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CONTENTS

Ainura Maxyutova, Saule Kaliyeva
Empirical Analysis of the Readiness of Kazakhstan's Labor Resources Transformation to a "Green" Economy **5**

Lena Khuanysh, Zhanar Dauletkhanova, Aliya Yerniyazova
Scenario Analysis of Risks and Opportunities in Kazakhstan's Industrial Transition to Carbon Neutrality **19**

Ankhbileg Khurelbaatar
Capital Market Development as a Driver of Economic Growth: The Case of Mongolia ... **36**

Murat Abutalipov, Marat Kamysbayev, Nazym Zhunusbekova, Dinara Satybaldiyeva
Economic Freedom and Foreign Direct Investment in Central Asia: Short-Run and Long-Run Evidence **56**

Anel A. Kireyeva
Structural Transformation of Higher Education in Kazakhstan: Educational, Economic and Social Dimensions **73**

Lyailya Akhmetova, Yerzhan Domalatov, Alma Baiguzhinova, Igor Dubina, Madina Bazhigaliyeva
Digitalization of Agribusiness and its Impact on Productivity and Sustainability: A Systematic Literature Review **88**

Rab Nawaz Lodhi
Institutional Drivers of Agrohub Development: Evidence from a Transition Economy . **104**

Marzhan U. Daurbaeva, Elmira E. Zhussipova, Asem A. Dossaliyeva, Sultanpatsha S. Ubaeva
Secondary Education Financing in Kazakhstan: Challenges and Efficiency **119**

Nursulu K. Sarkulova, Bakhytzan I. Satenov, Dariga A. Zhoshibayeva
Financial Drivers of Innovation in Kazakhstan's Agriculture: An Econometric Analysis **137**

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ORIGINAL ARTICLE

Empirical Analysis of the Readiness of Kazakhstan's Labor Resources Transformation to a "Green" Economy

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Abstract
In Kazakhstan, the transition to a green economy remains insufficiently empirically researched, despite the availability of strategic documents on innovative development. The aim of the study is to assess the readiness of Kazakhstan's workforce for the transition to a "green" economy based on an analysis of factors affecting the number of people employed in "green" jobs.The methodological base of the study includes correlation analysis and the method of statistical equations of dependencies, which identify the stability of relationships in conditions of multicollinearity of factors and a limited length of time series. The empirical study is based on official statistical data from the Bureau of National Statistics for the period 2020-2024. The results of the correlation analysis showed a high degree of correlation between the dynamics of "green" employment and a number of factors (10 out of 19), including GDP per capita, investment in fixed assets, R&D expenditures, and financing of "green" economy projects. However, the application of the method of statistical equations of dependencies revealed the absence of stable functional relationships between the number of people employed in "green" jobs and most of the analyzed factors. The only variable for which a stable statistical relationship was recorded (stability coefficient $K > 0.7$) was the unemployment rate. The prospects for further research include analyzing institutional mechanisms that shape demand for "green" competencies, expanding the time series of data, and conducting a comparative analysis with practices in EU countries.

KEYWORDS
Economy, Green Economy, Green Job, Labor Market, Labor Resource, Human Capital, Unemployment, Demography

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1 | INTRODUCTION

The global shift toward a green economy has emerged as a central paradigm of contemporary economic development, driven by the growing urgency of climate change, environmental degradation, and resource constraints. This transition extends beyond technological modernization and environmental regulation; it entails big structural changes in production systems, consumption patterns, and, critically, labor markets. As economies reorient toward sustainability goals, the capacity of labor resources to adapt to new requirements becomes a decisive factor shaping the effectiveness and pace of the green transition.

In advanced economies, the transition to a green economy has been accompanied by the systematic formation of green employment as a distinct and increasingly stable segment of the labor market. Countries of the European Union provide a clear example of this process, where environmental objectives are embedded within broader economic and social policies. Regulatory frameworks, targeted investment instruments, labor market policies, and education systems are aligned to support the creation of environmentally oriented jobs and the development of relevant skills. As a result, employment in green sectors in these countries demonstrates predictable and statistically observable relationships with macroeconomic indicators, investment in renewable energy and environmental technologies, innovation activity, and human capital development. Green employment thus functions not as a residual or declarative category, but as an integrated component of economic growth and labor market dynamics. In contrast, the situation in economies undergoing structural transformation requires a more cautious and empirically grounded assessment. In the Republic of Kazakhstan, the transition to a green economy is articulated in a range of strategic documents addressing sustainable development, environmental modernization, and decarbonization. These policy frameworks outline ambitious targets related to energy efficiency, renewable energy, and environmental protection. However, the structural characteristics of the national economy - most notably its resource-oriented model, significant role of the state, and limited diversification - raise questions about the extent to which these strategic objectives are reflected in actual labor market transformations.

In this context, employment in green jobs is a particularly informative indicator of labor resource transformation. Unlike investment volumes or policy commitments, employment outcomes capture the realized interaction between economic demand, institutional conditions, and workforce capabilities. Analyzing the number of individuals employed in green jobs allows for an assessment of whether the green transition in Kazakhstan is generating tangible labor market effects or remains largely confined to the level of strategic intentions.

Despite the expanding body of international research on green employment, empirical evidence for Kazakhstan remains fragmented. Existing studies often proceed from the assumption that the drivers of green employment observed in developed economies - such as environmental investment, innovation intensity, education levels, and overall economic growth - are universally applicable. However, such assumptions may not hold in transitional economies, where market mechanisms are intertwined with administrative regulation and policy-driven resource allocation. This necessitates empirical verification rather than theoretical extrapolation. The present study aims to contribute to this gap by examining the readiness of Kazakhstan's labor resources for the transition to a green economy through an analysis of the factors influencing employment in green jobs. Using official statistical data, the study investigates the relationship between the number of people employed in green jobs and a broad set of socio-economic, investment, innovation, and educational indicators. The central research hypothesis posits that, under current conditions, growth in green employment in Kazakhstan is not consistently and significantly dependent on these

factors and is shaped predominantly by institutional and political decisions rather than by market-based drivers.

The scientific contribution of this research lies in its methodological and conceptual approach. Rather than treating the absence of stable dependencies as a limitation, the study interprets it as a meaningful empirical result that reflects the actual state of labor market transformation. By demonstrating that parallel movements of indicators do not necessarily imply causal linkages, the research challenges conventional expectations regarding green employment dynamics. The findings suggest that the development of green jobs in Kazakhstan remains largely adaptive and policy-driven, highlighting a gap between strategic declarations and structural labor-market change. This underscores the need to transition from declarative environmental objectives to coherent policies that stimulate genuine demand for green competencies and sustainable employment. Thus, the study aims to assess the readiness of Kazakhstan's workforce for the transition to a "green" economy based on an analysis of factors affecting the number of people employed in "green" jobs.

2 | LITERATURE REVIEW

The transition to a green economy and its implications for labor markets have become central themes in contemporary economic research, driven by the global climate agenda, the energy transition, and the restructuring of production systems. In the international literature, this process is predominantly examined through the lens of employment restructuring, the creation of green jobs, shifts in skill requirements, and the role of public policy in facilitating labor market adaptation to new development trajectories.

A substantial body of empirical research focuses on the employment effects of environmental regulation and energy transition. Early studies primarily emphasized the potential costs of environmental policies, including job losses and higher production costs (Berman & Bui, 2001; Bezdek et al., 2008). More recent contributions, however, increasingly highlight compensatory mechanisms through job creation in environmentally oriented sectors, suggesting that the net employment effect of environmental regulation depends critically on institutional conditions, sectoral structure, and the degree of economic diversification (Barra & Ruggiero, 2019). Within this strand of literature, renewable energy development is widely identified as a key driver of green job creation. Empirical evidence from Germany, the Netherlands, and other OECD countries demonstrates that employment growth in renewable energy industries is closely linked to consistent government support, long-term investment strategies, and well-functioning labor market institutions (Lehr et al., 2008; Bulavskaya & Reynès, 2018; Destek et al., 2020). At the same time, these studies emphasize that the employment effects of green technologies are not automatic and depend on the economy's capacity to reallocate labor across sectors.

Research focusing on European Union countries further reveals relatively stable relationships between green employment, sustainable development indicators, and innovation dynamics. Swain et al. (2022) showed that green job growth in the EU is particularly pronounced in regions with advanced innovation systems, strong educational infrastructure, and supportive institutional environments. Using micro-level data, Bluedorn et al. (2023) provided additional evidence that the green transition reshapes labor demand and generates new skill requirements, reinforcing the structural nature of employment changes in advanced economies.

A growing literature also addresses the skill-biased effects of the green transition. Empirical findings suggest that environmental policies and energy transformation tend to increase demand for highly skilled labor, while simultaneously raising adjustment risks for

low-skilled workers (Briggs et al., 2022; Černý et al., 2024; Javed & Usman, 2025). Consequently, the green transition is increasingly framed not only as an environmental challenge, but also as a socio-economic one, requiring targeted education and retraining policies.

Another important stream of research examines the role of environmental innovation and green technologies. Firm-level studies indicate that innovation activity can mitigate the potentially negative employment effects of environmental regulation and contribute to job creation (Cainelli et al., 2011; Huang et al., 2023). However, the positive labor market impact of innovation appears to be significantly stronger in countries with mature institutional frameworks and well-developed mechanisms for supporting technological change.

In contrast, empirical evidence for developing and transition economies remains relatively limited. Studies focusing on China and other economies with a strong state role reveal heterogeneous and often indirect employment effects of environmental policies, largely shaped by institutional reforms and governance models (Li & Li, 2024; Liu et al., 2023). Similar conclusions are drawn in analyses of resource-oriented economies, where green transformation is frequently constrained by structural rigidities and institutional bottlenecks (Côté, 2018; Osorio-Aravena et al., 2025).

Overall, existing research suggests that in economies with well-developed institutions and coherent green policies, green employment tends to exhibit stable statistical relationships with investment, innovation, and educational indicators (Ram et al., 2020; Ma & Wang, 2025). By contrast, in economies at an early stage of green transformation, such relationships are often weak, unstable, or entirely absent.

Despite the growing literature, an important methodological gap persists regarding countries in which the green economy has been institutionally declared but has not yet been embedded in labor market structures. In particular, limited attention has been paid to whether the absence of stable statistical relationships between green employment and commonly cited determinants may itself constitute a meaningful empirical finding, reflecting the immaturity and fragmentation of transformation processes. This gap motivates the present study and informs its methodological approach. To capture both the presence and absence of stable relationships under conditions of limited data availability and high interdependence among factors, the study employs correlation analysis and the statistical dependency equation method, as discussed in the following section.

3 | RESEARCH METHODS

The objective of this study is to examine the readiness of labor resources for transformation during the transition to a green economy. Given the early stage of green labor market formation in the Republic of Kazakhstan and the limited availability of long and consistent statistical time series on green employment, the research design prioritizes methodological robustness and interpretability over the mechanical application of standard econometric techniques. Accordingly, a stepwise empirical strategy is employed, combining exploratory correlation analysis with the method of statistical dependency equations. This combination enables an initial diagnostic assessment of co-movements among variables, followed by a more structured evaluation of the stability and direction of pairwise dependencies under conditions of multicollinearity and institutional regulation.

The empirical analysis relies exclusively on official statistical data obtained from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan. The use of a single official data source ensures methodological consistency, comparability of indicators, and uniform data-collection procedures throughout the observation period.

The dependent (result) variable is defined as the number of persons employed in "green jobs". This indicator is selected because it reflects the actual scale of environmentally oriented employment and captures labor market outcomes rather than declarative policy intentions. As such, it serves as a quantitative proxy for the extent of labor resource transformation within the green economy framework.

Independent variables were selected from several conceptual blocks, including macroeconomic development, investment activity, innovation performance, education and human capital, environmental expenditures, and labor market conditions. The selection of indicators was guided by theoretical considerations from labor economics and the green growth literature, as well as by practical constraints on statistical availability. In total, nineteen explanatory variables were included in the initial analytical set. In the first stage of the empirical analysis, pairwise correlation coefficients were calculated to assess the direction and strength of the co-movements between green employment and the selected independent variables. The purpose of this stage was not to establish causal relationships, but to conduct an exploratory diagnostic assessment of whether changes in green employment evolve alongside changes in key socio-economic, investment, and innovation indicators.

Correlation analysis is interpreted in this study strictly as a descriptive tool. The presence of moderate or relatively high correlation coefficients is not considered sufficient evidence of structural or causal dependence. In institutionally regulated processes - such as the transition to a green economy - parallel movements of indicators may reflect common policy impulses, macroeconomic conditions, or external shocks rather than direct functional relationships.

The results of the correlation analysis indicate that most factors exhibit moderate correlations with green employment. However, these findings also demonstrate that similarity in temporal dynamics does not necessarily imply a stable linkage between explanatory variables and the expansion of green jobs. This limitation motivated the application of a more appropriate analytical method at the next stage of the study.

Classical regression analysis was not employed as the primary analytical tool for several methodological reasons. First, a high degree of multicollinearity was identified among many explanatory variables, particularly those related to investment, innovation, and macroeconomic performance. Such interdependencies undermine the stability and interpretability of regression coefficients. It should be noted that according to econometric theory, multicollinearity of factors occurs when the correlation between two independent variables is higher than the correlation of each independent factor with the dependent (result) variable.

Second, the time span of available data for several indicators relevant to the green economy remains relatively short, which significantly constrains the reliability of multivariate econometric estimations. Third, the process under investigation is largely shaped by institutional and policy-driven mechanisms, including state programs, regulatory decisions, and targeted financing instruments. These influences are not adequately captured through conventional regression-based models and may lead to distorted inference. Given these constraints, the method of statistical equations of dependencies was adopted as the principal analytical tool. This method is particularly suitable for analyzing socio-economic transformation processes under conditions of limited data availability and strong interdependence among explanatory variables (Kaliyeva et al., 2025).

The method focuses on analyzing paired dependencies between the dependent variable and individual independent variables without imposing rigid assumptions about functional form. It minimizes distortions caused by multicollinearity and enables the identification of directional and structural features of transformation processes. In this study, linear

dependency equations were constructed according to formulas (1) and (2), which are applied depending on whether the relationship between the independent variable and green employment is assumed to be increasing or decreasing:

$$y_x = y_{\min}\left(1 + b \cdot d_{(x_i/x_{\min}-1)}\right) \tag{1}$$

$$y_x = y_{\min}\left(1 + b \cdot d_{(1-x_i/x_{\max})}\right) \tag{2}$$

where:
y_x – result variable;
$y_{\min}$ – minimum value of the result variable;
b – ratio of the sum of deviations from the unit of the calculated coefficients of comparison of the result and independent factors;
d_{x_i} – comparison coefficient of the independent factor as a whole;
$d_{x(\min)}$ – comparison coefficient to the minimum value of the independent factor;
$d_{x(\max)}$ – comparison coefficient to the maximum value of the independent factor.

To verify the adequacy of the estimated dependency equations, additional calculations were conducted to evaluate the strength and stability of the relationships between the dependent (result) variable and each explanatory (independent) factor considered separately. The stability assessment focused on those variables for which the pairwise correlation coefficient exceeded the threshold value of 0.7.

For these factors, stable dependence coefficients were calculated and required to meet a minimum threshold of 0.7. The concurrence of high correlation and stable dependence coefficients was interpreted as evidence that the estimated equations capture persistent relationships rather than coincidental co-movements. This verification procedure provides additional support for the methodological validity and internal consistency of the analytical results.

4 | RESULTS

This section presents the study's empirical findings, focusing on a quantitative assessment of the extent to which Kazakhstan's labor force is prepared for structural adjustment during the transition to a green economy. The dependent (result) variable (Y) is defined as the number of individuals employed in "green jobs", interpreted as an integrated measure reflecting the degree of labor market participation in environmentally oriented and technologically sustainable economic activities. This indicator allows for an assessment of the actual involvement of labor resources in the emerging green segment of the economy.

In order to identify potential determinants of changes in green employment, a system of nineteen explanatory variables was constructed, encompassing socio-economic conditions, investment activity, environmental expenditures, innovation dynamics, and educational characteristics. All statistical indicators were sourced from the Bureau of National Statistics of the Republic of Kazakhstan, which guarantees uniformity in data collection methods and ensures temporal and methodological comparability across variables. The independent factors considered in the present research are given in Table 1.

The selection of explanatory (independent) factors was grounded in established theoretical frameworks in labor economics and green growth, as well as in empirical evidence from the international research literature. Particular attention was given to factors commonly identified as drivers of green job creation in developed economies, thereby enabling a structured evaluation of their relevance within Kazakhstan's institutional and economic

Table 1 Independent variables used in the empirical analysis

No.	Variable	Indicator	Unit
1	X1	GDP per capita	tenge
2	X2	Investment in fixed capital	tenge
3	X3	Unemployment rate	%
4	X4	Gross enrollment ratio in higher education	%
5	X5	Gross enrollment ratio in secondary education	%
6	X6	Graduates in environmental specialties	persons
7	X7	Domestic R&D expenditure	tenge
8	X9	Enterprises with environmental innovations	units
9	X10	Share of environmental innovations	%
10	X11	Non-energy resource productivity	international dollars
11	X12	Number of licenses issued in the field of environmental protection	units
12	X13	Number of patents issued	units
14	X14	Volume of greenhouse gas emissions trading transactions	tons of CO_2
15	X15	Profitability (loss) of water supply and sanitation enterprises	%
16	X16	Official development assistance	thousand tenge
17	X17	Environmental taxes	thousand tenge
18	X18	Investments aimed at environmental protection	thousand tenge
19	X19	Amount of funds allocated to finance scientific and scientific-technical projects on the “green economy”	thousand tenge

Note: compiled by the authors.

context. In the first stage of the study, correlation analysis was applied to examine the direction and magnitude of the association between the dependent (result) variable and the selected explanatory factors (independent factors). Given the limited length of the time series, correlation analysis is used exclusively as a diagnostic tool rather than as evidence of causal relationships. The results of the correlation analysis, summarized in Table 2, indicate that 10 of the 19 variables analyzed exhibit high correlations with the result indicator, with correlation coefficients exceeding the threshold of 0.7.

Table 2 Correlation matrix of green employment and explanatory variables

	Y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19
Y	1																			
X1	0,79	1																		
X2	0,82	1	1																	
X3	−0,96	−0,88	−0,91	1																
X4	−0,94	−0,84	−0,86	0,88	1															
X5	0,10	0,32	0,33	−0,36	0,10	1														
X6	0,78	0,97	0,97	−0,92	−0,75	0,54	1													
X7	0,63	0,83	0,81	−0,61	−0,84	−0,23	0,66	1												
X8	0,87	0,72	0,77	−0,94	−0,69	0,57	0,84	0,31	1											
X9	0,65	0,97	0,95	−0,74	−0,78	0,18	0,88	0,91	0,52	1										
X10	−0,99	−0,69	−0,73	0,92	0,91	−0,06	−0,69	−0,54	−0,85	−0,54	1									
X11	0,79	0,99	0,99	−0,91	−0,80	0,44	0,99	0,75	0,79	0,93	−0,70	1								
X12	−0,13	−0,15	−0,18	0,34	−0,15	−0,95	−0,40	0,42	−0,61	0,04	0,13	−0,29	1							
X13	−0,21	−0,01	0,00	−0,04	0,43	0,94	0,22	−0,52	0,31	−0,13	0,23	0,12	−0,93	1						
X14	0,93	0,53	0,57	−0,79	−0,87	−0,17	0,50	0,49	0,71	0,19	−0,97	0,51	0,05	−0,42	1					
X15	−0,18	−0,72	−0,69	0,43	0,24	−0,64	−0,75	−0,47	−0,36	−0,76	0,05	−0,75	0,38	−0,46	0,19	1				
X16	0,54	0,07	0,09	−0,28	−0,59	−0,72	−0,06	0,35	0,14	0,03	−0,62	−0,01	0,56	−0,82	0,79	0,63				
X17	0,62	0,87	0,85	−0,63	−0,82	−0,14	0,71	1	0,34	0,95	−0,52	0,79	0,35	−0,44	0,45	−0,55	0,26	1		
X18	0,45	−0,15	−0,11	−0,19	−0,39	−0,57	−0,20	0,01	0,18	−0,26	−0,57	−0,18	0,32	−0,60	0,75	0,79	0,93	−0,07	1	
X19	0,93	0,92	0,94	−1	−0,86	0,41	0,95	0,63	0,93	0,79	−0,88	0,94	−0,36	0,09	0,73	−0,52	0,19	0,66	0,10	1

Values $|r| \geq 0.7$ indicate high correlation

Note: compiled by the authors.

The group of highly correlated factors comprises indicators reflecting public and private environmental expenditures, investment activity, innovation intensity, macroeconomic development, and labor market conditions. The strongest correlations with green employment were observed for GDP per capita, investment in fixed capital, the unemployment

rate, the gross enrollment ratio in higher education, domestic R&D expenditure, the number of graduates in environmental specialties, the share of environmental innovations in total innovation activity, non-energy natural resource productivity, the volume of greenhouse gas emissions trading transactions, and the amount of public funding allocated to scientific and scientific-technical projects in the field of the green economy. The strong correlations among these indicators suggest that their dynamics parallel changes in the number of people employed in green jobs. This finding does not imply a causal relationship. However, it provides a basis for reducing the initial set of explanatory variables and selecting factors for subsequent analysis using statistical dependency equations.

However, the identification of a strong correlation does not imply a causal relationship, particularly given the limited length of the time series and the high interdependence among the factors. In this regard, the next stage of the study involved using statistical dependence equations to assess the stability of the relationship between the outcome and the influencing factors, without constructing multidimensional regression models that are sensitive to multicollinearity.

Calculations performed using statistical equations for 10 selected factors revealed that the vast majority do not form a stable, statistically significant relationship with the number of people employed in "green jobs". Despite high correlation coefficients, the resulting equations did not support the existence of a stable functional relationship between the dependent variable and independent variables such as environmental investment volume, R&D expenditures, enterprises' innovative activity, the share of environmentally friendly products, human capital indicators, and macroeconomic development.

The only factor for which a stable statistical dependence was identified (stable dependence coefficient (K) > 0.7) was the unemployment rate, with the relationship being inverse: an increase in unemployment is accompanied by a decrease in the number of people employed in "green jobs." This result indicates that employment in the green economy in Kazakhstan does not currently serve a compensatory function in the labor market and does not drive labor redistribution amid a deteriorating overall economic situation.

For clarity, Table 3 presents calculations of the parameters and stability of the relationship between the number of people employed in "green jobs" (Y) and the unemployment rate (X3).

Table 3 Results of the statistical dependency analysis between green employment and the unemployment rate

Year	Y	X3	d_y	d_x	bd_x	Estimated Y*	$d_x \cdot d_y$	d_x^2	d_y^2	$\frac{d_y - bd_x}{bd_x}$
2020	48453	4.9	0.00807	0	0	48065	0	0	0.00006	0.00807
2021	48065	4.9	0	0	0	48065	0	0	0	0
2022	48895	4.9	0.01726	0	0	48065	0	0	0.00029	0.01726
2023	57135	4.7	0.18870	0.04081	0.17070	56270	0.00770	0.00167	0.03560	0.01799
2024	54187	4.7	0.12736	0.04081	0.17070	56270	0.00519	0.00167	0.01622	0.04333
$b =$	4,1823052	r	0,00017	0,97826		K		0,746130408		

Note: compiled by the authors.

The results indicate a stable inverse relationship between the unemployment rate and the number of people employed in green jobs, confirming the importance of this factor in statistical analyses of dependencies. Calculations show that, with a decrease in the unemployment rate from 4.9% in 2020-2022 to 4.7% in 2023-2024, employment in green jobs increased from 48,065 to 57,135, as reflected by positive relative deviations of the

effective indicator.

Similar calculations were performed with other factors, for which the coefficient of stable dependence ranged from 0.29 to 0.67. For example, Table 4 presents the parameter estimates and the stability of the dependence of the number of people employed in "green jobs" (Y) on Investments in fixed assets (X2).

Table 4 Results of the statistical dependency analysis between green employment and the investments in fixed assets

Year	Y	X2	d_y	d_x	bd_x	Estimated Y*	$d_x \cdot d_y$	d_x^2	d_y^2	$\frac{d_y - bd_x}{bd_x}$
2020	48453	12270.1	0.00807	0	0	48065	0	0	6.51637	0.00807
2021	48065	13242.2	0	0.79225	0.02008	49030.42	0	0.00627	0	0.02008
2022	48895	15251.1	0.01726	0.24294	0.06159	51025.53	0.00419	0.05902	0.00029	0.04432
2023	57135	17649.3	0.18870	0.43839	0.11114	53407.25	0.08272	0.19219	0.03560	0.07755
2024	54187	19461.3	0.12736	0.58607	0.14858	55206.80	0.07464	0.34348	0.01622	0.02121
$b =$	0.2535278	r	0.03137	0.91225		K		0,498385162		

Note: compiled by the authors.

The results indicate that the calculated stability coefficient between green employment and investments in fixed assets equals 0.49, which remains below the threshold value adopted in this study for identifying stable dependencies. This finding implies that the observed high correlation does not translate into a structurally stable relationship. In other words, although green employment and fixed-asset investment exhibit parallel trends over time, statistical dependency analysis indicates that changes in investment levels cannot be interpreted as a consistent or reliable driver of green employment growth.

From a methodological perspective, this result reinforces the distinction between correlation-based evidence and stability-based dependency analysis. Particularly in institutionally driven transformation processes such as the transition toward a green economy, high correlation may reflect common macroeconomic or policy-related influences rather than direct functional dependence between variables.

Table 5 presents calculations in which the coefficient of stable dependence between the number of people employed in "green jobs" (Y) and the amount of funds allocated to finance scientific and scientific-technical projects on the "green economy" within the framework of grant- and program-targeted financing (X19) was 0.67.

It should be noted that this value does not meet the threshold for stable dependence but is very close to it, which helps interpret the identified relationship as emerging or quasi-stable. The presence of a borderline stability coefficient indicates the potential impact of scientific and technical funding on the formation of "green" employment, which, at the current stage, is not yet systematic but shows a tendency to strengthen.

Since a high stability coefficient for the number of people employed in green jobs was identified only with respect to the unemployment rate, further analysis was limited to this factor. The estimated stability coefficient exceeded the threshold value (K = 0.746 > 0.7), indicating a stable inverse relationship between green employment and the unemployment rate. The strength of this relationship is supported by a high correlation coefficient (r = 0.978). At the same time, the estimated sensitivity parameter (b = 4.18) suggests a pronounced response of green employment to changes in labor market conditions.

The absence of stable dependencies between the number of people employed in "green jobs" and most of the factors analyzed indicates that the process of transforming labor resources as part of the transition to a "green" economy is incomplete and fragmented.

Table 5 Results of the statistical dependency analysis between green employment and the amount of funds allocated to finance scientific and scientific-technical projects on the "green economy"

Year	Y	X19	d_y	d_x	bd_x	Estimated Y*	$d_x \cdot d_y$	d_x^2	d_y^2	$\frac{d_y - bd_x}{bd_x}$
2020	48453	163998.4	0.00807	0	0	48065	0	0	6.51637	0.00807
2021	48065	175215.8	0	0.06839	0.00124	48124.8302	0	0.00467	0	0.00124
2022	48895	221931.8	0.01726	0.35325	0.00642	48373.9993	0.00610	0.12478	0.00029	0.01083
2023	57135	1566782.9	0.18870	8.55364	0.15566	55547.0295	1.61409	73.1648	0.03560	0.03303
2024	54187	1768727.5	0.12736	9.78502	0.17807	56624.1412	1.24631	95.7467	0.01622	0.0507
$b =$	0.018198	r	8.82310	0.96503		K		0,67567687		

Note: compiled by the authors.

The coincidence of trends across multiple indicators is more likely to reflect economic or programmatic factors. It does not reflect the formation of stable demand mechanisms for green labor.

The results obtained indicate that, in Kazakhstan, the development of employment in the green economy is largely determined by institutional and political decisions rather than by market, investment, or innovation factors. Unlike in developed countries, where green jobs are created through systematic government policy, regulatory measures, and targeted incentives to stimulate demand for environmental skills, this process is not yet structural in Kazakhstan. Thus, the absence of stable statistical dependencies should be viewed not as a limitation of the study but as empirical confirmation of the labor market's insufficient readiness for the green transition, thereby justifying a review of public policy approaches to employment and human capital development.

5 | DISCUSSION

The results obtained in the course of the study confirm the hypothesis that, in the Republic of Kazakhstan, employment in the green economy does not exhibit a stable dependence on socio-economic, investment, innovation, and educational factors. Despite high correlations between the performance indicator and several factors, the application of the statistical equation method revealed the absence of stable functional relationships across virtually all areas of analysis. The only exception was the unemployment rate, which showed a stable inverse dependence.

This result fundamentally distinguishes the situation in Kazakhstan from that in developed countries, such as those in the European Union, where employment in the green economy is shaped by targeted government policy and integrated into the overall labor market architecture. In EU countries, the number of people employed in environmentally oriented sectors shows a stable dependence on the volume of green investments, expenditure on research and development, the development of renewable energy, the level of environmental innovation, and institutional support for green skills. Thus, European economies are seeing a clear translation of public policy into real changes in the structure of employment.

In Kazakhstan, however, the correlation between individual indicators and the number of people employed in "green jobs" is mainly macroeconomic in nature and does not reflect the formation of sustainable demand for environmentally oriented labor. The absence of stable dependencies indicates that "green" employment is not yet an independent segment of the labor market, but is developing in a fragmented manner, within the framework of

individual programs and projects that do not have a systemic effect.

Particularly significant is the inverse dependence between the level of unemployment and the number of people employed in "green jobs." In EU countries, the development of a "green" economy is often regarded as a means of mitigating the effects of structural unemployment associated with decarbonization and digital transformation. In contrast, in Kazakhstan, rising unemployment is accompanied by a decline in employment in green sectors, indicating their vulnerability and dependence on the overall state of the economy. This suggests that the green economy does not yet play a stabilizing role in the labor market and cannot compensate for negative employment shocks. A comparative analysis suggests that the key factor distinguishing Kazakhstan from EU countries is the institutional component. In European countries, the development of green jobs is based on strict environmental regulations, a system of financial incentives, green competency standards, and active policies in the field of education and retraining. In Kazakhstan, however, the transition to a green economy is largely programmatic and declarative in nature. It has not yet been accompanied by a transformation of the mechanisms that shape labor demand.

Thus, the study's results confirm the hypothesis that, in Kazakhstan, the transformation of labor resources during the transition to a green economy is primarily driven by political and institutional decisions rather than by market or economic factors. The absence of stable statistical dependencies between the number of people employed in "green jobs" and most of the indicators analyzed (independent variables) should be interpreted as an indicator of the immaturity of the relevant labor market segment. The conclusions underscore the need to borrow and adapt the experience of EU countries, in which green employment is the result of comprehensive policies rather than a byproduct of economic growth. Without the creation of institutional conditions that ensure long-term demand for green jobs, quantitative growth in employment in environmentally oriented sectors in Kazakhstan will remain unstable and weakly linked to key economic development indicators.

6 | CONCLUSION

The shift toward a green economy is increasingly recognized as a structural trajectory of long-term socio-economic development, with implications that extend well beyond technological change and energy systems to encompass the organization and functioning of labor markets. Against this background, the present study set out to examine the extent to which the Republic of Kazakhstan's labor resources are positioned to adapt to this transition and whether the foundations for sustainable green employment are already emerging within the national economy.

The empirical results demonstrate that, despite the formal advancement of environmental priorities at the strategic and policy levels, measurable changes in employment in environmentally oriented sectors remain weakly linked to most socioeconomic, investment, and innovation indicators. The analysis incorporated a broad spectrum of factors characterizing labor market conditions, economic performance, capital formation, research and development activity, and environmental expenditures. Nevertheless, the findings indicate that these variables do not yet translate into stable statistical relationships with the number of workers employed in green jobs.

A persistent and statistically meaningful association was identified only with the unemployment rate. This outcome suggests that the observed expansion of green employment in Kazakhstan is currently driven primarily by general labor-market adjustment processes rather than by a structurally embedded green-growth model. In this context, green jobs appear to function as an adaptive employment segment absorbing labor during periods of

macroeconomic adjustment, rather than as an autonomous engine of workforce transformation grounded in environmental innovation and long-term investment.

Importantly, the absence of stable dependencies between green employment and most explanatory factors should not be interpreted as a methodological shortcoming. On the contrary, this result constitutes a substantive empirical finding, reflecting the early and fragmented nature of labor market transformation in the green economy. In contrast to European Union countries, where green employment dynamics are underpinned by coherent regulatory frameworks, sustained public investment, and the systematic incorporation of green competencies into education and training systems, Kazakhstan's transition remains largely uncoordinated.

