysis is a strategic planning method involving the construction of plausible alternative future scenarios and analysing their impact on organisational activity. The primary aim is not to predict exact outcomes but to define a range of potential situations for which the company must be prepared (Salimi *et al.*, 2021). Unlike traditional forecasting methods based on a single most probable scenario, scenario analysis accounts for multiple potential futures. A key aspect of scenario analysis is its non-linearity. Whereas classical forecasting seeks to predict the future based on current trends, the scenario approach assumes that the future may be ambiguous and dependent on numerous interrelated factors. It is important not only to consider possible threats but also to identify hidden opportunities that may arise in various scenarios.

The scenario analysis method was originally applied in military planning. Its concept began to take shape during the Second World War (1939-1945), when analysts used different campaign developments to inform

strategic decisions. However, in business management, scenario analysis gained prominence in the 1960s and 1970s due to the work of American futurist Herman Kahn, who first applied scenario forecasting to global risk analysis (Campa, 2023). Further development occurred at Royal Dutch Shell, where, thanks to Pierre Wack and his team, scenario analysis became a core element of strategic management. This approach helped the company successfully adapt to the 1973 oil crisis, when a sudden rise in oil prices caused significant economic upheaval. While most competitors relied on stable forecasts, Shell anticipated possible market volatility and prepared appropriate strategies, enabling it to maintain competitive advantages (Cornelius *et al.*, 2005). Since then, scenario analysis has been widely adopted not only in the energy sector but also in finance, automotive, technology, and other industries where flexible future management is critical.

The scenario analysis process consists of several key stages. First, the main external and internal factors affecting the corporation's activities are identified. These may include macroeconomic indicators, technological trends, legislative changes, competitor behaviour, and more. Both obvious factors, such as demand fluctuations, and less apparent influences, such as social or environmental transformations, should be considered. Next, the primary driving forces of change most significant to future developments are determined. For example, in the automotive industry, key drivers might include vehicle electrification, artificial intelligence advancements, and changes in environmental legislation (Kubiczek & Hadasik, 2021). Following this, alternative future scenarios are developed, typically divided into optimistic, pessimistic, and baseline (most likely) cases. Occasionally, extreme scenarios are also created to account for unlikely but impactful events. The next step involves assessing the consequences of each scenario and devising strategic responses. It is important not only to identify risks but also to uncover new opportunities arising from change. The final stage includes ongoing monitoring and regular updating of scenarios, as the business environment continuously evolves, requiring companies to adjust their strategies accordingly.

Scenario analysis offers several significant advantages. Firstly, it reduces uncertainty by enabling preparation for different possible futures and minimising risks. Secondly, it promotes strategic flexibility, allowing corporations to adapt their plans to a changing environment. Thirdly, it improves the quality of managerial decisions by providing top executives with deep analyses of potential scenarios. Lastly, companies employing scenario analysis typically achieve greater competitiveness, as they are better prepared for market challenges than those relying solely on traditional forecasting methods (Mietzner & Reger, 2005). However, scenario analysis also has limitations. Scenario development heavily depends on expert judgement, which can introduce subjectivity. The process is complex and demands considerable analytical resources and time. Moreover, even the best scenarios cannot encompass all possible future

developments, representing an inherent drawback of the method (Wright *et al.*, 2019).

The main methodological approaches to scenario analysis may vary depending on the company, industry, and market context. Nevertheless, scenario construction and impact analysis commonly employ several core approaches. One widespread method is expert elicitation, which involves a panel of experts from various fields analysing key factors influencing future developments. Experts provide assumptions about possible event trajectories, enabling the creation of multiple scenario options. This approach has the advantage of incorporating diverse perspectives and expertise but carries a degree of subjectivity that may affect analysis accuracy (Makedon *et al.*, 2019).

Another important method is the "key factors and trends" approach, which involves identifying and assessing crucial macro- and micro-factors determining future developments. This includes pinpointing key trends – such as economic shifts, technological advancements, political changes, or social movements – that may significantly impact the business. This method facilitates deeper analysis of external influences and supports scenario development based on these factors (Makedon *et al.*, 2024). A novel and promising approach is "stress testing", which evaluates how different business strategies and organisational models withstand extreme or crisis conditions. This process is particularly vital for large corporations with complex operational structures. The method helps identify potential vulnerabilities in company strategies and business models, aiding preparation for unexpected shocks (Linkov *et al.*, 2022).

In turn, the "system dynamics" method leverages mathematical models to analyse intricate interrelationships among various systems and factors. This approach enables the study of long-term trends and the system's response to changes in different variables. It helps forecast potential consequences of strategic decisions by integrating data from diverse sources and allows the creation of more complex and detailed models of event development (Schwaninger & Grösser, 2020). Each of these approaches has its advantages and limitations, but their combination makes it possible to develop more comprehensive and well-founded scenarios that assist in strategic management. Moreover, it is important to note that scenario analysis is a flexible tool that can be adapted to the specific conditions of a company and its industry.

Scenario analysis differs significantly from other strategic forecasting methods. One of the main approaches to strategic forecasting is trend extrapolation, which is based on analysing current trends and assuming that they will continue into the future. However, this method has significant limitations because it does not account for the emergence of new, unpredictable factors or changes in conditions that may substantially affect the course of events (Li *et al.*, 2022). Unlike trend extrapolation, scenario analysis is not limited to a single linear forecast but considers a multitude of possible developments, which helps reduce risks associated with unforeseen changes.

Another common method is PEST analysis (Political, Economic, Social, and Technological factors), which focuses on the macroenvironment and examines broad societal and economic trends. This method is well suited for identifying general factors that may influence the development of an industry or market. However, its drawback is that it usually does not provide specific scenarios for event development and is less flexible in forecasting crises or unpredictable changes. Scenario analysis, on the other hand, allows consideration of a wider range of options and helps develop more specific strategies for different future conditions.

The SWOT analysis method, which involves identifying a company's strengths, weaknesses, opportunities, and threats, is another popular strategic forecasting tool. This method helps understand the current state of the enterprise and its market position, but it often focuses on internal factors and does not consider complex interactions with external factors. Unlike SWOT, scenario analysis helps incorporate a larger number of external variables and potential future situations, allowing more flexible strategy adaptation

(Li et al., 2022). Compared to the sensitivity analysis method, which examines changes in a few critical variables to assess their impact on the business, scenario analysis is more flexible and diverse. Since it is not focused on only one or several factors but considers a broad range of possible outcomes, it provides a more comprehensive picture and enables companies to prepare for multiple possible futures.

Thus, scenario analysis is a powerful tool that offers greater capabilities for anticipating different development options, reducing risks, and strategically preparing for unpredictable changes in the external environment. It significantly surpasses other forecasting methods in terms of flexibility, consideration of multiple options, and potential risks.

Kernel company has a significant vertical integration that allows it to control all stages of the production process – from raw material cultivation to the final product. Kernel owns substantial land resources in Ukraine and also has facilities for processing and storing agricultural products. An important element of Kernel's activity is export. Table 1 presents the company's key financial indicators.

Table 1. Kernel's key financial indicators for 2019-2024, USD million

Indicators	2019	2020	2021	2022	2023	2024
Revenue	3.992	4.107	5.647	5.332	3.455	3.581
EBITDA	346	443	929	220	544	381
Profit	178	123	643	-41	299	168
Assets	2.463	3.165	3.997	4.186	3.885	3.397
Equity	1.346	1.494	2.083	1.687	1.744	1.866

Source: compiled by the authors based on Kernel (2025)

An analysis of Kernel's financial indicators reveals instability linked to external factors, notably the war, logistical challenges, and market volatility. The company's revenue grew until 2021, after which it began to decline due to export restrictions and logistical difficulties. EBITDA also peaked in 2021 (USD 929 million) but sharply fell in 2022 (USD 220 million), signalling a decline in business profitability amid the crisis. The company's profit fluctuated, reaching its highest point in 2021 (USD 643 million) but incurred losses in 2022 (USD -41 million), which can be attributed to the impact of the war and operational challenges. Kernel's assets increased until 2022 (USD 4,186 million) but then started to decrease, possibly indicating asset sales or revaluation. Meanwhile, Kernel's equity demonstrates relative stability, having recovered following a decline in 2022. These trends suggest that the company has endured a difficult period but has managed to partially adapt, stabilise its financial metrics, and gradually restore profitability in 2023–2024.

One of the company's main challenges is the geopolitical situation in Ukraine, especially in the context of the conflict that began in 2014 and sharply escalated in 2022. This conflict has profoundly altered the economic environment for agribusiness, particularly for large companies like Kernel, whose operations depend directly on stable raw material supplies and the secure transportation of products. The war has disrupted logistics chains, blocked seaports, destroyed infrastructure, and caused significant

problems in transporting grain and oil, all of which have seriously affected the company's financial results.

Due to the armed conflict, many key agricultural regions in Ukraine have been threatened or are directly within combat zones, raising doubts about the feasibility of growing and harvesting crops in these areas. Moreover, the blockade of ports on the Black Sea has complicated product exports, especially of grain. This has forced the company to seek alternative transport routes, including through Ukraine's western borders. Against the backdrop of war, Kernel is also facing instability in the domestic market, where the economic situation remains challenging. The conflict has led to inflation, national currency devaluation, and a reduction in purchasing power. All these factors make conducting business in Ukraine riskier and impact domestic consumption levels as well as the availability of credit resources for company development.

Nonetheless, despite these difficulties, Kernel continues to be one of the largest agribusiness companies in Ukraine. The company is actively adapting to new conditions, including through the diversification of its operations, seeking new sales markets, and strengthening its position in international markets. Furthermore, significant investments are being made in modernising production facilities and technologies to improve efficiency and reduce costs.

Another important challenge is the climatic conditions and seasonal fluctuations in crop yields, as the

agribusiness is heavily dependent on weather. In the event of adverse weather conditions (drought, frost, or excessive rainfall), the company may suffer substantial losses due to reduced agricultural output. Despite the challenging domestic market, Kernel continues to actively operate on the international stage, aiming to minimise risks through market diversification. The company is working to strengthen its presence in countries across Europe, Asia, and the Middle East, thereby reducing dependence on any single group of consumers. Kernel, as one of Ukraine's largest agro-industrial holdings, operates amid high uncertainty caused by the geopolitical situation, economic instability, logistical constraints, and global fluctuations in agricultural commodity prices. Based on an analysis of its financial indicators from 2019 to 2024, three main development scenarios for the next three to five years can be outlined: optimistic, base, and pessimistic.

The optimistic scenario ("Development through Stabilisation") envisages a significant improvement in the external business environment. A key factor driving this outcome could be the end of the war, or at least a reduction in the intensity of hostilities, that enables the restoration of exports through seaports. Such an event would radically change the situation for the company, as current logistical constraints – particularly costly overland exports via the EU – reduce business profitability. An additional positive factor might be a global rise in grain and oil prices, which would ensure higher profits for Kernel even with unchanged production volumes. A vital element of this scenario would be increased investment in modernising elevator capacities, transport infrastructure, and the production of high value-added products. Under these conditions, the company could return to revenue levels exceeding USD 5.5 billion, with EBITDA rising to between USD 800 million and USD 1 billion, substantially strengthening its financial resilience. Profitability is expected to rebound to over USD 500 million annually, allowing Kernel to restore international investor confidence, attract new financial resources, and expand its activities in global markets.

The base scenario ("Adaptation to Wartime Conditions") assumes the continuation of the current situation, with the war ongoing but exports remaining partially possible via alternative routes, including the grain corridor and rail transport through the European Union (EU). At the same time, the company must adapt to higher logistical costs, significantly reducing operating margins. In this scenario, global prices for grain and oil remain at moderate levels, while Kernel focusses on cost optimisation and improving production efficiency. This strategy allows it to maintain relative financial stability, albeit without significant growth. Company revenues would remain around USD 3.5-4 billion, EBITDA would fluctuate between USD 400 million and USD 600 million, and net profit would range from USD 150 million to USD 300 million. Asset sales may occur to preserve liquidity and finance operating activities. The base scenario foresees that the company can hold its market position, but significant development is unlikely until the war ends and full seaborne trade resumes.

The pessimistic scenario ("Crisis and Contraction") is the most threatening for Kernel and assumes further escalation of the war, potentially resulting in a complete blockade of maritime exports and a sharp decline in global grain prices. In this situation, the company faces a significant drop in revenue, rising costs, and an inability to compete effectively in the international market due to high production costs. This scenario may also involve new government restrictions or additional tax burdens, further complicating business operations. Consequently, the company could lose a substantial market share, with revenues falling to USD 2.5-3 billion, EBITDA shrinking to USD 150–300 million, and profitability turning negative, with losses reaching USD 50 million or more. Such an outcome would force Kernel to sell assets, scale down production, and potentially reconsider its business model. In the worst-case outcome, partial bankruptcy or debt restructuring could occur, leading to a loss of leadership in the sector. Table 2 presents the key results of the company's scenario analysis.

Table 2. Scenario analysis of Kernel's development

Factor	Optimistic scenario ("Development through stabilisation")	Base scenario ("Adaptation to wartime conditions")	Pessimistic scenario ("Crisis and contraction")
Geopolitical Situation	End of the war or significant reduction in hostilities. Restoration of stability	Prolonged war, but maintenance of the grain corridor and land exports	Escalation of war, full blockade of ports, increased military risks
Logistics	Resumption of exports via the Black Sea, reduced transportation costs	Partial reliance on alternative routes (Romania, Poland)	Export difficulties, high costs, possible closure of enterprises
Product Prices	Global rise in prices for grain and oil, increased demand	Moderate prices allowing for maintained profitability	Sharp drop in global prices, making profitable export impossible
Financial Indicators	Revenue over USD 5.5 billion, EBITDA USD 800-1,000 million, profit over USD 500 million	Revenue USD 3.5-4 billion, EBITDA USD 400-600 million, profit USD 150-300 million	Revenue USD 2.5-3 billion, EBITDA USD 150-300 million, possible losses up to USD -50 million
Market and Competition	Market share recovery, expansion of international operations	Maintaining positions, operating under intense competition	Loss of market share, contraction of operations, possible exit from some markets

Table 2, Continued

Factor	Optimistic scenario ("Development through stabilisation")	Base scenario ("Adaptation to wartime conditions")	Pessimistic scenario ("Crisis and contraction")
Investments	Active investor engagement, production modernisation	Partial financing for capacity upgrades, cost optimisation	Investment cuts, asset sales to maintain liquidity
Human Resources Policy	Staff expansion, creation of new jobs	Retention of key employees, limited expansion	Staff reductions, possible workforce restructuring

Source: compiled by the authors based on Kernel (2025), Ministry of Agrarian Policy and Food of Ukraine (n.d.), World Bank (n.d.), International Monetary Fund (n.d.)

Kernel must implement a strategy of flexibility and adaptability to effectively respond to any possible scenarios. One of the key directions is diversifying logistics, since dependence on the Black Sea ports remains risky due to the ongoing war. The company needs to more actively develop alternative export routes along western borders, utilising railway infrastructure to deliver products to ports in Poland, Romania, and the Baltic countries. Establishing its own trans-shipment facilities in EU ports could significantly reduce transportation costs and mitigate logistical risks. Equally important is improving operational efficiency. Kernel should invest in technological upgrades for elevators and processing plants, optimise supply chains, and implement digital technologies for monitoring operational performance. Reducing unproductive expenses, reorganising internal processes, and adopting modern management practices will help increase profitability even under challenging conditions. The company's financial stability largely depends on active engagement with international partners. Kernel must strengthen cooperation with the European Bank for Reconstruction and Development (EBRD), the World Bank, and other financial institutions to secure long-term financing. Additionally, the sale of stakes in certain assets may be considered a way to raise additional capital, ensuring liquidity and stable operations.

Reducing dependence on raw material exports is also a strategically important task. Kernel should develop the production of high value-added products, particularly refining and packaging oil, to enhance competitiveness in international markets. Investing in biofuel or animal feed production will diversify the business model, and utilising agricultural waste for energy generation will help reduce dependence on external resource suppliers. Finally, strategic flexibility and adaptability must become the foundation of long-term planning. Kernel should develop multiple scenarios for possible developments and respond swiftly to changes in the external environment. Creating alternative business plans, expanding partnerships with international traders, diversifying funding sources, and accumulating reserve funds will enable the company to act effectively even in unpredictable conditions. Thanks to these measures, Kernel will maintain its market position and lay the groundwork for stable future growth.

Scenario analysis allows Kernel to forecast potential risks and opportunities amid uncertainty. The most realistic scenario at present is the baseline scenario, which

assumes continuation of the war but retention of partial export capabilities through alternative routes. However, the company must be prepared for both a pessimistic scenario, which requires strict cost optimisation, and an optimistic scenario, which enables active investment in development. To ensure stability, Kernel must expand logistical capabilities, improve production efficiency, attract international financing, develop processing, and maintain strategic flexibility. These actions will allow the company not only to adapt to current conditions but also to secure long-term growth despite challenges.

Discussion

The study results indicate that in unstable environments, traditional strategic forecasting methods become less effective, highlighting the importance of scenario analysis. Global challenges such as rapid technological changes, economic crises, legislative shifts, environmental issues, and social transformations significantly complicate long-term planning. At the same time, scenario analysis enables companies not only to respond to changes but also to be proactive in developing strategies for various possible future scenarios. F. Khosravi & U. Jha-Thakur (2019) investigated the effectiveness of scenario analysis under high uncertainty, particularly in financial and technological sectors. They demonstrated that this approach helps companies adapt to changes and make more informed strategic decisions, though it does not always allow predicting all potential risks, especially amid rapid technological development. S. Chinta (2021) emphasised the importance of integrating scenario analysis with forecasting algorithms and machine learning to improve prediction accuracy. Their approach somewhat differs from the current study, which focuses more on macroeconomic and geopolitical risks, notably the consequences of the war in Ukraine for the agricultural sector. M. Kitsing (2022) examined the role of geopolitical risks in corporate strategic planning, particularly in the energy sector. He found that companies actively using scenario analysis respond faster to changes and minimise losses. His findings align with those in the current study, especially regarding international politics and regulatory impact. However, the present study places more emphasis on logistics and financial aspects.

A main part of scenario analysis is that it doesn't follow a straight line and looks at different possible future paths, which helps lessen uncertainty and get ready for possible

risks and chances (Prokhorova *et al.*, 2025). This method differs from traditional approaches such as trend extrapolation, PEST analysis, or SWOT analysis by offering a deeper analysis of external and internal factors affecting the business. V. Cerqueira *et al.* (2020) also compared scenario analysis with other forecasting methods, concluding that traditional methods often fail to account for sudden changes and can be less effective for long-term planning. This corresponds with the current study's results, which also note that scenario analysis allows for anticipating unexpected events. However, unlike some authors who dismiss classical methods as outdated, the current study acknowledges their usefulness in specific contexts.

Methodological approaches to scenario analysis indicate that the most effective methods include expert assessments, key factors and trends analysis, stress testing, and system dynamics. Each method has strengths and limitations, but their combination provides a comprehensive view of future opportunities and threats. For example, expert assessments expand perspectives on possible scenarios but contain subjective bias that can introduce errors (Teymurova *et al.*, 2024). Conversely, the "key factors and trends" method enables more structured evaluation of macro- and microeconomic influences. B.S.K. Patnam & N.M. Pindoriya (2021) approached scenario analysis from a mathematical modelling perspective, exploring how quantitative methods, including stochastic modelling and simulation forecasting, could improve scenario planning accuracy. F. Ackermann & C. Eden (2020) demonstrated that formal methods significantly increase the justification of strategic decisions, particularly in fields where risks can be assessed from historical data. The current study also mentions system dynamics but focuses more on combining qualitative and quantitative approaches. Thus, the authors' approach is more formalised, whereas this study prioritises flexibility and adaptability to real-world conditions. A. Fergnani (2022) researched the role of scenario analysis in strategic management of large corporations in unstable markets, finding that companies that regularly update their scenarios and actively involve experts achieve better long-term results. His approach aligns with the current study's emphasis on adaptive scenario analysis but focuses more on internal corporate decisions, while this study stresses external risks.

Analysis of Kernel's operations shows it functions in a highly uncertain environment, especially considering geopolitical factors, logistical challenges, and market instability. The company's financial results fluctuate significantly, illustrating the need for a flexible strategic approach. Developing three scenarios-optimistic, baseline, and pessimistic-allows an assessment of potential developments and preparation for various challenges. The optimistic scenario assumes external stabilisation enables export recovery and investment growth. The baseline scenario focuses on adaptation and risk minimisation to maintain relative stability. The pessimistic scenario foresees further deterioration, possibly leading to reduced operations and

fundamental business model changes. This approach helps company leadership set strategic priorities and select the most effective management decisions. B. Gajdzik & R. Wolniak (2021) studied scenario analysis's use during economic crises, analysing how automotive companies employed it during the 2008 financial crisis and the COVID-19 pandemic. They found that companies considering even extreme scenarios adapted faster. This aligns with the current study's conclusions, which also examine crisis scenarios related to war and export restrictions. However, those authors focused more on global financial shocks, while this study emphasised regional geopolitical risks.

An important aspect is that scenario analysis helps respond to risks and opens up new business opportunities. For example, the diversification of logistics routes, the development of products with higher added value, and the implementation of advanced technologies can significantly strengthen a company's position, regardless of the development scenario (Shahini & Shtal, 2023; Hlushko, 2024). In addition, cooperation with international financial institutions and expanding presence in international markets can help mitigate the impact of local risks. R. Ranjan (2025) examined how scenario analysis influences investment decision-making in the banking sector. His study showed that financial institutions that actively use this method allocate risks more effectively and respond to crises in a timely manner. These findings partially align with the results of the present study, which also highlight that companies applying scenario analysis can manage their finances more efficiently. However, the key difference lies in the fact that R. Ranjan focused exclusively on financial institutions, while the present research examines the real economy, specifically the agricultural sector. R. Hinz *et al.* (2020) investigated the use of scenario analysis in forecasting agricultural production under conditions of climate change. They demonstrated that this method enables a more accurate assessment of the potential consequences of weather-related disasters, supply chain disruptions, and changes in international agricultural markets. Their conclusions partially overlap with those of the present study, which also explores instability in supply and export chains. However, the main distinction is that their focus was predominantly on environmental aspects, whereas the current study emphasises political and economic factors. Thus, the findings of this research confirm that scenario analysis is a powerful strategic management tool, particularly under conditions of high uncertainty. Its application allows not only for forecasting possible developments but also for developing adaptive strategies that ensure business resilience in the long term.

Conclusions

In a context of rapid change and high uncertainty, companies face numerous challenges that complicate the strategic planning process. Traditional forecasting methods are losing effectiveness, while scenario analysis is gaining increasing popularity as a tool for proactive preparation for potential

changes. Compared to other forecasting methods, the scenario-based approach offers a considerable advantage as it enables consideration of multiple development paths, thereby reducing the risks associated with unpredictable changes. Scenario analysis helps not only to respond to changes but also to prepare for them proactively.

The analysis of the agri-industrial company Kernel demonstrates that it is one of the key players in Ukraine's agricultural market, yet it is also significantly affected by external factors such as war, economic instability, logistical constraints, and fluctuations in global prices for grain and oilseeds. Kernel's financial performance from 2019 to 2024 shows both periods of growth and significant challenges. In particular, up until 2021 the company experienced stable revenue growth, reaching USD 5,500 million, but in 2022 this figure fell to USD 3,500 million due to export restrictions and logistical difficulties. Net profit in 2021 stood at USD 643 million, while in 2022 the company incurred a loss of USD 41 million. Despite these difficulties, the financial indicators for 2023-2024 reflect a gradual recovery, indicating the company's ability to adapt to challenging conditions. The scenario analysis of Kernel's development identified three main future trajectories. The optimistic scenario ("Growth through Stabilisation") assumes a reduction in hostilities, the reopening of Black Sea ports, and an increase in global prices for grain and oil. This could result in revenue exceeding USD 5,500 million, EBITDA rising to USD 800-1,000 million, and net profit exceeding USD 500 million. The baseline scenario ("Adaptation to Wartime Conditions") anticipates ongoing conflict, continued logistical restrictions, and the need to export through alternative

routes. In this case, revenue is expected to remain in the range of USD 3,500-4,000 million, EBITDA at USD 400-600 million, and net profit at USD 150-300million. The pessimistic scenario ("Crisis and Contraction") includes a worsening of the war, a complete blockade of maritime routes, and a decline in global agricultural prices. This could lead to revenue falling to USD 2,500-3,000 million, EBITDA to USD 150-300 million, and net losses exceeding USD 50 million, forcing the company to reduce assets and reconsider its business model.

To ensure stability and further development, Kernel should focus on diversifying logistics routes, increasing operational efficiency, attracting international financing, developing value-added processing, and implementing flexible strategic planning. These measures will allow the company to reduce risks, enhance competitiveness, and secure long-term growth even under adverse conditions. The limitations of this study include the potential subjectivity in scenario formulation and the constraints related to the availability of data. Future research could focus on improving scenario analysis methods by incorporating new technologies and global trends, as well as examining the impact of instability factors on corporate strategies.

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Розвиток стратегічного управління корпорацією через впровадження сценарного аналізу

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Анотація. Робота направлена на дослідження впливу сценарного аналізу на процес стратегічного управління корпорацією для її підвищення адаптивності та конкурентоспроможності. У дослідженні розглядався метод сценарного аналізу як ключового інструменту стратегічного планування в умовах невизначеності. Дослідження охоплювало історичний аналіз розвитку сценарного підходу, зокрема його застосування в корпораціях. Описано основні етапи сценарного аналізу: ідентифікація ключових факторів, визначення рушійних сил змін, формування альтернативних сценаріїв, їх оцінка та розробка стратегічних відповідей. Також розглянуто основні підходи до побудови сценаріїв, зокрема метод експертних оцінок, аналіз ключових факторів і трендів, стрес-тестування та системну динаміку. Як практичний кейс досліджено діяльність української аграрної компанії Kernel, що працює в умовах високої невизначеності, спричиненої геополітичними та економічними факторами. Проведений сценарний аналіз включав три можливі варіанти розвитку компанії на найближчі 3-5 років: оптимістичний (відновлення стабільності та зростання), базовий (адаптація до воєнних умов) та песимістичний (криза та скорочення діяльності). Для кожного сценарію оцінено вплив зовнішніх чинників, прогнозовано ключові фінансові показники та розроблено стратегічні рекомендації. Результати дослідження засвідчили, що використання сценарного аналізу допомагає компаніям підвищити гнучкість управлінських рішень, адаптуватися до нестабільного середовища та зменшити стратегічні ризики. Запропоновані рекомендації для Kernel включають диверсифікацію логістичних маршрутів, підвищення операційної ефективності, активну співпрацю з міжнародними фінансовими інституціями та розвиток продуктів із високою доданою вартістю. Практичні рекомендації, розроблені на прикладі Kernel, можуть бути адаптовані іншими аграрними холдингами України та світу для розробки сценаріїв у відповідь на економічні виклики

Ключові слова: аналіз ризиків; прогнозування; гнучкість; підприємницькі можливості; технологічні тренди

Economic efficiency of solar panel implementation in irrigated agriculture: Cost assessment, comparative cost analysis and economic justification

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Abstract. This study aimed to assess the economic efficiency of implementing photovoltaic (PV) systems in irrigated agriculture, taking into account the technical, financial and environmental aspects of their application. To achieve this objective, the energy efficiency levels of pumping stations, the cost of PV system installation, and mechanisms of government support were analysed. The findings showed that the introduction of solar energy in irrigation complexes reduced average electricity costs to USD 0.05-0.12 per kWh, compared to USD 0.20-0.35 for diesel generators and

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USD 0.10-0.30 for centralised electricity supply. It was determined that the average payback period of PV systems in irrigated farming is 5-8 years, which is significantly shorter than for diesel generators, which are not cost-effective due to high operating expenses. The research confirmed that the use of modern PV systems combined with intelligent pumps reduced energy consumption of irrigation units by 20-30%, increasing their autonomy and operational stability. Environmental impact analysis demonstrated that PV systems contributed to a 60-80% reduction in CO₂ emissions compared to conventional energy sources, which is a crucial factor in the transition to sustainable agricultural production. It was established that subsidy programmes, the Net Metering mechanism, and concessional loans helped reduce initial capital investment and encouraged farming enterprises to adopt solar power plants. Based on the findings, recommendations were developed for optimising financial incentive mechanisms for the implementation of PV systems in irrigated agriculture, improving the technological parameters of PV installations, and utilising digital platforms for energy management. In practice, the results can be used to justify public-private partnership projects for the construction of solar power stations at irrigation pumping facilities

Keywords: renewable energy sources; photovoltaic systems; circular economy; energy independence; energy consumption optimisation

Introduction

The relevance of this research stems from the need to enhance the energy independence of the agricultural sector amid energy market volatility and rising tariffs. The use of traditional energy sources entails high costs and dependence on external factors, necessitating the integration of renewable energy sources, particularly photovoltaic (PV) systems. Their application in irrigated agriculture enables reduced electricity costs, improved enterprise autonomy and lower CO₂ emissions (Havrysh *et al.*, 2020). At the same time, the effectiveness of such technologies depends on technical, economic and natural-climatic factors, necessitating a comprehensive analysis.

O. Holovnia & Y. Chemerys (2024) explored innovative technologies that are transforming agricultural production through information and communication technologies, the Internet of Things (IoT), artificial intelligence (AI), machine learning, automation and robotics. Their work highlighted the potential of Real Time Kinematic for precision navigation of agricultural machinery and the use of drones for crop condition monitoring. S.A. Kalysh (2024) investigated the ecological and economic aspects of energy conservation in crop production, identifying key energy consumption areas and methods of determining energy intensity and production costs, as well as possible measures to improve the efficiency of energy use. The study reviewed energy optimisation strategies for agricultural machinery fleets and ways to reduce fuel and energy resource consumption in greenhouse farming. However, these studies did not address the economic feasibility of alternative energy sources or the specifics of their implementation.