Comparative insights drawn from European experience reveal a pronounced gap between the declared objectives of green development and the practical mechanisms that generate demand for green labor. Limited alignment between environmental investment and employment outcomes, insufficient incentives for private-sector participation, and weak integration of green skills into human capital development constrain the development of a stable green labor market.

Overall, the findings support the research hypothesis that, under current conditions, the transformation of labor resources in Kazakhstan is shaped less by market-driven economic and innovation factors than by the scope, consistency, and orientation of public policy. The establishment of a sustainable green employment framework requires a shift from fragmented initiatives toward a comprehensive institutional strategy aimed at long-term restructuring of employment patterns and skill formation. These conclusions contribute to the broader understanding of green labor market development in economies in the early stages of environmental transition and underscore the importance of further research into the institutional and policy determinants of green employment.

AUTHOR CONTRIBUTION

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CONFLICT OF INTEREST

No conflict of interest/competing interest is reported by the authors.

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ORIGINAL ARTICLE

Scenario Analysis of Risks and Opportunities in Kazakhstan's Industrial Transition to Carbon Neutrality

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Abstract
The transition to carbon neutrality represents a strategic imperative for large industrial companies in Kazakhstan in the context of global climate challenges and increasingly stringent environmental requirements. The purpose of this study is to develop an integrated risk and opportunity management framework for industrial decarbonization in Kazakhstan based on scenario modelling and expert assessment. The study uses a mixed methodological approach combining quantitative and qualitative methods of analysis. The empirical basis of the study was made up of sectoral data on greenhouse gas emissions in Kazakhstan's industry for 2015-2024, official statistics from government agencies, corporate non-financial reports, as well as the results of 32 semi-structured expert interviews with representatives of industrial companies, government regulators and international organizations. The results of the study show that Kazakhstan's industrial CO_2 emissions increased 18.1% from 224.7 million tonnes (2015) to 265.4 million tons (2024), with metallurgy accounting for 35.9%, energy 28.1%, oil and gas 22.8%, and chemicals 13.4%. Scenario analysis shows that under the business-as-usual scenario, emissions could increase to 322.5 million tons of CO_2 by 2050, while the moderate scenario reduces emissions to 102.3 million tons (55% compared to 2024), and the ambitious scenario to 35 million tons (-84%). This research extends sustainability theory by demonstrating how to transition economy characteristics-legacy infrastructure, resource dependence, institutional capacity-shape decarbonization pathways, providing actionable insights for climate policy formulation and corporate strategy in resource-rich developing nations.

KEYWORDS
Economy, Transition Economy, Carbon Neutrality, Decarbonization, Green Transformation, Climate Strategy, Energy Transition, Sustainable Development

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1 | INTRODUCTION

In the context of the global climate crisis and strengthening international commitments to reduce greenhouse gas emissions, the transition to carbon neutrality is becoming a central element of strategic development for industrial companies worldwide (Fankhauser et al., 2022). The Republic of Kazakhstan, as a country with an economy heavily dependent on carbon-intensive industries-metallurgy, energy, the oil and gas sector, and the chemical industry-faces particular challenges in the decarbonization process (Karatayev & Clarke, 2016).

Kazakhstan's adoption of commitments to achieve carbon neutrality by 2060 and ratification of the Paris Agreement have created a new paradigm for domestic industrial companies (President of the Republic of Kazakhstan, 2023). According to the updated Nationally Determined Contribution (NDC), Kazakhstan plans to reduce greenhouse gas emissions by 15% by 2030 compared to 1990 levels (Republic of Kazakhstan, 2023). This requires large-scale transformation of the industrial sector, which accounts for more than 60% of the country's total CO_2 emissions (Ministry of Ecology of the RK, 2024).

Large industrial companies in Kazakhstan face the need to simultaneously address several challenges: maintaining competitiveness in international markets amid the introduction of cross-border carbon regulation (hereinafter – CBAM), modernizing outdated production facilities, attracting investment in green technologies, and developing human capital to manage low-carbon processes (Montalvo et al., 2018).

The process of industrial decarbonization is characterized by high uncertainty and a range of risks, including technological, financial, regulatory, market, and social (Bataille et al., 2018). At the same time, it creates significant opportunities for innovation, efficiency improvements, access to new capital markets, and the strengthening of companies' reputations as responsible corporate citizens (Kiehbadroudinezhad et al., 2023; Kobashi et al., 2025).

Despite growing attention to carbon neutrality issues in the scientific literature, research specifically focusing on risk and opportunity management in the context of transition economies and carbon-intensive industries remains limited (Lioubimtseva & Henebry, 2009). Existing work predominantly focuses either on the technical aspects of decarbonization or on the macroeconomic consequences of climate policy, paying insufficient attention to the micro-level of decision-making in the corporate sector.

This study addresses this research gap through three distinct contributions. First, methodologically, we integrate LEAP-based quantitative scenario modelling with qualitative expert insights and SWOT-risk matrix analysis, thereby providing reproducible computational procedures that are lacking in prior conceptual studies. Second, empirically, we present the first comprehensive assessment of sectoral-level (metallurgy, energy, oil and gas, chemicals) decarbonization pathways in Kazakhstan with explicit quantification of investment requirements ($140-450 billion range), technological trajectories, and socio-economic trade-offs across multiple 2050 scenarios. Third, transition management theory demonstrates that legacy infrastructure lock-in, resource dependence, and institutional capacity constraints in resource-rich transition economies necessitate distinct decarbonization strategies relative to those of developed nations, thereby informing actionable frameworks for climate policy formulation in similar contexts (Azerbaijan, Mongolia, Uzbekistan). The purpose of this study is to develop an integrated risk and opportunity management framework for industrial decarbonization in Kazakhstan based on scenario modelling and expert assessment. To achieve this objective, the study addresses the following tasks:

(1) systematization of theoretical approaches to risk and opportunity management in

the context of sustainable development and decarbonization;

(2) identification and assessment of key risks and opportunities of the transition to carbon neutrality for various sectors of the Kazakh industry;

(3) analysis of the current state and dynamics of greenhouse gas emissions in the industrial sector of the Republic of Kazakhstan;

(4) development of decarbonization scenarios and assessment of their socio-economic consequences;

(5) formulation of recommendations for risk management and opportunity realization for industrial companies and government authorities.

2 | LITERATURE REVIEW

The concept of carbon neutrality is based on the need to balance anthropogenic greenhouse gas emissions with their absorption to limit global warming, in accordance with the goals of the Paris Agreement (IPCC, 2018). Industrial decarbonization is the systematic reduction of the carbon intensity of production processes through the introduction of low-carbon technologies, improved energy efficiency, a transition to renewable energy sources, and the application of carbon capture and storage technologies (Rogelj et al., 2018).

Several theoretical approaches to analyzing decarbonization processes have emerged in the scientific literature. Ecological modernization theory views the transition to a low-carbon economy as an opportunity for innovation and enhanced competitiveness (Vakulchuk & Overland, 2021). The concept of carbon lock-in emphasizes the role of technological, institutional, and behavioral barriers that impede rapid transition to sustainable practices (Unruh, 2000; Seto et al., 2016). Transition theory focuses attention on the multilevel nature of socio-technical systems transformation (Geels, 2011; Köhler et al., 2019). The concept of a just transition plays an important role in understanding decarbonization processes, emphasizing the need to account for the social consequences of climate policy and to ensure the protection of workers and communities dependent on carbon-intensive industries (McCauley & Heffron, 2018; Stevis & Felli, 2020). For transition economies such as Kazakhstan, this aspect is particularly significant given the high dependence of the national economy on the extraction and export of carbon resources (Overland & Sovacool, 2020).

The literature on corporate climate risk management identifies several categories of risks associated with the transition to a low-carbon economy. Physical risks arise from the direct impacts of climate change on companies' operational activities (Kahn et al., 2021). Transition risks are associated with the process of adapting to a low-carbon economy and encompass political and regulatory risks, technological risks, market risks, and reputational risks (Sansyzbayev et al., 2025). Regulatory risks for industrial companies include the introduction of carbon pricing, tightening of environmental standards, and reporting requirements (Aldy & Stavins, 2012). The EU's CBAM is particularly relevant for export-oriented companies, as it may significantly affect the competitiveness of products from countries with high carbon-intensity production (Mehling et al., 2019; Cosbey et al., 2019). Technological risks are associated with the need for large-scale investments in production modernization amid high uncertainty regarding technological trajectories and commercial viability of low-carbon solutions (Aubakirova et al., 2023). For heavy industry, such as metallurgy and cement production, technological challenges are particularly significant due to the complexity of decarbonizing high-temperature processes (Bataille et al., 2018).

Financial risks include stranded assets, increased cost of capital for companies with high carbon footprints, and potential losses from delayed transition. Research shows

that investors are increasingly incorporating climate risks into their investment decisions, as reflected in the growth of ESG investing (Dimson et al., 2020). Simultaneously, the transition to carbon neutrality creates significant opportunities for companies. Investments in energy efficiency can substantially reduce operating costs, with relatively short payback periods (Wang et al., 2022). Development and implementation of low-carbon technologies open new markets and create competitive advantages (Ambec et al., 2013). Access to green financing, including green bonds, concessional loans, and grants, is becoming an important source of capital for decarbonization projects (Flammer, 2021; Fatica & Panzica, 2021). Improved environmental image and ESG performance contribute to attracting investment, increasing customer loyalty, and strengthening positions in markets with high environmental requirements (Friede et al., 2015; Fatemi et al., 2018).

Analysis of international experience shows a diversity of approaches to industrial decarbonization. The European Union implements a comprehensive climate policy, including the Emissions Trading System (EU ETS), promotion of innovation through research and development programs, and support for the circular economy (Pahle et al., 2018). Germany provides a successful example of energy-sector transformation (Energiewende), with the large-scale development of renewable energy sources (Amini et al., 2015). China, as the largest emitter of greenhouse gases, is actively investing in low-carbon technologies and clean energy development, while simultaneously facing challenges associated with the structural transformation of its carbon-intensive economy (Zhao et al., 2022). The national emissions trading system, launched in 2021, became the world's largest by emissions coverage (Zou et al., 2021). Gulf countries, whose economies have traditionally depended on the oil and gas sector, are developing diversification strategies with an emphasis on renewable energy and the development of a hydrogen economy (Munawer, 2018). Saudi Arabia and the UAE are investing billions of dollars in solar energy and green hydrogen production (Tawalbeh et al., 2021).

For Kazakhstan, the experience of countries with similar economic structures is of particular interest. Research shows that countries with carbon-intensive economies can successfully implement decarbonization with long-term political will, institutional support, and investments in human capital (Kern et al., 2019; Sovacool et al., 2020). However, the process requires careful management of social consequences, including worker retraining and support for regions dependent on carbon-intensive industries (Healy & Barry, 2017).

Studies on the decarbonization of Kazakhstan's industry have become more numerous in recent years, reflecting the topic's growing relevance. Karatayev and Clarke (2016) analyze the potential of renewable energy in Kazakhstan, noting rich solar and wind energy resources alongside existing institutional and financial barriers to their development. Vakulchuk and Overland (2021) investigated pathways for energy-sector decarbonization, emphasizing the need to modernize outdated infrastructure and improve energy efficiency.

Turekulova et al. (2023) analyzed the readiness of Kazakh companies to implement ESG principles and decarbonization, identifying a significant gap between declared goals and actual actions. The authors emphasize the importance of developing a national carbon accounting and reporting system and of creating incentives for private investment in green technologies. An important contribution to understanding the socio-economic aspects of decarbonization has been made by works analyzing the impact of climate policy on regional development and employment in carbon-intensive regions of Kazakhstan (Aubakirova et al., 2023). These studies emphasize the need to develop just transition programs that ensure social protection and create alternative employment opportunities.

Despite the growing number of works, the issue of risk and opportunity management

at the micro-level-the level of individual companies and industries-remains insufficiently studied. There is a need for comprehensive research that integrates the technological, economic, institutional, and social dimensions of decarbonization, while accounting for the specific characteristics of the Kazakh industrial sector. The present study aims to fill this gap. following section.

3 | RESEARCH METHODS

This study employs a mixed-methods approach that integrates quantitative and qualitative methods to provide a comprehensive analysis of the risks and opportunities of industrial decarbonization in Kazakhstan. The study's conceptual framework integrates risk management theory, sustainable development, and strategic management approaches. The research is structured into several interconnected stages:

(1) systematic analysis of statistical data on greenhouse gas emissions and energy consumption of industrial enterprises;

(2) expert interviews with representatives of large industrial companies and regulatory authorities;

(3) scenario modelling of decarbonization trajectories;

(4) SWOT analysis and risk matrix assessment;

(5) development of recommendations and a roadmap.

The study's temporal horizon covers 2015-2024 for retrospective analysis and projects development scenarios through 2050 in accordance with national climate goals. The sectoral focus of the study is concentrated on four key sectors of the Kazakh industry: metallurgy, energy, the oil and gas sector, and the chemical industry, which account for more than 85

Quantitative data were collected from several sources: official statistics from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, reports from the Ministry of Ecology and Natural Resources of the RK, corporate sustainability reports of the largest industrial companies, and databases of international organisations (IEA, World Bank, OECD). In total, more than 150 corporate reports and 80 regulatory and strategic documents were analyzed.

Qualitative data were obtained through a series of semi-structured expert interviews conducted from March to August 2024. The sample included 32 experts representing various stakeholders: top managers and heads of sustainability departments at large industrial companies (18), representatives of government agencies (8), and experts from international organizations and consulting companies (6). Interview duration ranged from 45 to 90 minutes. Expert selection was carried out based on criteria of experience relevance, position held, and sectoral representation. To ensure confidentiality and obtain maximally candid responses, interviews were conducted with guarantees of anonymity. All interviews were recorded with respondents' consent and transcribed for subsequent analysis. Data saturation was achieved after 28 interviews, with the subsequent 4 interviews confirming the absence of new themes.

Descriptive statistics, trend analysis, and scenario modelling were applied to analyse quantitative data. CO_2 emissions dynamics were analyzed using the index method and decomposition analysis to identify factors affecting changes in carbon intensity. The LEAP (Long-range Energy Alternatives Planning System) model, widely used for energy and climate planning, was employed to forecast future emissions trajectories. The LEAP model configuration for Kazakhstan's industrial sector included the following key parameters:

(1) baseline year 2015 with historical calibration through 2024;

(2) four sectoral modules (metallurgy, energy, oil and gas, chemicals) with sector-specific emission factors;

(3) technology database containing 45 decarbonization technologies with associated costs ($/tonne CO_2 abated), implementation timelines, and technical potentials;

(4) fuel mix parameters including emission intensities (tCO_2/TJ) for coal (94.6), natural gas (56.1), and oil products (73.3);

(5) annual GDP growth projections (3.5-4.2%) and industrial output elasticities (0.85-1.15) as demand drivers;

(6) renewable energy penetration rates varying by scenario (BAU: 3-8%, Moderate: 15-30%, Ambitious: 40-70%);

(7) carbon price trajectories ($0-15/tonne in BAU, $20-40 in Moderate, $80-150 in Ambitious scenarios);

(8) technology learning rates (5-15% cost reduction per doubling of capacity) for emerging technologies like hydrogen and CCUS.

Emissions were calculated using the IPCC Tier 2 approach: E = AD × EF × (1-ER), where E represents emissions, AD is activity data (energy/material consumption), EF is the emission factor, and ER is the emission reduction rate from implemented technologies. Model validation was performed on historical data from 2015-2024, achieving a mean absolute percentage error (MAPE) of 4.3

Development of decarbonization scenarios was based on IPCC methodology and considered three main trajectories: baseline scenario (business-as-usual), assuming continuation of current trends; moderate scenario, envisioning gradual strengthening of climate policy aligned with Kazakhstan's NDC commitments; ambitious scenario, oriented toward achieving the Paris Agreement's 1.5°C pathway targets by 2050, which is more aggressive than Kazakhstan's national carbon neutrality goal of 2060. For each scenario, necessary investments, technological trajectories, and socio-economic consequences were assessed.

Risk matrix construction involved systematic assessment of identified risks and opportunities across two dimensions: probability of realization (P) rated on a 0-1 scale based on expert consensus (0-0.3 low, 0.3-0.7 medium, 0.7-1.0 high), and impact magnitude (I) on business operations rated on a 0-1 scale considering financial, operational, and strategic consequences. The risk priority score (RPS) was calculated as RPS = P × I × W, where W denotes sector-specific weighting factors (metallurgy 1.2, energy 1.15, oil and gas 1.1, chemicals 1.0) reflecting sectoral emission intensity and exposure to climate policies. Risks scoring RPS greater than 0.6 were classified as critical, requiring immediate mitigation strategies, 0.3-0.6 as moderate, requiring monitoring and contingency planning, and less than 0.3 as low, requiring awareness. The SWOT framework integrated qualitative expert assessments with quantitative data: Strengths and Weaknesses were evaluated through analysis of company-level capabilities (technology readiness levels 1-9, financial capacity metrics, human capital indicators), while Opportunities and Threats were assessed through external market analysis (green premium potential, regulatory policy trajectories, competitive landscape shifts). Cross-impact analysis examined SWOT element interactions using a 5×5 matrix to identify strategic priorities maximizing strengths-opportunities alignment and minimizing weaknesses-threats exposure.

Qualitative data from interviews were analyzed using thematic analysis method. Transcripts were coded in NVivo using both inductive and deductive approaches. Initial codes

were grouped into thematic categories, which were subsequently combined into broader themes that reflected key risks, opportunities, and strategic priorities. The integration of quantitative and qualitative data was conducted during the interpretation of results. Quantitative data on emissions and economic indicators were contextualized through the lens of expert assessments and practitioners' opinions. Triangulation of multiple data sources and analytical methods ensured the reliability and validity of the results obtained.

This study has several limitations that must be considered when interpreting the results. First, the availability and quality of greenhouse gas emissions data at the individual enterprise level are limited, owing to incomplete corporate reporting and differences in accounting methodologies. Second, the expert sample, while representative of large industrial companies, does not cover small and medium-sized businesses. Third, the high degree of uncertainty regarding future technology development and political decisions limits the accuracy of long-term forecasts. Fourth, the figures presented in this manuscript are constrained by the original data visualization formats provided in corporate and government reports; while efforts were made to enhance clarity, readers should note that some graphical elements reflect source document limitations rather than analytical choices. Enhanced vector-format visualizations are planned for subsequent publications.

4 | RESULTS

Analysis of greenhouse gas emissions dynamics in Kazakhstan's industrial sector for the period 2015-2024 reveals a sustained upward trend in total CO_2 emissions, despite individual periods of decline. This growth is driven by the expansion of production capacity and increased industrial output. Figure 1 demonstrates that total industrial emissions increased from 224,7 million tons of CO_2 in 2015 to 265,4 million tons in 2024, representing a 18,1% increase.

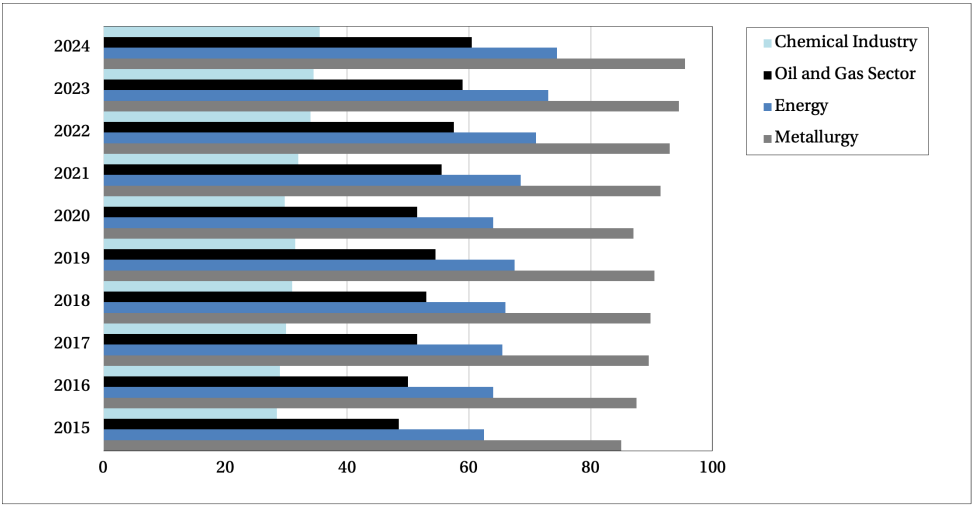

Figure 1 GHG emissions by industrial sectors in Kazakhstan, 2015–2024

The sectoral structure of emissions is characterized by dominance of the metallurgical sector, which accounts for 35,9% of total industrial emissions in 2024 (95,5 million tons of CO_2). The energy sector generates 28,1% of emissions (74,5 million tons), the oil and gas

sector - 22,7% (60,3 million tons), and the chemical industry - 13,2% (35,1 million tons). Notably, emissions growth rates differ across sectors: the highest rates are observed in the chemical industry (23.2% over the period) and the oil and gas sector (23.8%), while in metallurgy and energy, the growth was more moderate (12.1% and 19.6%, respectively). An important indicator is the carbon intensity of industrial production, which averages 425,6 tons of CO_2 per million US dollars of value added, significantly exceeding global averages and indicators of developed countries. This reflects the outdated technological base of the Kazakh industry and the predominance of energy-intensive production. A positive development is the recent trend toward reducing specific carbon intensity in some sectors, which is linked to the implementation of modernisation projects and energy-efficiency improvements. Descriptive statistics for key indicators indicate substantial variability across companies and sectors (Table 1).

Table 1 Descriptive statistics of indicators for industrial companies of Kazakhstan for 2015–2024

Indicator	Mean	Median	Std. Deviation	Minimum	Maximum
Total CO_2 emissions (million tons)	265,4	263,8	15,7	245,1	295,8
Carbon intensity (tons CO_2/million USD)	425,6	420,3	35,2	380,5	485,7
Share of RES (%)	3,8	3,5	1,2	2,1	6,2
Investments in decarbonization (billion USD)	2,4	2,2	0,8	1,2	4,1
Number of enterprises with carbon neutrality targets	17	–	4,5	12	26

Note: compiled by the authors

The standard deviation of total CO_2 emissions is 15,7 million tons, indicating significant heterogeneity among enterprises in terms of the scale of their environmental impact. The share of renewable energy sources in the industrial sector remains extremely low, averaging only 3,8%, with a maximum of 6,2% among the most progressive companies. Investments in decarbonization average 2,4 billion US dollars per year. The median value (2,2 billion dollars) indicates that most companies invest less than the average. The number of enterprises that have established carbon-neutrality targets increased from 12 in 2015 to 26 in 2024, indicating growing awareness of the importance of the climate agenda.

Based on SWOT analysis conducted using data from expert interviews and documentary sources, a comprehensive matrix of risks and opportunities for the transition to carbon neutrality for industrial companies in Kazakhstan was developed. The analysis identified key strengths (availability of natural resources for RES and large industrial capacity), weaknesses (high carbon intensity and technological lag), opportunities (access to green financing and new markets), and threats (regulatory risks and competition from low-carbon producers). Figure 2 presents the positioning of key risks and opportunities along the axes of probability of realisation and level of impact on the business.

Regulatory risks are assessed by experts as the most significant (probability 0,85, impact 0,90). These risks include the introduction of stricter carbon pricing, tightening of environmental standards, and, especially, the impact of the EU's CBAM. According to respondents' estimates, CBAM could increase export product costs by 15%-35% for the most carbon-intensive sectors. "The introduction of CBAM is a game-changer. We will have to either pay enormous carbon fees or radically change production technologies" notes the head of the sustainability department of one of the large metallurgical companies.

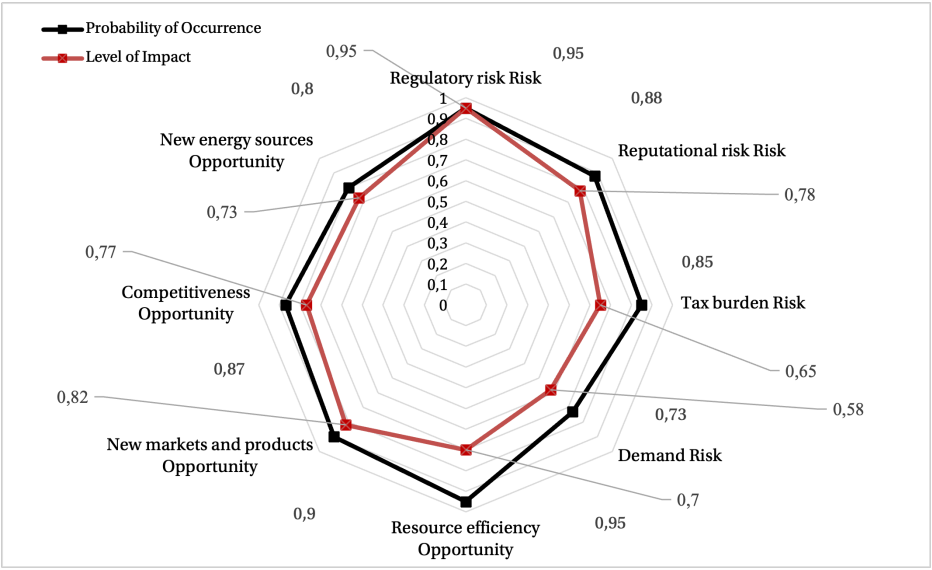

Figure 2 Risk and opportunity matrix for the transition to carbon neutrality

Financial risks (probability 0,75, impact 0,85) are associated with the need for large-scale capital investments amid limited access to long-term financing. Experts point to the high cost of borrowed capital in Kazakhstan and the insufficient development of green financing instruments. Modernization of a single metallurgical plant is estimated at 1,5-2,5 billion US dollars, which is comparable to the annual revenue of an average enterprise in the sector. Technological risks (probability 0,70; impact 0,75) arise from uncertainty regarding optimal technological pathways for decarbonization, particularly in heavy industry. Many promising technologies, such as hydrogen metallurgy and carbon capture and storage, are in early stages of commercialization. Dependence on imported technologies creates risks to technological sovereignty and increases implementation costs.

Market risks (probability 0,65, impact 0,80) include changes in demand structure, increased competition from companies that have already implemented decarbonization, and volatility in energy prices. Reputational risks (probability 0,60; impact 0,70) are associated with growing expectations from investors, customers, and the public regarding companies' environmental responsibility.

Alongside risks, the transition to carbon neutrality creates significant opportunities. Improving energy efficiency (probability 0,80; impact 0,85) is considered the most accessible and economically attractive strategy. According to expert estimates, the potential for reducing energy consumption in industry is 20-30% with investment payback periods of 3-5 years. "We have already implemented several energy efficiency projects that not only reduced our emissions but also provided substantial savings on energy costs" shares the production director of a large chemical company.

Implementation of new technologies (probability 0,65; impact 0,90) creates opportunities to develop competitive advantages and enter new markets. The development of green hydrogen production, CO_2 capture, and the circular economy can position Kazakh companies as technological leaders in the region. Access to green financing (probability 0,70,

impact 0,75) is becoming increasingly realistic as the sustainable finance market develops and investor interest in ESG indicators grows. Strengthening competitive advantages (probability 0,75; impact 0,80) entails improving reputation, enhancing investment attractiveness, and ensuring long-term access to European markets. "Customers are already asking about the carbon footprint of our products. In 5-10 years, this will become a mandatory requirement for operating in international markets," predicts an export manager at a metallurgical company.

Analysis of decarbonization plans of Kazakh industrial companies reveals different priorities and approaches depending on sectoral specifics. Figure 3 illustrates the distribution of investments across decarbonization strategies by key industrial sectors.

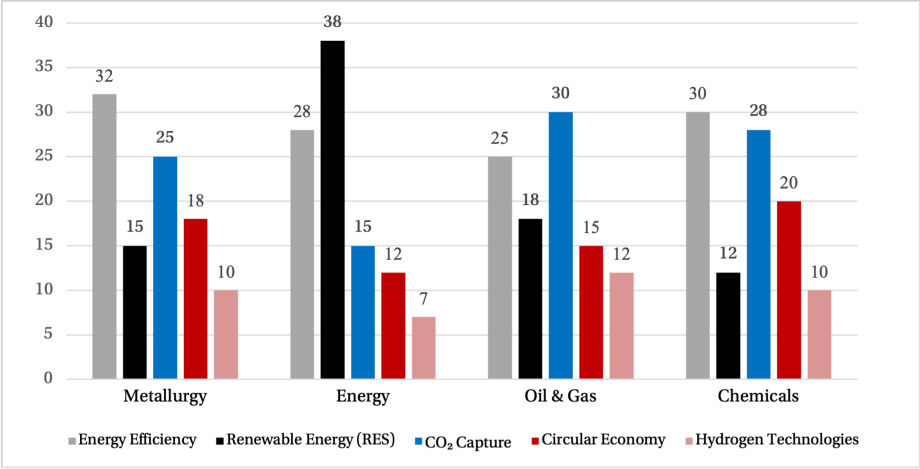

Figure 3 Distribution of investments in decarbonization strategies by sectors

For the metallurgical sector, priority areas are improving energy efficiency (32% of investments) and CO_2 capture technologies (25%). This reflects the high carbon intensity of production and the limited availability of short-term technological alternatives. Hydrogen metallurgy is regarded as a long-term prospect and currently accounts for only 10% of investment. Development of the circular economy, including waste utilization and material reuse, receives 18% of investments.

In the energy sector, renewable energy sources receive the largest share of investments (38%), consistent with the national goal of increasing the share of RES in the energy balance to 15% by 2030. Kazakhstan has significant solar and wind energy potential, and the development of these resources is becoming a key priority for decarbonization. Improving the energy efficiency of thermal power plants accounts for 28% of investments, and CO_2 capture technologies account for 15%.

The oil and gas sector focuses on CO_2 capture technologies (30% of investments), driven by sector-specific conditions and the availability of geological formations suitable for carbon storage. Reducing associated gas flaring and methane leaks (25% of the energy efficiency category) is also an important direction. The development of green hydrogen production accounts for 12% of investments, reflecting a diversification strategy.

The chemical industry directs the largest share of investments (30%) to energy efficiency, including process optimization and equipment modernization. The circular economy and

waste processing receive 20% of investments, reflecting the sector's potential for closed production cycles. CO_2 capture technologies attract 28% of investments, especially in ammonia and methanol production.

Expert interviews revealed that the choice of decarbonization strategies is determined not only by technological feasibility but also by financing availability, regulatory requirements, and market factors. "We would like to invest more in breakthrough technologies such as hydrogen, but banks are not ready to finance projects with long payback periods and high technological risks," comments the financial director of an energy company.

Based on analysis of technological capabilities, economic conditions, and political factors, three scenarios for the development of industrial CO_2 emissions in Kazakhstan through 2050 were developed. Figure 4 demonstrates emissions trajectories under different scenarios.

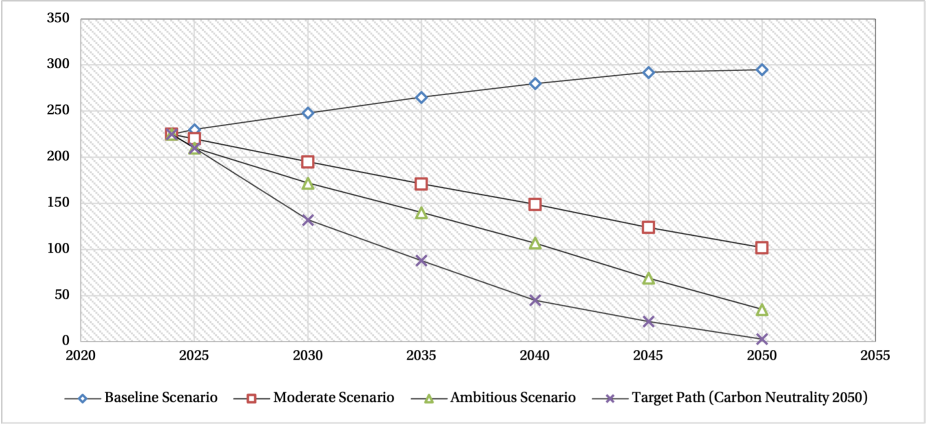

Figure 4 Forecast scenarios for reduction of CO_2 emissions in Kazakhstan's industry for 2024-2050

The baseline scenario (business-as-usual) assumes continuation of current trends without significant strengthening of climate policy. Under this scenario, emissions continue to rise, reaching 322,5 million tons of CO_2 by 2050. This scenario accounts for natural energy-efficiency improvements resulting from technological progress and the replacement of outdated equipment, but does not assume deliberate decarbonization efforts. Implementing this scenario contradicts national climate commitments and will pose significant regulatory and market risks to the Kazakh industry. This contradiction manifests in the following aspects: first, the baseline scenario assumes emissions growth of 19,2% by 2050 compared to 2024, while Kazakhstan's updated NDC provides for a 15% emissions reduction by 2030 relative to 1990 levels, and the Carbon Neutrality Strategy through 2060 requires substantial emissions reductions in the coming decade. Second, maintaining carbon-intensive production makes the Kazakh industry extremely vulnerable to the EU's CBAM, which will impose additional carbon costs of 50-120 US dollars per ton on exported products and may lead to a loss of competitiveness in the European market. Third, ignoring global climate trends increases the risk of excluding Kazakh companies from international supply chains, where requirements for product carbon footprints are becoming increasingly important.