Studies by U. Andrusiv *et al.* (2020), I. Sierov (2024), examined the role of eco-innovations in ensuring the sustainable development of agribusiness, substantiating the need for environmentally orientated technologies and outlining key directions for innovation in this domain. They identified major obstacles to implementation and proposed solutions such as government support, research investment and improved awareness among agricultural producers. However, the studies did not offer a quantitative analysis of

the effectiveness of these measures, the economic feasibility of implementing eco-innovations, or the influence of global environmental trends. Ye.M. Kryvokhyzha *et al.* (2024) explored resource management strategies in Ukraine's agricultural sector during the energy crisis, analysing the efficiency of energy-saving initiatives and the adoption of renewable energy sources. Bibliometric analysis of scientific publications revealed key trends and confirmed the strategic importance of energy resource diversification for food security. Nonetheless, the study lacked an assessment of the economic efficiency of the proposed measures, regional specifics of implementation, and regulatory aspects.

O. Petrenko (2023) examined the features of the green revolution in the agricultural sector, focusing on its impact on sustainable economic development and efficient resource use. The analysis confirmed that implementing environmentally friendly technologies reduces environmental impacts, optimises energy and water use, and increases yields. The study stressed the need for government support and collaboration between research institutions, industry, and rural communities to ensure the effective implementation of green innovations. However, it did not include a quantitative analysis of the economic benefits of the technologies discussed, nor did it consider the barriers to implementing green practices in small and medium-sized farms or compare the effectiveness of different international support models for the green revolution.

O.S. Froter & A.O. Revutska (2024) addressed the greening of agricultural production as part of innovative development but paid insufficient attention to the mechanisms of government support and funding – an essential aspect of implementation. Moreover, their study lacked a comparative analysis of international experience in the sustainable development of the agricultural sector. In V. Lazarenko's (2024) research, the post-war recovery of Ukraine's agricultural sector was examined in relation to achieving the Sustainable Development Goals. Focus was placed on soil resource management, water source conservation, biodiversity management and the development of renewable

energy. However, the study did not offer a comprehensive assessment of economic compensation mechanisms or their integration into the international environmental finance system. D. Bytko & I. Krylova (2022) explored the impact of alternative energy sources on the operations of agricultural enterprises, with a particular focus on the potential utilisation of solar, wind and biomass energy. However, their study did not provide an in-depth analysis of the economic efficiency of these solutions, nor did it address the technical aspects of implementation or the potential regulatory barriers. Furthermore, the issue of state regulation and incentives for the development of renewable energy in Ukraine's agricultural sector remained largely unexplored.

A review of the relevant academic literature has shown that previous research has primarily focused on the general benefits of using alternative energy sources in agriculture, particularly in terms of reducing energy costs, enhancing energy independence, and delivering environmental benefits. However, there is still not enough detailed study on important areas, such as measuring how cost-effective renewable energy technologies are, how they are adopted in different regions, the laws and rules surrounding them, and the financial support available. The aim of this study was to assess the economic feasibility of implementing PV systems in irrigated agriculture, taking into account their impact on energy efficiency, the financial resilience of agricultural enterprises, and the environmental safety of agricultural production.

Materials and Methods

The study covered the period from 2020 to 2024, enabling the inclusion of the most recent academic publications and trends in the fields of renewable energy and agricultural technologies. A comprehensive methodological approach was adopted to assess the economic efficiency of PV system implementation in irrigated agriculture. Economic analysis was applied to evaluate the viability of solar panel use in irrigation systems, including the calculation of energy supply costs, potential savings, and return on investment for PV systems. The assessment of economic feasibility was based on a comparison of costs incurred by agricultural enterprises when using conventional versus renewable energy sources, alongside an evaluation of potential long-term financial benefits. The cost of electricity generated by PV systems was analysed using data from the International Renewable Energy Agency (2024), which provides average electricity generation costs from renewable sources. Additionally, global energy market trends were taken into account, as presented in the International Energy Agency (2024) report, which includes forecasts on the development of renewables and their impact on the agricultural sector. Information from the World Bank (2024) on the deployment of sustainable energy solutions in the context of the Sustainable Development Goals was used to highlight the role of clean energy in enhancing the efficiency of agricultural systems. The analysis of regulatory requirements based on these data sources enabled an assessment of the level of state support and incentive mechanisms available to

agricultural enterprises investing in solar energy. National and international programmes supporting subsidies, tax benefits and financial incentives for the adoption of renewable energy were also reviewed.

A comparative analysis was conducted to evaluate the efficiency of various energy sources used in irrigation agriculture. PV systems, centralised electricity supply, and diesel generators were compared to identify the most economically viable options for meeting the energy needs of agricultural enterprises. The analysis considered parameters such as initial capital investment, operational costs, payback period, and the degree of energy independence. Techno-economic modelling was used to design an energy supply scheme for irrigation systems powered by PV installations and to assess its efficiency under various scenarios. The analysis included parameters such as solar irradiation levels, panel capacity, the need for energy storage systems, and their influence on the stability of power supply to pumping stations. Optimal PV configurations were identified to ensure uninterrupted water supply, which is particularly important for the agricultural sector under changing climatic conditions.

To validate the forecast results, the model outcomes were compared against real-world data from implemented PV-based agricultural projects. This analysis included a comparison of electricity generation, cost savings, and payback periods with actual case studies of autonomous energy supply systems used by agricultural enterprises in different climatic zones. The use of an integrated approach allowed for a comprehensive assessment of the feasibility of PV systems in irrigation agriculture, considering economic, technical, and environmental factors. The findings contributed to the development of evidence-based conclusions on the prospects for solar energy development in agriculture and the formulation of recommendations to enhance the effectiveness of PV systems in irrigation complexes.

Results

Economic efficiency of solar panel implementation in irrigated agriculture

Irrigated agriculture is a vital component of modern farming, particularly in regions characterised by unstable water balance and periodic droughts. Irrigation systems help maintain optimal soil moisture levels, which contributes to improved crop yields, production stability, and risk mitigation in the face of climate change. The efficiency of irrigation infrastructure is largely dependent on a stable electricity supply, as most modern pumping stations rely on electrical energy. Power outages can disrupt irrigation schedules, negatively affecting crop growth and development. Irrigation systems are powered by pumping equipment that transports water from surface or underground sources to irrigated fields. The energy consumption of pumps depends on their type, capacity, lift height, and system output. Surface pumps drawing water from open sources typically consume between 0.5 and 5 kWh per cubic metre of water. Deep-well pumps, which extract water from boreholes,

may require up to 10 kWh per cubic metre. Although drip irrigation systems consume less water overall, they require consistent system pressure, which also demands substantial energy input. To ensure effective operation, irrigation systems utilise various types of pumps, each differing in

output, energy consumption, and operating pressure. The selection of a particular pump type depends on the water source, required system pressure, and overall water demand. Table 1 presents a comparative overview of the main types of pumping equipment used in irrigated agriculture.

Table 1. Comparative characteristics of pumping equipment

Pump type	Flow rate (m ³ /h)	Operating pressure (bar)	Energy consumption (kWh/m ³)	Approximate cost of water pumping (USD/m ³)	Main application
Centrifugal surface pump	10-50	2-6	0.5-5	0.03-0.12	Open irrigation, water pumping from rivers and canals
Submersible pump	5-30	5-20	2-10	0.08-0.25	Pumping water from artesian wells
Screw pump	2-10	1-4	1-3	0.05-0.15	Use in high-pressure irrigation systems
Diaphragm pump	1-5	0.5-3	0.5-2	0.04-0.10	Mobile and autonomous irrigation systems
Low-pressure Pump for Drip System	0.1-1	0.2-1	0.1-0.5	0.01-0.05	Automated drip irrigation

Source: developed by the authors based on O. Glovatskii *et al.* (2023), J. Dyer & J. Shapiro (2023)

An analysis of pumping equipment characteristics reveals significant differences in energy consumption depending on the type of irrigation system. Centrifugal surface pumps, which are most commonly used in open irrigation systems, exhibit a wide range of performance capacities and energy consumption levels, which vary based on water lift height and required pressure. Deep-well pumps demonstrate the highest energy consumption, primarily due to the complexity of lifting water from substantial depths. In contrast, drip irrigation, despite its relatively low water output, is the most energy-efficient solution owing to the use of low-pressure pumps. The choice of optimal pumping equipment determines the overall level of energy expenditure in irrigated agriculture. The implementation of energy-efficient solutions, such as drip irrigation systems or low-pressure pumps, can significantly reduce electricity consumption. At the same time, for systems that require large volumes of water or operate with deep boreholes, the use of alternative energy sources – particularly photovoltaic (PV) systems – can be a key factor in economic optimisation. Thus, the evaluation of energy consumption by pumping equipment is a crucial component in assessing the economic feasibility of implementing solar panels in irrigated agriculture.

The high electricity costs associated with irrigated agriculture underscore the need to seek energy-efficient solutions. Traditionally, centralised power supply and diesel generators are used. While centralised electricity tends to have relatively stable tariff levels, its availability in remote areas is not always guaranteed. Diesel generators, although offering autonomy, entail high operational costs due to fuel prices and the need for regular technical maintenance. There is also the possibility of installing biogas power plants to supply electricity to irrigation systems, but

this solution is only viable in the presence of large-scale livestock farms (Kalinichenko & Havrysh, 2019). The integration of PV systems into irrigated agriculture enables a substantial reduction in electricity costs and enhances the energy independence of agricultural enterprises. Solar energy is a renewable source that minimises dependence on unstable tariffs and fuel prices. The average cost of electricity generated by PV systems ranges between USD 0.05-0.12 per kWh, which is considerably lower than the cost of centralised electricity or diesel-generated power (International Renewable Energy Agency, 2024).

The effectiveness of solar panel usage in irrigation systems depends on climatic conditions, the level of solar irradiance, the technical specifications of the pumping equipment, and the capacity to utilise energy storage solutions. In regions with an average annual solar radiation exceeding 4.5 kWh/m² per day, the use of PV systems can provide an uninterrupted power supply for pumping stations. The use of battery storage or hybrid solutions (solar energy combined with grid or generator power) contributes to stabilising energy supply and enhancing the reliability of irrigation systems. To ensure the efficient and autonomous operation of a solar-powered irrigation system, it is necessary to integrate a range of technological components that facilitate the accumulation, conversion, and distribution of electricity to power the pumping equipment. Figure 1 presents the operating principle of such a system, which includes PV modules, an inverter, an automated water supply system, and storage tanks.

The diagram illustrates how solar panels generate electricity, which is delivered via a power management system to an inverter for converting direct current (DC) into alternating current (AC). The energy is then directed to pumping equipment that lifts water from a borehole into

a storage tank. The system also allows for the integration of alternative energy sources, such as a centralised power grid or a generator, ensuring stable operation in periods of insufficient solar activity. A dedicated pump automation subsystem is highlighted, enabling real-time control of water supply and optimising electricity consumption. A key feature of this system is the possibility of using wireless control devices for monitoring and regulating the irrigation process. This enhances the efficiency of water

resource management by allowing water supply parameters to be adjusted based on the needs of specific crops. The presence of a storage tank makes it possible to regulate water supply independently of real-time solar generation, which is crucial for ensuring uninterrupted system operation. The overall concept of this solution contributes to increasing the energy efficiency of irrigation complexes while minimising operational costs through the use of renewable energy sources.

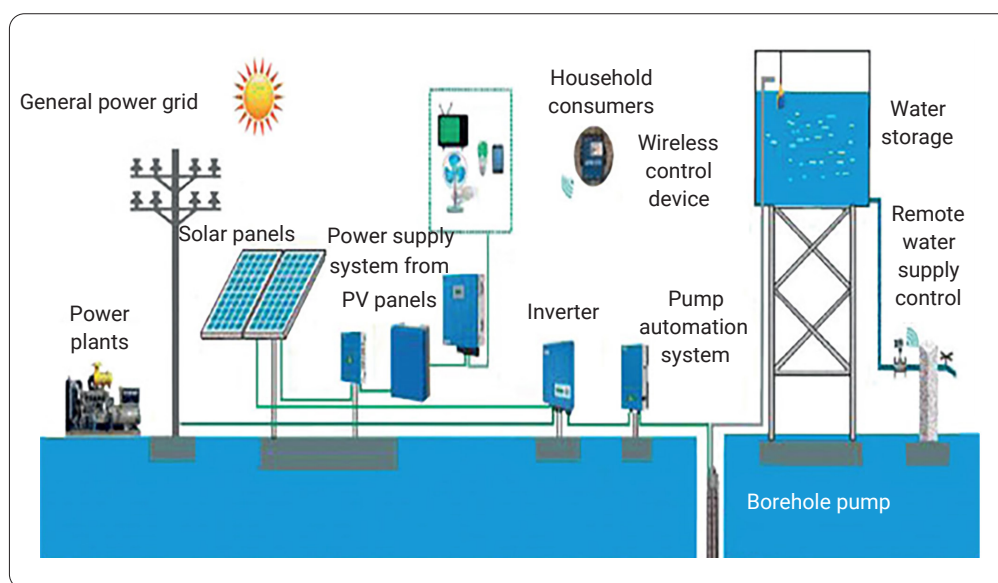


Figure 1. Power supply scheme of the irrigation system

Note: water from the well is supplied to the storage tank, from where it is distributed for irrigation. Integration with the power grid or a backup generator is provided for stable operation in case of insufficient solar generation. Automated pump control optimises water delivery, reducing energy and water consumption. The system can also supply household consumers and operate remotely

Source: S. Mikhnenko (2024)

The implementation of solar panels to power irrigation systems brings not only economic but also environmental benefits. Replacing diesel fuel reduces CO₂ emissions, contributing to the environmental sustainability of agro-industrial production. Moreover, using PV systems in combination with intelligent irrigation management algorithms allows for the optimisation of both water and energy consumption, thus increasing the operational efficiency of agricultural enterprises. The economic viability of using solar energy in irrigated agriculture is supported by calculations of electricity costs and operating expenses. However, to justify the selection of the most optimal energy supply option, a detailed comparative analysis of the costs associated with different energy sources is required.

Comparative cost analysis and payback assessment

Irrigation systems are among the most energy-intensive technologies in agriculture and require a reliable electricity source for the stable operation of pumping equipment. The choice of an energy supply system is determined by economic feasibility, technical specifications, and the availability of energy resources. The main options include

connection to a centralised power grid, diesel generators, and photovoltaic (PV) systems. Comparing the costs associated with these sources makes it possible to determine the optimal energy strategy for irrigation complexes. Centralised electricity supply is one of the traditional energy sources for irrigation systems. Its advantages include relatively stable power delivery and the capacity to connect a large number of pumping stations without the need for local generators. However, the initial connection costs may be significant due to the need to install power lines and transformer substations and adapt the network infrastructure to accommodate high-power equipment. Electricity tariffs depend on regional policy and may fluctuate, introducing additional financial uncertainty. The selection of an energy source for irrigation systems is crucial for ensuring their economic efficiency. Initial capital expenditures, electricity costs, and operational expenses vary significantly depending on whether a centralised grid, diesel generators, or PV systems are used. Table 2 presents a comparative overview of the costs associated with these energy sources, enabling an assessment of their profitability and appropriateness for use in agriculture.