The moderate scenario envisions gradual strengthening of climate policy and implementation of medium-efficiency decarbonization technologies. Emissions begin to decline after

2027, reaching 102,3 million tons of CO_2 by 2050-a 55% reduction compared to 2024. This scenario assumes: introduction of carbon pricing at 20-40 dollars per ton of CO_2, increasing the share of RES in the energy balance to 30%, modernization of 60% of production capacity with implementation of energy efficiency technologies, and limited deployment of CO_2 capture technologies.

The ambitious scenario is oriented toward achieving the goals of the Paris Agreement and assumes aggressive decarbonization using advanced technologies. Emissions decline to 35 million tons of CO_2 by 2050-an 84% reduction. Key elements of this scenario include: carbon pricing at 80-150 dollars per ton of CO_2, RES share in the energy balance reaching 70%, large-scale implementation of hydrogen technologies in metallurgy and chemical industry, deployment of carbon capture, utilization and storage (CCUS) technologies at 80% of large industrial facilities, and transition to circular economy with utilization of 90% of industrial waste.

The target path to carbon neutrality assumes achieving net-zero emissions by 2050, in accordance with the Paris Agreement's 1.5°C pathway, which is more ambitious than Kazakhstan's official national target of 2060. This scenario requires substantial effort through a combination of radical emissions reductions and compensation mechanisms, which are the most costly, but it ensures full compliance with global climate science recommendations and eliminates long-term regulatory risks associated with international climate frameworks.

Assessment of investment needs shows that the moderate scenario requires cumulative investments of 180-220 billion US dollars through 2050, while the ambitious scenario requires 350-450 billion dollars. These amounts include both direct costs for decarbonization technologies and investments in infrastructure modernization, RES development, and human capital. "Such sums are beyond the capabilities of individual companies and even entire industries. Comprehensive financing mechanisms are needed, including government support, international financing, and private capital" emphasizes a representative of an investment bank specializing in green financing.

Socio-economic consequences differ between scenarios. The ambitious scenario, despite high initial costs, ensures the creation of 150-200 thousand new jobs in RES sectors, hydrogen production, and green technologies. Simultaneously, it requires the retraining of 80-100 thousand workers from carbon-intensive industries. The moderate scenario assumes a smoother transition with lower social costs, but also lower potential for creating new added value.

Based on the conducted analysis, a multi-level risk and opportunity management system for decarbonization was developed for industrial companies in Kazakhstan. The system comprises strategic, tactical, and operational levels and assumes the integration of climate factors across all aspects of corporate governance.

At the strategic level, companies are recommended to: 1) develop a long-term climate strategy with establishment of science-based targets for emissions reduction (Science Based Targets); 2) integrate climate risks into the corporate risk management system in accordance with TCFD recommendations; 3) create corporate governance structures for oversight of climate strategy implementation, including board-level committees; 4) develop a top management compensation system linked to achievement of climate goals.

At the tactical level, key elements include: 1) implementation of carbon accounting and reporting systems in accordance with international standards (GHG Protocol, ISO 14064); 2) development of a decarbonization project portfolio with assessment of economic efficiency and prioritization; 3) establishment of partnerships with technology providers, financial institutions, and research organizations; 4) development of personnel competencies in

climate management and green technologies.

Tactical measures ensure practical implementation through carbon accounting systems (e.g., GHG Protocol, ISO 14064), the development of decarbonization project portfolios with efficiency assessments, partnerships with technology providers and financial institutions, and the development of personnel competency in climate management. The operational level includes: implementation of energy management in accordance with ISO 50001 standard; optimization of production processes to reduce emissions and energy consumption; monitoring of key performance indicators (KPIs) in decarbonization; engagement of suppliers in emissions reduction programs throughout the value chain.

Operational measures include energy management implementation (ISO 50001), production process optimization for emissions reduction, monitoring key performance indicators, and supplier engagement in reduction programs throughout the value chain (addressing Scope 3 emissions which constitute 60-80% of total carbon footprint for many industrial companies).

Special attention should be paid to regulatory risk management, which requires: 1) active participation in formation of national climate policy through industry associations; 2) monitoring of international regulatory trends and their potential business impact; 3) preparation for CBAM introduction through emissions data collection and seeking reduction pathways; 4) use of the transition period before full CBAM implementation for production modernization.

Special attention should be paid to regulatory risk management through active participation in policy formulation, monitoring international trends, preparing for the implementation of CBAM, and leveraging the 2026-2034 transition period for production modernisation.

To realize decarbonization opportunities, companies are recommended to: 1) actively engage with international financial institutions for access to green financing; 2) position low-carbon products in markets with high demand for sustainable goods; 3) participate in pilot projects for implementing breakthrough technologies with government support; 4) develop cooperation with international technology leaders for knowledge and competency transfer.

To realize decarbonization opportunities, companies should engage with international financial institutions for green financing, position low-carbon products in sustainable markets, participate in pilot technology projects with government support, and develop cooperation with international technology leaders for knowledge transfer.

5 | CONCLUSION

This study provides a comprehensive analysis of the risks and opportunities faced by large industrial companies in Kazakhstan during the transition to carbon neutrality. The research results confirm that industrial decarbonization is a large-scale challenge that requires significant investments, technological innovations, and institutional changes. At the same time, it opens important opportunities for production modernization, enhanced competitiveness, and creation of new added value.

Key findings of the study include the following. First, Kazakhstan's industrial sector is characterized by high carbon intensity, with emissions continuing to rise despite declared climate goals. Total industrial emissions increased by 18.1% during the period 2015-2024, indicating an insufficient decarbonization effort. Second, the main transition risks are associated with regulatory uncertainty, high capital costs, technological challenges, and limited access to financing. The introduction of CBAM poses a particular threat to export-

oriented companies and necessitates preemptive measures.

Third, decarbonization strategies differ by industry, reflecting their technological specifics and economic capabilities. For metallurgy, energy efficiency and CO_2 capture technologies are priorities; for the energy sector, RES development; for the oil and gas industry, carbon capture and hydrogen production. Fourth, scenario analysis shows that achieving the Paris Agreement's carbon neutrality target by 2050 (more ambitious than Kazakhstan's national 2060 goal) is technically feasible but requires cumulative investments of 350-450 billion US dollars and radical transformation of the industrial sector, while the moderate scenario aligned with the 2060 national target requires 180-220 billion US dollars.

Fifth, successful management of the transition to carbon neutrality requires an integrated approach that combines strategic planning, technological innovation, financial mechanisms, and human capital development. Coordination between business, government, and the financial sector is critically important. Sixth, international cooperation, technology transfer, and access to green financing are key success factors, particularly for a transition economy.

The practical significance of the study lies in the development of specific recommendations for various stakeholders.

For industrial companies: (1) integrate climate factors into strategic planning and corporate governance systems; (2) start with energy efficiency improvement projects as the most economically attractive; (3) actively engage with international partners for access to technologies and financing; (4) invest in personnel competency development.

For government agencies: (1) create a stable and predictable regulatory framework with long-term signals for investors; (2) implement effective carbon pricing mechanisms with gradual increase in carbon price; (3) provide targeted support for decarbonization projects through tax incentives, subsidies, and government guarantees; (4) develop infrastructure for RES and hydrogen economy; (5) implement just transition programs for workers and regions dependent on carbon-intensive industries.

For the financial sector: (1) develop green financing instruments, including green bonds, concessional loans, and specialized funds; (2) integrate ESG factors and climate risks into investment decision-making processes; (3) create mechanisms for co-financing large decarbonization projects with participation of international financial institutions.

The study's limitations open directions for future work. More detailed technical and economic studies of the decarbonization of specific production processes, considering local conditions, are needed. It is important to deepen the analysis of social aspects of the transition, including the impact on employment, population income, and regional development. The development of tools to assess the effectiveness of various policy measures supporting decarbonization is required. A promising direction is comparative analysis of decarbonization experience in countries with similar economic structures.

In conclusion, the transition to carbon neutrality is not only an environmental necessity but also a strategic opportunity to modernize Kazakh industry. Companies that proactively manage this transition will be able to strengthen their competitive positions, gain access to new markets and financing sources, and contribute to the country's sustainable development. Delay, however, threatens growing regulatory and market risks that could undermine business viability. The time for action is now.

AUTHOR CONTRIBUTION

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Formal analysis and investigation: Lena Khuanysh, Zhanar Dauletkhanova, Aliya Yerniyazova.
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Software and supervisions: Lena Khuanysh, Zhanar Dauletkhanova, Aliya Yerniyazova.
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Visualization: Lena Khuanysh, Zhanar Dauletkhanova.
Writing review and editing research: Lena Khuanysh.

CONFLICT OF INTEREST

No conflict of interest/competing interest is reported by the authors.

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Capital Market Development as a Driver of Economic Growth: The Case of Mongolia

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Abstract
The development of capital markets in emerging economies is considered a key factor in ensuring sustainable economic growth and enhancing financial stability. Given Mongolia's high dependence on commodity exports and external shocks, the study of the stock market's role in economic growth dynamics is increasingly relevant. The objective of this study is to empirically test the role of Mongolia's capital market in economic growth. The methodological basis of the study comprises stationarity tests (ADF, KPSS), the ARDL model with the bounds-testing procedure for detecting cointegration, the vector error-correction model (VECM) for causality analysis, and the FMOLS and DOLS methods for testing the stability of long-run coefficients. The empirical base comprises quarterly data for 2000-2024, sourced from the National Statistical Office of Mongolia, the Central Bank of Mongolia, and the Mongolian Stock Exchange. The results of the ARDL model confirm the existence of a long-term cointegration relationship between GDP and capital market indicators (F-statistic = 4.538, which exceeds the upper critical limit of 3.99 at the significance level of 1%). In the long term, market capitalisation has a statistically significant positive impact on economic growth (coefficient 0.956; $p < 0.01$), while the TOP-20 index shows a negative relationship. The results from FMOLS and DOLS confirm the stability of the estimates. The findings indicate the structural importance of capital market development for Mongolia's long-term economic growth, however, the identified market concentration and limited liquidity may constrain its potential contribution to the economy.

KEYWORDS
Economy, Economic Growth, Capital Market, Market Capitalization, Stock Market, Finance, Financial Stability, Mongolia

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1 | INTRODUCTION

Mongolia's economic trajectory, shaped by its vast natural resources, has been marked by a gradual shift toward economic diversification and deeper integration into the global financial system. As Mongolia seeks to advance its financial markets, particularly in terms of investment attraction, capital market development, and economic stability, collaboration with neighboring Central Asian countries offers significant opportunities. These nations, which share similar economic challenges and growth potential, are natural partners for Mongolia in fostering financial market integration. Strengthening cooperation in this field is not merely a strategic advantage but a critical step toward ensuring long-term stability and growth.

A strong and well-functioning financial sector is a cornerstone of sustainable economic growth. It enhances market efficiency, mitigates systemic risk, and improves capital mobility. At its core, a financial system serves three critical functions: facilitating a robust payment system, allocating resources efficiently, and managing risk. Within this framework, capital markets have emerged as a pivotal force in global economies, playing an increasingly developmental role by influencing corporate finance and activity. Their primary function is to mobilize and channel capital from diverse institutions to productive sectors.

In recent years, Mongolia has made significant strides in enhancing its financial cooperation with Central Asian countries, aligning these efforts with its broader "Third Neighbor" policy. This policy aims to diversify Mongolia's international partnerships beyond its traditional neighbors, Russia and China. By engaging more actively with Central Asia, Mongolia seeks to foster stronger regional ties, contribute to regional economic growth, and reduce dependence on its immediate neighbors, thereby creating a more balanced geopolitical and economic position. A central component of Mongolia's strategy in Central Asia has been its involvement in the Central Asia Regional Economic Cooperation (CAREC) Program. Since joining in 2003, Mongolia has actively participated in a variety of projects, investing over $1.4 billion. These projects have largely focused on improving infrastructure and enhancing trade connectivity, which are critical to Mongolia's economic development. For example, the construction of a logistics centre in Zamyn-Uud has proven pivotal in facilitating trade between Mongolia, China, and Russia, making Mongolia a key player in the Middle Corridor linking East Asia to Europe (CAREC, 2025).

Despite the increasing relevance of capital market development, empirical evidence on the relationship between Mongolia's stock market performance and economic growth remains limited. Existing studies largely provide descriptive analysis or focus primarily on the banking sector, while rigorous time-series econometric testing of capital market–growth dynamics is scarce. In particular, the potential long-run equilibrium relationship and regime-dependent effects have not been comprehensively examined in the Mongolian context.

The objective of this study is to empirically test the role of Mongolia's capital market in economic growth. The expected outcomes of our research will be valuable to researchers, policymakers, and analysts interested in investing in Mongolia's capital market. Empirical studies investigating the relationship between financial development and economic growth also show, in general, that financial development causes economic growth. The research issue addresses the paucity of studies on Mongolia's financial sector, specifically the capital market and its association with economic growth, namely GDP growth.

2 | LITERATURE REVIEW

Internationally, researchers employ various methodologies to study the relationship between capital markets and economic growth. Initially, they focused on the banking sector's role in economic growth. Still, as the capital market developed, greater attention was paid to its role in the economy and to the relationship between the stock market and economic growth. The results of this type of basic research show that capital market development promotes long-term economic growth.

Although extensive research examines the relationship between capital market development and economic growth, no clear conclusions have been reached. As the capital market develops, it mobilises savings, increases investor activity, promotes the equitable and fair distribution of capital, and supports the development of companies. It has been hypothesized that it will have an effect on risk distribution, and different conclusions have been reached depending on the specifics of the country, the concentration of the financial market, government policy, and the development of the banking sector (Masoud, 2013).

The development of capital markets in Central Asia plays a key role in stimulating economic growth, enhancing financial stability, and diversifying regional economies. Although the financial markets in Central Asian countries such as Kazakhstan, Uzbekistan, and Kyrgyzstan have faced significant challenges, recent empirical studies indicate that their development has had a positive impact on economic performance. This literature review provides an overview of recent empirical research on the economic effects of capital market development in these countries and highlights their importance for regional integration and economic growth.

Empirical evidence from Central Asia generally supports a positive association between capital market development and economic growth; however, results vary with financial depth, market concentration, and institutional quality. For example, Dzhankobaev and Piedra (2005) found a long-run positive relationship in Kazakhstan using time-series data, whereas evidence from smaller markets, such as Kyrgyzstan, suggests that institutional constraints may limit the growth-enhancing effects of stock market development. For countries with economies in transition, achievement of a significant level of economic growth is a prerequisite for the formation of a stable capital market and banking system, that will subsequently have a significant positive impact on economic growth (Nichkasova et al., 2022). The problem of inequality in the labor market remains as the most important factor limiting the use of human capital and the potential for sustainable economic growth (Bekturganova and Serikova, 2025). Empirical studies measure the gender pay gap and analyze its relationship with macroeconomic indicators such as GDP and inflation using statistical and econometric methods.

Uzbekistan's recent financial market reforms provide evidence of the growth-enhancing potential of capital market liberalization in transition economies. Empirical findings by Khodjaev and Tursunov (2022), based on time-series analysis for 2005–2022, indicate that stock and bond market expansion contributed to economic diversification and reduced reliance on natural resource sectors. Their results suggest that financial market deepening improves access to capital and supports structural transformation, although the magnitude of these effects depends on institutional quality and regulatory consistency. In contrast, evidence from Kyrgyzstan indicates more constrained outcomes in smaller, less liquid markets. Oskonbaeva (2018) showed that improvements in market infrastructure and regulatory reforms have supported macroeconomic stabilisation. However, the limited size and depth of the Kyrgyz capital market restrict its broader growth impact. These findings imply that while financial market development can enhance economic resilience, its effectiveness is

conditional upon market scale, liquidity, and institutional strength. A study by Saidmamatov et al. (2021) compared the development of the risk attitudes toward traveling during the COVID-19 pandemic through consideration of sociodemographic characteristics. Futhermore, Nurasheva et al. (2024) logical conclusions, the selection of necessary information, and systems analysis when considering the business environment and state regulation measures in the countries of the region. It is noted that the banking sector of Kazakhstan is the most integrated one into the global financial system. Uncertainty in the development of banks in Kyrgyzstan, the isolation of the banking sector in Turkmenistan, and the dependence of credit institutions in Uzbekistan and Tajikistan on administrative intervention are presented.

The role of financial market integration in driving economic growth in Central Asia is explored by Balbaa et al. (2024). The development of large-scale transport infrastructure projects, such as the China–Kyrgyzstan–Uzbekistan railway within the digitalized framework of the eTIR Convention, demonstrates how strategic investments can stimulate economic growth and expand international trade integration. Empirical results based on an ARDL (2,1) model indicate a direct linear relationship between GDP growth and trade-related income flows, highlighting the macroeconomic sensitivity of growth to cross-border economic activity. At the same time, financial sustainability, geopolitical risks, and governance quality remain critical factors determining whether infrastructure-driven capital mobilization translates into stable and long-term economic development.

The empirical research reviewed in this section underscores the importance of capital market development for economic stability and growth in Central Asia. Kazakhstan and Uzbekistan, with their more advanced capital markets, offer valuable insights into how financial market development can attract foreign investment, reduce economic dependence on natural resources, and support sustainable economic growth. Kyrgyzstan, though still developing its financial infrastructure, shows that even smaller markets can play a role in economic stabilisation if supported by adequate regulatory reforms.

In general, research on Central Asian countries confirms a positive relationship between capital market development and economic growth. However, the results vary depending on the depth of the market, the level of liquidity, the institutional environment, and the degree of concentration. In addition, most of the work relies on standard econometric methods. About Mongolia, analysis of the long- and short-term relationship between stock market development and GDP remains limited. This gap determines the relevance of this study.

3 | RESEARCH METHODS

This study examines the relationship between capital market development and economic growth in Mongolia, focusing on the key indicators used by international organisations, such as the International Monetary Fund (IMF) and the World Bank (WB), to assess financial market development in both developed and developing countries. The four primary indicators considered in this analysis are market capitalisation, the market capitalisation-to-GDP ratio, market liquidity, and the share price index. These indicators are widely used because they provide a comprehensive view of how capital markets are performing relative to the broader economy.

The study period spans from the first quarter of 2000 to the fourth quarter of 2024, providing a robust dataset for examining the dynamics of Mongolia's capital markets over nearly a quarter-century. The explanatory variables selected for this analysis are chosen to capture the most important aspects of the country's capital market development:

(1) Total Market Capitalization: This represents the total value of all publicly traded

companies on Mongolia's stock exchange. It serves as a crucial measure of market size and investor engagement in financial markets.

(2) Value of Share Trading: This variable represents the total value of shares traded on the Mongolian Stock Exchange. It provides insight into market liquidity and investor activity, reflecting the ease with which assets can be bought or sold.

(3) TOP 20 Index: This index tracks the performance of the 20 largest companies listed on the Mongolian Stock Exchange. It serves as a key trend indicator, helping assess the overall performance of Mongolia's stock market.

To explore the strength of the relationship between capital market development and economic growth, three important macroeconomic covariates are included in the regression models. These variables are widely used in economic literature to control for factors that might influence GDP growth. They include:

(1) Consumer Price Index (CPI): Inflation plays a significant role in affecting the real value of all economic variables, including those related to capital markets. By adjusting for inflation with the CPI, the analysis ensures that the data reflect real values rather than being influenced by price changes.

(2) Consumer Price Index (CPI): Inflation plays a significant role in affecting the real value of all economic variables, including those related to capital markets. By adjusting for inflation with the CPI, the analysis ensures that the data reflect real values rather than being influenced by price changes.

(3) Growth Rate of Foreign Direct Investment (FDI): FDI is a crucial factor in the economic growth of developing countries. By including this variable, the study accounts for the impact of external capital flows, which can boost domestic markets and foster economic development.

All variables in this study are adjusted for inflation using the CPI to ensure the accuracy of the analysis, focusing on real, rather than nominal, values. The study's dependent variable is Gross Domestic Product (GDP), measured in constant 2015 Mongolian Tugrik (MNT), reflecting the real output of Mongolia's economy. By treating GDP as the dependent variable, the study assesses how the development of capital markets influences economic growth, while controlling for other macroeconomic factors. The National Statistics Office (NSO) of Mongolia and the Central Bank of Mongolia (BoM) gathered and organised the data for this study, the quarterly statistics in 2024. In addition, some of the data is sourced and cross-checked from the Mongolian Stock Exchange (MSE).

The variables, their definitions, abbreviations, and data sources are summarised in Table 1.

Following the presentation of descriptive statistics, the empirical analysis proceeds in several stages. First, unit root tests are conducted to determine the order of integration of the variables. Second, the existence of a long-run relationship among the variables is examined using the Autoregressive Distributed Lag (ARDL) bounds testing approach developed by Pesaran et al. (2001). Third, both short-run and long-run dynamics are estimated within the ARDL error-correction framework. Fourth, a Vector Error Correction Model (VECM) is employed to assess the direction of causality. Finally, Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) estimators are used to verify the robustness of the long-run coefficients.

The general vector of endogenous variables is defined by formula (1):

Table 1 Some information on variables

Indicator	Abbreviation	Resource
Dependent Variable		
Gross Domestic Production	GDP	NSO
Independent Variable		
Total Market Capitalization	MV	MSE
Value of share trading	VS	MSE
Top 20 Index	INDEX	MSE
Control Variable		
Consumer Price Index	CPI	NSO
Foreign Direct Investment	FDI	BoM
Real Effective Exchange Rate	REER	BoM

*Some of the quantitative data used in the study were multiplied by the GDP deflator, and a seasonal component of the variables was adjusted for seasonal effects using the Census X-13 test.

Note: compiled by the author

$$Z_t = (GDP, FDI, CPI, REER, MV, VS, INDEX) \tag{1}$$

where:

GDP – the natural logarithm of real gross domestic product;
FDI – the natural logarithm of foreign direct investment inflows;
CPI – the consumer price index, controlling for inflation;
$REER$ – the real effective exchange rate, capturing external competitiveness;
MV – the natural logarithm of total market capitalization, capturing stock market size;
VS – the natural logarithm of trading value;
$INDEX$ – the natural logarithm of the TOP-20 index, reflecting stock price dynamics.

The next step is to test the unit root properties of the variables. The stationarity of the variables is critical for policy implications.

After testing the stationarity of the series, we apply the ARDL (Autoregressive Distributed Lag) bounds testing approach developed by Pesaran et al. (2001) to investigate the cointegration of the long-run relationship between gross domestic product, total market capitalization, top 20 index, value of share trading, consumer price index, real effective exchange rate, and the foreign direct investment of the Mongolian economy. This method has multiple econometric advantages. It appears to be flexible with respect to the stationarity properties of the variables. The bounds testing ARDL is applicable irrespective of whether variables are I(0) or I(1).

Moreover, ARDL bounds testing provides efficient and consistent empirical evidence for small-sample data. Moreover, a dynamic unrestricted error-correction model can be derived from ARDL bounds testing via a simple linear transformation. The dynamic unrestricted error-correction model integrates short-run dynamics with long-run equilibrium. Consequently, in this paper, the ARDL bounds testing is used, since some variables are integrated of order I (0) and others are first-order I (1). The ARDL models used by formula (2):

$$\begin{aligned}\{\Delta LnGDP_t = \beta_0 &+ \sum_{i=1}^{n} \beta_{1i}\Delta LnGDP_{t-i} + \sum_{i=1}^{n} \beta_{2i}\Delta LnINDEX_{t-i} + \sum_{i=1}^{n} \beta_{3i}\Delta MV_{t-i} \\ &+ \sum_{i=1}^{n} \beta_{4i}\Delta LnFDI_{t-i} + \sum_{i=1}^{n} \beta_{5i}\Delta LnVS_{t-i} + \sum_{i=1}^{n} \beta_{6i}\Delta CPI_{t-i} \\ &+ \sum_{i=1}^{n} \beta_{6i}\Delta CPI_{t-i} + \delta_1 lnGDP_{t-1} + \delta_2 lnMV_{t-1} \\ &+ \delta_3 lnINDEX_{t-1} + \delta_4 lnFDI_{t-1} + \delta_5 lnVS_{t-1} + \delta_7 \Delta REER_t + \varepsilon_t\}\end{aligned} \tag{2}$$

where:

Δ – the first difference operator;

ε_t – the error term assumed to be independently and identically distributed (i.i.d);

Ln – symbol of the natural logarithm.

Given that, it is known that the calculation of ARDL bounds testing is flexible in the selection of the lag length, we choose the optimal length of lags from the first difference of dependent variables based on the minimum value of the Akaike criterion, according to the following models (3):

$$\begin{aligned}\{\Delta LnGDP_t = \beta_0 &+ \sum_{i=1}^{n} \beta_{1i}\Delta LnGDP_{t-i} + \sum_{i=1}^{n} \beta_{2i}\Delta LnINDEX_{t-i} + \sum_{i=1}^{n} \beta_{3i}\Delta MV_{t-i} \\ &+ \sum_{i=1}^{n} \beta_{4i}\Delta LnFDI_{t-i} + \sum_{i=1}^{n} \beta_{5i}\Delta LnVS_{t-i} + \sum_{i=1}^{n} \beta_{6i}\Delta CPI_{t-i} \\ &+ \sum_{i=1}^{n} \beta_{7i}\Delta REER_{t-i} + \vartheta_t\end{aligned} \tag{3}$$

where:

β_1 to β_7 – the short-run effects of changes in market capitalisation (MV), stock index (INDEX), trading value (VS), foreign direct investment (FDI), inflation (CPI), and the real effective exchange rate (REER);

ϑ_t – the error term.

Pesaran et al. (2001) proposed an F-test to examine the joint significance of the lagged level variables in the ARDL specification. The null hypothesis of no cointegration is:

$$H_0 : \lambda_1 = \lambda_2 = \cdots = \lambda_7 = 0 \tag{4}$$

Against the alternative hypothesis:

$$H_1 : \text{at least one } \lambda_j \neq 0 \tag{5}$$

Two sets of critical values for a given significance level can be determined. The first critical value is obtained on the assumption that all variables included in the ARDL specification are I(0), while the second level is obtained on the assumption that the variables are I(1). Upon establishing cointegration, the ARDL model is reparameterized into an error correction model (ECM) form (4):

$$\Delta\, GDP = \cdots + ECM_{t-1} + u_t \tag{6}$$

where:

ECM_{t-1} – the error correction term.

The coefficient of the error correction term (ECM_{t-1}) should be negative and statistically significant. This coefficient shows the adaptation speed, in other words, we could say that shows how fast the variables return to the long-run equilibrium.

Markov-Switching regression model

To account for potential nonlinearities and regime-dependent dynamics, a two-state Markov-switching model is employed. Following Hamilton (1989), this approach allows key parameters to vary across latent regimes, typically interpreted as expansionary and contractionary states. Markov regime-switching models have been widely used in macroeconomic analysis to capture asymmetric and nonlinear behaviour in time-series data (Hamilton, 1989; Goodwin, 1993; Gray, 1996; Hansen, 1992; Cologni & Manera, 2008). The regime variable follows a first-order Markov process, with transition probabilities determining the likelihood of remaining in a given state or of switching to another. This framework enables the model to identify shifts between high-growth and low-growth regimes and to estimate regime-specific effects of capital market development on economic growth.

4 | INSTITUTIONAL AND REGIONAL BACKGROUND

Mongolia's collaboration extends beyond infrastructure, as it also partners with the International Monetary Fund (IMF) through the Central Asia Regional Capacity Building Centre (CCAMTAC). In September 2024, the country hosted a national workshop in Ulaanbaatar focused on macroeconomic analysis and financial programming. This initiative was aimed at strengthening the public financial management system in Mongolia and enhancing the capacity of policymakers to forecast economic trends effectively (CCAMTAC, 2024). Furthermore, Mongolia has sought to improve its support for micro, small, and medium-sized enterprises (MSMEs) by partnering with the European Bank for Reconstruction and Development (EBRD) and the European Union (EU). These partnerships have led to an additional €25 million in EU-backed guarantees allocated to local financial institutions in Mongolia, which are expected to support approximately 3,500 businesses across Mongolia and Central Asia. These efforts are designed to enhance access to finance for small businesses, helping to promote entrepreneurship and stimulate further economic growth (EBRD, 2021).

Through these multifaceted collaborations, Mongolia is not only strengthening its position as a regional economic partner but also contributing to the overall development and integration of Central Asia. These efforts reflect Mongolia's commitment to sustainable and diversified economic growth and its proactive role in fostering cooperation in Central Asia. The historical connections between Mongolia and the Central Asian countries lay the groundwork for their evolving economic and financial cooperation. Over the years, these regions have shared similar economic challenges, including a heavy reliance on raw material exports and the need for infrastructure development. These shared experiences have facilitated deeper ties and collaboration in recent decades. In the 20th century, during the Soviet era, Mongolia and the Central Asian republics were part of the same centralized economic system. This created the foundation for economic exchanges and mutual understanding. However, with the collapse of the Soviet Union and Mongolia's transition to a market economy in the early 1990s, Mongolia's relationship with Central Asia shifted to reflect new regional dynamics.

Mongolia's economic engagement with Central Asia should be viewed in the context of

the post-Soviet transition and the restructuring of Eurasian trade and financial linkages. Following market-oriented reforms in the 1990s, both Mongolia and Central Asian economies sought deeper integration into global markets. Given shared structural constraints such as dependence on natural resources and limited financial depth, regional cooperation has emerged as a potential channel for diversifying trade, investment, and financial connections. This regional nexus, therefore, warrants empirical examination.

Given the relatively small scale of Mongolia's financial sector, deeper cooperation with regional counterparts Kazakhstan, Kyrgyzstan, Uzbekistan, and Turkmenistan may be particularly relevant. Like Mongolia, these economies have undergone prolonged structural transformation and continue to face comparable development constraints in financial depth, market infrastructure, and institutional capacity. Financial cooperation across borders serves as a bridge, connecting markets that might otherwise be isolated. It opens access to new sources of capital, reduces barriers to investment, and enables a more efficient allocation of resources. According to the World Bank, financial integration in the Central Asian region leads to better access to credit, lower costs of borrowing, and more diversified financial instruments, factors that are crucial for emerging markets such as Mongolia to grow (World Bank, 2020). Moreover, financial market cooperation can stabilise Mongolia's economy, which is highly dependent on commodity exports.

Financial cooperation between Mongolia and Central Asian countries, particularly Kazakhstan and Uzbekistan, has become increasingly important for strengthening Mongolia's financial system and expanding its access to regional capital. Kazakhstan's experience in financial market reforms and investment promotion has supported Mongolia in attracting foreign investment, especially in mining and infrastructure, while also providing practical lessons in transparency and regulatory development. At the same time, cooperation with Uzbekistan in capital market development and corporate governance has offered valuable insights into modernizing financial institutions and improving investor protection. Regional collaboration in infrastructure financing and fintech has further contributed to enhancing financial inclusion, diversifying funding sources, and modernizing payment systems in Mongolia. Overall, this regional financial partnership plays a strategic role in reducing Mongolia's reliance on the mining sector and in building a more resilient and diversified financial market.

Since 2010, the market capitalization of the capital market in Mongolia has exceeded 1 trillion MNT, and its share in GDP has also increased. In 2021, the total market capitalization (MV) reached 5.9 trillion MNT for the first time, and this indicator has almost doubled (98 percent increase) compared to the same period of the previous year. Since 2007, foreign direct investment has increased in our country, the growth of the capital market has taken place, and between 2010 and 2012, the price of the commodity in the world market has increased, as well as the price of copper and coal has increased 2-3 times as a result of the Chinese government's overexpansion policy. The sharp rise in government spending was a big boost to the capital market. In those years, foreign investors were interested in investing in Mongolia; however, between 2013 and 2016, due to the decline in commodity prices, they began to withdraw.

During 2017-2020, in addition to the high profitability (ROE) of major domestic minority companies, market capitalisation grew steadily due to the issuance of 133.1 billion MNT in shares and 1 trillion MNT in bonds in the primary market (see Figure 1).

As of 2024, the World Bank has not yet released specific liquidity indicators for countries with income levels below the global average, including Mongolia. However, as of June 2024, the global average liquidity indicator stands at 16.3%, which is slightly lower than 16.2% in

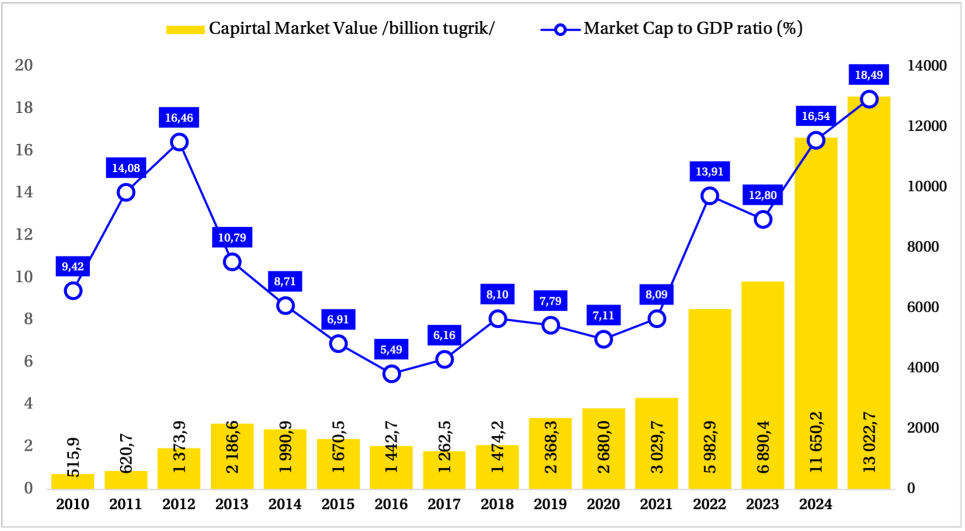


Figure 1 Market capitalization in Mongolia

the same period last year. Mongolia, classified as a low-income country, likely continues to exhibit lower liquidity indicators than high-income nations. In comparison, high-income countries typically report much higher liquidity levels, reflecting their more developed financial markets and greater access to capital. During the reporting period, stock market liquidity increased by 0.67 points relative to the previous quarter and by 0.98 points relative to the same period last year, reaching 2.48%. However, the market's overall liquidity remains low, largely due to the high concentration of shares. By the end of 2024, an analysis of the share distribution within the TOP-20 index revealed a significant concentration, with 81.80% of shares held by investors with more than 5% (see Figure 2).

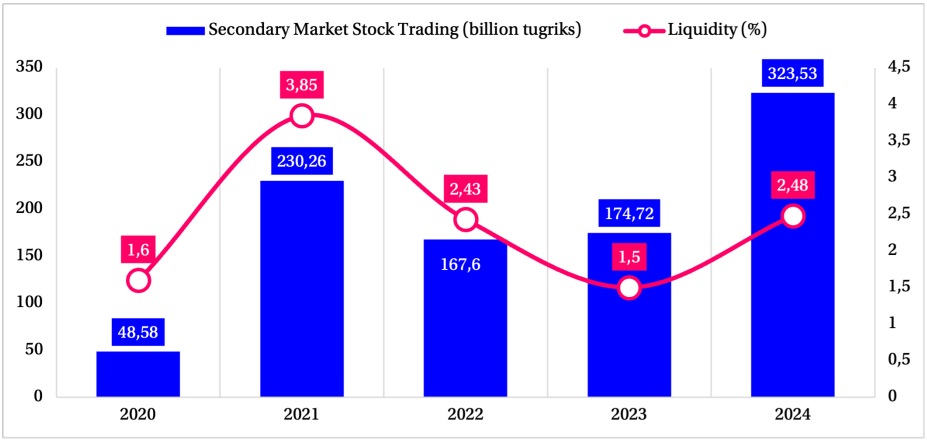


Figure 2 Market liquidity in Mongolia

A Comparative Analysis of Financial Market Development in Central Asia and Mongolia: This section of the research compares capital market development in Mongolia with that of three Central Asian economies: Kazakhstan, Uzbekistan, and Kyrgyzstan. The primary metric used for this analysis is the market capitalisation-to-GDP ratio, which serves as a key indicator of financial depth and market size. The data for this analysis were sourced from reputable international organisations and financial data providers, including the Asian Development Bank (ADB), the World Bank, CEIC Data, and TheGlobalEconomy.com. The market capitalisation-to-GDP ratio is calculated by dividing the total market value of all publicly traded companies by the country's gross domestic product (GDP) for a given year.

The data presented in Figure 3 reveal significant disparities in the level of financial market development across the studied countries.

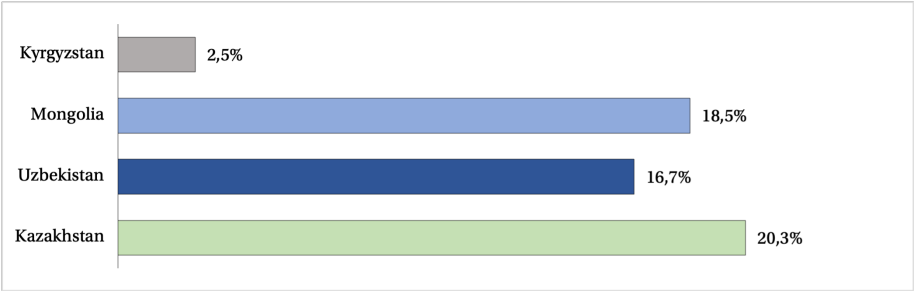


Figure 3 Market capitalization to GDP Ratio for Central Asia and Mongolia

Kazakhstan leads the group with a 20.3% ratio as of 2022, reflecting its status as the region's largest economy and a relatively mature capital market. However, this ratio remains low compared to the averages of well-developed economies, which often exceed 100%, indicating substantial room for further market deepening. Uzbekistan shows promising progress, with its ratio reaching 16.7% in 2024. This growth can be attributed to recent economic reforms and the government's policies to liberalize the financial sector and attract investment. Mongolia, with a 19% share in 2024, has a financial system in which the banking sector continues to dominate. The low market capitalisation ratio underscores the need to strengthen the capital market to diversify financing sources, attract long-term investment, and support economic diversification. Based on 2012 data, Kyrgyzstan had a very low capital market ratio of 2.5%, suggesting a nascent capital market with limited influence on the broader economy. This could be linked to political and economic instability, as well as a more restricted investment environment.

5 | RESULTS

The empirical findings are reported stepwise to facilitate reproducibility and interpretation. First, First, summary statistics for all variables employed in the estimations are presented. Second, the time-series properties of the data are assessed to confirm the admissible integration orders required for the ARDL approach. Third, long-run relationships are examined using the ARDL bounds procedure, and both long-run estimates and the associated error-correction dynamics are reported. The analysis concludes with a policy-relevant discussion.

Real economic activity, proxied by GDP (MNT millions), shows substantial variation over the sample, with a mean of 3,930,722 and values ranging from 190,998 to 24,884,433, indicating pronounced changes in macroeconomic scale across time. Stock market development

indicators also exhibit wide dispersion. Market value (MV; MNT millions, quarter-end value) averages 1,250,521, but spans from 29,135 to 12,974,256, reflecting periods of markedly different market depth. The Top 20 index (INDEX; MNT, quarter-end value) has a mean of 11,583 and ranges from 318 to 44,824, suggesting substantial shifts in equity price levels over time. Trading activity, measured by VS (MNT millions, quarter-end value), averages 17,536 with a range of 74 to 134,928, indicating episodes of very low and very high market activity consistent with liquidity fluctuations (Table 2).

Table 2 Summary statistics

Variable	Mean	Maximum	Minimum	Std. Dev	Observations
GDP	3930722.00	24884432.60	190998.30	3458540.00	100
MV	1250521.00	12974256.00	29135.45	1223949.00	100
INDEX	11583.32	44824.39	317.91	10182.61	100
VS	17535.82	134927.90	74.32	26725.87	100
CPI	86.30	147.20	35.90	30.54	100
REER	107.24	127.86	92.60	9.09	100
FDI	1480294.00	2850813.00	612493.60	579389.90	100

Note: compiled by the author

Macro and external-sector controls display comparatively smaller ranges in index terms but remain economically meaningful. Consumer prices (CPI) average 86.30 (min 35.90, max 147.20), while the real effective exchange rate (REER) averages 107.24 (min 92.60, max 127.86). Foreign direct investment (FDI; MNT millions) shows notable volatility, with a mean of 1,480,294 and values between 612,494 and 2,850,813, underscoring the importance of controlling for external financing conditions. The magnitudes and standard deviations suggest that both capital market variables and key macroeconomic fundamentals experienced considerable time variation, providing informative dynamics for time-series estimation.

Table 3 presents the Jarque–Bera (J–B) normality test results for all variables used in the estimations.

Table 3 Result of Jarque-Bera test

Variable	Jarque-Bera	Probability
GDP	*8.58*	*0.013*
MV	*30.88*	*0.000*
INDEX	*19.86*	*0.000*
VS	*199.76*	*0.000*
CPI	*93.79*	*0.000*
REER	*6.93*	*0.031*
FDI	*211.42*	*0.000*

Note: compiled by the author

The null hypothesis of normally distributed residuals is rejected for most series at conventional significance levels. In particular, MV, INDEX, VS, CPI, and FDI show p-values reported as 0.000, indicating strong evidence against normality. GDP (J–B = 8.58; p = 0.013) and REER (J–B = 6.93; p = 0.031) also depart from normality at the 5% level. Such distributional features are frequently observed in macro-financial time-series data, especially for market-related variables characterized by skewness and excess kurtosis and they motivate careful diagnostic checking and the use of robust inference where appropriate in the subsequent ARDL and regime-switching estimations.

The paper examine the correlation between dependent, independent, and control variables. Table 4 report the correlation coefficient for Mongolia.

Table 4 Correlation coefficients matrix for Mongolian sample

Correlation	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GDP	*1.000*						
MV	*0.892* *0.000****	*1.000*					
INDEX	*0.837* *0.000****	*0.777* *0.060**	*1.000*				
VS	*0.598* *0.000****	*0.721* *0.000****	*0.722* *0.000****	*1.000*			
CPI	*−0.168* *0.117*	*−0.006* *0.954*	*0.062* *0.564*	*0.122* *0.256*	*1.000*		
REER	*0.216* *0.042***	*0.288* *0.006****	*0.344* *0.001****	*0.155* *0.147*	*0.285* *0.007****	*1.000*	
FDI	*0.650* *0.000****	*0.669* *0.000****	*0.630* *0.000****	*0.675* *0.000****	*−0.016* *0.878*	*−0.070* *0.518*	*1.000*

***p<0.01, p<0.05
** p<0.10
*(i.e., ***, ** and * show significant at 1%, 5%, and 10% levels)

Note: compiled by the author

There is a positive correlation between total market capitalization and gross domestic product in Mongolia with a value of 0.892 which is relatively high. On the other hand, the correlation between CPI and GDP is -0.168, whereas the correlation with INDEX is approximately 0.837.

Before estimating the ARDL and Markov-switching models, it is necessary to examine the time-series properties of the variables, particularly whether they are stationary or contain a unit root. Regressions involving non-stationary series may yield spurious relationships, where statistically significant coefficients arise from common trends rather than meaningful economic linkages. Moreover, the validity of the ARDL bounds testing approach requires that the regressors be integrated of order I(0) and/or I(1). At the same time, the presence of I(2) variables invalidates the critical values and undermines inference. For this reason, the study conducts unit-root testing to (i) verify that none of the variables is I(2), (ii) determine the integration order of each series, and (iii) justify the subsequent cointegration testing and error-correction representation within the ARDL framework. To enhance robustness given that individual tests may differ in power and maintain distinct null hypotheses, the analysis applies both the Augmented Dickey–Fuller (ADF) test and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test, providing complementary evidence on stationarity.

In economic literature, the Augmented Dickey-Fuller (Fuller, 1995) and Kwiatkowski-Phillips-Schmidt-Shin et al. (Kwiatkowski et al., 1992). Tests are conducted to examine the long-run relationship stationarity among the assigned variables. The results of these tests are presented in Table 5.

The ARDL bounds testing procedure based on the unrestricted error-correction specification provides evidence of a long-run relationship between GDP and the set of capital-market and macroeconomic variables (MV, REER, CPI, VS, INDEX, FDI). Using the selected lag structure (2,1,0,0,1,0,2), the estimated F-statistic (4.538) exceeds the upper critical bound

Table 5 ADF test result

Variable	Augmented Dickey-Fuller		Remarks
	Level	1st difference	
GDP	−1.73	−10.76***	I(1)
MV	−1.60	−4.04***	I(1)
INDEX	−1.01	−7.42***	I(1)
VS	−2.69*	−10.23***	I(0)
CPI	−1.29	−15.45***	I(1)
REER	−2.54	−8.21***	I(1)
FDI	−3.91***	7.41***	I(0)

Note: compiled by the author

reported for the 1% significance level I(1)=3.99I(1)=3.99 (with I(0)=2.88I(0)=2.88). This leads to rejection of the null hypothesis of no cointegration, implying that the variables move together in the long run and converge toward an equilibrium relationship. On this basis, the subsequent ARDL estimation proceeds with reporting both the long-run coefficients and the error-correction adjustment dynamics (see Table 6).

Table 6 The results of the ARDL cointegration test

Bound testing for cointegration			Critical value as the significance level of 1%	
Estimated models	Optimal lag length	F-statistics	Lower bound I(0)	Upper bound I(1)
F_{GDP} (GDP, MV, REER, CPI, VS, INDEX, FDI)	(2, 1, 0, 0, 1, 0, 2)	4.538***	2.88	3.99
k=6				

Note: compiled by the author

The ARDL models fulfil the assumptions of normality, autoregressive conditional heteroskedasticity (ARCH), functional forms, and serial correlation. After examining the cointegration between the dependent and independent variables, this research estimated static short-term spillover coefficients for GDP, INDEX, MV, and VS using the ARDL model.

For the most part, Figure 4 shows the strength of the selected model criteria.

Having completed the foregoing analysis, the superiority of the Akaike information criterion over other criteria is based on the following: 20 ARDL models were estimated. The lower value of AIC will be selected; that is, ARDL (2, 1, 0, 0, 1, 0, 2) gives the lowest value of AIC. The estimation results of the ARDL model are presented in Table 7.

Lagged GDP one and two periods are positive and statistically significant, and the magnitude of economic growth is increased. Besides that, both FDI and lagged FDI for one period are positive, but not statistically significant. In this case, it is expected that market capitalization (MV) will impact the growth of GDP positively, which imply the MV is statistically significant at a 1 percent level. Other things equal, a 1 percent rise in the MV will cause 0.102 percent boost in GDP.

Share price index ($INDEX$) is not statistically significant at 10 percent level. This variable indicates that Mongolia looks at the directions of the capital market through the market share index. Coefficient of determination points out which high causal relationship between the dependent variable, $LnGDP$, and dependent variable $LnMV, LnVS, LnINDEX, LnFDI, CP$ and $REER$ are given by R^2. This indicates that 99.7 percent of independent variables to-

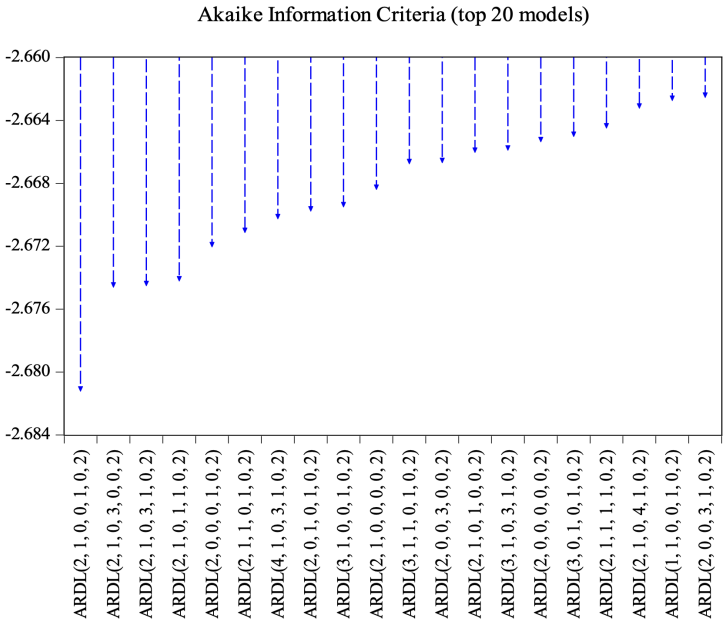


Figure 4 Akaike Information Criteria (AIC) - Top 20 models

Table 7 The ARDL regression model

Variable	Coefficient	Std. Error	T-Statistic	Probability
LnGDP(−1)	0.765***	0.113	6.734	0.000
LnGDP(−2)	0.201*	0.112	1.797	0.070
LnMV	0.102***	0.021	4.857	0.001
LnMV(−1)	−0.071*	0.041	−1.707	0.091
REER	−0.001	0.001	−1.560	0.122
CPI	0.001	0.001	1.172	0.245
LnVS	−0.008	0.011	−0.735	0.464
LnVS(−1)	0.017	0.010	1.655	0.102
LnINDEX	−0.008	0.042	−0.191	0.848
LnFDI	0.005	0.012	0.422	0.673
LnFDI(−1)	0.002	0.012	0.164	0.869
LnFDI(−2)	−0.026***	0.009	−2.788	0.006
Constant	0.337*	0.188	1.789	0.077
R-squared	0.997			
Adjusted R-squared	0.997			
F-statistic	2794.075			
Prob (F-statistic)	0.000			
D-W	2.027			

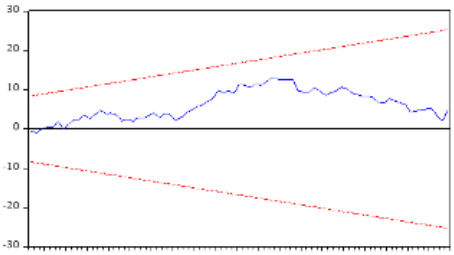
Note: compiled by the author

gether explain the systematic variations in $LnGDP$. Then, the $D-W$ test gave a good fit and there is no presence of a serial correlation problem.

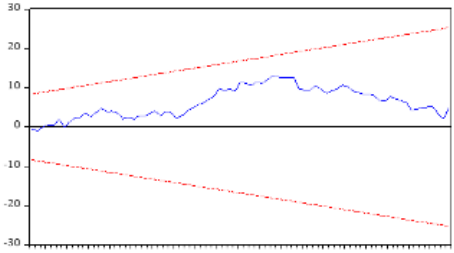
From the results, the long-run function of total market capitalization that an increase of growth at 1% will result in an increase of GDP at 0.956%, while the long-run function of growth an increase of total value of shares at 10% will result in an increase of growth at 2.73% (Application 1).

The negative and statistically significant estimation of $ECM_(t-1)$ in function at 0.032 respectively show a short run relationship among the variables of the model under study. This means that, in the short run, deviations from the long-run equilibrium are corrected by 3.2% each year. All diagnostic tests in the short-run model appear to be satisfactory. According to the diagnostic tests, the serial correlation LM test showed no serial correlation, and there was no heteroskedasticity.

The existence of cointegration coming from equations 6 and 7 does not necessarily imply that the estimated coefficients are stable. This is why (Pesaran et al., 1999, 2001) suggested the test of stability of the estimated coefficients in the estimated models using the tests of (Brown et al., 1975), which are known as the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMQ). The error-correction specification is adopted to facilitate the parameter stability tests proposed by Brown et al. (1975). The corresponding graphical diagnostics are presented in Figure 5.



Plot of cumulative sum of recursive residuals



Plot of cumulative sum of squares of recursive residuals

Figure 5 Squares stability diagnostics

As it arises from the above figures, all the plots of statistics CUSUM and CUSUMQ are inside the critical bounds at 5% level of significance, which entails that all the coefficients in the error correction model are constant. The result of the test shows that is a unidirectional causality running total market capitalization (MV) to economic growth in Mongolia. After testing stability in ECM, we examine the causality test, which is presented in Table 8.

Table 8 The VECM Granger causality test

	Dependent variable: $\Delta(\mathbf{GDP}_t)$	
Variable	χ^2	Probability
$\Delta(\mathrm{MV}_t)$	27.989***	0.000

Reject the null hypothesis if the p-value is less than 1% significance level, ***, **, and * show significance at 1%, 5%, and 10% levels.

Note: compiled by the author

FMOLS and DOLS are used as robustness checks for the ARDL long-run results. In cointegrated time-series models, standard OLS estimates can be biased due to endogeneity

and serial correlation; FMOLS corrects these problems through fully modified adjustments, while DOLS does so by adding leads and lags of differenced regressors. If the key coefficients remain similar across ARDL, FMOLS, and DOLS, the long-run relationship is considered more stable and reliable. Table 9 illustrates regression test results.

Table 9 Robustness regression test results

Variable / Model	FMOLS	DOLS
LnINDEX	−0.002	−0.054*
LnMV	0.125***	0.037***
LnFDI	−0.091**	−0.259***
LnVS	−0.036	0.214**
Constant	10.282***	11.045***
Control variables		
CPI	−0.006	0.012**
REER	−0.008**	−0.003
LnFDI	−0.091**	−0.259***
R-squared	0.990	0.994

Note: compiled by the author

FMOLS and DOLS are employed as robustness checks for the ARDL long-run results. In cointegrated time-series models, conventional OLS estimators may be subject to endogeneity and serial correlation; FMOLS addresses these issues through fully modified corrections, whereas DOLS incorporates leads and lags of differenced regressors. The robustness estimates are broadly consistent with the main ARDL findings. LnMV remains positive and statistically significant in both specifications, confirming the growth-enhancing role of market capitalization. LnFDI exhibits a negative and significant coefficient, while LnINDEX shows a negative effect and becomes statistically significant under DOLS, suggesting that market concentration may have adverse growth implications. Liquidity (LnVS) is insignificant in FMOLS but positive and significant in DOLS. Overall, the consistency of coefficients across specifications supports the stability of the long-run relationship.

6 | CONCLUSION

This study assesses the contribution of capital market (stock market) development to Mongolia's economic growth using quarterly observations spanning 2000: Q1-2024: Q4. Using an ARDL framework complemented by a Markov-switching specification to account for regime-dependent dynamics, the empirical results indicate a positive and statistically significant association between capital market development and economic growth in both the short run and the long run. Specifically, the estimates suggest that a 10% increase in market capitalization is associated with a 1.02% increase in GDP in the short run and a 9.56% increase in the long run. The negative and statistically significant error-correction term (-0.032) implies a gradual convergence toward the long-run equilibrium, which is consistent with the slow-moving and structural character of financial deepening in a small open economy.

Regime-switching evidence further indicates that market value supports GDP growth across regimes, whereas the Top 20 index exhibits a negative association in both high- and low-growth regimes, pointing to persistent market concentration and broader structural constraints in Mongolia's equity market. Taken together, these findings suggest that sustaining the growth-enhancing effects of capital market development requires reforms that expand participation, strengthen disclosure and corporate governance, and deepen liquid-

ity, thereby improving the likelihood that financial expansion translates into more inclusive and stable economic outcomes.

The analysis also documents the recent acceleration of Mongolia's capital market, including the rise in market capitalization observed in the post-COVID-19 period. This pattern is consistent with a portfolio reallocation toward capital market instruments under macroeconomic conditions that compress the real returns available on deposits. From a policy standpoint, the empirical evidence aligns with national development priorities that emphasize capital market strengthening and regulatory modernization, underscoring the relevance of measures that improve market infrastructure, enhance investor protection, and reinforce the institutional foundations of governance among listed firms.

Finally, while the core econometric estimation is Mongolia-specific and based on time-series methods, the study explicitly incorporates a regional perspective by assessing Mongolia's capacity for deeper cooperation with Central Asian economies. Rather than invoking regional integration as a descriptive claim, cooperation potential is framed through comparable indicators of market depth, liquidity, and price-index dynamics for Kazakhstan, Kyrgyzstan, Uzbekistan, and Turkmenistan. This approach is intended to identify contexts in which Mongolia is most plausibly positioned to pursue practical collaboration, such as information exchange, learning from regional reform experiences, facilitation of cross-border investment, and gradual regulatory coordination—while keeping the principal inference centred on Mongolia's growth–market nexus. Overall, the results support the conclusion that Mongolia's ongoing capital market development is economically consequential and that structured, indicator-based cooperation with Central Asian counterparts is a relevant strategic direction for strengthening market functionality and resilience.

AUTHOR CONTRIBUTION

Writing – original draft: Ankhbileg Khurelbaatar.
Conceptualization: Ankhbileg Khurelbaatar.
Formal analysis and investigation: Ankhbileg Khurelbaatar.
Development of research methodology: Ankhbileg Khurelbaatar.
Software and supervisions: Ankhbileg Khurelbaatar.
Data collection, analysis and interpretation: Ankhbileg Khurelbaatar.
Visualization: Ankhbileg Khurelbaatar.
Writing review and editing research: Ankhbileg Khurelbaatar.

CONFLICT OF INTEREST

No conflict of interest/competing interest is reported by the authors.

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Economic Freedom and Foreign Direct Investment in Central Asia: Short-Run and Long-Run Evidence

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Abstract
In the context of the transformation of post-socialist economies and increasing global competition for capital, the analysis of institutional factors in attracting foreign direct investment is of particular importance. The aim of the study is to assess the short– and long-term impact of economic freedom on the inflow of foreign direct investment in five Central Asian countries over the period 1998-2024. Using a panel autoregressive distributed lag (ARDL) approach with the Pooled Mean Group (PMG) estimator, the analysis distinguishes between short-run and long-run effects while accounting for cross-sectional dependence and heterogeneity across countries. Panel unit root tests indicate that the variables are integrated of mixed order, justifying the application of the panel ARDL framework. The results showed that there is a stable long-term relationship between economic freedom and investment inflows. The long-term coefficient of economic freedom is 0.095 ($p < 0.01$), which indicates a positive and statistically significant impact of institutional quality on the investment attractiveness of the region. In the extended model specification, this effect persists (0.114; $p < 0.01$). The error correction factor is -0.65 ($p < 0.01$), which indicates a correction of about 65% of short-term deviations from equilibrium during one period. The short-term effects turned out to be statistically insignificant, which confirms the inertial nature of investment decisions. The results have important policy implications, highlighting the need for sustained institutional reforms aimed at improving economic freedom to foster stable and long-term foreign investment inflows

KEYWORDS
Economy, Economic Freedom, Economic Growth, Investment, Foreign Direct Investment, Institutional Quality, Central Asia

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1 | INTRODUCTION

Since the 1980s, the deepening of globalization processes has been accompanied by the structural transformation of national economies and the strengthening of market institutions in ensuring economic growth. In parallel, the neoliberal paradigm, promoted by international financial organizations through structural adjustment mechanisms and credit support instruments, has encouraged developing countries to implement institutional and macroeconomic reforms. These reforms were aimed at trade liberalization, market deregulation, the strengthening of property rights, and fiscal consolidation, which collectively contributed to the expansion of economic freedoms and the integration of countries into the global economic system.

From a theoretical perspective, economic freedom (hereinafter – EF) is regarded as a factor that facilitates increased inflows of foreign direct investment (hereinafter – FDI) by reducing administrative barriers, strengthening the rule of law, enhancing the predictability of the institutional environment, and reinforcing competitive market mechanisms (Hall & Lawson, 2013). Improvements in institutional conditions reduce transaction costs and investment risks, thereby increasing a country's attractiveness to foreign investors. In turn, FDI, by ensuring the inflow of capital, modern technologies, managerial competencies, and integration into global value chains, may contribute to the expansion and increasing complexity of the export structure, the formation of new industries, and the transition toward a more diversified and higher-income development model (Fonchamnyo, 2015; Gamariel et al., 2022). Thus, EF acts as a determinant of FDI inflows, while FDI itself represents one of the key channels for ensuring sustainable economic growth (Azretbergenova et al., 2022; Serikkyzy et al., 2024).

This issue assumes particular research significance in Central Asia, where countries have been undergoing institutional transformation since the dissolution of the Soviet Union in 1991. The transition from a centrally planned to a market-based model was accompanied by the restructuring of state institutions, the reform of property rights systems, the liberalization of foreign economic activity, and the gradual formation of market infrastructure. Under these conditions, the analysis of the relationship between the level of EF and FDI inflows enables empirical assessment of the effectiveness of institutional reforms and their impact on the trajectory of economic development.

The present study aims to identify and quantitatively assess the relationship between EF and FDI in the Central Asian countries, including Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, and Tajikistan, while accounting for their post-socialist specificity and institutional dynamics. Prior to 1991, the countries of Central Asia operated under conditions of a centralized planned economy and politically authoritarian regimes. Following the dissolution of the Soviet Union, they entered a phase of systemic transformation characterized by the transition from an administrative-command model to a market economy and the gradual institutional restructuring of political systems. However, unlike the countries of Central and Eastern Europe, where transformation processes were relatively rapid and accompanied by accelerated institutional convergence with European standards, the transition in Central Asia was more protracted and heterogeneous. Even more than three decades later, institutional constraints, structural imbalances, and elements of incomplete market transformation persist (Kakizhanova et al., 2025).

In Central Asia, FDI volumes declined by 39 per cent to United States dollars 4 billion (net inflow), while the number of new greenfield projects decreased by 11 per cent, from 158 to 140. According to McKinsey, the structure of global FDI has changed radically over the past five years: whereas capital investments in services and traditional industries previously

accounted for the largest share, since 2022, there has been a shift toward capital-intensive technology sectors (Heritage Foundation, 2025).

Differences in transition trajectories have generated increased scholarly interest in the analysis of post-socialist economies. In recent years, there has been a growing number of empirical studies devoted to the assessment of institutional reforms, investment dynamics, and structural changes in these countries. Nevertheless, the existing literature contains a limited number of studies that consider EF as an independent determinant of FDI inflows, particularly in the context of its influence on structural transformation and export diversification (Ydyrys & Sharhanova, 2022; Pobirchenko & Shutaeva, 2025).

In contrast to previous studies, the present work seeks to provide a comprehensive analysis of the relationship between the level of economic freedom, FDI inflows, and the degree of export diversification in the Central Asian countries. The limited number of empirical studies that integrate these variables into a unified analytical model served as the primary motivation for this research.

The purpose of this study is to assess the short- and long-term effects of EF on FDI inflows in five Central Asian countries–Kazakhstan, Kyrgyzstan, Turkmenistan, Tajikistan, and Uzbekistan–over the period 1998–2024. To achieve this objective, the study conducts a comprehensive statistical analysis of FDI and EF indicators, determines the average EF level in the region, performs panel unit root tests, and examines cross-sectional dependence among the variables. Furthermore, the existence of a long-run equilibrium relationship between EF and FDI is tested using the Doan and Pedroni panel cointegration approaches, while the short- and long-run dynamics are estimated within the PMG Panel ARDL framework. The analysis is based on a balanced panel covering 1998–2024, ensuring data consistency, improving the reliability of econometric estimates, and enhancing the comparability of the empirical results.

2 | LITERATURE REVIEW

The question of the impact of economic freedom, institutional quality, and trade liberalization on FDI inflows constitutes one of the key directions of contemporary empirical literature. Studies demonstrate a stable relationship among the institutional environment, the level of economic openness, and countries' investment attractiveness. However, the results vary by sample of countries, time period, and methodology employed. Early empirical studies focused on the role of trade liberalization and membership in international organizations. For example, Binh and Haughton (2002), based on an analysis of 16 Asian countries for the period 1990–1999 using panel ordinary least squares, demonstrated that trade liberalization and membership in the World Trade Organization contribute to FDI growth, with the effect of World Trade Organization membership strengthening both in the short and long term. This study laid the foundation for subsequent analyses of institutional determinants of investment attractiveness.

Expanding the geographical scope, Quazi and Rashid (2004) used a sample of 67 developing countries for 1995–2000 and found that EF and trade openness exert a statistically significant and positive effect on FDI. Their findings confirm the hypothesis that liberal economic policies create a favorable investment environment. The institutional dimension of the investment climate is examined in greater detail in the study by Dutta and Roy (2009), who employing two-stage least squares and ordered probit models for 115 countries, demonstrated that freedom of the press, democracy, and the level of education positively influence FDI inflows, whereas dependence on natural resources has a negative effect. This indicates the risks associated with the resource curse and underscores the importance of

high-quality institutions.

The relationship between FDI and structural economic transformation is analyzed in the study by Shin (2010) for countries of the Organisation for Economic Co-operation and Development. The author established that FDI contributes to export diversification and mitigates the adverse effects of crises, thereby highlighting the role of foreign investment as a mechanism for enhancing economic resilience. A systematization of accumulated empirical findings is presented in the meta-analysis by Hall and Lawson (2013), encompassing 402 studies. The authors concluded that EF is generally positively associated with economic growth, investment, and welfare levels, which indirectly confirms its significance for attracting FDI. Subsequent studies emphasize the interaction between economic and political freedoms. Sambharya and Rasheed (2015), applying panel generalized least squares to 95 countries, demonstrated that economic and political freedoms stimulate FDI, whereas corruption and excessive government intervention reduce it. Similar conclusions were reached by Ghazalian and Amponsah (2019), where ordinary least squares and generalized method of moments estimations confirmed the central role of the rule of law, market openness, and regulatory freedom.