Table 2. Economic comparison of energy supply options for irrigation systems

Energy source	Initial costs (USD)	Electricity cost (USD/kWh)	Operating costs (USD/year)	Payback period (years)	Environmental impact
Centralised power supply	5,000-20,000 (grid connection)	0.10-0.30	Depends on tariffs	Not applicable	Depends on generation source
Diesel generators	10,000-20,000 (generator)	0.20-0.35	5,000-10,000 (fuel, maintenance)	Not cost-effective (high expenses)	High CO ₂ emissions
PV Systems	24,000-36,000 (30 kW PV system)	0.05-0.12	300-500 (minimal maintenance)	5-8	Low CO ₂ emissions

Source: developed by the authors based on International Energy Agency (2024), International Renewable Energy Agency (2024), World Bank (2024)

An analysis of the cost characteristics of energy supply reveals significant differences in expenditure structures depending on the selected source. Grid electricity requires an initial investment for connection, while subsequent costs depend on electricity tariffs, which may fluctuate in accordance with the state's economic policy. However, this option ensures a stable power supply, which constitutes its primary advantage. The use of diesel generators provides autonomy, yet the high cost of fuel and the need for regular technical maintenance make this option less economically attractive in the long term. Additionally, the high level of CO₂ emissions represents a considerable environmental drawback of diesel units.

Photovoltaic (PV) systems involve the highest initial investment; however, their low operational costs allow for relatively rapid payback. Due to the absence of fuel expenses and minimal maintenance requirements, PV systems represent a financially viable option in regions with sufficient solar irradiation. Furthermore, the use of renewable energy significantly reduces environmental impact, which is a crucial factor in the development of sustainable strategies for the agricultural sector.

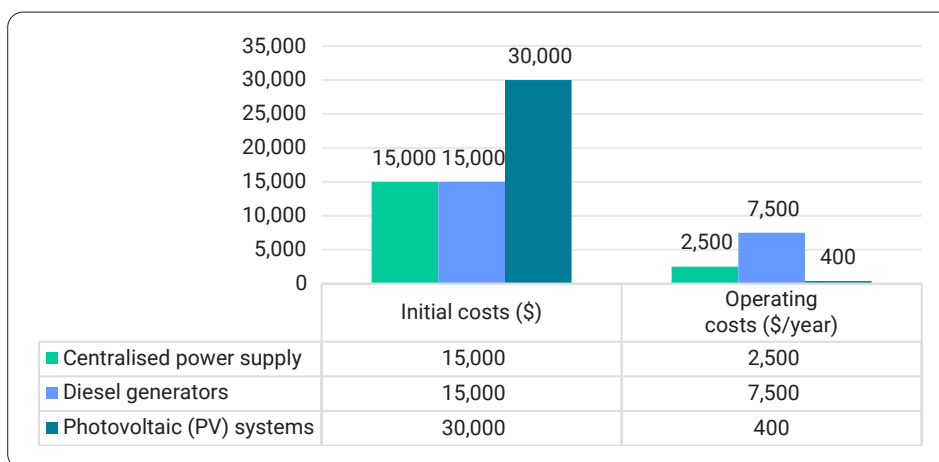
Diesel generators are used in cases where grid electricity is either unavailable or economically unfeasible. They provide autonomy in operating pumping equipment, which is advantageous in remote agricultural regions. Nonetheless, the use of diesel generators entails significant operational

costs, including fuel, regular maintenance, oil, and filter replacements. Moreover, diesel units pose environmental disadvantages due to high CO₂ emissions and noise pollution, rendering them less attractive in the long run.

The implementation of PV systems in irrigated agriculture enables a substantial reduction in operational expenses, as solar energy is a free and widely available resource. Initial investments in PV systems include the cost of solar panels, inverters, battery storage (if required), and power control automation systems.

The payback period for PV systems depends on the level of insolation, investment costs, and the availability of financial incentives. On average, it ranges from 5 to 8 years, which is a competitive indicator compared to traditional energy supply options. For diesel generators, the payback period may be shorter due to a lower initial investment, but high operational costs make them less economically viable in the long term. In the case of grid electricity, payback is determined by the applicable tariffs and the cost of connection to the distribution network.

To assess the economic feasibility of various energy supply sources in irrigated agriculture, it is necessary to compare their payback periods by accounting for initial investments and operating costs. Figure 2 presents a comparative chart containing statistical data on the key parameters of the payback period for grid electricity, diesel generators, and PV systems.

**Figure 2.** Assessment of the economic feasibility of using renewable energy sources

Source: developed by the authors based on International Energy Agency (2024), International Renewable Energy Agency (2024), World Bank (2024)

Analysis of Figure 2 highlights significant differences among the energy supply options. The centralised electricity supply requires substantial initial investment; however, its payback period is not typically calculated in the conventional sense, as ongoing costs are determined by electricity tariffs, which may fluctuate depending on political and economic factors. Diesel generators also fail to reach payback due to their high operating costs, which significantly exceed those of alternative systems. Dependence on fuel markets and the need for regular technical maintenance make this option economically unviable in the long term. PV systems, despite higher upfront costs, incur the lowest operational expenses, allowing for an average payback period of approximately 6.5 years. Key factors influencing the speed of payback include the level of solar irradiation in the region, the availability of government subsidies, and the efficiency of battery storage systems. In areas with high solar exposure, the payback period can be significantly reduced, making PV systems the most promising long-term solution for powering irrigation facilities.

The economic viability of PV systems also depends on the availability of financial support mechanisms, such as state subsidies, grant programmes, or cost-compensation schemes for PV installation. In several countries, renewable energy incentive programmes enable agricultural enterprises to receive financial assistance for the implementation of solar panels. Access to such mechanisms can reduce the payback period of PV systems and make them more

accessible to a broader range of agricultural producers. A comparative cost analysis of different energy sources indicates the feasibility of adopting PV systems for irrigation complexes, particularly in regions with high solar irradiation. However, the implementation of such technologies requires not only economic justification but also consideration of regulatory factors that may influence their accessibility and operational effectiveness.

Financial and regulatory aspects of implementation

The financial and regulatory aspects of PV system deployment in agriculture are key determinants of their adoption scale. Government support, international grant programmes, and tax incentives stimulate the development of renewable energy by lowering the financial barrier to the adoption of PV technologies. However, the implementation of such projects may be complicated by regulatory requirements related to grid connection, equipment licensing, and component certification. Analysing financing mechanisms and regulatory frameworks enables the assessment of the effectiveness of solar energy incentive policies in different countries. To promote the deployment of PV systems in agriculture, various countries have introduced support programmes that include subsidies, grants, tax relief, and concessional loans. These mechanisms can significantly reduce the capital costs of installing solar power systems and accelerate their payback. Table 3 below outlines the main government support programmes in the EU, the USA, and China.

Table 3. State financial support programmes for PV system implementation in agriculture

Country	Program	Main support mechanisms	Maximum cost compensation (%)	Additional incentives
EU	European Agricultural Fund for Rural Development	Grants and subsidies for PV system installation in agriculture	75	Preferential loans, technical support
USA	Rural Energy for America Program	Funding of up to 50% of costs for renewable energy installations	50	Tax incentives, reduced loan interest rates
China	Golden Sun Program	Subsidies, tax benefits, and financing for PV power plant construction	60	Duty-free import of PV components, government procurement of PV systems

Source: developed by the authors based on International Energy Agency (2024), International Renewable Energy Agency (2024), World Bank (2024)

An analysis of government support programs demonstrates an active policy promoting the adoption of solar energy in agriculture. In the EU, the highest level of cost compensation – up to 75% – makes the installation of PV systems highly accessible for farmers. In the USA, financial support is provided through the Rural Energy for America Program, which covers up to 50% of costs, while additional tax incentives and access to preferential loans further encourage the development of renewable energy. China's Golden Sun Program offers subsidies for the installation of PV stations, support for solar equipment manufacturers, and simplified import procedures for system components,

contributing to the widespread deployment of solar power plants across the country.

The availability of public financial support significantly reduces the payback period of PV systems, enhances their economic attractiveness, and facilitates the broader use of renewable energy in agriculture. However, the effectiveness of such programmes depends on the ease of accessing funds, the level of bureaucratic barriers, and the degree of integration of PV systems into the country's overall energy policy. Financing mechanisms for PV projects include not only state grants but also concessional lending, investment funds, and private initiatives. Banking institutions in

countries with well-developed renewable energy sectors offer special low-interest loan programmes for agricultural enterprises investing in solar generation. The green bond mechanism plays an important role by enabling the attraction of funds for environmentally sustainable projects, including the installation of solar power plants in agriculture. Despite the availability of substantial financial support, the deployment of PV systems may be hindered by regulatory barriers. The main challenge remains the complexity of connecting to centralised power grids, which requires obtaining permits and technical approvals. In some countries, the connection process for PV generation may take several months to a year, thereby delaying project implementation.

Innovative energy solutions for irrigation

The implementation of PV systems in irrigated agriculture represents a key strategy for optimising energy consumption and enhancing energy independence in the agro-industrial sector. The technical aspects of such systems include the selection of PV modules, integration with pumping equipment, automation of water supply processes,

and the use of battery storage systems to retain surplus energy. The application of modern technologies increases the efficiency of irrigation systems and reduces operational costs associated with pumping equipment. The use of bifacial solar panels is a promising direction in the development of PV technologies, as these modules can generate electricity from both direct and reflected solar radiation. This capability enables an overall increase in electricity output by 10-20% compared to standard monocrystalline panels. Bifacial PV modules are particularly effective in environments with open ground and high albedo or when combined with white surfaces that enhance the reflection of sunlight. The choice between standard monocrystalline and bifacial solar panels is determined by their technical specifications, efficiency levels, and installation costs. Bifacial panels are capable of using reflected light, which boosts their productivity, while standard monocrystalline modules remain a more economical option for conventional solar power plants. Table 4 presents the key parameters of both panel types, allowing for a comparison of their effectiveness in the context of irrigated agriculture.

Table 4. Comparative characteristics of standard and bifacial monocrystalline solar panels

Characteristic	Standard monocrystalline panels	Bifacial monocrystalline panels
Efficiency (%)	18-22	20-24
Electricity generation (kWh/m ² /year)	1,400-1,600	1,600-1,900
Temperature sensitivity (W/°C)	-0.3	-0.28
Additional generation from reflected light (%)	None	10-20
Average service life (years)	25-30	25-30
Installation cost (USD/kW)	800-1,000	900-1,200
Estimated cost of generated electricity (USD/kWh)	0.0167-0.0286	0.0158-0.03

Source: developed by the authors based on International Energy Agency (2024), International Renewable Energy Agency (2024), World Bank (2024)

Bifacial solar panels offer a higher electricity output due to their ability to capture both direct and reflected solar radiation. This feature enhances system efficiency, particularly in regions with high surface reflectivity – such as light-coloured soils or specially prepared reflective coatings. However, to achieve maximum performance, the panels must be precisely placed, which may require additional expenditures related to installation and tilt angle optimisation. Despite their higher electricity generation potential, bifacial panels entail increased initial installation costs, potentially affecting their payback period. On the other hand, their resistance to overheating and their more efficient utilisation of solar radiation make them attractive for use in autonomous energy systems, particularly in irrigation agriculture. The optimal choice between bifacial and conventional monocrystalline modules depends on specific operational conditions, available budget, and required energy supply levels. Estimates show that even though bifacial panels cost more to install at first, they can produce electricity at a lower cost (between USD 0.0158 and

0.030 per kWh) compared to traditional monocrystalline panels (USD 0.0167 to 0.0286 per kWh). This advantage is primarily due to their increased energy output and extended operational lifetime, which can significantly reduce long-term energy expenses for agricultural enterprises. Moreover, the need for additional investment in mounting and configuration can be offset by enhanced productivity and a shorter payback period in regions with favourable solar irradiation.

The increasing energy demand in irrigation agriculture, coupled with climate change, necessitates the adoption of energy-efficient and resource-conserving technologies. The integration of PV systems, implementation of bifacial solar panels, use of energy storage solutions, automation of water supply processes, and hybrid energy configurations contribute to reduced energy consumption, more efficient water use, and improved financial stability of agricultural enterprises. Table 5 presents comparative performance indicators of these technologies, including capital investment, energy savings, water cost reduction, and payback periods.

Table 5. Economic efficiency of innovative technologies in irrigation

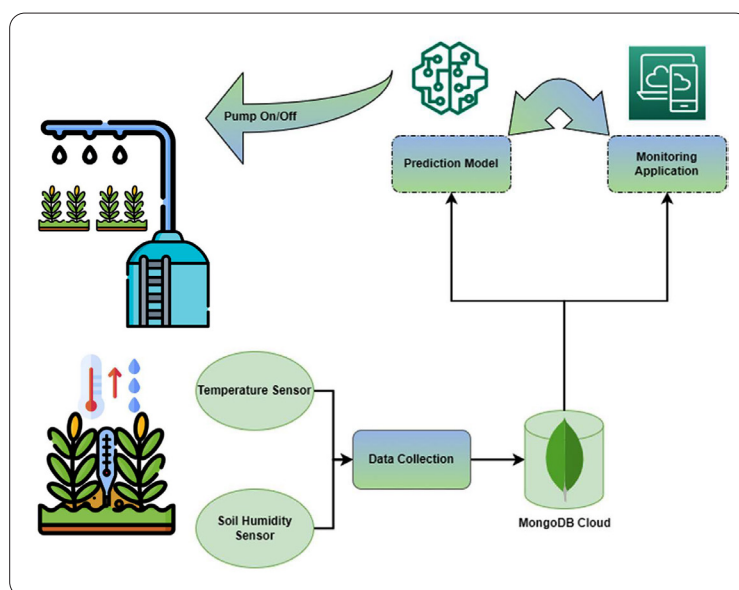
Technology	Investment costs (USD/ha)	Energy savings (%)	Reduction in water supply costs (%)	Payback period (years)
Installation of PV systems	1,200-2,500	40-60	20-35	5-8
Use of bifacial solar panels	1,500-3,000	50-65	25-40	6-9
Integration of energy storage systems	1,800-3,500	55-70	30-45	7-10
Floating solar panels (Floating PV)	2,000-4,000	60-75	35-50	6-10
Automated irrigation with IoT and AI models	2,500-5,000	70-85	40-60	4-7
Hybrid system (solar + wind + biogas)	3,000-6,000	80-90	50-70	8-12

Source: developed by the authors based on International Energy Agency (2024), International Renewable Energy Agency (2024), World Bank (2024)

The analysis of the presented data indicated that the implementation of PV systems required relatively low capital investment while enabling a reduction in energy costs by 40-60% and a decrease in water supply expenses by 20-35%. Bifacial solar panels improved electricity generation efficiency, contributing to additional energy savings; however, their deployment required a higher initial investment and exhibited longer payback periods. The highest energy savings (up to 90%) were observed in hybrid energy systems, although they were also associated with the highest capital costs and payback periods exceeding 8 years. The adoption of automated irrigation systems using IoT and AI models resulted in the largest reductions in energy consumption (up to 85%) and water supply costs (up to 60%), yielding relatively short payback periods of 4–7 years. At the same time, energy storage technologies and floating PV systems demonstrated considerable potential for enhancing energy autonomy in agricultural enterprises. However, their efficiency strongly depended on regional climatic conditions and the availability of water resources.