Regional studies demonstrate heterogeneity of effects. For example, Fonchamnyo (2015), analyzing countries of the Central African Economic and Monetary Community, identified a positive impact of FDI and trade openness on export diversification but noted a negative effect of natural resource rents. In the study by Lee et al. (2015) focusing on Kazakhstan, FDI was shown to stimulate economic growth. However, its contribution to diversification was limited, particularly in the manufacturing sector.

The use of dynamic models has enhanced the empirical robustness of conclusions. Naanwaab and Diarrassouba (2016), employing the generalized method of moments for 137 countries, confirmed the positive influence of EF on FDI but noted that in low-income countries this effect is weaker and significantly dependent on the level of human capital. Similar results are presented in the study by Osakwe et al. (2018), where trade liberalization and institutional quality promote export diversification.

Recent studies have focused on financial factors and macroeconomic stability. Paul and Jadhav (2020) demonstrated that infrastructure and institutional quality increase FDI, whereas corruption and high trade costs reduce it. In the study by Yusuf et al. (2020), using a panel autoregressive distributed lag approach, it was established that in the long term, FDI contributes to economic growth; however, political instability diminishes this positive effect. For African countries, issues of financial development and institutional quality are particularly relevant. Kwablah and Amoah (2022) found that EF strengthens the impact of FDI on growth under conditions of low financial vulnerability. Shikur (2024), employing the system generalized method of moments, confirmed the positive influence of EF and financial development on FDI but emphasized that high tax pressure and weak infrastructure offset this effect. A regional comparative analysis by Singh and Gal (2020) likewise demonstrates that economic and trade freedom positively affect FDI, whereas tax burden and corruption negatively affect it.

In economic literature, the positive impact of EF on attracting FDI is explained by the fact that a liberal institutional environment creates conditions for the more effective integration of foreign investors into the national economy. First, FDI facilitates the transfer of modern technologies to host countries. Second, foreign companies introduce advanced methods of business organization and management under market conditions. Third, high-technology employment opportunities are created, thereby increasing the level of human capital and contributing to the structural modernization of the economy.

Practical confirmation of these propositions can be observed in several countries of Southeast Asia, such as China, Vietnam, Singapore, and Malaysia, which have used FDI as a strategic instrument for technological modernization and the enhancement of international competitiveness. These countries have succeeded in integrating foreign investment into long-term development strategies, thereby ensuring sustainable economic growth and production diversification (Abutalipov & Deger, 2024; Platonova, 2025; Yuan, 2024). A study conducted by Socol and Iuga emphasizes that EF and institutional quality play an important but ambiguous role in shaping the investment and financial environment. Analyzing data for 27 European Union countries for the period 2001–2020 using a dynamic panel GMM approach, the authors show that democracy and high-quality institutions contribute to the stability and efficiency of the financial sector, while EF in developed markets can have a negative impact due to increased competition and risks. These results indicate that the impact of EF on capital inflows depends on the institutional and macroeconomic context (Socol & Iuga, 2025). Similar conclusions were reached in the work of Dang and Anh, which confirms that the effect of EF on the stability of banking systems and the investment attractiveness of countries is conditional and depends significantly on the level of economic policy uncertainty. In conditions of institutional stability, EF contributes to the formation of a favorable investment climate, while in conditions of high political uncertainty, its impact may be neutral or negative (Socol & Iuga, 2025).

Gidage and Bhide (2025) showed that the quality of institutions and EF have a sustained positive impact in the long term, emphasizing the importance of distinguishing between short-term and long-term effects using an ARDL panel model. These findings are consistent with the results of Kunawotor et al. (2025) identified the positive impact of EF and the quality of institutions on economic well-being and emphasize the role of strong institutions in mitigating the negative effects of public policy in developing countries. Toms and Lin (2025) add to this literature by showing that increased EF and financial liberalization without adequate institutional control can lead to systemic risks and a decline in investor confidence. From a theoretical perspective, Fatah et al. (2025) emphasised the limitations of the neoliberal approach and argued that EF must be accompanied by institutional stability and social inclusion to ensure sustainable development. Empirical results from East Asian countries confirm that not all institutional components are equally important for economic growth, with the quality of regulation and control of corruption playing a key role–factors directly related to the investment decisions of foreign investors. Taken together, the existing literature points to the need to analyze the short- and long-term effects of EF on FDI in Central Asian countries (Iskandar et al., 2025).

Despite the extensive empirical literature, the Central Asian countries remain insufficiently studied in the context of the impact of economic freedom on foreign direct investment inflows, given their post-socialist institutional specifics. Most studies do not distinguish between short-term and long-term effects and do not account for cross-country dependence and heterogeneity, which limits the interpretation of the results. Thus, a methodological and regional gap remains, necessitating a dynamic panel analysis of the long- and short-term impacts of economic freedom on investment flows in Central Asia.

3 | RESEARCH METHODS

This study is based on a panel data analysis of five Central Asian countries–Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan–for the period 1998–2024. The selected time span ensures the availability of complete and comparable statistical data for all countries, allowing the construction of a balanced panel dataset. Countries with incomplete or

inconsistent data were excluded to preserve the reliability and consistency of the empirical analysis. The empirical model includes the following variables: FDI, EF, GDP, and Inflation (INF). FDI is measured as net inflows as a percentage of GDP. EF is represented by the overall EF Index score. GDP is measured as annual real GDP growth (percentage), reflecting each country's macroeconomic performance and economic expansion. Inflation is captured using the annual GDP deflator (percentage), which reflects overall price dynamics in the economy (Table 1).

Table 1 Variables used in the study

Abbreviation	Definition	Measurement	Source
FDI	Foreign Direct Investment	Net FDI inflows (% of GDP)	World Bank (2024)
EF	Economic Freedom	Economic Freedom Index (overall score)	The Heritage Foundation (2024)
GDP	Market Size / Economic Development	Real GDP (annual %)	World Bank (2024)
INF	Inflation	GDP deflator (annual %)	World Bank (2024)

Note: compiled by the author

All data was obtained from internationally recognized databases, primarily the World Bank's World Development Indicators and The Heritage Foundation database. The use of harmonized international sources ensures cross-country comparability and consistency over time. The study uses the Index of EF, published annually by the Heritage Foundation, as a key indicator of institutional performance. This index reflects a country's level of EF based on 12 indicators characterizing the rule of law, the size of the state, the effectiveness of regulation, and the openness of markets, and is measured on a scale from 0 to 100. The final value is calculated as a weighted average of these components, with higher index values indicating a more favorable institutional environment for free economic choice and competition, which is theoretically associated with increased investment activity and sustainable long-term economic growth.

The empirical strategy follows a stepwise panel econometric procedure. First, panel unit root tests are conducted to determine the variables' integration properties and confirm that none are integrated of order two. Second, cross-sectional dependence tests are applied to assess potential interdependence among the countries. Third, panel cointegration tests are performed to verify the existence of a long-run equilibrium relationship between EF and FDI. Finally, the long-run and short-run dynamics are estimated using the Pooled Mean Group Panel ARDL estimator, which allows for heterogeneous short-run adjustments across countries while imposing homogeneity on long-run coefficients. Econometric calculations and empirical analysis were conducted using the EViews software package.

4 | RESULTS

Prior to the econometric analysis, a preliminary statistical examination of the variables included in the model is conducted. This analysis provides an overview of the central tendencies, dispersion, and distributional characteristics of the data, allowing for an initial assessment of variability and potential heterogeneity within the panel. Table 2 presents the descriptive statistics for FDI, EF, GDP, and INF for the selected Central Asian countries over the period 1998–2024.

Table 2 Descriptive statistics

Statistic	FDI	EF	GDP	INF
Mean	4.536	52.186	6.310	14.765
Median	3.170	52.200	6.500	11.869
Maximum	22.520	71.100	16.500	87.876
Minimum	−4.850	31.050	−7.150	−5.153
Std. Deviation	4.100	8.311	3.412	13.222
Skewness	1.367	−0.087	−0.332	2.005
Kurtosis	5.497	2.454	4.815	9.826
Jarque–Bera	77.100	1.848	21.014	352.539
Probability	0.000	0.397	0.000	0.000
Observations	135	135	135	135

Note: authors' calculations using EViews

The results indicate that the average EF level is approximately 52 points, reflecting a moderate level of institutional development in the region. The FDI variable exhibits considerable variability, with a relatively high standard deviation and positive skewness, indicating the presence of several periods characterized by substantial investment inflows. GDP shows moderate dispersion and slight negative skewness, suggesting that extremely high-growth episodes were less frequent than moderate growth periods.

INF demonstrates significant variability and pronounced positive skewness, reflecting episodes of high price instability in certain years. The Jarque–Bera statistics indicate that most variables deviate from a normal distribution, particularly FDI and INF, which exhibit higher kurtosis. Overall, the descriptive statistics highlight substantial heterogeneity in macroeconomic and institutional conditions across Central Asian countries during the analyzed period.

Overall, visual analysis indicates a positive correlation, whereby countries with higher EF levels tend to have higher FDI volumes. Figure 1 shows the cross-country relationship between EF levels and FDI in Central Asian countries.

Kazakhstan (KAZ) demonstrates both a high EF and significant FDI, which is consistent with general theoretical expectations. Kyrgyzstan (KGZ) and Tajikistan (TJK) occupy intermediate positions, reflecting moderate values for the indicators analyzed. Uzbekistan (UZB), despite a comparable level of FE, is characterized by relatively lower volumes of FDI. At the same time, Turkmenistan (TKM) is a special case: despite a relatively low EF, the country attracts significant FDI volumes. This discrepancy can be explained by the specific structure of FDI, which is mainly focused on the raw materials and energy sectors and is largely shaped by state and intergovernmental agreements rather than market institutional conditions.

Overall, the descriptive analysis shows a positive relationship between EF and FDI. At the same time, the identified cross-country heterogeneity points to the need for more rigorous panel econometric methods, which justifies the use of PMG-Panel ARDL models to assess short- and long-term effects.

When analyzing the temporal properties of variables in the study, panel tests for unit roots were applied, including Levin–Lin–Chu (LLC), Im–Pesaran–Shin (IPS), ADF-Fisher, and PP-Fisher. The results of the corresponding tests are presented in Table 3.

The results of the panel unit root tests reported in Table 3 provide evidence on the stochastic properties of the variables included in the model. To ensure robustness, four complementary panel unit root tests were applied: Levin–Lin–Chu (LLC), Im–Pesaran–Shin

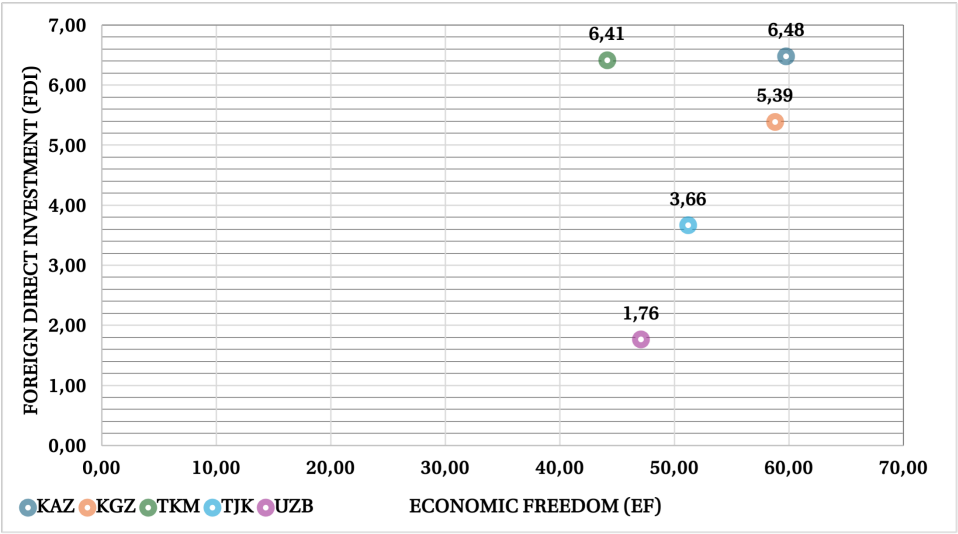

Figure 1 Relationship between Economic Freedom and Foreign Direct Investment in Central Asian Countries

(IPS), ADF-Fisher, and PP-Fisher. The order of integration was determined based on the consistency of results across these tests, following a majority decision rule. The findings indicate that GDP and INF are stationary at levels, as all applied tests consistently reject the null hypothesis of a unit root at the 1% significance level. For EF, most tests also reject the null hypothesis at conventional significance levels, although the statistical evidence is comparatively weaker; therefore, EF can be classified as weakly stationary at level, i.e., I(0).

Table 3 Panel unit root test result

Variable	LLC	IPS	ADF-Fisher	PP-Fisher	Conclusion
EF	−2.28**	−2.01**	19.17**	22.31**	Stationary (weak)
FDI	−1.41*	−1.02	12.15	31.50***	Mixed
GDP	−2.81***	−3.49***	30.51***	43.48***	Stationary
INF	−2.96***	−3.46***	31.29***	54.43***	Stationary
ΔEF	−4.72***	−5.25***	46.00***	73.12***	Stationary
ΔFDI	−7.20***	−8.16***	73.99***	125.04***	Stationary
ΔGDP	−8.04***	−8.03***	72.43***	118.37***	Stationary
ΔINF	−7.80***	−10.03***	92.46***	105.19***	Stationary

*, **, *** denote rejection of the unit root null at 10%, 5%, and 1% significance levels, respectively.

Note: authors' calculations using EViews

In contrast, the evidence for FDI at the level is mixed. While the PP-Fisher statistic suggests stationarity, the LLC and IPS tests do not uniformly reject the null hypothesis of a unit root, preventing a definitive classification of FDI as I(0). However, all panel unit root tests applied to the first-differenced series (ΔFDI) strongly reject the null hypothesis at the 1% level, confirming that FDI becomes stationary after first differencing. Moreover, the

first differences of all variables (ΔEF, ΔFDI, ΔGDP, and ΔINF) are found to be statistically stationary. Accordingly, the variables can be classified as follows: FDI – I(1); EF – I(0) (weakly stationary); GDP – I(0); and INF – I(0).

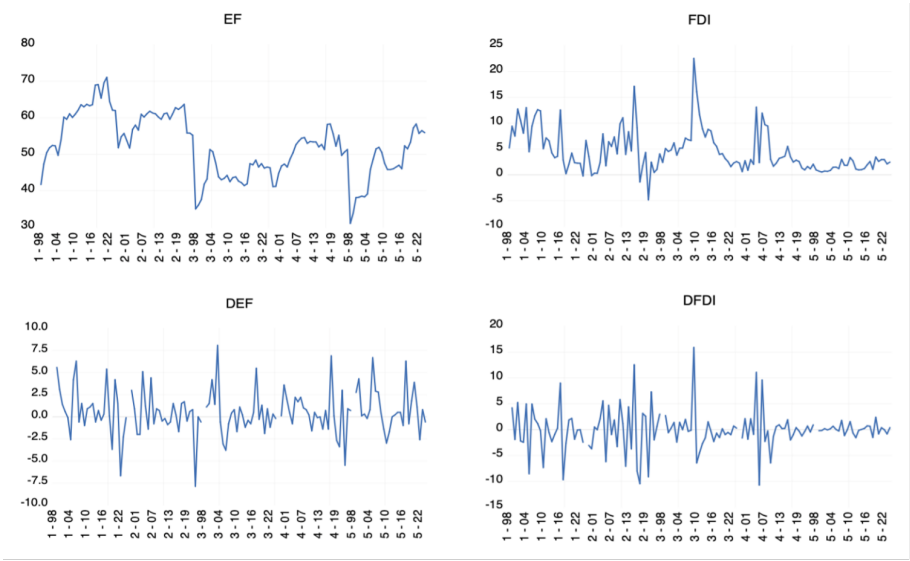

Figure 2 Level and first-difference series of EF and FDI

The results of panel unit root tests show that the first differences of both variables are statistically stationary at the 1% level, as confirmed by all applied tests. The analysis of cross-sectional dependence in panel data is traditionally based on the Breusch–Pagan LM test, which is widely used to identify horizontal dependence. However, the literature notes that this test can yield biased results when the group mean is zero, but the individual means differ significantly from zero.

In this regard, the Pesaran CD test has become widely used, especially in panels with a large number of countries (N) and a relatively short time horizon (T), as it is based on the average pairwise correlation between cross-sections and demonstrates high statistical power under such conditions. In addition, the Pesaran scaled LM test was developed to address the classical LM test's excessive sensitivity and is considered more reliable for both small and large samples.

This study takes a comprehensive approach that considers the historical development and methodological improvements mentioned above, using a set of tests that includes the Breusch–Pagan LM, the Pesaran-scaled LM, and the Pesaran CD. This multifaceted approach enables more reliable and consistent identification of various aspects of horizontal dependence. The hypotheses tested in the horizontal dependence tests are formulated as follows:

H0: There is no cross-sectional dependence

H1: There is cross-sectional dependence

The results of the analysis of cross-sectional dependence on panel data are presented in Table 4.

The results of the cross-sectional dependence tests reported in Table 4 allow us to re-

Table 4 Cross-section dependence and slope heterogeneity test results

Test	EF	FDI	GDP	INF
Breusch–Pagan LM	126.880***	21.421**	35.753***	39.151***
Pesaran scaled LM	26.135***	2.554**	5.759***	6.518***
Bias-corrected scaled LM	26.039***	2.458**	5.662***	6.422***
Pesaran CD	10.856***	2.587***	3.161***	5.665***

***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.
The null hypothesis for all tests is no cross-sectional dependence.

Note: authors' calculations using EViews

ject the null hypothesis of no cross-sectional dependence for all variables included in the empirical model, namely EF, FDI, GDP, and INF. The Breusch–Pagan LM, Pesaran scaled LM, bias-corrected scaled LM, and Pesaran CD statistics are statistically significant at conventional levels, indicating the presence of horizontal dependence across the panel units. These findings suggest that economic shocks affecting one country are likely to transmit to other countries within the region. Such interdependence may arise from regional economic integration, common external shocks, similar macroeconomic structures, and institutional linkages. The presence of cross-sectional dependence among EF, FDI, GDP, and INF implies that the panel units are not independent, which has important implications for subsequent econometric modelling and supports the use of panel techniques that account for cross-sectional interactions (Table 5).

Table 5 Results of panel cointegration tests (Doan and Pedroni)

Test	Statistic	p-value	Conclusion
Pedroni (within-dimension)			
Panel v-statistic	0.176	0.430	No cointegration
Panel rho-statistic	−4.485	0.000***	Cointegration
Panel PP-statistic	−4.238	0.000***	Cointegration
Panel ADF-statistic	−1.542	0.062*	Cointegration
Pedroni (between-dimension)			
Group rho-statistic	−3.723	0.000***	Cointegration
Group PP-statistic	−5.362	0.000***	Cointegration
Group ADF-statistic	−2.126	0.017**	Cointegration
Kao ADF test	−0.289	0.386	No cointegration

*, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.
The null hypothesis for all tests is no cointegration.

Note: authors' calculations using EViews

The results of the Pedroni (2001) test provide convincing evidence in favor of cointegration, since most of the within-dimension and between-dimension statistics reject the null hypothesis of no long-term relationship. At the same time, the Doan test results do not allow us to reject the null hypothesis. This discrepancy is expected and can be explained by the Kao test's more stringent assumption of homogeneity of cointegration vectors for all cross-sections. Given the identified horizontal (cross-country) dependence and heterogeneity of slope coefficients, priority is given to the Pedroni test, which allows for cross-country

heterogeneity, when interpreting the results. Overall, the results indicate a stable long-term cointegration relationship between EF and FDI.

To examine the relationship between EF and FDI in Central Asian countries, this study employs the Panel Autoregressive Distributed Lag (Panel ARDL) model estimated using the Pooled Mean Group (PMG) estimator developed by Pesaran and Yamagata (2008).

The Panel ARDL framework is justified for several reasons. First, ARDL models allow for the inclusion of variables integrated of order I(0) and I(1), provided that none of the variables is integrated of order I(2). The panel unit root test results indicate a mixed order of integration across variables, making the ARDL approach particularly appropriate. Second, the Panel ARDL specification enables simultaneous estimation of both short-run dynamics and long-run equilibrium relationships within a single framework. Third, it is suitable for panels with relatively small cross-sectional dimensions (N) and moderate time dimensions (T), which corresponds to the structure of the dataset used in this study (N = 5 countries, T = 27 years).

The PMG estimator is selected because it allows for heterogeneity in short-run dynamics, adjustment speeds, and error variances across countries while restricting long-run coefficients to be homogeneous. This assumption is theoretically reasonable, as Central Asian economies share similar structural and institutional characteristics but may differ in their short-term adjustment processes. Compared to alternative estimators such as the Mean Group (MG) or Dynamic Fixed Effects (DFE), PMG provides a balance between efficiency and flexibility when long-run homogeneity is plausible.

As an additional robustness check, a VAR lag-order selection procedure was conducted prior to estimating the dynamic model. The results indicate that the optimal lag length lies between 1 and 2 lags, according to the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SC). Based on these findings, the maximum lag length in the panel ARDL specification was restricted to 1 or 2 lags to avoid over-parameterisation and ensure model parsimony.

Next, the study conducted a PMG-Panel ARDL assessment. Taking into account the confirmed presence of panel cointegration, the long-term and short-term dynamics of the relationship between EF and FDI are assessed using the PMG-Panel ARDL estimator. This approach allows for heterogeneity in short-term dynamics and adjustment rates between countries, provided that long-term coefficients are homogeneous. The results of the PMG-Panel ARDL assessment are presented in Table 6.

Table 6 PMG-Panel ARDL estimation results

Variable	Coefficient	Std. Error	t-statistic	p-value
Long-run relationship				
EF	0.0951	0.0174	5.464	0.000***
Short-run dynamics				
ΔEF	0.0536	0.0704	0.761	0.448
ECM (COINTEQ)	−0.6467	0.1268	−5.100	0.000***

Note: authors' calculations using EViews

The results of the PMG-Panel ARDL model assessment indicate a stable, statistically significant long-term relationship between the level of EF and FDI inflows in Central Asian countries. The positive sign and high statistical significance of the long-term coefficient for

the EF variable have a stimulating effect on FDI in the long term. Consequently, reducing regulatory restrictions, strengthening property rights protection, and increasing market openness create more favorable conditions for foreign investors and enhance the investment attractiveness of the economy.

The error correction coefficient (ECM) is negative and statistically significant, confirming the existence of a stable long-term equilibrium relationship between EF and FDI. The obtained coefficient value indicates that approximately 65% of short-term deviations from the long-term equilibrium level of FDI are eliminated within one period. This testifies to the high speed of adaptation of investment flows to changes in the institutional environment and indicates a fairly rapid restoration of equilibrium after temporary shocks.

At the same time, the assessment of short-term coefficients shows that changes in the EF level do not have a statistically significant impact on FDI in the short term. This result indicates that foreign investors do not react immediately to institutional changes, reflecting the inertial nature of investment decisions. Thus, the impact of EF on FDI is realized mainly through long-term structural and institutional mechanisms. At the same time, short-term fluctuations in EF do not lead to instantaneous changes in investment flows.

For further verification of the stability of the empirical results, the PMG–Panel ARDL model was re-estimated using an extended specification that includes additional macroeconomic control variables, namely GDP and INF. The results of this alternative specification are presented in Table 7.

Table 7 Robustness check: alternative PMG–Panel ARDL specification

Variable	Coefficient	Std. Error	t-statistic	p-value
Long-run relationship				
EF	0.1136	0.0252	4.501	0.000***
GDP	0.1809	0.0893	2.026	0.045**
INF	0.0298	0.0154	1.937	0.055*
Short-run dynamics				
ΔEF	0.0833	0.0531	1.568	0.120
ΔGDP	−0.0903	0.0908	−0.995	0.322
ΔINF	−0.0102	0.0306	−0.332	0.741
ECM (COINTEQ)	−0.6475	0.1097	−5.905	0.000***

Note: authors' calculations using EViews

The long-run estimates confirm the stability of the main findings. EF retains a positive and statistically significant effect on FDI at the 1% significance level. The magnitude and significance of the EF coefficient remain consistent with the baseline model, indicating the robustness of the positive institutional effect to the inclusion of additional macroeconomic factors. This consistency suggests that the relationship between EF and FDI has a structural foundation rather than being driven by omitted variable bias.

GDP demonstrates a positive, statistically significant long-run impact on FDI, supporting the market size hypothesis and confirming that larger, more economically dynamic economies tend to attract higher levels of FDI. INF shows only weak statistical significance and does not reach the conventional 5% significance level. This indicates that although macroeconomic stability may influence FDI decisions, its impact appears less substantial than that of institutional factors.

The ECM remains negative and statistically significant at the 1% level, confirming the

existence of a stable long-run equilibrium relationship among the variables. The estimated coefficient (approximately -0.65) indicates that around 65% of short-run deviations from the long-run equilibrium level of FDI are corrected within one period. The similarity in the adjustment speed across specifications further supports the stability of the model's dynamic structure.

Consistent with the baseline results, the short-run coefficients remain statistically insignificant, suggesting that FDI does not respond immediately to short-term fluctuations in EF, GDP, or INF. Instead, the effects of EF and macroeconomic fundamentals on FDI are primarily realized through long-run structural channels.

5 | CONCLUSION

This study provides an empirical assessment of the relationship between EF and FDI in five Central Asian countries over the period 1998–2024 using advanced panel econometric techniques. The preliminary analysis revealed significant cross-sectional dependence across countries, indicating a high degree of regional interconnection and justifying the application of panel methods that account for horizontal dependence. The results of the panel unit root tests indicate a mixed order of integration among the variables included in the model. Specifically, EF is found to be weak stationary at level (I(0)), GDP and INF are stationary at level (I(0)), while FDI is integrated of order one (I(1)). The stationarity of the first differences of all variables further confirms these classifications. This mixed integration structure supports the appropriateness of the panel ARDL framework. The results of the Doan and Pedroni (2001) panel cointegration tests confirm the existence of a stable long-run equilibrium relationship between FDI and EF.

The estimates obtained using the PMG–Panel ARDL approach reveal a positive and statistically significant long-run effect of EF on FDI. This finding implies that improvements in institutional quality, reductions in regulatory constraints, and stronger protection of property rights contribute to higher FDI inflows in the region. The robustness analysis, which incorporates GDP and INF as additional control variables, confirms the stability of this long-run institutional effect. GDP demonstrates a positive and significant long-run impact on FDI, supporting the market size hypothesis. In contrast, INF does not exhibit strong statistical significance at the conventional 5% level, suggesting a comparatively weaker role of macroeconomic stability relative to institutional factors.

At the same time, the short-run coefficients remain statistically insignificant, indicating that FDI does not respond immediately to short-term fluctuations in EF, GDP, or INF. This suggests that the influence of institutional and macroeconomic fundamentals on FDI operates primarily through long-term structural channels rather than through short-term adjustments. The negative and statistically significant ECM coefficient confirms the presence of a stable long-run equilibrium and indicates a relatively rapid speed of adjustment toward equilibrium.

The empirical findings of this study are largely consistent with a substantial body of literature emphasizing the positive role of institutional quality and EF in attracting FDI. In particular, the identified long-run positive and statistically significant effect of EF on FDI aligns with the results of Quazi and Rashid (2004), Naanwaab and Diarrassouba (2016), Ghazalian and Amponsah (2019), and Shikur (2024), who document a stable institutional effect on foreign investment inflows across developing economies. The results also support the conclusions of Gidage and Bhide (2025), who highlight the importance of distinguishing between short- and long-term institutional effects using panel ARDL techniques. Furthermore, the positive role of GDP growth is consistent with the market-size and economic

performance hypothesis widely discussed in the literature.

At the same time, the absence of statistically significant short-run effects of EF on FDI is consistent with the contextual and dynamic interpretation proposed by Socol and Iuga (2025) and Dang and Anh (2025), who argue that EF's influence depends on institutional stability and macroeconomic conditions. Unlike some studies that find immediate or strong short-term institutional effects, the present results suggest that in Central Asian countries, the impact of EF materializes primarily through long-term structural channels. Thus, the findings contribute to the literature by providing region-specific evidence that confirms the long-run institutional hypothesis while highlighting the limited short-run responsiveness of FDI to institutional changes.

Overall, the findings demonstrate that EF exerts a positive, economically meaningful impact on FDI, predominantly in the long run, across Central Asian countries. From a policy perspective, the results suggest that reforms aimed at strengthening EF should be accompanied by consistent institutional development and macroeconomic stability to enhance the region's investment attractiveness. The study is limited by the relatively small cross-sectional dimension (five countries) and the set of variables included in the model. Future research could expand coverage to additional countries, incorporate additional institutional and macroeconomic controls, and apply alternative econometric specifications to further assess the robustness of the results.

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CONFLICT OF INTEREST

No conflict of interest/competing interest is reported by the authors.

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Structural Transformation of Higher Education in Kazakhstan: Educational, Economic and Social Dimensions

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Abstract
The development of the higher education system is considered one of the key factors in the formation of human capital, the increase in innovation activity, and long-term economic growth. The purpose of the article is to analyse the structural transformation of of Kazakhstan's higher education system by identifying interrelations among educational, economic, and social indicators for 2004-2024. The methodological basis of the study consists of correlation analysis and principal component analysis (PCA) with Varimax orthogonal rotation, which enables the identification of hidden structural factors and the assessment of the consistency of indicator dynamics. The empirical basis of the study was made up of annual statistical data from the Bureau of National Statistics of the Republic of Kazakhstan for 2004-2024, including such indicators as the number of students and teachers, the number of universities, the unemployment rate, household incomes, spending on science, innovation activity, the Gini index, the share of education spending in GDP and average wages. The results reveal strong structural relationships between economic development and science financing (r = 0.986) and between income and wages (r = 0.985). Principal component analysis shows that the first component explains 73.6% of the variance. In comparison, the first two components explain 88.9% of the variance, indicating a structural transformation of higher education associated with the development of the knowledge economy. Future research may extend the analysis by incorporating regional data, panel econometric models, and additional institutional indicators to assess causal relationships between higher education development, labour market outcomes, and innovation dynamics.

KEYWORDS
Education, Higher Education, Education Policy, Human Capital, Knowledge Economy, Research Funding, Science Expenditure

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1 | INTRODUCTION

In modern conditions, as the role of knowledge, technology, and intellectual resources increases, higher education is becoming one of the key factors in long-term development. Universities are increasingly viewed not only as organizations providing education, but also as important elements of the scientific, innovative and institutional system of society. Expanding access to education, increasing the number of students, changing the structure of personnel training, developing the scientific activities of universities, digitalizing the educational environment and strengthening international integration are creating new conditions for the interaction of education, economy and society. However, the quantitative expansion of the higher education system alone does not guarantee an improvement in its quality, a reduction in social inequality, or an increase in labor market efficiency.

The world's scientific literature has accumulated a significant body of research on various aspects of the functioning and development of higher education. Researchers analyze the impact of education on economic growth, social mobility, employment structure, and innovation activity (Makinde et al., 2013; Kusakabe, 2013; Márquez-Ramos et al., 2020). The expansion of the higher education system contributes to the development of professional skills, increased employment and income growth, and the formation of the economy's innovative potential (Delgado et al., 2014; Janssen et al., 2021). In the context of the knowledge economy, universities perform not only an educational, but also a research function, acting as important participants in national innovation systems. A separate area of research is devoted to accessibility of education, social inequality, and the role of universities in shaping the innovation environment (Verhofstadt et al., 2007; Yang, 2018; Rohrbacker & Weber, 2014). Despite a significant body of research, most studies analyse individual aspects of higher education's functioning, while comprehensive studies that combine educational, economic, and social indicators are much less common.

This problem is especially relevant for Kazakhstan. The need for such an analysis is further reinforced by the fact that in Kazakhstan, the development of higher education is taking place in the context of broader institutional transformations. The higher education system is involved in the processes of economic modernization, digital transformation, the development of science and innovation, as well as in solving the tasks of increasing the competitiveness of human capital. In these circumstances, it is important to understand whether the observed changes reflect only quantitative growth in the system or indicate a deeper structural transformation affecting the links among education, the labor market, economic development, and the social sphere. All this requires an analysis that allows us to consider higher education not in isolation, but in connection with broader structural processes.

As a result, there remains a research gap in the scientific literature regarding the lack of comprehensive research on the structural dynamics of the higher education system. Unlike most existing works that consider individual aspects of educational development, this study analyzes the joint dynamics of several groups of indicators, enabling the identification of structural patterns in their change and possible latent factors underlying the observed processes. Thus, the purpose of the article is to analyse the structural transformation of Kazakhstan's higher education system by identifying relationships among educational, economic, and social indicators for 2004-2024.

2 | LITERATURE REVIEW

Higher education in modern scientific literature is considered one of the main institutions for the formation of human capital, increasing labor productivity and ensuring long-term

socio-economic development. Its importance goes beyond personnel training, as the higher education system is increasingly associated with the expansion of innovation potential, the development of research infrastructure and the strengthening of the knowledge economy. Thus, the transformation of higher education is of interest not only as an industry process but also as an important element of broader structural changes affecting the labor market, population incomes, and social inequality.

Existing research confirms that the impact of higher education on societal development is multidimensional. On the one hand, the growth of educational coverage and professional development of the population contributes to employment and income growth (Makinde et al., 2013; Kusakabe, 2013; Janssen et al., 2021). On the other hand, the effects of educational expansion are not unambiguous, as they depend on the quality of institutions, the scale of funding for science, the ability of universities to participate in innovation processes, as well as the nature of the social distribution of development outcomes (Delgado et al., 2014; Márquez-Ramos et al., 2019). This makes it necessary to consider higher education not in isolation, but in relation to economic, innovative and social indicators.

Higher education is considered in modern literature to be one of the key mechanisms for accumulating human capital, since investments in education increase skills, productivity, and future economic outcomes for the population. Hashimoto (1995) highlighted that investments in labor relations, including the development of professional skills and the improvement of the reliability of intra-company communications, contribute to productivity growth, strengthening cooperation and greater flexibility in employment. Makinde et al. (2013) showed that employment expansion, agricultural development, technology transfer and SME support can be considered as key measures to reduce unemployment and insecurity in Nigeria. Laird (2017) showed that after the Great Recession, the US public sector stopped fully fulfilling its levelling function, as black workers, especially women, found themselves in the most vulnerable position in terms of job loss and transition to the private sector. Theodorovicz et al. (2023) argued that companies' investments in employees' general skills, even in flexible forms of employment, can strengthen long-term cooperation and increase the value created if training is perceived as caring for employees' development.

In many countries, the development of higher education has been accompanied by a transition from an elite model to mass enrollment, which is considered one of the key stages in the transformation of university systems in the literature (Trow, 2007; Smolentseva et al., 2017; Scott, 2019). Mass growth was accompanied by increased access, greater institutional diversity, and a shift in the sector's structure, but quantitative expansion alone did not guarantee improved quality or equivalent academic performance (Mok & Jiang, 2017). The expansion of the system was often accompanied by processes of segmentation, hierarchization, and redistribution of resources among different types of universities (Carpentier, 2021). The impact of higher education on the labor market and social inequality is assessed ambiguously in the literature. Some studies show that a higher level of education is associated with better job outcomes, a higher probability of employment, and higher incomes, which confirms the importance of higher education as a tool for expanding economic opportunities (Verhofstadt et al., 2007; Rohrbacker & Weber, 2014). Some studies emphasized that increased participation in higher education can reduce inequalities in access and completion, but does not necessarily reduce differences in skills and subsequent market outcomes (Borgonovi & Marconi, 2020; Chen et al., 2025). To analyze the transformation of higher education, it is not enough to take into account only quantitative educational parameters; it is also necessary to take into account social indicators reflecting the labor market and distributional effects, including unemployment and inequality (Yang, 2018).

In the knowledge economy, universities are considered not only as educational organizations, but also as important research institutions involved in the creation and dissemination of knowledge. The contribution of higher education goes beyond personnel training and includes the development of research potential, participation in national and regional innovation systems, as well as the formation of an environment for technological and organizational innovations (Caniëls & Bosch, 2011). The literature also highlights the close relationship between the development of science, human capital, and innovative competitiveness, so the transformation of the higher education system should not be considered in isolation (Hoareau et al., 2013). The educational and research missions of universities complement each other and collectively influence economic outcomes and innovation potential (Bonaccorsi et al., 2023). Individual studies also confirm that the human capital generated by the higher education system contributes to the growth of innovation activity at the firm and regional levels (Wu & Liu, 2021).

Despite the significant body of research, the literature still predominantly consists of studies analysing separate channels through which higher education exerts its influence, primarily focusing on its relationship with income, employment, accessibility, training quality, or innovation. Even in studies on Kazakhstan, researchers more often examine either mismatches between the education system and the labor market, issues of social inequality, or the influence of individual educational factors on regional or economic development, whereas an integral analysis of these dimensions is encountered much less frequently (Busurmanov et al., 2019; Karabayev et al., 2023; Arynova et al., 2025; Zeinolla et al., 2025). Therefore, for Kazakhstan, this issue has indeed been studied in a fragmented manner, as confirmed by both the content of existing studies and recent reviews of the higher education sector, which note the fragmentation of thematic areas and the limited number of systemic empirical models.

The conducted literature review enables several conclusions to be drawn. First, higher education is a multidimensional institution whose impact extends beyond workforce training to encompass human capital formation, labor productivity, income, and innovation activity. Second, the expansion of the higher education system is not always accompanied by comparable improvements in quality and reductions in inequality, and therefore should be considered not only a quantitative but also a structural process. Third, the impact of higher education on the labor market and social inequality is ambiguous and depends on the institutional context. Fourth, in the knowledge economy, universities perform not only an educational but also a research function, acting as important participants in innovation systems.

Despite the significant body of research, most studies analyze separate channels of higher education's influence, such as employment, income, accessibility, training quality, or innovation. For Kazakhstan, this gap is especially evident, since the existing studies are mainly fragmented in nature and focus on individual aspects of the interaction between higher education, the labor market, social inequality, and economic development. Therefore, the purpose of the article is to analyze the structural transformation of Kazakhstan's higher education system by identifying the relationships between educational, economic, and social indicators for 2004–2024.

Taking into account the purpose of the study and the logic of the empirical analysis, the following hypotheses are proposed.

H1. There are stable and statistically significant relationships among educational, economic, and social indicators for 2004–2024, reflecting the system's general structural dynamics.

H2. The joint variability of the indicators under study is determined by a dominant latent factor that integrates transformations in higher education, economic development, expenditures on science, and innovation activity.

H3. Indicators of social inequality and the labor market constitute a separate structural dimension, partially autonomous of the economic and innovation factors.

H4. The identified changes reflect a transition from the quantitative expansion of the higher education system to a model of institutional consolidation associated with the development of the knowledge economy.

3 | RESEARCH METHODS

The present study aims to identify the interrelationships among educational, economic, and social indicators in Kazakhstan for the period 2004-2024. The methodological logic of the analysis is based on the assumption that the transformation of the higher education system does not occur in isolation, but in close connection with changes in employment, income, scientific financing and innovation activity. For empirical verification, hypotheses H1–H4 were proposed regarding the existence of stable relationships among educational, economic, and social indicators within the institutional consolidation model. In this regard, the study focuses on identifying both the observed statistical relationships among indicators and the latent factors that govern their joint dynamics.

The analysis was carried out in several successive stages. In the first stage, a correlation analysis was performed to determine the degree and direction of linear relationships among the indicators. In the second stage, Principal Component Analysis (hereinafter – PCA) was applied to reduce the data size and identify underlying structural dimensions. The use of PCA is due to the variables under consideration being closely interrelated and potentially reflecting more general latent factors of structural transformation rather than individual, autonomous processes. In the third stage, Varimax orthogonal rotation was used to increase the interpretability of the selected components, enabling the distinction of factor loadings and the identification of relatively independent groups of indicators corresponding to different dimensions of the system under study. At the final stage, factor maps of observations in the space of the initial and rotated components were constructed, which provided a visual interpretation of the temporal dynamics and allowed us to trace the distribution of observation years in the coordinates of the identified latent factors.

A more detailed sequence of research steps, analytical procedures and interpretation of the results is shown in Figure 1.

The empirical base of the study was made up of annual statistical data for 2004-2024, taken from the annual data of the Bureau of National Statistics of the Republic of Kazakhstan (Bureau of National Statistics, 2025). For the analysis, we selected indicators that allow us to trace the relationship between the institutional parameters of higher education and broader socio-economic processes. The study includes the number of students, the number of teaching staff, the unemployment rate, the number of higher education institutions, the average income of the population, spending on science, the level of innovation activity, the Gini index, the share of education spending in GDP and average wages. The variables are shown in more detail in Table 1.

The choice of these variables is due to the need to cover several interrelated dimensions of the system under study. Firstly, the educational dimension reflects the scale and institutional configuration of the higher education system through indicators such as the numbers of students, faculty, and universities. Secondly, the economic and innovation dimension characterizes the processes related to income growth, financing of science, in-

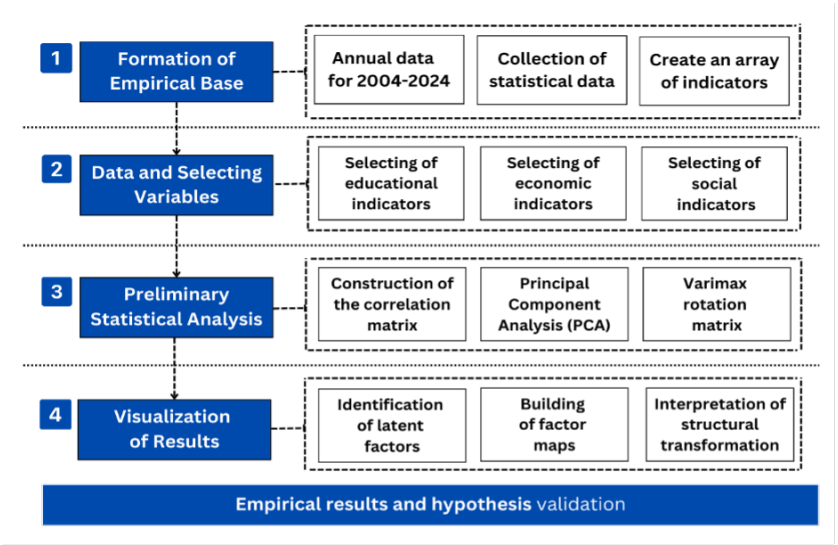


Figure 1 Logic of research, stages of analysis and hypothesis testing

novation activity and the role of education in the economy. Thirdly, the social dimension enables consideration of the state of the labour market and the distributional aspects of development, as reflected in indicators of unemployment and social inequality. Taken together, these indicators enable a comprehensive assessment of how the transformation of the higher education system correlates with changes in society's economic, innovative, and social structures.

Descriptive statistics for the study variables, including mean values, standard deviations, and minimum and maximum values, are presented in Table 2.

Table 1 Coding of study variables

Variable	Unit of measurement	Description of variable
Year	year time	Observation period (2004–2024)
STUDENTS	person	The total number of students in the higher education system
FACULTY	person	Total number of teaching staff
UNEMPL	%	The share of the unemployed in the total workforce
HIGHER_EDU	units	Total number of higher education institutions
INCOME	KZT	Per capita monetary income of the population
EXP_SCIENCE	million KZT	Government spending on research and development
INNOV_ACTIV	%	The share of organizations engaged in innovative activities
GINI_INDEX	coefficient	An indicator of the level of social inequality
GDP_EDU	% of GDP	Government spending on education as a percentage of GDP

Note: compiled by the author

It should be borne in mind that the study is based on aggregated annual data, which limits the possibilities of a strict causal interpretation of the identified relationships. High correlation coefficients and factor loadings may partially reflect the general trend movement of variables over time. In this regard, the results of PCA and correlation analysis should be interpreted primarily as a tool for identifying the structural consistency of indicators, rather

Table 2 Descriptive statistics

Variable	Medium (Mean)	Min	Max	Standard deviation
STUDENTS	603 879	459 369	775 762	92 984
FACULTY	39 189	36 307	43 382	2 061
UNEMPL	5,62	4,7	8,4	1,05
HIGHER_EDU	142	112	181	22,8
INCOME	141 253	23 128	364 295	98 964
EXP_SCIENCE	63 543	11 643	172 586	41 965
INNOV_ACTIV	7,13	2,1	11,7	3,16
GINI_INDEX	0,289	0,267	0,315	0,013
GDP_EDU	3,48	2,26	4,63	0,69
MED_SALARY	159 810	60 000	450 000	118 778

Note: compiled by the author

than as evidence of the direct causal influence of some variables on others.

To ensure comparability of indicators measured in different units, all variables were standardized using the z-transform before the multidimensional analysis was performed by formula (1):

$$z_i = \frac{x_i - \bar{x}}{s} \tag{1}$$

where:

x_i – the observed value of the indicator;

$\bar{x}$ – the observed value of the indicator;

s – the standard deviation.

After data standardisation, the PCA method was applied to identify the latent structure of the relationships among the studied indicators. This method allows you to transform the original set of interrelated variables into a system of new uncorrelated components, each of which is a linear combination of the original variables by formula (2):

$$PC_k = a_{k1}X_1 + a_{k2}X_2 + \cdots + a_{kp}X_p \tag{2}$$

where:

PC_k – the principal component;

a_{kj} – factor loads;

X_j – standardized source variables.

To increase the interpretability of the factor structure after extracting the main components, orthogonal Varimax rotation was applied, enabling clearer differentiation of variables across the selected components. To visually represent the distribution of observations in the component space, factor maps were constructed. Nevertheless, the use of correlation analysis, PCA, and Varimax rotation allows us to identify stable latent dimensions of the system under study and gain a holistic understanding of how the transformation of higher education correlates with changes in income, employment, inequality, scientific financing, and innovation activity.

The empirical analysis was conducted in Python, including correlation analysis, variable standardization, PCA, Varimax rotation, and factor map visualization.

4 | RESULTS

The empirical analysis aims to identify the structural relationships among educational, economic and social indicators for the period 2004-2024. The current institutional restructuring

and the transition to a knowledge-economy model are accompanied by a changing role of higher education in shaping employment, income, and the distribution of resources. In this regard, it is necessary to determine whether changes in the higher education system constitute a single structural factor alongside economic development, or whether the social consequences of transformation develop independently.

In this regard, according to the research methodology, a correlation analysis was initially carried out, which makes it possible to assess the nature and direction of statistical relationships between variables. The correlation matrix provides a general idea of the degree of consistency in changes across indicators over time and allows us to identify potential blocks of interrelated indicators that require further factorial and econometric analyzes. The results of the correlation analysis are presented in Table 3.

Table 3 Correlation matrix

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
STUDENTS	1.000	0.598	0.799	0.838	−0.459	−0.500	−0.634	0.744	−0.543	−0.328
FACULTY	0.598	1.000	0.690	0.799	−0.769	−0.732	−0.739	0.426	−0.700	−0.724
UNEMPL	0.799	0.690	1.000	0.948	−0.720	−0.735	−0.837	0.730	−0.735	−0.603
HIGHER_EDU	0.838	0.799	0.948	1.000	−0.814	−0.833	−0.893	0.674	−0.749	−0.714
INCOME	−0.459	−0.769	−0.720	−0.814	1.000	0.986	0.882	−0.283	0.841	0.985
EXP_SCIENCE	−0.500	−0.732	−0.735	−0.833	0.986	1.000	0.875	−0.331	0.820	0.962
INNOV_ACTIV	−0.634	−0.739	−0.837	−0.893	0.882	0.875	1.000	−0.356	0.726	0.812
GINI_INDEX	0.744	0.426	0.730	0.674	−0.283	−0.331	−0.356	1.000	−0.358	−0.167
GDP_EDU	−0.543	−0.700	−0.735	−0.749	0.841	0.820	0.726	−0.358	1.000	0.804
MED_SALARY	−0.328	−0.724	−0.603	−0.714	0.985	0.962	0.812	−0.167	0.804	1.000

Note: compiled by author

The correlation results indicate strong relationships among indicators of economic development, research funding, and innovation activity. Strong positive correlations were identified between indicators of economic development and the scientific and innovation sphere. Thus, the relationship between average income and science expenditure is r = 0.986, while the relationship between average income and average wages is r = 0.985, indicating that these indicators change almost synchronously. The strong positive correlation between science expenditure and the level of innovation activity (r = 0.875) confirms that increased funding for the scientific sphere is associated with an expansion of innovation processes. At the same time, social indicators also demonstrate significant relationships. The unemployment rate has a high positive correlation with the number of universities (r = 0.948) and the Gini index (r = 0.730). These coefficients reflect the joint structural dynamics of the higher education system and socio-economic conditions at different stages of the period under consideration. In particular, a greater institutional presence of the higher education system was characteristic of the early stage of the analysis and was simultaneously associated with higher levels of unemployment and inequality.

Overall, the correlation analysis indicates the presence of stable statistical relationships among indicators of economic development, research funding, and innovation activity. Pronounced negative correlations were identified between the number of higher education institutions and indicators of economic development, as well as between the number of universities and innovation activity. This relationship may reflect the processes of structural consolidation in the higher education system and resource concentration. During the analysed period, the reduction in the number of universities occurred in parallel with rising incomes, increased research funding, and higher innovation activity, which may indicate a transition from a quantitative model of expansion to a model of qualitative concentration.

It can be concluded that the high values of several correlation coefficients may be partially due to the general time trend of the indicators. The joint trend movement of variables increases the likelihood of spurionic (false) correlations. In this regard, the high correlation of most variables with the time factor indicates the need for further econometric analysis (in particular, eliminating the trend component and checking the stationarity of the series) for the correct interpretation of cause-and-effect relationships.

To identify hidden (latent) factors that determine the joint variability of social, economic, and educational indicators during 2004-2024, the PCA method was applied. Before performing PCA, the initial variables were standardized (z-transform), which ensures comparability of indicators measured in different units. The results of the analysis showed the dominance of the first principal component (PC1), which accounted for the bulk of the explained variance. PC1 loadings have positive signs for income, science spending, innovation activity, the share of education spending in GDP, and average wages, and a negative sign for the number of students, teachers, universities, the unemployment rate, and the Gini index. In general, the PCA results confirm the presence of a dominant structural factor characterizing the transformation of higher education in the context of the development of the knowledge economy, and also identify a separate socio-distributional dimension related to the dynamics of inequality (Table 4).

Table 4 Principal component loadings for social, economic and educational indicators

Variable	PC1	PC2
STUDENTS	−0.754	0.590
FACULTY	−0.865	−0.040
UNEMPL	−0.929	0.321
HIGHER_EDU	−0.989	0.217
INCOME	0.948	0.371
EXP_SCIENCE	0.950	0.313
INNOV_ACTIV	0.944	0.118
GINI_INDEX	−0.575	0.758
GDP_EDU	0.883	0.180
MED_SALARY	0.875	0.503

Note: compiled by the author

The results demonstrate a clear dominance of the first principal component (PC1), which accounts for the largest share of the total variance of the indicators and constitutes the system's key structural dimension. PC1 is characterised by high positive loadings on economic and innovation indicators: science expenditure (0.950), average income (0.948), innovation activity (0.944), the share of education expenditure in GDP (0.883), and average wages (0.875). At the same time, pronounced negative loadings are observed for the number of higher education institutions (-0.989), the unemployment rate (-0.929), the number of academic staff (-0.865), the number of students (-0.754), and the Gini index (-0.575).

The configuration of the loadings indicates the presence of a systemic structural shift. The reduction in the number of universities, students, and academic staff coincided with rising household incomes, increased science expenditure, and stronger innovation activity over time. The particularly large absolute values of the loadings for the number of universities (-0.989) and the unemployment rate (-0.929) suggest that the processes of consolidation in the higher education system were accompanied by a decline in the unemployment rate. Thus, PC1 reflects a transition from a mass model of higher education to a more concentrated system oriented towards the knowledge economy, in which resources become more

focused and economic indicators improve.

The second principal component (PC2) forms a separate socio-distributive dimension. The highest loading on PC2 is observed for the Gini index (0.758), indicating the relative autonomy of social inequality dynamics from the innovation-economic factor represented by PC1. Additional positive loadings are observed for the number of students (0.590) and average wages (0.503). Thus, PC2 shows that changes in the education system and wage levels are accompanied by changes in the level of social inequality.

Overall, the PCA results confirm the existence of a dominant factor of economic and innovation transformation accompanied by the institutional consolidation of higher education, while also identifying a separate social dimension related to the dynamics of inequality. To refine the interpretation of the factor structure and to achieve a clearer separation of the latent dimensions, an orthogonal Varimax rotation was applied after the initial extraction of the principal components. The use of Varimax rotation redistributes factor loadings so that each variable is more strongly associated with a single component, facilitating the interpretation of the factors. RC1 combines indicators associated with economic growth and the development of science (income, wages, science expenditure, innovation activity, and the share of education expenditure in GDP). RC2 combines indicators reflecting the social and educational structure of society (number of students, number of universities, unemployment rate, and the Gini index).

Table 5 presents the results of the orthogonal Varimax rotation for the two extracted components, RC1 and RC2.

Table 5 Rotated Varimax (component matrix) for social, economic and educational indicators

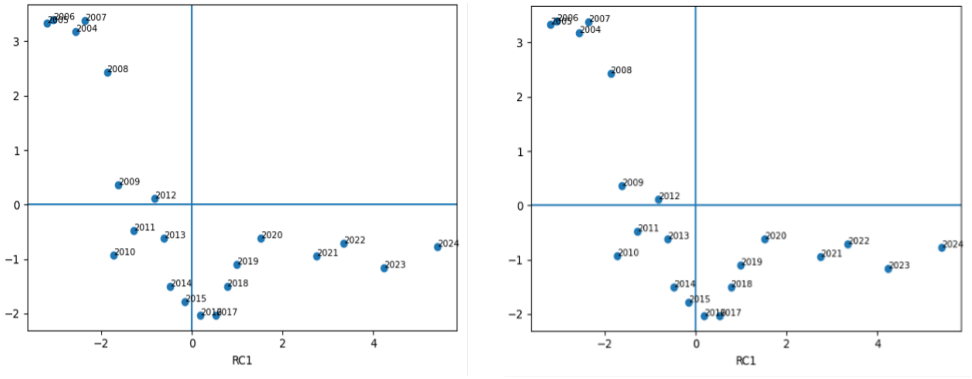
Variable	RC1	RC2
STUDENTS	−0.278	0.916
FACULTY	−0.731	0.465
UNEMPL	−0.575	0.797
HIGHER_EDU	−0.684	0.746
INCOME	0.989	−0.241
EXP_SCIENCE	0.957	−0.290
INNOV_ACTIV	0.841	−0.446
GINI_INDEX	−0.035	0.951
GDP_EDU	0.825	−0.361
MED_SALARY	1.005	−0.092

Note: compiled by the author

The results of Varimax rotation demonstrate a clear distinction between the two latent factors. The first rotated component (RC1) shows pronounced positive loadings for income (0.989), average salary (1.005), spending on science (0.957), innovation activity (0.841), loads in terms of income (0.989), average salary (1.005), spending on science (0.957), innovation activity (0.841) and the share of education spending in GDP (0.825). At the same time, negative pressures are recorded for this component in terms of the number of universities (-0.684), the number of teachers (-0.731), the unemployment rate (-0.575) and the number of students (-0.278). Thus, income growth and the development of the scientific and innovative sphere occurred in parallel with the institutional consolidation of the higher education system and the reduction of unemployment. The particularly significant module loads in terms of income, wages, and science expenditures confirm that RC1 reflects the process of strengthening the knowledge economy as the dominant direction of structural change.

The second rotated component (RC2) forms a separate socio-educational dimension. The greatest burden on RC2 falls on the Gini index (0.951), which indicates a pronounced autonomy of the dynamics of social inequality relative to the economic and innovation factors presented in RC1. Significant positive pressures are also observed in the number of students (0.916), the unemployment rate (0.797) and the number of higher education institutions (0.746). In other words, the scale of higher education, employment dynamics and the level of social inequality in the analyzed period changed consistently and form a separate structural dimension of social development.

Furthermore, to visualise the revealed factor structure in the space of the main components, factor maps of the observations are constructed (Figure 2).



Factor map (PC1–PC2) Varimax (RC1–RC2)

Figure 2 Factor score plots for social, economic and educational indicators

Factor maps showed the distribution for 2004-2024 in the space of two main components. The first component (PC1) explains 73.6% of the total data variance, while the second component (PC2) explains 15.3%. In total, they explain 88.9% of the variation, which means that the two-dimensional projection reflects the structure of the initial indicators quite well. The time dynamics can be clearly traced along the axis of the first component (PC1): 2004-2008 are located in the zone of negative values; 2020-2024 are located in the zone of positive values. This indicates the existence of a common long-term trend of social, economic and innovative development, which reflects the first main component. The axis of the second component (PC2) reflects changes that are not related to this time trend. So, to a greater extent, it is mainly related to the influence of social factors, such as the level of inequality, unemployment, and others. The graph shows especially noticeable differences along this axis in the period 2009-2016, when the most noticeable transformation processes took place in the system.

Thus, the PCA factor map shows the gradual development of the system under study — from the initial stage to a period of more sustainable economic and innovative growth. The orthogonal rotation of Varimax made it possible to make the structure of the factors more understandable, while the total proportion of the explained variance did not change. After the rotation, the factors became easier to interpret. Compared to the original PCA map, the rotated model shows a clearer separation of the two main dimensions – economic and innovative and socio-educational. This confirms that the dynamics of the studied indicators has a two-factor structure.

The factor maps also clearly show the presence of a leading factor related to socio-economic development and an additional factor reflecting the system's social and educational structure. The results obtained indicate a gradual structural transformation of the higher education system and the scientific and innovative sphere during the period under review, accompanied by an increase in income, increased funding for science and increased innovation activity. Thus, Figure 2 visually illustrates the two-factor structure of the observed dynamics, whereas Table 6 summarizes the proposed hypotheses and the results of their empirical verification.

Table 6 Summary of research hypotheses and their empirical verification

Hypothesis	Content of hypothesis	Empirical status
H1	There are stable and statistically significant relationships among educational, economic, and social indicators for 2004–2024, reflecting the system's general structural dynamics.	Confirmed
H2	The joint variability of the indicators under study is determined by a dominant latent factor that integrates transformations in higher education, economic development, expenditures on science, and innovation activity.	Confirmed
H3	Social inequality and labor market indicators form a distinct structural dimension that is partially autonomous from the economic and innovation factors.	Confirmed
H4	The identified changes reflect a transition from the quantitative expansion of the higher education system to a model of institutional consolidation associated with the development of the knowledge economy.	Partially confirmed

Thus, the results presented in Table 6 confirm the existence of stable relationships among educational, economic and social indicators, as well as a two-factor structure in the dynamics under study.Hypotheses H1–H3 are confirmed by the results of correlation and factor analysis, while hypothesis H4 has received partial confirmation and is interpreted at the level of the identified structural trend. The results indicate that the transformation of Kazakhstan's higher education system during the period under review occurred in close relation to economic, innovative, and social changes.

5 | CONCLUSIONS

The study was aimed at identifying the structural relationships between educational, economic and social indicators characterizing the transformation of Kazakhstan's higher education system in 2004-2024. The results showed that changes in the higher education sector should not be considered as an isolated sectoral process, but as part of a broader socio-economic and innovative transformation related to the development of the knowledge economy. The following conclusions were reached.

Firstly, the literature review and the study's logic indicate that higher education should be considered a multidimensional institution, whose impact is not limited to personnel training and the accumulation of human capital. In the context of the knowledge economy, it is an important element of a broader socio-economic system related to the dynamics of employment, income, scientific potential, innovation activity and social inequality. Consequently, the transformation of the higher education system should be analyzed not only through quantitative parameters of its development, but also through structural changes reflecting its place in the knowledge economy, innovation processes and the social structure of society.

Secondly, the analysis showed that the transformation of Kazakhstan's higher education system in 2004-2024 was accompanied by stable interrelations among educational, economic and social indicators. Correlation analysis, the principal component method, and Varimax rotation confirmed the presence of a dominant economic and innovation factor combining income growth, spending on science, innovation activity, and changes in the parameters of the higher education system, and identified a separate socio-educational dimension related to the dynamics of unemployment, inequality, and the scale of the sector.

The practical significance of the results lies in their potential use in the development of state policy in the fields of higher education, science, and innovation. The findings indicate that the evaluation of the effectiveness of the higher education system should not be limited to quantitative indicators of coverage or the number of organizations. A more reasonable approach is one that takes into account the relationship of higher education with the labor market, scientific financing, innovation, and social inequality.

The prospects for further research are related to the deepening of the analysis in several directions. First, it is advisable to supplement the macro-level approach with regional and institutional data, which will reveal interregional differences in the trajectories of higher education transformation. Secondly, it seems important to use econometric methods that account for time trends, stationary series, and potential causal relationships. Thirdly, further development of the topic may be related to the inclusion of additional indicators of the quality of education, digitalization, university research productivity and international academic integration.

AUTHOR CONTRIBUTION

Writing – original draft: Anel A. Kireyeva.
Conceptualization: Anel A. Kireyeva.
Formal analysis and investigation: Anel A. Kireyeva.
Development of research methodology: Anel A. Kireyeva.
Software and supervisions: Anel A. Kireyeva.
Data collection, analysis and interpretation: Anel A. Kireyeva.
Visualization: Anel A. Kireyeva.
Writing review and editing research: Anel A. Kireyeva.

CONFLICT OF INTEREST

No conflict of interest/competing interest is reported by the authors.

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ORIGINAL ARTICLE

Digitalization of Agribusiness and its Impact on Productivity and Sustainability: A Systematic Literature Review

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Abstract
Digital transformation of the agro-industrial complex is seen as a key factor in increasing the productivity and resilience of agri-food systems in the face of climate instability and increasingly complex global supply chains. Despite the rapid growth of scientific publications, research results remain fragmented, and the mechanisms by which digital technologies influence economic and sustainability indicators are poorly systematized.
The purpose of this study is to summarize and critically analyze the scientific literature on the impact of digital technologies on efficiency of agricultural production, the sustainability of agri-food systems, and the role of data and platforms in shaping these effects. The paper addresses the following research questions: how do digital technologies influence agricultural productivity; to what extent do they contribute to environmental and economic sustainability; and what organizational and institutional conditions determine the effectiveness of digital transformation.
The study was conducted as a systematic review of scientific publications covering the period 2015-2025. Following a multi-stage selection process from an initial pool of over twenty-two thousand publications, fifty-six studies meeting criteria for topical relevance and methodological transparency were included in the final analysis.
The analysis shows that digitalization is creating a new production infrastructure based on data and analytics, which contributes to increased resource efficiency, reduced uncertainty, and improved coordination in supply chains. However, the sustainability of these effects significantly depends on the institutional environment, the level of infrastructure development, and the quality of data management. It is concluded that the long-term effectiveness of digital transformation is determined not only by the implementation of technologies but also by the alignment of organizational, infrastructural, and managerial factors.

KEYWORDS
Agriculture, Agro-Industrial Complex, Agribusiness, Productivity, Economic Sustainability, Digitalization, Digital Ecosystem

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1 | INTRODUCTION

In the 21st century, the agro-industrial complex is evolving under the influence of climate instability, volatility of global food markets, and increasing complexity of agri-food supply chains, which intensifies pressure on natural resources and raises demands for efficiency and sustainability. In this context, digital technologies such as remote sensing, artificial intelligence, digital platforms, and big data analytics are increasingly viewed as a key infrastructure for modern agricultural systems rather than merely auxiliary tools (FAO, 2019).

Digitalization has become one of the key drivers of transformation in modern agriculture and agribusiness. The rapid development of digital technologies, including artificial intelligence, the Internet of Things (hereinafter – IoT), blockchain, big data analytics, and digital platforms, is reshaping production processes, management systems, and supply chains in agri-food systems. These technologies enable more efficient resource use, improve decision-making, and contribute to increased agricultural productivity and sustainability. At the same time, existing policy analyses highlight several barriers that limit the large-scale adoption of digital technologies, including insufficient digital infrastructure, limited digital competencies among farmers, institutional constraints, and emerging risks associated with data ownership and market concentration (Jouanjean et al., 2020; OECD, 2022; World Bank, 2023).

The academic literature on the digitalization of agri-food systems has expanded rapidly over the past decade and now covers a wide range of technological and managerial topics. Existing studies examine the application of Internet of Things architectures, remote sensing technologies, artificial intelligence in precision agriculture, blockchain-based traceability systems, digital platforms for agricultural data exchange, and the role of digital technologies in strengthening supply chain resilience (Abbasi et al., 2022; Abiri et al., 2023; Shamshiri et al., 2024). In addition, several recent studies emphasize the growing role of digital platforms and data infrastructures in coordinating interactions between actors within agri-food systems, thereby reshaping value chains and market structures (Ahoa et al., 2026; Quan et al., 2024; Stanescu et al., 2025). Moreover, the integration of digital technologies with environmentally oriented farming practices is increasingly seen as an important factor influencing enterprise efficiency, food security, and the long-term sustainability of the agricultural sector (Akhmetkyzy et al., 2024; Baiguzhinova et al., 2025; Wang et al., 2025).