Floating solar panels represent another effective solution, offering additional electricity generation while reducing water evaporation in irrigation reservoirs. Installing

PV modules on water surfaces allows the use of natural cooling to improve performance, minimising overheating risks and panel degradation. Moreover, floating solar plants help optimise land use, as they do not occupy agricultural areas while ensuring a stable power supply to pumping systems. The automation of irrigation systems through IoT technologies enables the development of adaptive water management models based on real-time data on soil conditions, climate parameters, and crop needs. Moisture, temperature, and weather sensors transmit data to a cloud platform that automatically adjusts irrigation schedules according to current requirements. The use of AI algorithms for forecasting evapotranspiration and water consumption improves irrigation efficiency and minimises water losses. IoT- and AI-based automation of irrigation systems significantly enhances the management of water resources in agriculture. The integration of soil moisture sensors, temperature monitors, and cloud-based data analytics platforms ensures the optimisation of irrigation schedules tailored to crop needs. Figure 4 shows how an intelligent irrigation management system works by monitoring soil conditions, analysing data to predict needs, and automatically controlling the pumping equipment.

**Figure 3.** Intelligent system of automated irrigation management based on IoT and AI

Source: M.S. Hossain et al. (2023), Y. Tace et al. (2022)

Figure 4 illustrates the operating principle of an automated irrigation system that employs sensor technologies for data collection and further processing in a cloud environment. Soil temperature and moisture sensors record the current state of the agroecosystem and transmit the data to MongoDB Cloud for subsequent analysis. The use of cloud technologies enables the centralised storage of large volumes of agroclimatic data, which forms the basis for accurate forecasting and optimal water resource allocation. A predictive model analyses the collected data, assessing the plants' irrigation needs and generating recommendations for starting or stopping the pumping equipment. A control system connected to a Monitoring Application enables automatic water supply management, ensuring timely irrigation with minimal losses. The integration of IoT and AI technologies into irrigation systems enhances the efficiency of water use, reduces dependence on human intervention, and facilitates the adaptation of agricultural production to changing climate conditions.

Hybrid power supply systems that combine PV modules with other energy sources, such as wind turbines or biogas plants, enable the development of comprehensive energy solutions for the agricultural sector. The combination of PV systems with wind generation ensures electricity production during both sunny and windy periods, enhancing the stability of energy supply (Szafraniec *et al.*, 2021). The use of biogas installations allows for the additional generation of electricity from organic agricultural waste, contributing to the energy independence of farming enterprises. Energy storage systems are a critical component for improving the efficiency of solar energy use in irrigation systems. Modern lithium-ion and flow batteries make it possible to power pumping equipment during periods of insufficient solar activity. Energy consumption management based on forecasting algorithms enables the efficient distribution of energy resources and helps avoid system overloads.

The future development of solar energy in agriculture depends on technological innovations, regulatory conditions, and investment levels in PV systems. Using advanced automation, combining different energy systems, and applying smart resource management will help improve energy supply efficiency in irrigated agriculture. Further advancement of PV technologies will ensure the stable operation of the agro-industrial complex and reduce dependence on conventional energy sources.

Discussion

The introduction of PV systems in irrigated agriculture has contributed to increased energy independence of agricultural enterprises and reduced electricity costs. An analysis of behavioural factors influencing decisions on the adoption of solar technologies was conducted by A. Rahmani & A.B. Naeini (2023). The authors identified key motivational factors as economic benefit, reduced reliance on unstable energy sources, and the long-term efficiency of such solutions. Comparative analysis confirmed that in addition to

technical and economic aspects, subjective factors such as farmers' awareness and access to financial support played a significant role. The relevance of integrating PV systems into irrigated agriculture was confirmed by their capacity to reduce electricity expenses and improve the energy efficiency of agricultural enterprises. A study by M. Trommsdorff *et al.* (2023) demonstrated the economic advantages of agrivoltaic systems that combine electricity generation with crop cultivation. Optimal placement of solar panels contributed to lower energy costs and efficient use of land resources. The comparative results confirmed that such systems can provide synergistic benefits by integrating renewable energy into agricultural processes without negatively affecting crop yields.

PV systems have shown potential for ensuring stable water supply, which is a critical factor in irrigated agriculture. The study by S.W. Sharshir *et al.* (2023) explored the use of solar energy for drying agricultural produce, which helped reduce energy costs. However, it did not address the use of PV systems in irrigation complexes. Comparative findings highlight the need for further research on the integration of such technologies into water supply systems. Lower operational costs and the optimisation of water use are key benefits of implementing PV technologies in agriculture. The work of F. Raza *et al.* (2022) demonstrated the socio-economic impact of solar irrigation systems, which contributed to water supply stability and energy savings. The transition of agricultural enterprises to PV systems reduced dependence on centralised power supply, aligning with conclusions on the increased economic efficiency of such technologies. The effectiveness of solar pumps with single-axis tracking systems for irrigation was confirmed by the study of P. Abhilash *et al.* (2021). These technologies improved water delivery performance by optimising panel orientation relative to solar radiation. Data analysis indicated that combining such technologies with intelligent energy management systems enhanced the efficiency of irrigation systems.

A study by I.M. Bezhenar (2023) on the financial aspects of solar energy development in Ukrainian farms confirmed the importance of expanding state support programmes in this field. The author found that the availability of financial incentives could foster wider adoption of PV systems in agriculture. Comparative analysis showed that investment accessibility and subsidies are key factors for the effective expansion of renewable energy technologies in irrigated farming. The architectural features of PV systems and their impact on agroecosystems were examined in a study by M.A. Zainol Abidin *et al.* (2021). The authors concluded that the optimal spatial arrangement of solar panels could enhance crop yields by creating a favourable microclimate. Comparative results confirmed that integrating PV systems into irrigation complexes not only reduces energy costs but can also have a positive effect on agricultural productivity.

The application of PV systems in irrigated agriculture increased the energy efficiency of agricultural enterprises.

es and reduced operational costs. In a study by A. Lingayat *et al.* (2021), the use of solar energy across various industrial sectors, including agriculture, was analysed. The authors found that solar power plants have considerable potential to meet the energy needs of agricultural enterprises, helping to reduce their reliance on fossil fuels and centralised power grids. The comparison showed that using solar energy in irrigation systems fits well with the worldwide move towards renewable energy and helps farms become more self-sufficient in their energy use. The economic feasibility of applying PV technologies in agriculture has largely depended on the availability of financial incentives (Ismanzhanov *et al.*, 2012). The study by I. Sotnyk *et al.* (2022) highlighted the development of solar energy in households in Ukraine and Latvia, emphasising the importance of state support. The authors found that subsidies, preferential loans, and Net Metering mechanisms contributed to the active deployment of solar power plants. A comparison of the findings confirmed that financial mechanisms played a key role in the development of PV systems in agriculture, reflecting general trends in the promotion of renewable energy.

The integration of PV systems into irrigation complexes enabled simultaneous optimisation of energy consumption and rationalisation of water use. The study by D. Soto-Gómez *et al.* (2024) demonstrated that agrivoltaic systems facilitated the combined production of electricity and agricultural crops without significant yield losses. Optimal placement of solar panels promoted efficient land use and supported microclimatic conditions. A comparison of the results confirmed the need to improve management methods of PV installations in irrigated farming, which could offer additional economic and environmental benefits. The stability of power supply to pumping equipment is a critical factor for the effective operation of irrigation systems. The work by S. Gorjian *et al.* (2021a) explored the integration of PV, photovoltaic-thermal, and solar thermal collectors in greenhouse complexes. It was found that these technologies contributed to a significant reduction in CO₂ emissions and energy consumption optimisation. A comparative analysis highlighted the importance of energy storage systems in irrigation setups to ensure the reliable operation of pumping equipment and mitigate the impact of variable PV generation.

Financial support has been an important factor in expanding the use of PV systems in agriculture. The study by A.K. Thakur *et al.* (2022) found that government subsidies, concessional loans, and other financial incentives significantly accelerated the adoption of solar technologies in Indian farming enterprises. A comparison of the results confirmed that expanding financing mechanisms in irrigated agriculture could enhance its energy efficiency and resilience. The use of PV technologies in agriculture contributed to increased productivity through automated production processes. The study by M.A. Muñoz-García & L. Hernández-Callejo (2021) showed that autonomous energy systems improved resource management and reduced

CO₂ emissions by decreasing dependence on fossil fuels. A comparative analysis confirmed that PV-powered autonomous pumping stations had significant potential for optimising irrigation processes by ensuring stable water supply and reducing energy costs.

PV systems contributed to improved water use efficiency in agriculture. The study by G.H. Tariq *et al.* (2021) revealed that the implementation of solar energy in irrigation systems enhanced water delivery control, reduced moisture losses, and increased the overall productivity of the agricultural sector. A comparison of the findings emphasised the need to modernise the energy infrastructure of irrigation systems to ensure optimal energy consumption and sustainable water resource management. Climatic and topographical conditions had a significant impact on the performance of PV systems in agriculture (Semenenko *et al.*, 2024). The study by A. Ashraf & K. Jamil (2022) found that solar irradiance levels, temperature fluctuations, and local terrain characteristics substantially affected PV module productivity and their capacity to provide a stable energy supply. The comparison of results showed that it is important to adjust pumping stations to fit local conditions, which includes choosing the best PV system setups, using battery storage, and combining different energy sources to make the irrigation energy supply more reliable.

The use of PV-powered pumping stations in irrigated agriculture allowed for a reduction in operating costs and ensured a stable energy supply independent of fossil fuels. In the study by S. Hilarydoss (2023), a comparative analysis of the economic efficiency of PV and diesel pumps was conducted, demonstrating the financial advantages of solar generation. The author found that despite higher initial capital costs, PV systems had lower operating expenses and a longer service life, resulting in faster investment payback. A comparison of findings confirmed the economic viability of solar generation for irrigation systems, in line with broader trends toward sustainable energy solutions in the agricultural sector. The adoption of alternative energy sources enhanced the resilience of food production and energy supply stability in agriculture (Yerniyazova *et al.*, 2024). The study by Y. Majeed *et al.* (2023) found that integrating solar power with other renewable energy sources ensured stable operation of irrigation systems while reducing reliance on unstable centralised power grids. A comparative analysis confirmed the need for integrated energy resource management in agriculture, including the use of PV systems, energy storage, and hybrid solutions to guarantee uninterrupted energy supply.

PV systems contributed to reducing the environmental impact of the agricultural sector by cutting CO₂ emissions and lowering fossil fuel use (Dovgal *et al.*, 2024). In the study by C.M. Kumar *et al.* (2023), it was shown that the implementation of solar energy in Indian agriculture significantly reduced greenhouse gas emissions and supported the transition to environmentally sustainable energy solutions. A comparison of findings confirmed that

the use of PV systems was aligned with general trends in sustainable agricultural technology development, providing both economic and environmental benefits. The use of solar technologies in agriculture enabled reductions in operational costs and increased the energy autonomy of the agricultural sector (Ismanzhanov & Tashiev, 2016). In the study by S. Gorjian *et al.* (2021b), the economic aspects of solar technology implementation in agriculture were analysed, confirming their ability to reduce energy supply costs through the use of renewable energy sources. The authors found that transitioning to PV systems allowed agricultural enterprises to avoid significant expenses for fuel and centralised electricity while also mitigating financial risks associated with tariff instability. A comparison of findings confirmed the economic effectiveness of solar technologies in agriculture, which could become a key factor in their further adoption in irrigation systems.

Diversification of energy sources contributed to increasing the energy independence of agricultural enterprises and ensured the resilience of energy supply. The study by S. Mathur *et al.* (2022) established that a combination of biofuels, solar, and wind energy allowed for the optimisation of energy consumption, a reduction in dependence on conventional energy resources, and the enhancement of operational stability in agricultural enterprises. A comparison of results confirmed the prospects of implementing PV technologies in agriculture, particularly when combined with other renewable energy sources to create integrated energy solutions. The application of PV systems in irrigated agriculture proved to be economically viable, contributing to reduced electricity costs, improved energy efficiency of agricultural enterprises, and lower CO₂ emissions. The analysis showed that integrating PV technologies into irrigation systems ensured stable water supply, reduced reliance on unstable centralised networks, and could be effectively combined with other renewable energy sources. A comparison of the results obtained with previous scientific studies confirmed the importance of financial incentives, optimal panel placement, and advancements in energy storage technologies for improving the efficiency of PV systems in agriculture.

Conclusions

The study assessed the economic feasibility of using PV systems in irrigated agriculture, considering financial, technical, and environmental aspects of their implementation. The analysis of energy supply costs revealed that the use of PV stations enabled a reduction in operational expenses for agricultural enterprises through the utilisation of renewable energy. It was found that transitioning to solar power stations enhanced the energy autonomy of agricultural production and reduced dependence on fluctuating tariffs for conventional energy resources. Furthermore, it was demonstrated that the availability of Net Metering mechanisms and government funding programmes

facilitated the wider adoption of PV systems in agriculture. The technical analysis indicated that integrating PV systems into irrigation complexes contributed to the improved efficiency of pumping stations. The use of modern inverter technologies, energy storage systems, and automated power regulation algorithms enabled the optimisation of energy consumption and ensured the stable operation of pumping equipment. It was established that the performance of PV systems largely depended on the level of solar insolation, the design features of the panels, and the capabilities of energy consumption automation. In addition, it was confirmed that combining solar panels with energy-efficient pumps contributed to a reduction in overall electricity consumption and increased the productivity of irrigation systems.

The environmental analysis showed that the use of PV systems in irrigated agriculture significantly reduced CO₂ emissions by decreasing the consumption of traditional energy resources. The introduction of solar technologies helped lower environmental pollution levels, improve the ecological sustainability of agricultural production, and rationalise water resource use. It was confirmed that agri-voltaic systems had the potential to increase crop yields by protecting plants from overheating and conserving soil moisture. Based on the results obtained, recommendations were formulated regarding the expansion of PV system use in irrigated agriculture. One of the key factors in scaling up solar energy is the development of financial support mechanisms, including government subsidy programmes and preferential crediting. It was found that the implementation of energy storage technologies, optimisation of electricity consumption management algorithms, and the development of digital monitoring platforms would enhance the efficiency of solar energy use in the agricultural sector.

Further research in the field of PV system integration into irrigation complexes may focus on the development of models for forecasting electricity generation and consumption under various climatic conditions. The issue of assessing the long-term stability and reliability of PV panels in regions with high insolation levels and seasonal water consumption fluctuations remains relevant. A promising research direction is the integration of solar generation into comprehensive water resource management systems, which would enable the optimisation of both energy and natural resource use in agriculture.

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Conflict of Interest

None.

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Економічна ефективність впровадження сонячних панелей в зрошувальному землеробстві: оцінка витрат, порівняльний аналіз витрат та економічне обґрунтування

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Анотація. Метою цього дослідження було оцінити економічну ефективність впровадження фотоелектричних (ФЕ) систем у зрошувальному землеробстві з урахуванням технічних, фінансових та екологічних аспектів їх застосування. Для досягнення цієї мети було проаналізовано рівні енергоефективності насосних станцій, вартість встановлення ФЕ систем та механізми державної підтримки. Результати дослідження показують, що впровадження сонячної енергії в зрошувальних комплексах знизило середні витрати на електроенергію до 0,05-0,12 доларів США за кВт·год порівняно з 0,20-0,35 доларів США для дизельних генераторів та 0,10-0,30 доларів США для централізованого електропостачання. Було визначено, що середній термін окупності ФЕ систем у зрошувальному землеробстві становить 5-8 років, що значно менше, ніж для дизельних генераторів, які не є економічно ефективними через високі експлуатаційні витрати. Дослідження підтвердило, що використання сучасних ФЕ систем у поєднанні з інтелектуальними насосами зменшило споживання енергії зрошувальними установками на 20-30 %, підвищивши їхню автономність та стабільність роботи. Аналіз впливу на навколишнє середовище показав, що фотоелектричні системи сприяють скороченню викидів CO₂ на 60-80 % порівняно з традиційними джерелами енергії, що є вирішальним фактором переходу до сталого сільськогосподарського виробництва. Було встановлено, що програми субсидування, механізм нетто-лічильника та пільгові кредити сприяють зменшенню початкових капіталовкладень та стимулюють сільськогосподарські підприємства до впровадження сонячних електростанцій. На основі отриманих результатів розроблено рекомендації щодо оптимізації механізмів фінансового стимулювання впровадження фотоелектричних систем у зрошувальному землеробстві, покращення технологічних параметрів фотоелектричних установок та використання цифрових платформ для управління енергією. На практиці результати можуть бути використані для обґрунтування проектів державно-приватного партнерства з будівництва сонячних електростанцій на зрошувальних насосних спорудах.

Ключові слова: відновлювані джерела енергії; фотоелектричні системи; циркулярна економіка; енергетична незалежність; оптимізація енергоспоживання

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Digital transformation in the transport and logistics sector of Kazakhstan: Challenges and opportunities for global integration

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Abstract. The purpose of the study was to identify the key advantages and challenges of digitalisation in the transport and logistics sector of Kazakhstan and assess its impact on economic growth and international cooperation. The study employed methods of analysis, evaluation, and forecasting to determine the effects of digital technologies on various dimensions of the transport and logistics system of Kazakhstan, including productivity, investment appeal, and global integration. Findings indicated that digital transformation enhances effectiveness, reduces transaction costs, and improves investment attractiveness of the sector. The introduction of digital platforms, automation of customs procedures, and use of artificial intelligence (AI) accelerated cargo processing and optimised operations. Analysis indicated that digitalisation fosters growth in foreign investment by increasing transparency and predictability in transport processes. Private infrastructure investments were projected to reach USD 500-800 million, yielding returns of 15-20% over 3-5 years, while public subsidies may amount to USD 200-300 million with returns of 10-12% over 1-3 years. International projects are estimated to generate USD 600-900 million in investment with expected returns of 18-25% over 4-6 years. Public-private partnerships are anticipated at the level of USD 400-600 million, offering returns of 12-18% over 2-4 years, and investments in start-ups are expected to total USD 100-200 million with returns of 25-35% over 2-3 years. The development of digital solutions across international transport corridors strengthened the role of Kazakhstan as a logistical hub. However, major challenges persisted, including inadequate digital infrastructure, cyber threats, low levels of digital literacy, and financial constraints faced by small and medium-sized enterprises. Effective transformation requires strong public-private cooperation and the creation of “smart” logistics hubs. Digitalisation within the transport and logistics sector thus presents substantial potential for positioning the country as a leading logistical hub in Central Asia

Keywords: investment; automation; international corridors; cybersecurity; logistics infrastructure; global integration

Introduction

The transport and logistics sector of Kazakhstan plays a pivotal role in facilitating connections between Asia and Europe, positioning the country as a key actor within global trade networks. Considerable efforts were made to develop logistics infrastructure, with the aim of achieving deeper integration into international transport systems and enhancing competitiveness in the global marketplace. A critical dimension of this development involves digital transformation, which entails the adoption of advanced technologies to improve efficiency, reduce costs, and strengthen collaboration with international partners. Digitalisation of transport and logistics processes presents new opportunities for optimising freight operations, lowering transaction costs, and raising service standards. Nonetheless, several challenges persist, including the need for infrastructure modernisation, cybersecurity, and adequate personnel training. Successful digital transformation in the transport and logistics sector has the potential not only to improve internal operational efficiency but also to reinforce the country's strategic position within the global economy.

The core issue underlying digital transformation in this sector involves the integration of new technologies aimed at increasing efficiency, enhancing international connectivity, and reducing operational expenditures. G.D. Yesenzholova & R.T. Dulambaeva (2024) highlighted that automation of customs procedures may significantly accelerate transactions and reduce administrative barriers, thereby fostering stronger international links. They also emphasised the role of digital technologies in enhancing transparency and reducing wait times. C.H. Chang *et al.* (2022) stressed the importance of implementing digital logistics platforms, noting their ability to substantially decrease operational costs and improve national competitiveness. These authors also identified the benefits of blockchain technology

in ensuring the security and transparency of transport operations. G. Ping *et al.* (2024) examined the application of artificial intelligence (AI) and big data for demand forecasting and route optimisation in logistics. Their findings demonstrated that such technologies considerably improve the efficiency and accuracy of freight transport processes. U. Plesner & L. Justesen (2022) investigated the legislative implications of digitalisation, underscoring the importance of not only introducing new technologies but also establishing supportive regulatory frameworks. They emphasised the need to adapt legal systems to digital realities and protect business rights within a digital environment. Y. Ding *et al.* (2021) explored the potential for creating “smart” logistics hubs based on the Internet of Things (IoT) and AI technologies. These hubs were found to considerably enhance data processing and accelerate transport operations, potentially serving as key enablers for integration into global logistics chains.

R. Attah *et al.* (2024) emphasised that successful digital transformation in the transport and logistics sector requires substantial investment in infrastructure. Without the modernisation of existing facilities and the establishment of new innovation hubs, digitalisation would remain limited. A. Odimarha *et al.* (2024) drew attention to cybersecurity concerns, which had become increasingly critical in the context of expanding digital systems in transport and logistics. Their study proposed comprehensive data protection strategies, including the deployment of blockchain technologies to ensure the security of transport operations. C. Chen *et al.* (2021) examined the role of government support programmes in the digitalisation of the transport sector, arguing that such initiatives are essential for stimulating the development of small and medium-sized enterprises. Government subsidies and grants were considered

instrumental in accelerating technology adoption and reducing barriers for smaller market participants. J. Njoku *et al.* (2023) explored the potential for integration into international digital transport networks, asserting that such integration would unlock new opportunities for exports and transit flows. The authors underlined the importance of expanding infrastructure to connect with global logistics ecosystems. A. Gupta *et al.* (2022) highlighted the need to improve the digital literacy of personnel to enable the effective implementation and utilisation of new technologies within the logistics industry. Without high-quality training and upskilling of professionals in transport and logistics, the deployment of digital solutions would face obstacles. However, certain areas remain underexplored, including the integration of digital solutions with existing infrastructure and the complexities of cooperation between public and private actors throughout the digital transformation. Furthermore, cybersecurity risks and challenges across all stages of digital transformation have not yet been sufficiently investigated.

The purpose of this study was to analyse the impact of digital transformation on the development of the transport and logistics sector, identify key challenges and opportunities for global integration, and assess the potential economic benefits for the country.

Study objectives:

1. Assess potential pathways for attracting investment in the digitalisation of logistics infrastructure and the development of new technologies aimed at modernising the transport system.
2. Examine the prospects for implementing IoT, AI, and Big Data technologies in logistics hubs to improve freight efficiency and optimise logistical processes.

Materials and Methods

The study analysed the impact of digital technologies on the efficiency and competitiveness of the transport and logistics sector in the country. The potential application of innovative solutions in logistics was examined, including automation, AI, IoT, blockchain, and Big Data. Methods for enhancing sector performance were evaluated according to indicators such as resource utilisation efficiency, improvements in data processing speed, and reductions in operational time. The role of digitalisation in decreasing logistics costs and strengthening the competitiveness of both individual enterprises and the national economy was also considered.

The study explored the effects of implementing electronic documentation, such as the e-CMR (electronic Consignment Note) (International Road and Transport Union, n.d.) and the “Astana-1” system (It is now..., 2024), on the reduction of transactional costs. These technologies were assessed in terms of their capacity to simplify administrative processes and reduce bureaucratic barriers. The contribution of electronic documentation to lowering logistics expenditure, increasing operational transparency, improving responsiveness to changes in transport flows, and minimising overall costs was investigated.

The development of international transport corridors was also a key focus. Approaches to integrating the country into global transport networks were reviewed, including participation in initiatives such as the Belt and Road Initiative (World Bank, 2020) and the Trans-Caspian International Transport Route. The analysis employed indicators such as border crossing times, the proportion of digital operations within total processes, and the number of required transactional procedures. Digital solutions such as automated cargo monitoring and management systems were evaluated for their role in accelerating integration into international transport initiatives, improving transit speed, and enhancing coordination among participating countries.

The study also addressed the integration of the country into global digital platforms aimed at increasing supply chain transparency and traceability, while reducing transactional risks. Company reports and analytical sources from projects such as TradeLens and Alibaba Logistics (TradeLens digital platform..., 2020) were used to assess these developments. The findings highlighted the role of involvement in such ecosystems in enhancing national competitiveness in the global market, ensuring high standards of cargo handling and monitoring, reducing risk, and improving control over logistics processes.

Attention was also given to the role of developing “smart” logistics hubs. The feasibility of integrating IoT, AI, and Big Data technologies into logistics centres in Almaty and Astana was examined with the objective of enhancing the efficiency of freight transportation. The study employed an effectiveness analysis method, considering indicators such as data processing speed, real-time monitoring accuracy, reductions in logistics costs, and improved coordination among stakeholders. Potential benefits from optimising logistics processes, improving monitoring, and enhancing the management of goods movement through the use of these technologies were assessed. A SWOT analysis was conducted to examine the challenges of digitalisation in the country, drawing on analytics provided by the World Bank (2024). These sources offered deeper insight into the current strengths and weaknesses of the digital infrastructure and the opportunities for growth and development presented by digitalisation across the logistics sector and the wider economy.

Investment in the digitalisation of logistics infrastructure was another area of focus. Investment needs were evaluated through an analysis of strategic development programmes, infrastructure case studies, and international comparisons with practices in the European Union, China, and Southeast Asian countries (Panjee *et al.*, 2025). The analysis highlighted the requirement for substantial investment from both public and private actors to implement digital solutions in logistics. Possible strategies for increasing investment volumes in the sector were discussed, along with the influence of successful technological integration on the development of digital infrastructure that supported the modernisation of the national transport and logistics systems.

Results

Digitalisation plays a pivotal role in enhancing the productivity and competitiveness of the transport and logistics sector. The adoption of new digital technologies has the potential to improve efficiency by accelerating processes, reducing costs, and increasing delivery speed. For example, the introduction of electronic document management systems at certain customs posts in Kazakhstan reduced cargo processing times from 2–3 days to just a few hours (Kazbekov *et al.*, 2024). Situated at the crossroads of key trade routes, Kazakhstan has the opportunity to leverage such changes not only to improve national logistics but also to strengthen its position in the international arena. One of the most crucial components of this advancement is process automation. The integration of modern information systems for freight management and documentation enables faster application processing, expedites customs procedures, and minimises the risk of human error. A project implementing automated monitoring systems on Kazakhstani railways, for instance, led to a 30% reduction in delivery schedule discrepancies. In turn, this contributes to cost savings and greater accuracy in order fulfilment, thereby improving customer service levels and enhancing corporate reputation.

Technologies such as IoT, AI, and blockchain create new possibilities for real-time monitoring and management of transport assets. These innovations support route optimisation, predictive failure analysis, and rapid response to shifting conditions. IoT solutions, in particular, facilitate continuous monitoring of vehicle and cargo conditions, which helps prevent losses caused by damage or misplacement (Tan & Sundarakani, 2021).

Moreover, digitalisation contributes to the reduction of administrative barriers. In Kazakhstan, similar to other countries, issues related to bureaucracy and procedural complexity can impede the speed and efficiency of transport operations. The deployment of electronic systems for document submission and cargo tracking addresses these challenges by increasing transparency and accelerating the overall process. Shorter timeframes for resolving administrative matters represent a major step towards enhancing sector-wide efficiency. Digital technologies have a profound impact on the transport and logistics sector by enabling a substantial reduction in transaction costs. This has resulted in fewer bureaucratic procedures and lower logistical expenses, generating positive effects for the economy (Mikl *et al.*, 2021).

Paper-based documentation in transport logistics has long been a source of considerable cost for both carriers and clients, due to the need for physical delivery, storage, and the handling of numerous documents at various stages of transportation. The introduction of electronic documentation eliminates the reliance on physical paperwork and significantly accelerates operational processes. For instance, the use of the e-CMR system allows the transmission of cargo-related information, routing, and transport conditions in digital format, accessible in

real time by all participants within the supply chain (International Road and Transport Union, n.d.). Through the use of e-CMR, data processing speed increases by an average of 40%, while administrative and documentation costs are reduced by 30–50% due to the elimination of paper handling and storage.

The “Astana-1” system, introduced to manage and monitor international trade and customs clearance processes, also led to considerable reductions in costs associated with border crossings and customs procedures. Following the implementation of this system, customs declaration times fell from 3–4 hours to 15–30 minutes, and the number of document-related errors declined by 60% due to automated data verification. Furthermore, the digitalisation of procedures within the “Astana-1” framework reduced the number of physical cargo inspections by 20–25%, expediting border transit and lowering logistics costs. Overall, the use of electronic documentation and automated management systems contributes to substantial improvements in logistical efficiency, reduction in transaction costs, and enhanced transparency across the entire supply chain (It is now..., 2024).

One of the most noteworthy outcomes of implementing electronic documentation is the reduction of transaction costs. Within paper-based systems, substantial resources are expended on the transmission, processing, and verification of documents, alongside the resolution of errors and delays. Electronic systems accelerate these procedures, enabling enterprises to lower operational expenses and enhance overall efficiency. This is particularly important for logistics firms, which frequently manage high cargo volumes and face substantial costs related to document handling.

Lower transaction costs also contribute to improved competitiveness across the sector. Logistics firms adopting electronic systems are able to offer faster and more cost-effective services, increasing their attractiveness in the marketplace. Moreover, the implementation of digital solutions reduces the risks associated with document delays or losses, thereby minimising additional expenditures and supporting greater profitability. The use of electronic documentation also enhances transparency and trust in business operations. Digital systems record all actions and modifications in real time, reducing the likelihood of fraud or error in document processing. This is especially crucial in international trade, where compliance with regulations and standards is essential.

Digitalisation within the logistics sector offers considerable opportunities for attracting investment, which in turn supports infrastructure development and sectoral modernisation. The adoption of advanced technologies such as IoT, AI, process automation, and digital document management facilitates the creation of more efficient and adaptable logistics systems. Over the next five years, digitalisation is expected to lead to a substantial increase in investment in logistics infrastructure, with long-term positive implications for the broader economy (Table 1).

Table 1. Potential investment pathways for digitalising logistics infrastructure and developing new technologies

Potential investment pathways	Projected investment volume (USD million)	Expected return (as % of investment)	Implementation timeframe (years)
Private investment in digital infrastructure	500-800	15-20	3-5
Government subsidies and grants	200-300	10-12	1-3
International investment projects	600-900	18-25	4-6
Public-private partnerships	400-600	12-18	2-4
Investment in start-ups and innovative solutions	100-200	25-35	2-3

Source: compiled by the authors based on P. Panjee *et al.* (2025)

Potential pathways for attracting investment in the digitalisation of logistics infrastructure and the development of new technologies may be assessed through a range of funding sources and their respective characteristics. Private investment requires substantial capital and tends to be long-term, yet the prospect of high returns makes it appealing to the business sector. Government subsidies and grants contribute to the accelerated implementation of projects, providing a foundation for digital transformation with minimal risk. International investment initiatives highlight the scale and importance of these projects for the global integration of Kazakhstan into broader digitalisation processes. Public-private partnerships illustrate the potential for balanced cooperation between the state and the private sector, supporting the effective deployment of technological solutions. Investment in start-ups and innovative solutions involves a high degree of risk, but also offers considerable profitability and rapid return on investment, rendering it a promising avenue for advancing new technological directions. These forecasts collectively confirm the existence of extensive opportunities for financing the digital transformation of logistics infrastructure in Kazakhstan, where each type of investment plays a critical role in accelerating modernisation and enhancing national competitiveness.