Despite the rapid expansion of research in this field, the existing literature remains fragmented in several important respects. First, many studies examine technological innovations without systematically linking them to measurable economic or sustainability outcomes. Second, environmental and economic effects of digitalization are often analyzed separately, which limits the development of integrated analytical models of sustainability in agri-food systems. Third, issues related to agricultural data governance and the institutional regulation of digital platforms remain insufficiently explored empirically.

The study addresses three research questions:

RQ1. How do digital technologies influence agricultural productivity and production efficiency?

RQ2. To what extent do digital solutions contribute to the environmental and economic sustainability of agri-food systems?

RQ3. What organizational and institutional conditions determine the effectiveness of digital transformation in agriculture?

The novelty of this study lies in developing an integrated analytical perspective on the digital transformation of agri-food systems by linking three previously fragmented research dimensions: digital production infrastructures (including IoT, artificial intelligence, and

data platforms), measurable productivity and sustainability outcomes, and governance mechanisms related to data ownership, platform coordination, and value distribution within digital ecosystems. Thus, the study aims to conduct a systematic review of academic literature on digital technologies in agribusiness and evaluate their impact on productivity, sustainability, and governance in agri-food systems.

2 | METHODOLOGY

This study employs a systematic literature review (hereinafter – SLR) conducted in accordance with the PRISMA framework, which ensures transparency and reproducibility in the identification, screening, selection, and synthesis of scientific publications (Page et al., 2021). The use of PRISMA reduces the risk of selection bias and provides a structured procedure for documenting the formation of the final body of literature. This methodological approach is widely used in studies examining digital transformation and agri-food systems, as it facilitates systematic comparison of empirical findings and identification of research gaps (Rocha de Avila & Barbosa, 2025; Klerkx et al., 2019).

The literature search was conducted in January 2026 using the ScienceDirect database, which provides broad coverage of peer-reviewed journals in agricultural sciences, engineering, information technology, economics, and management. ScienceDirect was selected for its strong representation of interdisciplinary research on digital agriculture and agri-food systems. To reduce potential database bias, additional relevant studies were identified through manual searches of reference lists and Google Scholar. The review covers the period from 2015 to 2025, corresponding to the active development of the Agriculture 4.0 concept and the rapid growth of research on digital technologies in agriculture. Only publications written in English were included. The search was performed in the Title, Abstract, and Keywords fields to improve thematic precision. The analysis considered only peer-reviewed research articles and review papers.

To ensure relevance, subject filters related to agri-food systems and digital technologies were applied, including Agricultural and Biological Sciences, Environmental Science, Computer Science, Engineering, Energy, Business, Management and Accounting, Economics, Econometrics and Finance, and Social Sciences. Publications unrelated to agricultural production or agri-food systems were excluded during the screening stage. The search strategy was based on predefined keyword combinations reflecting the main analytical dimensions of the study, including digital transformation in agriculture, artificial intelligence applications, Internet of Things technologies in precision agriculture, digital platforms in agricultural value chains, and sustainability in digital agriculture. These keyword combinations were used to identify relevant studies addressing productivity, efficiency, resilience, and sustainability in agri-food systems.

The initial search results by year are presented in Table 1 and demonstrate a steady increase in publication activity, particularly in studies focusing on digital transformation and artificial intelligence in agriculture.

Research articles predominate in all queries, indicating the predominantly empirical nature of literature. At the same time, differences in the share of Review articles are noticeable across combinations, reflecting the varying degrees of theoretical systematization of the thematic areas. This structure confirms the feasibility of a high-quality thematic synthesis and explains the rejection of a meta-analysis due to the high heterogeneity of designs and metrics. Figure 1 shows the structure of the selected dataset by publication type (Research vs. Review) for five search combinations.

The final sample included studies that simultaneously met the following criteria:

Table 1 Number of publications by keyword combinations for 2015–2025

Year	Combination No.1	Combination No.2	Combination No.3	Combination No.4	Combination No.5
2015	2	52	4	0	0
2016	4	78	7	3	0
2017	20	132	20	3	1
2018	34	186	33	14	4
2019	88	339	73	42	1
2020	165	582	103	46	10
2021	340	850	134	113	28
2022	535	1318	250	126	32
2023	675	1687	255	151	62
2024	1269	3087	507	207	117
2025	1928	4938	1109	378	128

Note: compiled by the authors based on the ScienceDirect database

(1) Thematic relevance: the study examines the application of digital technologies in the agro-industrial complex or agri-food systems, including IoT, artificial intelligence and machine learning, remote sensing, FMIS/DSS systems, digital platforms, traceability technologies, and data analytics.

(2) Outcomes: the article provides empirical results or conceptual conclusions linking digitalization to productivity or efficiency indicators (e.g., yield, production costs, technical efficiency, total factor productivity, losses, product quality) and/or resilience indicators (resource efficiency, environmental performance, resilience to shocks, supply chain resilience, traceability).

(3) Mechanisms and context: the study analyzes implementation mechanisms and institutional conditions, including issues related to data governance, platform models, regulatory frameworks, competencies, and value distribution.

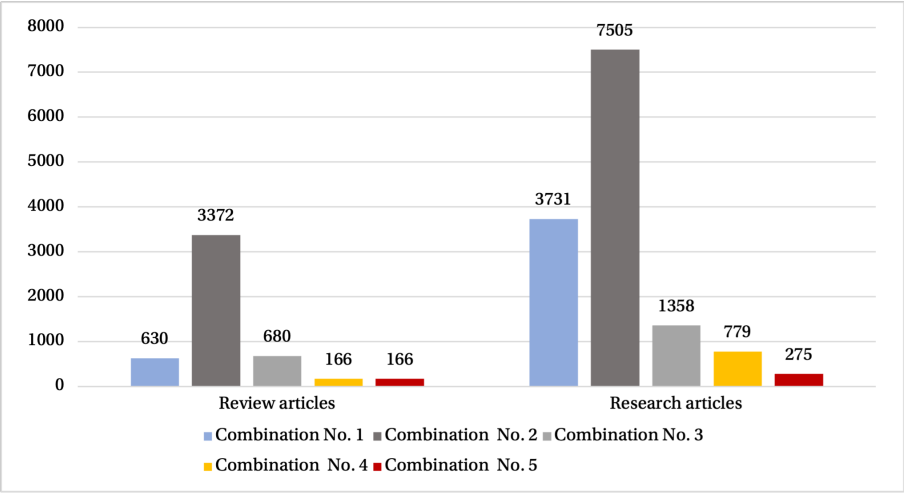

Figure 1 Number of scientific papers by type review articles and research articles for 2015-2025 according to the ScienceDirect database

The following types of publications were excluded from the analysis:

(1) Non-peer-reviewed and non-scientific materials: editorial notes, short communications, news and review reports without a description of methods, materials without a research design and without extractable results.

(2) Irrelevant research object: publications not related to the agro-industrial complex/agri-food chains or examining digital technologies outside of an agricultural context.

(3) Duplicates/versions: duplicate records and earlier versions of already included papers.

(4) Technology-only without outcome logic: articles that do not link digital technologies to productivity/sustainability outcomes or for which this link cannot be extracted from the text (e.g., descriptions of architectures without impact assessments and without analytical interpretation of the consequences).

(5) Disciplinary irrelevance: papers primarily related to clinical/biomedical topics without connection to agri-food systems were excluded as irrelevant.

The selection of publications was conducted according to the PRISMA framework, which comprises three main stages: identification, screening, and inclusion. The quantitative results of the selection process are presented in Figure 2.

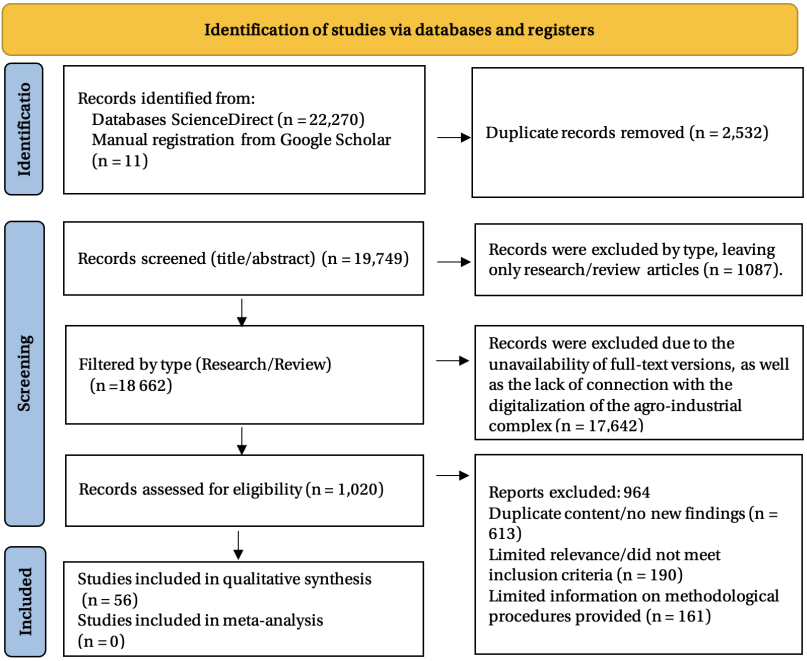

Figure 2 PRISMA flow diagram of the study selection process

To ensure methodological rigor and transparency, all studies included at the full-text eligibility stage were subjected to a standardized methodological quality assessment based on the logic of the Mixed Methods Appraisal Tool (MMAT). The framework was adapted to the interdisciplinary nature of research on digitalization in agri-food systems, with particular attention to the transparency of digitalization indicators, validity of analytical methods, and reproducibility of productivity and sustainability outcomes. The methodological assessment

included five criteria, each evaluated using a three-level scoring scale: 0 – missing or unclear; 1 – partially addressed; 2 – fully addressed and transparent.

The evaluation criteria were defined as follows:

(1) Data transparency: data sources, sample or object of analysis, study period, and contextual conditions are clearly described.

(2) Validity of methods: analytical methods are appropriate for the research objectives (e.g., econometric modelling, structural equation modelling, stochastic frontier analysis, simulation modelling, or qualitative methods) and applied correctly.

(3) Operationalization of digitalization: the digitalization construct or indicator is clearly defined and measurable in a reproducible manner.

(4) Operationalization of outcomes: productivity or sustainability indicators are clearly defined and supported by explicit causal logic.

(5) Bias management – robustness checks, sensitivity analysis, alternative model specifications, or discussion of methodological limitations are provided.

The overall methodological quality score for each study was calculated by formula (1):

$$Q_i = \sum_{k=1}^{5} C_{ik} \tag{1}$$

where:

Q_i – the total methodological quality score for study i;

C_{ik} – the score assigned to criterion k (ranging from 0 to 2);

k – index of the evaluation criterion.

The maximum possible score for each study is therefore given by formula (2):

$$Q_{max} = 10 \tag{2}$$

Publications were excluded if they contained critical methodological limitations that made their findings non-verifiable. Such limitations included the absence of a clear description of data sources and analytical methods, the lack of measurable outcome indicators, inconsistency between the research design and the stated conclusions, as well as non-transparent operationalization of digitalization variables or performance indicators. Based on the resulting scores, the methodological quality of the studies was interpreted according to the following classification. Studies scoring 8–10 points were classified as high quality, indicating a high level of methodological transparency and reproducibility. Studies scoring 5–7 points were considered moderate quality, reflecting acceptable methodological rigor with some limitations. Studies scoring 0–4 points were classified as low quality, indicating insufficient methodological transparency.

Following the PRISMA selection procedure, 56 studies were included in the final review. Among them, 31 studies were classified as high quality and 25 studies as moderate quality. The average methodological quality score across the included studies was 7.4, indicating generally acceptable methodological rigor in the reviewed literature. To assess the robustness of the findings, a sensitivity analysis was conducted by excluding studies classified as moderate quality and repeating the thematic synthesis using only high-quality studies. The exclusion of moderate-quality studies did not substantially alter the overall analytical patterns identified in the review, suggesting that the main findings are robust.

To enable systematic comparison across the reviewed literature, a standardized data extraction matrix was developed. The extraction process followed a predefined coding protocol designed to capture the key analytical dimensions of digital transformation in

agri-food systems, including technological, economic, and institutional characteristics of the analyzed studies. The coding framework allowed the consistent identification of digital technologies applied in agriculture, the segments of the agri-food value chain addressed, the productivity and sustainability outcomes analyzed, and the contextual factors influencing the adoption and performance of digital solutions.

The structure of the data extraction matrix used in the review is presented in Table 2.

Table 2 Data extraction matrix used in the systematic literature review

Analytical dimension	Extracted variable	Examples of indicators
Digital technologies	Type and class of digital technologies	IoT sensors, artificial intelligence and machine learning models, UAV and remote sensing systems, decision support systems, digital platforms, blockchain
Agri-food system segment	Segment of the agri-food value chain	Crop production, livestock farming, agricultural processing, agri-logistics, agricultural markets
Productivity outcomes	Indicators of production performance	Yield, total factor productivity, technical efficiency, cost reduction, product quality
Sustainability and resilience	Environmental and system resilience indicators	Water efficiency, energy efficiency, environmental performance metrics, supply chain resilience, traceability
Contextual moderators	Institutional and infrastructural factors	Digital infrastructure availability, investment intensity, digital competencies, institutional environment, data governance regimes

Note: compiled by the authors

The coding process enabled the systematic comparison of heterogeneous empirical studies and facilitated the thematic synthesis of the effects of digitalization on productivity, sustainability, and resilience within agri-food systems.

Given the heterogeneity of the included studies in terms of technologies, research designs, and evaluation metrics, a qualitative thematic synthesis was applied. This approach allowed the systematization of empirical and conceptual findings and the identification of consistent patterns in research on the digital transformation of agri-food systems.

The analysis was conducted in three stages. First, the selected studies were reviewed and coded according to key parameters, including the type of digital technology, productivity and sustainability outcomes, mechanisms of digitalization, and contextual implementation conditions. Second, the results were grouped into four thematic blocks: digital technologies as production infrastructure; productivity and efficiency effects; environmental, economic, and supply chain sustainability; and the role of platforms, data, and governance mechanisms.

Despite following PRISMA guidelines, the study has several limitations. First, the main dataset was derived from the ScienceDirect database, which may limit the coverage of studies published in other databases. Second, many analyzed studies focus on short-term effects of digital technology adoption, as digital transformation in agri-food systems remains a relatively recent research field. Third, the results depend on contextual factors such as institutional environments, levels of economic development, and digital infrastructure. These factors should be considered when generalizing the findings and highlight the need for further research.

3 | RESULTS

The analysis shows that digitalization in agriculture is increasingly interpreted not as the introduction of isolated technologies but as the development of an integrated production in-

frastructure combining data collection, analytics, and management decision-making within a unified cyber-physical system. In this framework, agricultural production is organized around a continuous cycle of data acquisition, processing, and operational intervention, enabling digital technologies to influence both productivity and sustainability. At the architectural level, such infrastructure typically integrates several technological layers, including farm management information systems (FMIS), sensor networks, data platforms, and decision-support tools. For example, Acharya Balkrishna et al. (2023) show that modern digital agricultural ecosystems are often built around FMIS-based structures integrating data from sensors, remote sensing platforms, and agricultural service applications. Similarly, Muhammed et al. (2024) demonstrate that the technological core of such infrastructures increasingly relies on AIoT architectures combining IoT sensor networks, artificial intelligence, and distributed computing for continuous monitoring of soil moisture, temperature, crop conditions, and livestock health. Navarro et al. (2020) further emphasize the importance of connectivity architectures, including wireless sensor networks, low-power wide-area networks, satellite communication, and cloud computing platforms, which enable interoperability between distributed agricultural data systems.

Mamabolo et al. (2025) show that integrating soil sensors, remote sensing technologies, and machine-learning algorithms enables early diagnosis of crop diseases and soil degradation, thereby improving the efficiency of agricultural resource use. Chin et al. (2024) propose the ROAM framework, which integrates sensor data streams, predictive analytics, and optimization algorithms to support adaptive farm management under uncertainty. In a broader sense, Wolfert et al. (2017) argue that the use of big data technologies in smart farming allows predictive analytics and real-time operational decision-making, thereby transforming traditional farm management models and reshaping agri-food supply chains.

Finally, the broader implications of digital agricultural infrastructure for sustainable development remain uneven across regional and institutional contexts. While technologies such as drone monitoring, sensor networks, and machine-learning analytics can improve resource efficiency and environmental performance (Gamage et al., 2024), their large-scale adoption is often constrained by infrastructural limitations, institutional barriers, and insufficient digital competencies among farmers (Fakhraddine et al., 2025).

Empirical evidence indicates that digital technologies significantly improve farm-level efficiency and production performance. For example, Yu et al. (2025) show that a 1% increase in digital investment raises technical efficiency by about 0.029%, while related technologies increase milk yields and profit margins, and Sargani et al. (2025) demonstrate that digital adoption and agricultural infrastructure explain up to 68% of the variance in agricultural productivity. Digital technologies also enhance productivity by reducing information asymmetry and improving farmers' access to services, finance, and market information. For instance, Kitole et al. (2024) show that digital tools significantly improve access to extension services, pest management, market information, and financial services among smallholder farmers in Tanzania, while Narayanamurthy et al. (2025) demonstrate that satellite-based data analytics reduces information asymmetry in agricultural lending and supports more accurate credit assessment.

At the organizational level, studies show that the productivity effects of digitalization depend not only on technological adoption but also on institutional and managerial capacity. For example, Santos et al. (2024) find that the digital maturity of agri-food cooperatives is shaped by factors such as digital infrastructure, organizational readiness, and technological capabilities, with significant variation explained by firm size and financial resources. At the operational and research levels, digital technologies such as IoT-based smart irrigation sys-

tems (Mamun et al., 2025) improve resource efficiency, while AI tools accelerate knowledge generation and data analysis in agricultural research (Lamanna et al., 2025).

From an environmental perspective, digital agricultural technologies primarily contribute to sustainability by improving resource efficiency, particularly in water, energy, and agrochemical use. A growing body of research highlights the role of smart irrigation systems that integrate IoT sensors, artificial intelligence algorithms, and renewable energy infrastructure. A systematic review by Nurmalitasari et al. (2025) shows that AI-driven solar-powered irrigation systems allow continuous monitoring of soil moisture, weather conditions, and crop water demand, enabling real-time adjustments to irrigation schedules. Empirical evidence summarized in the review indicates that such systems can increase water use efficiency by up to 70%, while crop yields may increase by 15-40% depending on crop type and climatic conditions. These technologies also reduce energy consumption by integrating photovoltaic systems, contributing to lower greenhouse gas emissions and improved environmental performance in agricultural production systems.

Digital technologies contribute to environmental sustainability by enabling precision crop protection and reducing excessive use of agrochemicals. For example, AI-based pest monitoring systems achieve identification accuracy of about 98%, allowing early detection of infestations and reducing the need for large-scale pesticide spraying (Javed et al., 2025). Similarly, deep learning models for plant disease detection often achieve classification accuracies exceeding 99% and significantly outperform traditional machine-learning approaches, highlighting the potential of artificial intelligence to improve environmental performance while maintaining agricultural productivity (Majdalawieh et al., 2025). In this regard, Aijaz et al. (2025) highlight that the diffusion of artificial intelligence technologies in agriculture remains constrained by several structural barriers, including insufficient digital infrastructure, limited digital literacy among farmers, and regulatory uncertainty related to agricultural data governance.

Digital agricultural platforms generate economic value by aggregating and processing large volumes of agricultural data, integrating sources such as satellite imagery, production data, weather monitoring, and market information into unified decision-support systems. Empirical evidence shows that such platforms reduce information asymmetries and improve production and marketing decisions for farmers (Borrero & Mariscal, 2022), while their governance reflects tensions between open data sharing and proprietary control within platform ecosystems (Bustamante, 2023). At the same time, the diffusion of digital platforms depends on infrastructural and socio-economic conditions, including digital infrastructure, technical knowledge, farm size, and data privacy concerns, while the absence of standardized indicators complicates cross-country comparisons of digital agriculture adoption (Dibbern et al., 2024).

Recent research increasingly links platform digitalization with sustainability and ESG governance, highlighting the rapid growth of this field and the expanding role of AI-driven platforms in monitoring and managing ESG performance across supply chains (Kumar & Shah, 2025; Nevi et al., 2025). At the same time, studies emphasize that the expansion of digital platform ecosystems creates new governance challenges related to market concentration, institutional capacity, and regulatory frameworks (Ochieng, 2024), while digital data systems are becoming essential for ensuring transparency and sustainability reporting in agri-food supply chains (Truant et al., 2024). Finally, stakeholder perceptions also play an important role, as digital agriculture technologies are associated with improved economic stability but still raise concerns about environmental and social impacts, highlighting the importance of trust and inclusive governance in digital transformation (MacPherson et al.,

Table 3 Comparative analysis of the effects of digitalization of the agro-industrial complex according to international literature

Digital transformation unit	Main results in the literature	Empirical effect	Institutional and technological constraints	Identified research GAP
Production infrastructure (IoT, AIoT, UAV, DSS)	Digitalization creates a continuous data-analytics-action loop (Acharya et al., 2023; Muhammed et al., 2024; Chin et al., 2024)	Increased resource management accuracy, reduced losses, and improved adaptability (Mamun et al., 2025)	High demands on energy, connectivity and equipment compatibility (Navarro et al., 2020)	Lack of universal architectures scalable for developing countries
Productivity and efficiency	Digital investments improve technical efficiency and reduce costs (Yu et al., 2025; Sargani et al., 2025)	Increased TFP, reduced feed and labor costs, improved market access (Kitole et al., 2024; Santos et al., 2024)	Heterogeneity of effects by farm size and region	There is no single indicator of "digital productivity premium"
Environmental sustainability	AI and IoT enable precise management of water, soils, and chemistry (Nurmalitasari et al., 2025)	Reduced water consumption, lower emissions, increased crop yields	Dependence on infrastructure and digital literacy of farmers (Fakhraddine et al., 2025)	Environmental effects are rarely integrated into economic models.
Supply chain resilience	Digitalization enhances knowledge integration and resilience supply chains (Sargani et al., 2025)	Reducing market risks, increasing transparency	Lack of data on small producers (Narayanamurthy et al., 2025)	Lack of quantitative models of the resilience effect
Platforms and data	Platforms are creating new markets but changing the balance of social and commercial values. (Bustamante, 2023; Borrero 2022, Agyekumhene et al., 2018)	Expanding access to credit and markets	Issues of trust, privacy, and governance	Lack of data governance research in the agro-industrial complex
AI and ESG models	AI in platforms can enhance ESG value and legitimacy (Nevi et al., 2025)	Improving chain monitoring and SDG compliance	Fragmentation of ESG data standards (Kumar & Shah, 2025)	Weak empirical validation in agriculture
AI in biological processes	AI is radically improving disease selection and diagnosis. (Dublino & Ercolano, 2025; Javed et al., 2025)	Increased accuracy, reduced chemical load	"Black-box" models, lack of high-quality datasets (Majdalawieh et al., 2025)	There is no connection between AI accuracy and environmental KPIs
Social and institutional sustainability	Digitalization depends on regulators, education, and trust (Anam et al., 2025; Fleming et al., 2021; Eastwood et al., 2021)	Growing farmer inclusion and community resilience	Risk of increasing inequality and digital divide	The Lack of Equitable Digitalization Models

Note: compiled by the authors based on a systematic review of the literature according to the PRISMA

2025).

Governance of digital agriculture also depends on stakeholder perceptions and the social acceptance of digital technologies. MacPherson et al. (2025) show that stakeholders associate digital agriculture with improved economic stability and resource efficiency, although concerns remain regarding environmental and social impacts. Foresight studies further indicate that the future development of Agriculture 4.0 will depend on the interaction between technological progress, institutional governance, and societal expectations, highlighting the importance of responsible innovation and anticipatory governance frameworks (Fleming et al., 2021; Eastwood et al., 2021).

Overall, the comparative synthesis of the reviewed literature indicates that digital platforms, data infrastructures, and governance regimes form the institutional backbone of the digital transformation of agri-food systems. While digital technologies provide the technical capacity for data-driven decision-making, their sustainability and scalability depend heavily on governance structures regulating data ownership, interoperability standards, trust mechanisms, and the distribution of economic value within platform ecosystems. Despite the rapid expansion of platform-based digital agriculture solutions, important research gaps remain, particularly regarding the quantitative evaluation of governance regimes and their influence on the economic performance, resilience, and sustainability of agri-food systems.

A comparative analysis of a corpus of 56 publications demonstrates that digital transformation in the agro-industrial complex is not a linear process of implementing individual technologies, but rather the formation of a complex production system in which technological, economic, and institutional factors are interconnected. Table 3 summarizes the key findings of the literature, including the main effects of digitalization, limitations to implementation, and identified research gaps.

A summary of the results shows that digital technologies have significant potential to improve the productivity and sustainability of agricultural and food systems, but this potential is realized unevenly and depends on the institutional environment, infrastructure, and human capital. The most significant gap in the literature remains the lack of integrated models that link digital technologies, data, economic outcomes, environmental impacts, and governance mechanisms into a unified analytical framework.

4 | CONCLUSION

This study aimed to systematize and critically analyze the international scientific literature on digitalization in the agro-industrial complex, focusing on its impact on the productivity and sustainability of agri-food systems. The use of a systematic review methodology in accordance with the PRISMA standard helps to structure this extensive and fragmented body of research and examine digital transformation not only as a technological phenomenon but also as a complex economic, institutional, and managerial process. The analysis revealed that the impact of digital technologies on productivity and sustainability is nonlinear and determined by a combination of interrelated factors. Digitalization is most effective when technologies are integrated into sustainable production, organizational, and management systems, supported by data infrastructure, competencies, and institutional support. In the opposite situation, implementing digital solutions can lead to limited or unstable outcomes, exacerbating structural imbalances, transaction costs, and digital inequality. This confirms the conclusion that the digital transformation of the agro-industrial complex is a multi-level process in which technological, organizational, and institutional factors act as mutually reinforcing elements. The analysis also revealed that the sustainability of agri-food systems is shaped by the intersection of environmental, economic, and logistical aspects. However,

existing literature often considers these dimensions separately. This limits the ability to construct integrated models that simultaneously assess the impact of digitalization on resource efficiency, supply chain stability, and long-term economic performance. Thus, one of the key findings of the article is the confirmation of the need for a comprehensive approach to assessing the effects of digitalization, taking into account the interrelationships between different types of sustainability. Data management and platform ecosystems are particularly important in the current digital transformation of agri-food systems. A literature review has shown that data governance regimes, interoperability standards, trust mechanisms, and the distribution of benefits among supply chain participants largely determine the sustainability and scalability of digital solutions. In this context, digital platforms act not only as technological tools but also as institutional coordination mechanisms that influence market structure, access to resources, and the balance of economic power. The scientific contribution of this study lies in the systematic integration of technological, economic, and institutional aspects of digitalization in the agro-industrial complex into a single analytical framework. This allows us to consider Agriculture 4.0 as a complex sociotechnical system in which performance is determined by the alignment of technologies, institutions, and management practices. This approach overcomes the fragmentation of existing research and clarifies directions for further development of the theory of digital transformation of agri-food systems. The practical significance of these results lies in their recognition of the need to shift from selectively implementing individual technologies to developing holistic digital ecosystems, including data infrastructure, platform services, regulatory mechanisms, and human capital development. For countries with emerging markets and a high share of small producers, such a systemic approach is essential for transforming digitalization from a source of structural imbalances into a tool for sustainable and inclusive development. At the same time, the study identifies several research gaps. In particular, the number of studies developing integrated models for assessing the effects of digitalization that simultaneously consider economic, environmental, and value chain indicators, as well as institutional data management regimes, remains limited. Long-term empirical studies that allow for assessing the sustainability of digitalization effects over time are also insufficient. In this regard, a promising direction for further research is the development of comprehensive analytical models that integrate indicators of productivity, sustainability, and the institutional characteristics of the digital environment, as well as comparative cross-country and longitudinal studies to identify sustainable patterns in the digital transformation of agri-food systems.

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CONFLICT OF INTEREST

No conflict of interest/competing interest is reported by the authors.

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ORIGINAL ARTICLE

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Institutional Drivers of Agrohub Development: Evidence from a Transition Economy

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Abstract
Despite the implementation of various government programs to support the agricultural sector, the institutional foundations for the formation of agrotechnological hubs remain insufficiently systematized and require a comprehensive analysis. The purpose of the study is to systematise the institutional conditions that influence the formation of agrohubs as key elements of the modernisation of Kazakhstan's agro-industrial complex. The research methods are based on an institutional approach and qualitative content analysis of government programs, strategic documents, and analytical reports on the development of the agro-industrial complex. The initial data include state strategic documents, analytical reports, and statistical indicators on agricultural development in Kazakhstan. The results of the study showed deviations between the planned and actual indicators of industry development. Investments in agricultural fixed assets amounted to 1672.7 billion tenge, against the planned level of 1800.7 billion tenge (–128 billion tenge), and labour productivity grew by 112.8 p.p., against the target of 122 p.p. (–9.2 p.p.). At the same time, gross agricultural output reached 9.8 trillion tenge, grain production amounted to 19.3 million tons, and industry implemented 286 investment projects totalling 279.6 billion tenge, reflecting positive dynamics in the sector's development. The findings suggest that Kazakhstan has developed a relatively comprehensive institutional framework for agricultural modernisation. The prospects for further research include a quantitative assessment of the effectiveness of agricultural policy instruments, spatial modelling of agrohub locations, and an analysis of the role of digital and innovative technologies in the development of agro-industrial clusters.

KEYWORDS
Agriculture, Agricultural Economy, Agribusiness, Agrohub, Economic Growth, Government Support, Modernisation

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1 | INTRODUCTION

The agricultural sector is one of the fundamental drivers of Kazakhstan's economic development. This is because it is a key factor in ensuring food security, employment, income, and exports. Kazakhstan has agricultural potential, given its large land area, diverse climatic conditions, and existing production capacity in grain, livestock, and oilseed sectors. However, the agricultural sector is also characterised by inefficiencies, including low productivity, limited processing facilities, technology gaps, and limited integration into global value chains. These inefficiencies affect the agricultural sector's potential to develop value-added products and its competitiveness in both local and international markets. To address existing inefficiencies in the agricultural sector, there is growing interest in developing agro-technological hubs, also known as "agrohubs". Agrohub development is a new approach to agricultural modernisation, shifting from a traditional production-oriented system to a value chain-oriented one. An agrohub can be defined as an institutional and organisational system that includes agricultural production, agro-processing industries, logistics, financial systems, and innovation systems.

The importance of developing agrohubs has increased substantially over the past few years, given global changes in agricultural production and trade. First, the complexity of global value chains requires agricultural producers to look for opportunities beyond the production of raw agricultural commodities. Second, the development of technology, particularly digital technologies in agriculture, requires a supportive environment for agricultural producers. Finally, the challenges of a sustainable environment demand more efficient use of resources and the development of agricultural production systems that can help balance the environment. Thus, the concept of agrohubs can provide a platform for integrating production efficiency, technology, and sustainability into a single framework. The development of agrohubs is particularly important for Kazakhstan, given the country's high regional disparities, fragmented agricultural production, and a high level of state support. Despite the country having formulated a wide range of agriculture-related policies and government initiatives in crop farming, livestock development, input subsidies, credit availability, and infrastructure development, these policies and initiatives have not been formulated in a coordinated and integrated manner.

Therefore, although the overall contribution of these policies and initiatives to the sector's growth is significant, their impact on the development of an integrated agro-industrial ecosystem is relatively limited. Theoretically, the development of agrohub is related to different conceptual approaches. These approaches include cluster theory, value chain analysis, institutional economics, and regional development theory. Cluster theory relates to the concept of geographical concentration and to the interactions among different agents in the economy. This concept is related to increasing overall productivity and the diffusion of innovation in the economy. Value chain analysis involves linking different sectors of the economy to increase overall value added. Institutional economics is concerned with the overall role of different governance structures in the economy.

Despite the increasing policy significance of agrohub development, there is a noticeable lack of scientific research addressing the institutional aspects of agrohub system formation in Kazakhstan. Existing studies have largely focused on issues related to agricultural productivity, rural development, or the effectiveness of specific policy tools, while paying little attention to the relationships between policy tools and the structural components of agro-industrial ecosystems. Specifically, there is a noticeable lack of research addressing the institutional aspects of the relationship between government support tools, value chains, and agrohub system formation. This is a considerable gap, especially considering that agro-

hub system formation depends not only on available resources but also on the institutional framework.