One of the key factors driving investment is the improvement in the efficiency and transparency of logistics operations. Digitalisation facilitates enhancements in supply chain management, optimises delivery routes, and reduces cargo handling times. As a result, the logistics sector becomes more attractive to both private and public investors seeking stable and predictable returns. Investment in digital technologies enables firms to reduce operational costs while improving service quality, which is a crucial consideration for attracting capital. Investors, in turn, focus on sectors exhibiting strong growth and a clear potential for improvement. Logistics, with its central objectives of process optimisation and faster delivery, remains a focal point. Automated management systems and digital platforms strengthen company competitiveness and increase their appeal to investors, thereby encouraging capital inflow into the sector (An *et al.*, 2021).

Digitalisation also supports the creation of innovative business models, including smart logistics hubs based on IoT and the development of blockchain-based solutions aimed at enhancing transparency and operational security. These innovations provide new opportunities for businesses and generate additional incentives for investing in logistics infrastructure development. More efficient and advanced solutions may also attract foreign investment, positively influencing the national economy and contributing to job creation. The implementation of digital technologies in logistics is closely linked to infrastructure enhancement, enabling the development of more complex and integrated transport and logistics systems. Modern cargo management systems that utilise real-time data improve the efficiency of ports, terminals, railways, and road networks. Infrastructure improvement, in turn, serves as a foundation for attracting investment from both national and international sources. Investors are keen to allocate capital to projects that support sustainable development and offer the potential for high returns, and digitalisation creates such opportunities (Polukhina & Mizanbekova, 2022).

The digital transformation of the logistics sector may also considerably enhance collaboration between the public and private sectors, thereby fostering a more favourable investment climate. The establishment of infrastructure that supports the adoption of new technologies expands the scope for long-term investment and contributes to its growth. The integration of digital solutions into logistics and transport infrastructure accelerates the country's involvement in key international initiatives, offering new opportunities for global trade and reinforcing its strategic position. Digitalisation helps remove existing barriers, improves coordination among transport process participants, and speeds up the transit of goods across the national territory. The Belt and Road Initiative represents a global infrastructure strategy aimed at developing trade routes connecting China with countries across Asia, Europe, and Africa. Situated at the crossroads of major trade corridors, Kazakhstan occupies a strategically important role in the implementation of this initiative. The digitalisation of logistics processes and the integration of

technologies such as freight terminal automation, real-time cargo tracking, and management systems facilitate the faster movement of goods along these routes. One example is the “Digital Kazakhstan” project, which introduced electronic documentation and monitoring systems, resulting in a 30% reduction in cargo processing times at border checkpoints and a 25% acceleration in customs clearance procedures. Through digital solutions, the country is becoming a more attractive and reliable partner for international trade, thereby strengthening its global position. For instance, the modernisation of logistics infrastructure at key nodes such as the port of Aktau led to a 40 per cent increase in container handling capacity, improving foreign trade and reinforcing ties with international partners (World Bank, 2020).

The Trans-Caspian International Transport Route, which links China, Central Asia, the Caucasus, and Europe, also benefits from the adoption of digital technologies. The digitalisation of routes and cargo flow management systems reduces transportation time, lowers costs, and enhances delivery accuracy. For instance, the integration of real-time cargo tracking systems along the Trans-Caspian route improved coordination and reduced errors by 15%. This development is particularly important for the growth of the Trans-Caspian corridor, which competes with other international routes, such as the maritime path via the Suez Canal. The implementation of technologies, including IoT, automated transport control systems, and blockchain for transparency and security contributes to process optimisation and increases the efficiency of cargo movement across the national territory. In particular, the application of blockchain technologies within the Customs Union accelerated declaration procedures and improved cargo security, making the Trans-Caspian route more competitive and reducing transactional risks. Digital solutions considerably enhance coordination among countries and stakeholders involved in international transport initiatives. The use of a unified digital platform for data exchange between public authorities, logistics providers, and other participants expedites customs procedures, minimises the risk of errors, and improves overall process transparency. This is especially important in the context of global initiatives, where the rapid and efficient movement of goods across multiple borders is essential for successful project implementation. A notable element of digitalisation is the establishment of “smart” transport hubs and logistics centres capable of efficiently handling large volumes of cargo. These hubs are equipped with advanced information systems that enable real-time tracking, effective flow management, and timely responses to changing conditions. Due to its geographical position and active digital technology deployment, the country is positioned to become a key logistics hub between East and West, thereby increasing its role in international trade (Parola *et al.*, 2021).

The digital transformation of the transport and logistics sector creates new opportunities for efficient supply

chain and transaction management on a global scale. TradeLens, a digital platform developed by a consortium led by Maersk and IBM, provides end-to-end cargo tracking and management capabilities. Through blockchain technology, the platform ensures full transparency of supply chain operations, from origin to final destination. Every action within the supply chain is recorded on the blockchain, rendering the process fully traceable and resistant to interference. Participation in such global ecosystems enables companies within the country to integrate more effectively into international trade, improve coordination with partners, and reduce the risk of errors typically associated with conventional supply chain management. Enhanced transparency also increases trust among supply chain participants, thereby lowering transactional risks such as fraud or delivery delays.

Alibaba Logistics, as part of the broader ecosystem-based approach of the Alibaba Group, represents a comprehensive platform for managing international logistics. This system integrates all aspects of logistics, including transportation, warehousing, documentation, and payments. The use of digital tools within this platform enhances supply chain control, facilitates cost management, and mitigates risks associated with international trade processes. Participation in such international ecosystems grants the country access to global supply networks and enables the adoption of advanced digital solutions to accelerate delivery processes and improve competitiveness. Integration into international digital platforms offers advantages for actors involved in transport and logistics operations. These include improved coordination and synchronisation of processes, reduced processing times, and lower operational costs. Such platforms provide real-time tracking of goods and deliver information on location and shipment status, allowing for the early identification and resolution of potential issues. This reduces risks linked to delays or product damage and increases overall customer satisfaction. Participation in international ecosystems also creates opportunities for small and medium-sized enterprises. Digital platforms enable businesses to enter global markets and establish partnerships with international stakeholders without the need for substantial infrastructure investment. These platforms reduce entry barriers to international trade and simplify engagement with logistics operators, regulatory authorities, and other participants in the supply chain (Falcone *et al.*, 2021).

Rapid adoption of innovative technologies in the logistics sector is improving the efficiency of transport processes (Sapiński & Pochopień, 2023). One of the most promising areas of development is the emergence of “smart” logistics hubs equipped with advanced technologies such as IoT, AI, and Big Data. The implementation of these technologies in logistics centres in Almaty and Astana led to substantial improvements in freight flow management, shorter processing times, and increased overall efficiency within the national transport system (Table 2).

Table 2. Implementation of IoT, AI, and Big Data technologies in logistics hubs

Category	Indicators/actions	Projected outcomes
IoT technologies	Deployment of sensors and smart devices for monitoring and control	Improved real-time tracking capabilities
Use of AI	Process automation and forecasting of transport service demand	Enhanced forecasting accuracy and operational optimisation
Application of Big Data	Analysis of transport flows and consumer trends	Route optimisation and reduced logistics costs
Freight efficiency	Reduction in processing and delivery times	Faster transport processes and lower operational expenses

Source: compiled by the authors based on A.C. Ikegwu *et al.* (2022), A.O. Ajayi & H. Kumkale (2023), L.A. Gómez *et al.* (2024)

IoT comprises a network of physical objects equipped with sensors, software, and other technologies for data exchange. Within a logistics context, IoT facilitates real-time monitoring of cargo location and condition, enhancing supply chain management and reducing risks associated with losses or delays (Gomez *et al.*, 2024). Implementation of such systems in logistics hubs located in Almaty and Astana enables the integration of all operations into a unified digital platform, increasing the accuracy and transparency of freight processing. This approach contributes to greater flexibility in logistics, more responsive adaptation to supply chain changes, and improved communication among transport process stakeholders.

Intelligent systems powered by AI play a critical role in optimising routing, planning, and forecasting processes. AI analyses large volumes of data related to freight transport, weather conditions, road congestion, and other variables to propose optimal delivery routes. This results in shorter transit times and reduced fuel and resource expenditure. In logistics hubs in Almaty and Astana, AI facilitates faster freight handling and enables automation of numerous processes, enhancing operational efficiency and decreasing reliance on manual intervention. Predictive capabilities of AI also support early identification of potential issues, such as delays or cargo damage, and provide solutions for their mitigation (Ajayi & Kumkale, 2023).

Big Data contributes to more informed and strategic decision-making by processing vast datasets from

multiple sources (Ikegwu *et al.*, 2022). In logistics hubs in Almaty and Astana, the application of Big Data allows for comprehensive analysis of transport operations, identification of bottlenecks, and implementation of corrective measures. Data-driven insights support the forecasting of transport demand, inventory optimisation, and overall improvement in logistics centre performance. Moreover, the use of Big Data enhances customer service quality by offering up-to-date information regarding the location and status of shipments.

The development of “smart” logistics hubs in Almaty and Astana contributes to the integration of Kazakhstan into global logistics chains, enhancing its competitiveness and attractiveness for international partners. These technologies improve freight transport efficiency, support more effective management of transport flows, and reduce operational costs. Through active implementation of innovative technologies, Kazakhstan is positioned to enhance the quality and speed of goods delivery both domestically and internationally, thereby strengthening its standing on the global stage (Baktymbet *et al.*, 2024). Digital transformation of the logistics sector in Kazakhstan may contribute to GDP growth of 2-3% and an increase in export volumes by 5-7%, owing to improved efficiency and cost reduction (Kredina *et al.*, 2022). A SWOT analysis is used to examine the challenges associated with this digital transition (Table 3).

Table 3. SWOT analysis of the digitalisation of the logistics sector in Kazakhstan

Strengths	Weaknesses	Opportunities	Threats
Potential GDP growth of 2-3%	Low levels of digital literacy among employees	Adoption of AI, Big Data, and IoT technologies to enhance efficiency	Cybersecurity risks and data protection concerns during the digital transition
Improved efficiency of logistics operations, resulting in cost reduction	Inadequate infrastructure for digital technology deployment in remote areas	Attraction of international investment into digital projects	Limited readiness of some businesses and public authorities for the adoption of new technologies
Enhanced international competitiveness due to improved logistics	Restricted investment in digital development by small and medium-sized enterprises	Creation of new employment opportunities in the IT and digital technology sectors	Difficulties in adapting outdated processes and technologies to modern digital systems
Reduction in transaction time and costs through process automation	Demand for skilled personnel capable of working with advanced technologies	Opportunity to improve cooperation with neighbouring countries in the context of international trade	Potential risks for conventional economic sectors if digital transformation is implemented ineffectively

Source: compiled by the authors based on World Bank (2024)

Digital transformation within the logistics sector in Kazakhstan holds significant potential for improving efficiency and supporting economic growth. Introduction of advanced technologies can lead to substantial cost reductions, enhanced logistics operations, faster delivery times, and improved global competitiveness. However, several challenges remain. These include low levels of digital literacy among workers, insufficient infrastructure in remote areas, and limited investment in digitalisation among small and medium-sized enterprises, all of which hinder the pace of technological advancement. Nonetheless, opportunities such as the deployment of AI and Big Data, the creation of new employment in the IT sector, and the potential for stronger international trade relations offer a positive outlook for future development. Therewith, threats relating to cybersecurity, difficulty in adapting legacy systems, and partial readiness among businesses and governmental institutions may impede progress. One of the most notable challenges is the limited availability of digital infrastructure. In the context of rapid technological advancement, logistics companies often face a shortage of modern IT solutions and equipment necessary for effective operations. Network technologies, automation systems, and data integration tools require further development to ensure continuous and efficient real-time information processing. Moreover, many regions in Kazakhstan still lack sufficient access to the Internet and digital platforms, which slows digital transformation and diminishes its overall impact.

Another major barrier involves the low level of digital literacy among personnel. At present, a significant proportion of employees within logistics companies and public institutions lack the necessary knowledge and skills required to operate new digital tools effectively (Krzywdzinski *et al.*, 2022). The implementation of advanced technologies such as AI, Big Data, and IoT demands a highly qualified workforce capable of applying these tools efficiently. Without proper training and education, the pace of digital transformation will remain slow, and even the most promising technological solutions will not be fully utilised. This creates a pressing need for both public and private sectors to invest in educational initiatives and skills development programmes. Several initiatives have already been launched or are under development to address this challenge, including the introduction of specialised digital skills courses for employees at all levels, reskilling and upskilling programmes for logistics professionals and public sector staff. Online learning platforms are also actively developing, allowing employees to learn new digital technologies at a convenient time. Furthermore, partnerships between government institutions and the private sector are increasingly important for the design of innovative educational programmes focused on skills development in areas such as AI, Big Data analytics, and IoT integration. Cybersecurity has also become an increasingly pressing issue with the expansion of digital platforms and automated systems. The integration of new technologies into logistics operations involves the connection of multiple stakeholders through digital platforms,

which raises the risk of data breaches, cyberattacks, and other security threats. Within the context of globalisation and integration into international logistics networks, the protection of information and transaction security has become critically important. Developing infrastructure capable of ensuring cybersecurity requires substantial investment in secure systems and software solutions.

Financial barriers also present a significant challenge to the implementation of digital technologies. High initial investment costs associated with digital infrastructure, equipment, training, and the recruitment of qualified professionals may prove prohibitive for many businesses, particularly small and medium-sized enterprises. In such cases, state support and subsidies play an essential role, although economic instability may still hinder companies from pursuing large-scale digital projects even in the presence of financial assistance. A comprehensive approach is required to overcome these challenges. This should involve the development of digital infrastructure, the establishment of targeted educational programmes to improve workforce qualifications, the enhancement of cybersecurity measures, and financial support mechanisms provided by the government. Public programmes and private initiatives must be strategically aligned to remove existing barriers, enabling rapid and effective digital transformation. This would ensure the sustainable development of the logistics sector and strengthen the position of Kazakhstan within the global economy. Kazakhstan occupies a strategically important geographical position, enabling it to play a key role in international transport and logistics flows by linking Europe and Asia (Jablonskis *et al.*, 2018). In recent years, the country has actively pursued efforts to strengthen its position as a major regional hub, and the integration of digital technologies presents significant opportunities in this regard. With the successful adoption of such technologies in the transport and logistics sector, Kazakhstan has the potential to emerge as the leading logistics centre in Central Asia, offering competitive advantages compared to other countries in the region.

The digitalisation of logistics infrastructure can improve the efficiency of freight transportation and streamline operational processes, both of which are essential for the development of a successful logistics hub. The introduction of technologies such as IoT, AI, blockchain, and Big Data will open up new opportunities for Kazakhstan in supply chain management, real-time cargo monitoring, and increased transparency of operations. All of these developments will render transport routes more efficient, reduce costs, and increase the speed of goods delivery, which constitutes a crucial factor for attracting international logistics operators. By becoming a regional hub, Kazakhstan may not only strengthen the internal economy but also become an important link in the global logistics chain, providing its partners from Europe, Asia, and the Middle East with fast and secure routes for goods transportation. The advantages of Kazakhstan as a regional hub are also found in the transport infrastructure,

which is actively developing, and in the support provided by the state, which is focused on improving the business climate and creating favourable conditions for investors. Key factors for success in this area include investment in the modernisation of transport infrastructure, development of intelligent logistics platforms, and improvement of personnel qualifications required to work with new digital technologies. Kazakhstan has all the necessary potential for the implementation of these tasks: strategic location, developing infrastructure, and support for digitalisation initiatives at both state and private levels.

Effective digital transformation in the logistics sector of Kazakhstan requires a focus on the development of digital infrastructure, in particular, the modernisation of existing platforms and the adoption of the latest technologies, including IoT, AI, and blockchain. Optimisation of digital transformation must include modernisation and unification of digital platforms through the development of common data exchange standards between different logistics systems, creation of a national digital logistics ecosystem integrated with international platforms (TradeLens, Alibaba Logistics), and adoption of blockchain solutions for automation and transparency of document circulation. It is also important to use advanced technologies to improve efficiency, including the deployment of IoT devices for real-time cargo monitoring, the introduction of AI algorithms for forecasting demand for transport services and route optimisation, and the development of automated customs systems allowing faster processing of transit goods. Another key area is training of personnel and development of digital competencies, which requires creation of educational programmes in digital logistics at universities and specialised centres, organisation of advanced training courses for employees of logistics companies and government bodies, and implementation of internship programmes and partnerships with international technology and logistics companies. Implementation of these initiatives requires investment and development of international cooperation, including the design of state programmes supporting digital logistics with subsidisation of key projects, attraction of foreign investors through creation of favourable conditions for implementation of innovative solutions, and active participation in international logistics alliances and development of public-private partnerships in logistics digitalisation. Implementation of these measures will allow Kazakhstan to reduce transactional costs, increase transparency in supply chains, and accelerate movement of goods across borders, ensuring the country remains competitive in the global transport system.

Discussion

The findings of the study confirm that digital technologies played a substantial role in enhancing the efficiency and competitiveness of the transport and logistics sector. The adoption of innovative solutions such as automation, IoT, and AI contributed to faster data processing and improved

coordination of logistics processes. The integration of these technologies not only increased the sector's productivity but also created favourable conditions for its continued development in line with global trends. This issue was also explored by M. Yang *et al.* (2021), who demonstrated that digital technologies substantially improve efficiency within the logistics industry by optimising transport and warehouse management processes. The implementation of GPS systems, IoT, and data analytics enhances real-time tracking and management of goods, minimising delays and reducing operational costs. These improvements contribute not only to cost savings but also to service quality enhancement, thereby making firms more competitive in the market. K. Lee *et al.* (2023) similarly demonstrated that the transport sector benefits from the integration of automated solutions and AI for demand forecasting and route optimisation. These technologies facilitate a reduction in carbon emissions, which is essential in light of increasingly stringent environmental standards. The use of digital platforms for interaction with clients and partners expands opportunities for cooperation and supports the development of more flexible and adaptive business models.

The implementation of digital technologies requires substantial investment in infrastructure and workforce training, which can present a barrier for small and medium-sized enterprises. However, such investments are justifiable for larger organisations, as they enhance profitability and reduce operational risks. With technological advancement, it is becoming possible to develop more flexible and scalable solutions that are accessible to a broader range of companies, thereby supporting the overall growth of the sector. Analysis of the impact of digital solutions on the reduction of transactional costs indicates that the use of electronic documentation simplifies administrative procedures and minimises bureaucratic barriers. This accelerates operational processes, improves transparency in logistics activities, and reduces the costs associated with document handling. Consequently, the digitalisation of administrative procedures has become a vital instrument for the optimisation of transport flows. D. Baviskar *et al.* (2021) concluded that the automation of document management in logistics reduces administrative obstacles by decreasing reliance on manual processing of paper documents and minimising the frequency of errors. Electronic data exchange systems and integration with other information platforms accelerate approval and coordination procedures, thereby reducing waiting times and increasing responsiveness. This is particularly important in international trade, where delays can disrupt supply chains and result in financial losses.

The study conducted by H. Gupta *et al.* (2022) identified the reduction of transactional costs as another important outcome of automating document management. Systems based on blockchain technology, electronic signatures, and other modern tools enhance transparency and security in transactions, thereby lowering the costs associated with auditing and verification. Furthermore,

automation reduces the workload of personnel by relieving them of routine tasks, allowing their expertise to be redirected toward more complex and professional operations. These findings support the research discussed earlier, as the implementation of automated systems indeed leads to a notable reduction in the time required for document processing and in the number of errors caused by human factors. The use of such technologies enables much faster data exchange among participants in the logistics chain and simplifies document verification and approval. As a result, automation creates a more transparent and efficient environment for information management, which improves overall productivity and reduces operational risks (Zavadska & Oksenyuk, 2023). The study also demonstrated that digital transformation encourages investment in logistics infrastructure. Enhancements to the digital ecosystem and process automation attracted the attention of private and public investors, opening up new opportunities for financing logistics modernisation (Artyukh *et al.*, 2023). Continued sectoral growth, however, requires ongoing efforts to build a favourable investment climate, including the development of regulatory frameworks and the expansion of governmental support.

Notably, the paper by H. Zhou *et al.* (2023) also highlighted that the sources and mechanisms of financing digitalisation in logistics involve both private and public investments aimed at upgrading infrastructure and implementing new technologies. Private enterprises are increasingly viewing investment in digitalisation as a long-term strategy for improving competitiveness, which draws interest from venture capital and private equity funds. Government initiatives, such as subsidies and tax incentives, continue to play a vital role in advancing digital transformation, particularly in cases where infrastructure projects demand substantial upfront capital. C. Wang *et al.* (2021), in turn, concluded that attracting investment in the development of logistics infrastructure requires the formulation of a clear strategy that demonstrates the potential and return on investment in digital technologies. Investors seek projects that promise substantial improvements in operational efficiency and the development of new business models. Public-private partnerships serve as an essential mechanism in this context, offering access to additional capital sources and distributing risk in a way that fosters favourable conditions for long-term investment in the modernisation of logistics systems. These findings are consistent with the arguments presented in the preceding section, as they confirm the importance of both private and public sources of funding in supporting the successful digitalisation of the logistics sector. The attraction of venture capital and private investment contributes to the implementation of innovative solutions capable of enhancing the competitiveness of enterprises. Therewith, government support through subsidies and tax incentives creates additional drivers for infrastructure development and the adoption of advanced technologies, thereby improving overall efficiency in the logistics sector.

The development of international transport corridors turned out to be inextricably linked with the introduction of digital solutions (Trushaj, 2023). Integration into global supply chains helped strengthen the country's role in international trade. Automated cargo monitoring and management systems reduced transit time and improved coordination with international partners, which increased the attractiveness of the country as a transit hub (Akhmet *et al.*, 2025). E. Tijan *et al.* (2021) also confirmed that digital solutions play a key role in accelerating the international integration of the transport sector, ensuring seamless communication between different participants in the supply chain. Modern technologies, including blockchain, supply chain management systems, and the automation of customs procedures, considerably streamline operations, increasing transparency and transaction speed. These developments allow for the creation of more efficient and predictable international freight routes, reducing delivery times and minimising operational risks. R. Palu & O.-P. Hilmola (2023) similarly found that the prospects for developing global logistics corridors are closely tied to the adoption of digital technologies that enable the integration of diverse transport networks and improve coordination among countries. In particular, digitalisation supports the effective management of large volumes of data and the analysis of demand trends, facilitating improved forecasting and route optimisation. Looking ahead, further advances in AI and IoT are expected to lead to the emergence of more adaptive and resilient global logistics corridors, capable of responding swiftly to shifts in market conditions and international policy.

A comparison of the study findings indicates that digitalisation does indeed accelerate the integration of international transport systems and improves coordination across regions. The adoption of technologies such as blockchain and IoT not only enhances transparency but also reduces the costs associated with information management and processing (Rama *et al.*, 2023). This leads to improved operational efficiency and a reduction in the time required for customs procedures, thereby accelerating the movement of goods through global logistics corridors. Integration into global digital platforms shows a positive impact on supply chain transparency and risk reduction. The use of such ecosystems minimised errors in cargo handling and increased trust among international partners (Matsiuk *et al.*, 2023). The implementation of intelligent logistics hubs also played a crucial role in enhancing the efficiency of transport operations, underscoring the need for further expansion of these solutions. Y. Issaoui *et al.* (2022) concluded that digital platforms are essential for supply chain optimisation, providing real-time tracking and control over cargo at every stage of the supply chain. These platforms enable synchronisation among all participants, from suppliers and carriers to end customers, improving coordination and reducing the likelihood of delays. Their implementation promotes

process automation, shortens order processing times, and enhances planning accuracy. T. Morgan *et al.* (2023) uncovered that the transparency offered by digital platforms lowers logistical risks by enabling the early identification of problems and the implementation of corrective measures. Monitoring and analytics systems help detect bottlenecks and predict potential disruptions, facilitating timely responses to changes. This reduces uncertainty and risk in the delivery of goods and strengthens trust among supply chain stakeholders.

The findings indicate that the use of digital platforms considerably improves coordination within supply chains, enhancing overall operational efficiency and precision. These solutions optimise planning and tracking processes and enable swift responses to change, which is an essential factor in maintaining uninterrupted supply flows. This confirms that digitalisation is a critical component of strategies aimed at boosting competitiveness and reducing risks within the logistics sector. Despite the positive outcomes, the study identified several challenges hindering the digital transformation of the logistics sector. Insufficient digital infrastructure, a shortage of qualified specialists, cybersecurity risks, and financial barriers slow the adoption of new technologies. Addressing these challenges effectively requires a comprehensive approach involving government support, educational initiatives, and improvements to the regulatory framework. Overall, the study demonstrated that through the active adoption of digital technologies, the country could strengthen its position as a regional logistics hub and enhance its competitiveness in the global market.

Conclusions

The study indicated that the introduction of digital technologies enhances the efficiency of the transport and logistics sector in the country. Process automation and the utilisation of AI, IoT, and Big Data led to notable improvements in sector productivity. The implementation of these technologies accelerated data processing, improved the coordination of logistics operations, and enabled the optimisation of delivery routes. These developments contributed to a reduction in logistics costs, which in turn supported the growth of competitiveness across individual enterprises and the industry as a whole. Particular attention was devoted to the adoption of electronic documentation, including the e-CMR and the "Astana-1" system. These technological solutions substantially reduced transaction costs by lowering bureaucratic barriers and streamlining administrative procedures. As a result, the number of errors decreased, the processing of transport documents was accelerated, and the transparency of operations improved. Electronic documentation also facilitated enhanced conditions for tracking and controlling shipments, thereby strengthening trust and increasing operational efficiency both domestically and in collaboration with international partners.

The digitalisation of transport logistics also contributed to a rise in investment directed towards the modernisation

of logistics infrastructure. The allocation of resources towards new technologies and the development of innovative platforms created favourable conditions for attracting investors. Forecasted investment volumes in digital infrastructure range between 500 and 800 million USD, with an anticipated return on investment of 15-20% over a period of three to five years. This supported growth in the construction of modern logistics hubs, infrastructure enhancement, and the development of new transport corridors. Estimated volumes for international investment projects are valued at 600 to 900 million USD, with projected returns of 18-25%, while public-private partnerships are expected to attract between 400 and 600 million USD, with returns of 12-18% over two to four years.

The study further demonstrated that the country succeeded in strengthening its position in international logistics through active integration into global transport initiatives such as the Belt and Road Initiative and the Trans-Caspian International Transport Route. Digital solutions, including automated cargo monitoring and management systems, accelerated integration into these initiatives, resulting in improved transit quality and speed, and enhanced coordination with participating countries. The study identified several challenges hindering the successful digital transformation of the transport and logistics sector, including insufficient digital infrastructure, low levels of digital literacy, and cybersecurity concerns. These barriers require a comprehensive approach involving the development of infrastructure and the implementation of educational programmes aimed at improving workforce qualifications. It is also essential to develop strategies for ensuring data security, which would enhance trust among international partners and accelerate the development of cross-border cooperation.

Thus, despite the existing challenges, digital transformation within the transport and logistics sector in the country demonstrates considerable potential for enhancing competitiveness and resilience on the international stage. With the continued adoption of innovative technologies and the removal of structural barriers, the country has the opportunity to become a key logistics hub in Central Asia, attracting international investment and generating new business opportunities. A more in-depth understanding of the long-term implications of digital technology adoption is required to evaluate its impact on the sustainability of the ecosystem and its effects on small and medium-sized enterprises.

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Цифрова трансформація в транспортно-логістичному секторі Казахстану: Виклики та можливості для глобальної інтеграції

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Анотація. Мета дослідження полягала у визначенні ключових переваг та викликів цифровізації в транспортно-логістичному секторі Казахстану та оцінці її впливу на економічне зростання та міжнародне співробітництво. У дослідженні використовувались методи аналізу, оцінки та прогнозування для визначення впливу цифрових технологій на різні аспекти транспортно-логістичної системи Казахстану, включаючи продуктивність, інвестиційну привабливість та глобальну інтеграцію. Результати дослідження показали, що цифрова трансформація підвищує ефективність, знижує транзакційні витрати та покращує інвестиційну привабливість сектору. Впровадження цифрових платформ, автоматизація митних процедур та використання штучного інтелекту (ШІ) прискорили обробку вантажів та оптимізували операції. Аналіз показав, що цифровізація сприяє зростанню іноземних інвестицій шляхом підвищення прозорості та передбачуваності транспортних процесів. Очікується, що приватні інвестиції в інфраструктуру досягнуть 500-800 мільйонів доларів США, що принесе 15-20 % прибутковості протягом 3-5 років, тоді як державні субсидії можуть сягнути 200-300 мільйонів доларів США з прибутковістю 10-12 % протягом 1-3 років. За оцінками, міжнародні проекти генеруватимуть 600-900 мільйонів доларів США інвестицій з очікуваною прибутковістю 18-25 % протягом 4-6 років. Очікується, що державно-приватне партнерство складе 400-600 мільйонів доларів США, пропонуючи прибутковість 12-18 % протягом 2-4 років, а інвестиції у стартапи становитимуть 100-200 мільйонів доларів США з прибутковістю 25-35 % протягом 2-3 років. Розвиток цифрових рішень у міжнародних транспортних коридорах посилює роль Казахстану як логістичного центру. Однак, основні проблеми залишились, включаючи неадекватну цифрову інфраструктуру, кіберзагрози, низький рівень цифрової грамотності та фінансові обмеження, з якими стикаються малі та середні підприємства. Ефективна трансформація вимагає тісної державно-приватної співпраці та створення «розумних» логістичних центрів. Таким чином, цифровізація в транспортно-логістичному секторі має значний потенціал для позиціонування країни як провідного логістичного центру в Центральній Азії

Ключові слова: інвестиції; автоматизація; міжнародні коридори; кібербезпека; логістична інфраструктура; глобальна інтеграція

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