Considering these aspects, this study focuses on systematising the institutional aspects of agro-technological hub system formation in Kazakhstan. The study is grounded in a qualitative institutional approach, in which content analysis is used to analyse available data on agro-industrial complex policies, government programs, and analytical studies. The main focus of the study is to identify the key policy instruments, institutional priorities, and structural mechanisms that play a significant role in the development of agrohub ecosystems. Emphasis is placed on the five interrelated aspects of support for agricultural production, input provision and technological modernisation, the development of agro-processing industries, financial and investment mechanisms, and institutional governance and infrastructure development. The contribution of the study is the comprehensive institutional analysis of the development of agrohub ecosystems, bridging the gap between policy analysis and value chain integration. The aim of the study is to systematise the institutional conditions and mechanisms for the development of agro-technological hubs in Kazakhstan through qualitative content analysis of existing agricultural policies and government support.

2 | LITERATURE REVIEW

The theory of agro-industrial development and agro-technological hubs formation has undergone several stages in its conceptualization. This is in line with the transition in the nature of agricultural development from production-oriented approaches to an integrated and institutionally coordinated system. The first conceptual framework for understanding agglomeration concentration and clustering effects was developed by Fujita et al. (1999). This team demonstrated the role of agglomeration economies in spatial concentration in enhancing productivity and the diffusion of innovation in the context of regional competitiveness.

In the early 2000s, studies in agricultural development focused on the institutional and policy aspects of the field. Dorward et al. (2004) pointed out that agricultural growth is driven not only by factor endowments but also by an appropriate institutional framework and high-quality governance. Further development of this institutional view was provided by Swinnen (2007), who examined the evolution of agri-food systems and demonstrated the significance of integration into global supply chains, as reflected in adherence to standards and the presence of institutional support. At the same time, Reardon and Timmer (2007) demonstrated the importance of structural changes in the food system, driven by urbanisation, market integration, and the emergence of modern supply chains.

The systemic view of agricultural development was promoted by the World Bank (2008), which highlighted the importance of integrating production, processing, infrastructure, and market access into a unified framework. This view was also promoted by FAO (2010), which highlighted the importance of developing the value chain as a tool to increase value added and support improved market participation, especially in developing and transition countries. Barrett et al. (2012) also highlighted the importance of the value chain for integrating small-scale producers into the market and improving livelihoods. However, in the 2010s, there has been a growing trend towards agro-industrial clustering as a tool for regional development and agricultural modernisation. Empirical studies have shown that agro-industrial clustering positively impacts employment creation, income growth, and competitiveness (Balcha et al., 2014; Trishin, 2020). This has further supported the earlier argument that a cluster of agricultural producers, processing enterprises, and service

providers positively impacts agricultural systems.

The evolution of agricultural systems in transition countries has also been analyzed in terms of their transformation (Buchenrieder et al., 2009), which has shown that institutional reforms, private sector development, and market-oriented restructuring in post-socialist agricultural systems are essential tools for development in transition countries. This has also shown that effective institutional systems are essential tools for large-scale agricultural development. However, in recent years (2020–2025), there has been a growing trend towards incorporating new dimensions, such as technology, innovation, and sustainability, into the agro-industrial development literature. For instance, studies have shown that digital agriculture positively impacts agricultural productivity (Muraru-Ionel et al., 2019; D'Oronzio & Sica, 2021; Gromenkova, 2022; Kniazieva et al., 2025). Moreover, biotechnology has also been identified as an essential tool for agricultural development (Najork, 2022).

Moreover, recent research underscores the significance of cluster-based and value-chain approaches in agricultural development. In this regard, Nikolaienko (2022) and Nikoliuk et al. (2022) demonstrate that agro-industrial clusters positively impact the coordination of value chain actors and the competitiveness of agricultural enterprises. Moreover, Mashrabovich and Toxtasinovna (2024) reveal that agro-industrial clusters operate as a unified system that integrates production and institutional support in a unified economic space. Other studies have also shown that cross-sectoral and innovation clusters positively impact cooperation between the agricultural sector and other sectors, which in turn leads to value chain integration (Muraru-Ionel et al., 2019). In this regard, it is worth mentioning that the formation of unified agro-industrial structures is also associated with cluster-based agricultural policies and institutional coordination mechanisms (Makhmadizoda & Mukhsinova, 2025). In this respect, Otsuka and Ali (2020) have underlined that agro-based clusters have a significant impact on structural and rural development.

The significance of policy support and institutional frameworks for agro-industrial development has been discussed in recent studies. According to various research studies, investments in infrastructure, research institutions, and extension services have played a significant role in creating a conducive environment for agro-industrial clustering (Salih, 2021; Yang & Li, 2021). In addition, smart specialisation strategies, regional policy coordination, and institutional frameworks have contributed to agro-industrial development, particularly by fostering innovation systems (Shvets et al., 2023). Recently, various studies have highlighted the importance of sustainability factors in agro-industrial development. Specifically, green clusters integrate environmental regulation, sustainability, and technological innovation (Voronkova et al., 2023). Furthermore, agro-industrial parks, aggregation centres, and their contributions to rural industrialisation have been discussed in recent studies (Kahuthia & Karanja, 2025; Zhang et al., 2023).

Despite recent studies on agricultural development, value chains, agro-industrial clustering, and related issues, certain limitations remain. First, various studies have discussed agro-industrial clustering, value chains, and institutional frameworks separately. On the one hand, while cluster theory is concerned with spatial concentration, value chain analysis with market linkages, and institutional studies with governance structures, there is a general lack of integrated approaches that account for all these aspects within a single framework.

Second, while recent studies increasingly recognise technological innovation and digitalisation, there is a general lack of attention to how these aspects are integrated into institutional systems that support agrohub development.

Third, there is a general lack of empirical studies on the institutional foundation of agro-technological hub formation in transition economies, such as Kazakhstan. Existing

studies on Kazakhstan's agricultural sector have mainly focused on productivity, investment, or policy measures, while there is a general lack of studies examining the link between policy instruments and the structural components of agro-industrial ecosystems.

It is, therefore, the institutional link between the government's policy instruments, the value chain, and the development of the agrohub ecosystem that forms the main gap in the research, which needs to be filled in order to fully comprehend the role that coordinated policy frameworks can have in the development of agro-technological hubs in the country's agricultural sector.

3 | METHODOLOGY

The research is grounded in a qualitative institutional research design, focusing on content analysis of policy, strategic, and analytical documents on the development of the agro-industrial complex in Kazakhstan. This approach is intended to reveal the institutional, governance, and policy conditions for the emergence of agro-technological hubs as an integral component of agricultural modernisation. In the context of the research, an agrohub is not only understood as a territorial concentration of agricultural activities but also as an institutional and organisational environment that encompasses agricultural production, agro-processing, logistics, infrastructure, finance, and innovation support under a single umbrella. The empirical base of the research comprises 28 official documents adopted between 2017 and 2025, reflecting the current state of agricultural policy development in Kazakhstan.

The document corpus includes the State Program for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan for 2017–2021, the National Project for the Development of the Agro-Industrial Complex for 2021–2025, the Concept for the Development of the Agro-Industrial Complex until 2030, strategic plans of the Ministry of Agriculture of the Republic of Kazakhstan, annual reports on the implementation of state programs, analytical reports on the development of the agro-industrial complex prepared by government bodies and the National Chamber of Entrepreneurs "Atameken," as well as statistical data from the Bureau of National Statistics. These documents provide comprehensive information on policy priorities, support mechanisms, and implementation outcomes in agriculture.

The selection of the documents is based on their institutional relevance, contribution to the development of the agro-industrial complex, and the presence of a well-defined set of policy instruments, objectives, and mechanisms of implementation. The documents related to agriculture, the agro-industrial complex, investment support, infrastructure development, and institutional governance were included in the analysis. Documents not related to the field of agriculture and the agro-industrial complex, and those with low policy content, were not included in the analysis. The rationale for choosing the qualitative content analysis method is grounded in the complexity of the research problem. The development of the agrohub is not only dependent on the results of the relevant economic indicators but also on the consistency of the policy instruments. The unit of analysis is either a policy statement or a fragment of the document that has a well-defined institutional meaning. This may include the provisions related to the subsidies, mechanisms of investments, infrastructure development, and modernisation of technologies.

The framework was built upon the conceptual understanding of what an agrohub is, as a system that integrates production, processing, infrastructure, finance, and innovation. Therefore, five analytical categories were used: support to agricultural production, provision of inputs and technological modernisation, agro-processing development, financial and

investment mechanisms, and institutional governance and infrastructure development. Each policy instrument was classified according to its contribution to these structural components.

The methodological framework used in this study is shown in Figure 1.

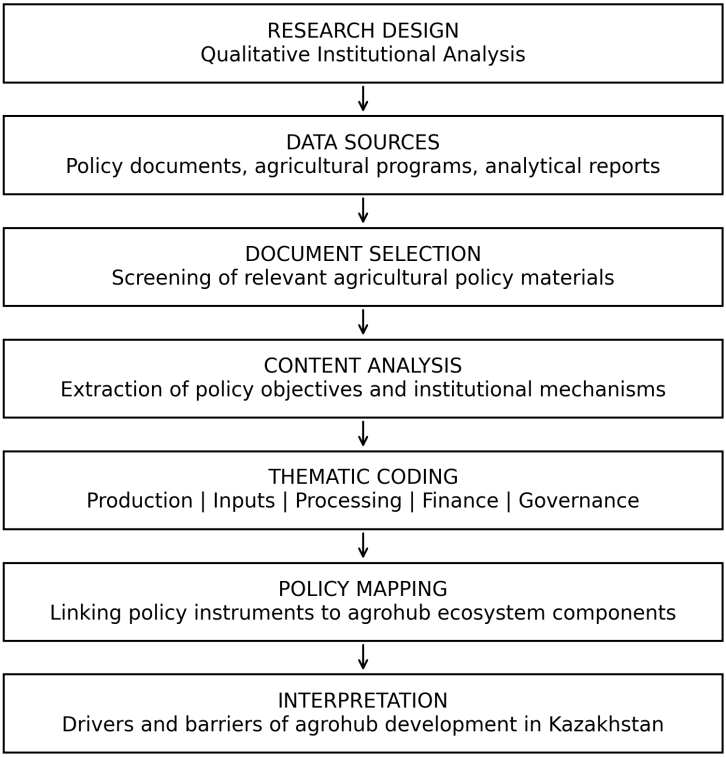

Figure 1 Research methodological framework

The analytical method involved a series of steps: identifying relevant documents, identifying key policy elements, coding, and, finally, policy mapping. The mapping process enabled the identification of relevant policy instruments and their structural components in relation to agrohub ecosystems. This enabled the assessment of the balance and coherence of institutional support. Moreover, the analytical method involved comparing sectoral indicators against plans and actual implementation, as presented in official documents. This enabled the assessment of the gap in policy implementation.

The paper also highlights institutional challenges to the effective implementation of agricultural policies. These challenges include inadequate financing for agrohub ecosystems, administrative challenges in allocating subsidies to farmers, inadequate credit for farmers, inadequate rural infrastructure, and poor coordination among state institutions. These challenges are considered critical to the formation of agro-technological hubs. Overall, the methodological framework provides an analytical framework for assessing agrohub ecosystems in Kazakhstan as an integrated system. This enables the identification of key

elements in agrohub ecosystems in Kazakhstan.

4 | RESULTS

The results of the content analysis reflect the main institutional mechanisms and policy instruments that determine the formation of agro-technological hubs in Kazakhstan. Analysing policy documents, analytical reports, and agricultural development programs helps identify key policy priorities, investment trends, and sectoral results that shape the formation of agro-industrial clusters. The analysis demonstrates that government policy focuses primarily on increasing productivity in the agricultural sector, promoting investment in agriculture, and enhancing agricultural processing and institutional governance. At the same time, it is shown that certain structural limitations lead to financing gaps and delays in program implementation.

The first stage of the analysis involves examining strategic indicators of agricultural development. These indicators reflect the implementation of government policies to develop and modernise the agricultural sector. It is necessary to compare planned and actual values to demonstrate that, although the agricultural sector shows positive growth dynamics, it is not achieving strategic targets. In particular, significant deviations are observed in investment levels, labour productivity growth, and the development of domestic seed supply systems. As shown in Table 1, these indicators reflect the implementation of government policies aimed at developing and modernising the agricultural sector.

Table 1 Implementation of key strategic indicators of agricultural development in Kazakhstan

Indicator	Planned value	Actual value	Deviation	Interpretation for agrohub development
Investment in fixed capital in agriculture	1,800.7 billion KZT	1,672.7 billion KZT	–128.0 billion KZT	Lower investment slows the modernisation of agricultural infrastructure
Labour productivity in agriculture	122 p.p.	112.8 p.p.	–9.2 p.p.	Technological modernisation progresses more slowly than expected
Share of domestic seeds in agricultural production	62.2 p.p.	No implementation	–62.2 p.p.	Weak seed production base for agrohub systems
Share of breeding livestock in the total herd	36 p.p.	28.2 p.p.	–7.8 p.p.	Slower development of livestock clusters
Certified organic producers	3 producers	12 producers	+9 producers	Emerging niche markets within agrohub ecosystems

Note: compiled by the author

The results show that the most significant gap was recorded in the development of domestic seed production systems, which is vital to the sustainability of agricultural productivity. The results also show that investment levels are too low to modernise the agricultural sector's production infrastructure, which negatively affects the development of agro-industrial clusters. However, a positive trend was observed in the certification of organic producers in the agricultural sector, indicating greater diversification of production systems.

According to the presented data, there are deviations between planned and actual values. Thus, investments in agricultural fixed assets amounted to 1,672.7 billion KZT, against the

planned level of 1,800.7 billion KZT, indicating insufficient investment support for industry modernisation. Labour productivity growth reached 112.8 p.p., with a target of 122 p.p., indicating a slower pace of technological renewal in agricultural production. There is also a significant lag in the development of the seed production system, although the planned share of 62.2 p.p. of domestic seeds was not achieved. At the same time, the number of certified organic producers has increased from 3 to 12, which indicates the emergence of new areas of agricultural business development. The results obtained make it possible to identify institutional constraints and conditions that influence the formation of agrotechnological hubs and the modernisation of the agro-industrial complex in Kazakhstan.

The second stage of the content analysis examines production outcomes and investment dynamics in the agricultural sector. These results indicate structural changes in Kazakhstan's agro-industrial complex. As shown in Table 2, agricultural production in Kazakhstan demonstrates positive growth trends.

Table 2 Agricultural production and investment dynamics in Kazakhstan

Indicator	Value	Analytical interpretation
Gross agricultural output (Jan–Sep 2025)	9.8 trillion KZT	Indicates stable growth of agricultural production
Growth of crop production	+7.8 p.p.	Driven by expansion of cultivated areas and increased productivity
Growth of livestock production	+3.3 p.p.	Moderate growth in the livestock sector
Grain harvest (after processing)	19.3 million tons	Reflects strong grain production capacity
Oilseed production	2.9 million tons	Expansion of export-oriented agricultural crops
Potato production	3.9 million tons	Stable domestic production levels
Vegetable production	4.9 million tons	Growth of horticultural production
Agricultural investment projects implemented	286 projects	Total value of 279.6 billion KZT

Note: compiled by the author

The results obtained indicate that the dynamics of the agricultural sector of Kazakhstan is generally positive in terms of production and investment. However, the results of the analysis also indicate that the dynamics of the sector is institutionally uneven and does not yet lead to the formation of integrated agro-technological hubs. The implementation of 286 investment projects totalling 279.6 billion KZT indicates that the state has created a significant platform for capital renewal in the agricultural production and processing sector. At the same time, the results of the analysis of the dynamics of grain, oilseed, vegetable, and livestock production should not be understood as evidence of sectoral growth. The results are important for the formation of the agrohub. The sector has several material preconditions for the development of the agrohub. However, the preconditions require a more consistent institutional background to be transformed into an agro-industrial ecosystem.

The next step of the analysis concerned the policy framework's thematic content, as reflected in the 28 documents. The content analysis highlighted that the institutional architecture of Kazakhstan's agricultural policy is built around five major thematic blocks, which correspond to the main structural dimensions of agrohub development: support to agricultural production, inputs and technological modernisation, support to agro-processing,

financial/investment mechanisms, and institutional governance/infrastructure. Nevertheless, there is a rather uneven spread of policy attention between these thematic blocks. The main focus remains on direct support for primary agricultural production, as well as on financial instruments to sustain activity levels, while innovation, digitalisation, inter-sectoral coordination, and the institutional integration of value chains receive limited attention. This is a critical aspect, as agrohub development not only requires the coexistence of different policy instruments, but their interaction, especially across the entire range of production, processing, finance, innovation, etc.

As illustrated in Table 3, the institutional architecture of agricultural policy is structured around five key thematic categories.

Table 3 Thematic structure of policy instruments identified in the corpus of 28 agricultural policy documents

Thematic category	Core content of identified policy instruments	Institutional function in agrohub formation	Dominant orientation of state support	Analytical interpretation
Agricultural production support	Crop support measures, livestock development instruments, productivity growth targets	Strengthening the raw-material base of agrohub ecosystems	Output expansion and stabilisation of primary production	Forms the quantitative production basis for agrohub development
Input provision and technological modernisation	Subsidies for seeds, fertilisers, pesticides, machinery renewal, breeding systems	Reducing production constraints and improving technological capacity	Cost reduction and partial technological renewal	Improves the operational capacity of farms
Agro-processing development	Support for food-processing enterprises, storage capacity, processing facilities	Moving the sector toward higher value-added production	Strengthening processing capacity and marketability	Critical for agrohub development
Financial and investment mechanisms	Investment subsidies, concessional lending, agricultural credit, capital support measures	Mobilising capital for agricultural expansion and modernisation	Maintaining investment activity and stimulating private participation	Financial instruments are visible but access is constrained
Institutional governance and infrastructure	Regulatory reforms, digitalisation of agricultural services, logistics support	Creating the institutional and physical environment for integrated agrohub ecosystems	Improving implementation conditions and administrative support	Strategic significance but less developed in practice

Note: compiled by the author

The results of thematic coding indicate that the basic institutional framework for Kazakhstan's agricultural policy is already in place to support the formation of an agrohub. However, it is also clear that the basic institutional content is not equally developed or balanced. The highest concentration of agricultural policy is observed in areas directly related to supporting agricultural output and providing financial instruments. This may indicate that agricultural policy remains primarily focused on maintaining and expanding agricultural production. On the other hand, the greater presence of agro-processing policy measures in the analysed corpus may signal a gradual change in agricultural policy from a simple production approach to a more complex one. This is an important change, as the feasibility of agrohubs is directly linked to the availability of processing capacity to transform agricultural output into new agro-industrial chains.

It was precisely the process of policy mapping that allowed us to transcend the level of thematic classification and evaluate the correspondence of the identified instruments with the structural components of agrohub ecosystems. It was established that policy support in Kazakhstan is allocated across the main components necessary for the development of agrohub ecosystems, with certain asymmetry in intensity and functional consistency. Table 4 illustrates the policy mapping of government support instruments to the structural components of agrohub ecosystems.

Table 4 Policy mapping of government support instruments onto structural components of agrohub ecosystems

Agrohub ecosystem component	Main policy instruments	Functional role within the agrohub model	Degree of institutional coverage	Key limitation identified
Agricultural production systems	Crop support programmes, livestock development initiatives, productivity targets	Formation of stable primary output and supply concentration	High	Strong support does not automatically translate into integrated downstream development
Agro-processing industries	Support for food-processing enterprises, processing investment projects	Creation of value-added links and industrial deepening	Medium to high	Coordination with raw-material supply systems and logistics remains incomplete
Agricultural infrastructure	Logistics development, storage facilities, transport-related support	Reducing transaction costs and improving supply-chain continuity	Medium	Infrastructure development remains uneven across regions
Financial ecosystem	Credit programmes, subsidised loans, investment subsidies	Providing liquidity and long-term capital for modernisation	High	Administrative barriers and delayed disbursement reduce effectiveness
Innovation and knowledge ecosystem	Digitalisation initiatives, selected research and technological modernisation	Supporting technological upgrading and long-term competitiveness	Low to medium	Innovation measures are fragmented and less institutionally embedded
Institutional coordination environment	Regulatory reforms, digital public services, inter-agency governance	Ensuring coherence of support instruments	Medium	Coordination remains fragmented across agencies

Note: compiled by the author

As shown by policy mapping results, Kazakhstan's agricultural policy institutional architecture includes almost all essential components needed to support the creation of agro-technological hubs. Nevertheless, one should not equate coverage with system integration. As shown by the results, the system is more extensive in scope than integrated, meaning that different tools exist, though not always functioning as complementary mechanisms. Figure 2 illustrates the policy-agrohub ecosystem relationship, as derived from content analysis.

Another aspect of the content analysis was the search for institutional barriers that affect the practical effectiveness of the existing support system. From the documents, it is evident that the major constraints are not only sectoral but also institutional and organisational. Issues such as financial constraints, policy implementation delays, inadequate access to credit, and poor infrastructure in rural areas are cited as major constraints. Table 5 shows institutional barriers constraining agrohub development in Kazakhstan.

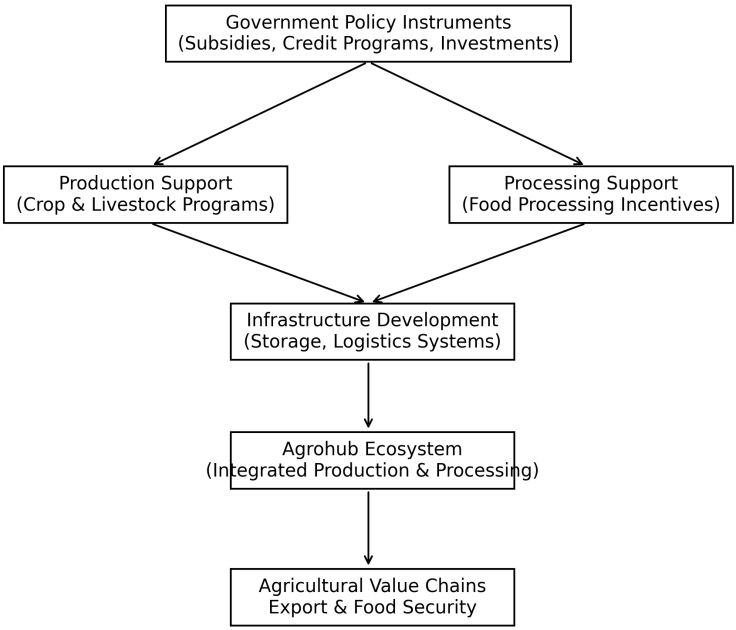

Figure 2 Policy–agrohub ecosystem relationship identified in the content analysis

The analysis of the institutional barriers revealed that the key limitation to agrohub development in Kazakhstan is not a lack of support tools but a low level of maturity in the institutional environment. Thus, the support for production, subsidies, and investment incentives is represented fairly well. At the same time, the tools for integrating these tools into a single ecosystem have not been sufficiently developed. This primarily applies to the domains of policy coordination, financing continuity, infrastructure completeness, and ecosystem innovation. Thus, the existing policy environment is viewed as a system that supports sectors rather than one that builds ecosystems.

The results of content analysis show that Kazakhstan has managed to create a certain, though not wide, institutional base for the development of an agro-technological hub. The results of the policy corpus content analysis confirm the presence of support measures in all major structural areas of the agrohub ecosystem. At the same time, the results are clear: the configuration of the institutional base of the support measures is asymmetrical. Thus, the highest level of support is observed in primary production and financial stimulation, while innovation, digital technologies, logistics connectivity, and inter-institutional coordination are less well articulated. Therefore, the main result of the research is that Kazakhstan's agricultural policy already possesses the formal preconditions for creating an agrohub, though developing an agro-industrial ecosystem from it requires greater vertical and horizontal integration of policy instruments. Thus, the main institutional task is not only to expand the range of support measures but also to integrate them more fully and align them with the value chain.

Table 5 Institutional barriers constraining agrohub development in Kazakhstan

Institutional barrier	Manifestation in the analysed documents	Mechanism of negative influence on agrohub development	Structural consequence
Insufficient financing of programmes	Underfinancing, delayed implementation of planned measures	Reduces the scale and continuity of infrastructure support	Slower formation of integrated agrohub infrastructure
Administrative delays in subsidy allocation	Time lags in disbursement, procedural complexity	Weakens the responsiveness of support instruments	Lower investment attractiveness and reduced policy efficiency
Limited access to agricultural credit	Unequal access to concessional finance, financing gaps	Restricts farm expansion, technological renewal	Uneven participation of producers in agrohub ecosystems
Infrastructure deficits in rural areas	Insufficient storage, logistics, transport connectivity	Increases transaction costs and limits territorial integration	Weak linkage between local production systems and value chains
Fragmented institutional coordination	Multiplicity of implementing bodies, incomplete alignment	Prevents the formation of a unified ecosystem approach	Institutional fragmentation of agrohub development policy
Weak innovation embedding	Innovation and digitalisation measures are less prominent	Limits the transition from extensive growth to knowledge-based development	Reduced long-term competitiveness of agrohub models

Note: compiled by the author

5 | CONCLUSION

The purpose of this study was to systematise the institutional conditions and policy mechanisms for the development of agro-technological hubs in Kazakhstan in the context of agricultural modernisation. The study examines the institutional foundations for the development of agro-technological hubs in Kazakhstan using qualitative content analysis of policy documents and strategic and analytical materials related to the agro-industrial complex. The study is based on the idea that the development of an agrohub should be understood not only as the concentration of agricultural production but also as the development of an integrated institutional environment. From this standpoint, the study allows for the assessment of the conditions for the development of agriculture not just as the aggregate of supporting measures but also as a system of interrelated tools.

From this analysis, it can be seen that a wide policy and institutional foundation has been developed in Kazakhstan, which can serve as a foundation for agrohub development. This foundation includes support for primary production, investment stimulation, agro-processing development, as well as certain elements of infrastructure development and institutional arrangements. This means that a shift has already occurred from a purely production-based model of agricultural development to one that also includes elements of value-added development and structural modernisation. In this regard, the institutional context of the agro-industrial complex includes a foundation necessary for the development of regionally embedded agrohub ecosystems.

At the same time, the study finds that the current policy mix is more supportive than integrative. From an institutional point of view, the main limitation is not the availability of policy instruments, but rather their incomplete coordination. To develop agro-technological hubs, it is necessary to enhance functional linkages among production systems, processing, logistics, finance, and innovation. However, according to the documents, these aspects are

still not developed uniformly, with a tendency to treat them as parallel directions of state support rather than parts of a single ecosystem strategy. Therefore, the current policy model is more supportive than integrative, meaning it is more effective at maintaining activity than at creating coordinated agro-industrial hubs.

The study also confirms that the quality of implementation is a key factor in determining the operational impact of the institutional framework. Thus, despite the existence of support instruments in theory, the impact of development is limited by financing volatility, administrative delays, underdeveloped infrastructure, and fragmented governance. Therefore, in order to tackle the issue of agrohub development in Kazakhstan, it is necessary not only to expand support programmes but also to strengthen implementation coherence and institutional complementarity. In this regard, it is necessary to underline that a key policy issue is how to move from a fragmented support system to a more cohesive development model.

Possible ways for further research include the extension of the current analysis in the following ways: extension of the current analysis by using quantitative assessments of the effectiveness of specific policy instruments based on the institutional patterns identified in this research; spatial analysis for identifying regional areas with the greatest potential for agrohub concentration and specialisation; further research may also focus on the role of digital agriculture, innovation ecosystems, and inter-organisational networks in the context of the long-term sustainability of agro-industrial hubs in Kazakhstan. The current research confirms that the transition to agrohub-based agricultural development is institutionally feasible in Kazakhstan, but it also depends on the extent to which specific policy instruments are integrated into a coherent system.

AUTHOR CONTRIBUTION

Writing – original draft: Rab Nawaz Lodhi.
Conceptualization: Rab Nawaz Lodhi.
Formal analysis and investigation: Rab Nawaz Lodhi.
Development of research methodology: Rab Nawaz Lodhi.
Software and supervisions: Rab Nawaz Lodhi.
Data collection, analysis and interpretation: Rab Nawaz Lodhi.
Visualization: Rab Nawaz Lodhi.
Writing review and editing research: Rab Nawaz Lodhi.

CONFLICT OF INTEREST

No conflict of interest/competing interest is reported by the author.

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Secondary Education Financing in Kazakhstan: Challenges and Efficiency

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Abstract
In the context of the transition to a knowledge economy and the increasing demands on the quality of human capital, the effectiveness of financing secondary education is becoming particularly relevant. The aim of the study is to assess the impact of financing mechanisms for secondary education on the quality of educational outcomes in Kazakhstan, considering infrastructural, human, and digital factors. The methodological basis of the research includes methods of descriptive statistics, correlation analysis, econometric modeling, and performance analysis. The empirical database is based on panel data for 17 regions of Kazakhstan for the period 2015–2025. The results of the study revealed a stable positive relationship between financing and the quality of education. Digitalization ($\beta = 3.45$) and infrastructure ($\beta = 2.63$) had the greatest impact, whereas the impact of financial expenses was more moderate ($\beta = 1.92$). The burden on teachers has a statistically significant negative impact ($\beta = -1.08$). The high coefficient of determination ($R^2 = 0.84$) confirms the model's significant explanatory power. The results of the DEA analysis demonstrate pronounced regional differentiation in efficiency, with Almaty (0.92) and Astana (0.90) occupying the leading positions, while the southern and western regions exhibit lower efficiency. The results show that financing is a necessary but insufficient condition for improving the quality of education. The research contributes to the development of the theory of educational financing by demonstrating the need to transition to an integrated resource management model focused on the effectiveness and quality of educational outcomes.

KEYWORDS
Education, education quality, secondary education, education economics, human capital, region, regional development, economic efficiency

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1 | INTRODUCTION

In the context of the transition to a knowledge economy and increasing global competition for human capital, the education system is becoming a key factor in long-term socio-economic development. In this regard, the effectiveness of education financing is of particular importance, since it is through resource allocation mechanisms that conditions are created to improve the quality of educational outcomes, develop cognitive skills, and ensure social mobility. The transition to a knowledge economy increases the demands on the quality, accessibility, and effectiveness of education, making the issues of financing the educational system particularly relevant. It is through financing mechanisms that the state creates conditions for the functioning of educational institutions, infrastructure development, teacher training, and the introduction of digital technologies.

In recent years, scientific research has increasingly raised the issue that increased spending on education alone does not guarantee improved educational outcomes. Within the framework of the classical theory of human capital, education is considered an investment that increases labour productivity and income (Becker, 1964; Mincer, 1974). In the macroeconomic context, this idea has been developed in economic growth models, where human capital is considered one of the key factors determining differences in countries' levels of development (Mankiw et al., 1992).

However, recent research shows that increased education funding does not always lead to improved educational outcomes (Pritchett, 2001; Afonso, 2006). At the same time, the quality of education is of particular importance and has a more significant impact on economic growth than its quantitative characteristics (Hanushek & Woessmann, 2015; Goczek et al., 2021). Research shows that the effectiveness of an educational system is determined not only by the volume of resources, but also by the conditions of their use, including institutional mechanisms, the quality of management, and the level of development of the educational environment (Churchill et al., 2015; Psacharopoulos & Patrinos, 2018). In recent decades, the scientific agenda has shifted from analysing funding levels to researching the effectiveness and efficiency of funding. The educational system is increasingly viewed as a multicomponent structure that includes not only financial resources, but also infrastructure, human resources, and the level of digitalization. In this context, the digital transformation of education is particularly important, as it increases the availability of educational resources, optimises learning and management processes, and reduces transaction costs.

The relevance of this study to Kazakhstan lies in the country's education system, which is undergoing active transformation and is heavily dependent on government funding. In recent years, education spending has increased, but a corresponding improvement in educational outcomes has not always followed. One of the reasons is the uneven distribution of resources between regions, as well as differences in infrastructure development and access to modern educational technologies. The process of digitalising education creates additional complexity that develops unevenly and requires both a technical foundation and relevant competencies from teachers. In an environment where digital solutions are being implemented faster than the skills to use them effectively are being developed, their potential is not being fully realized.

Despite the existence of a significant number of studies on education financing, most focus on specific aspects of the problem. At the same time, the complex impact of financial, infrastructural, and digital factors on the quality of educational outcomes, considering regional specifics, remains insufficiently studied. In addition, limited attention is paid to assessing the effectiveness of resource use in the territorial context. In this regard, the purpose of this study is to assess the impact of financing mechanisms for secondary education

on the quality of educational outcomes in Kazakhstan, considering infrastructural, human, and digital factors. To achieve this goal, a comprehensive methodological approach is used, including descriptive statistics, correlation analysis, econometric modelling, and efficiency assessment based on the Data Envelopment Analysis (hereinafter – DEA) method. The empirical basis of the study is panel data on Kazakhstan's regions for the period 2015-2025, which allows us to account for both temporal dynamics and interregional differences.

2 | LITERATURE REVIEW

Studying the mechanisms of financing secondary education in modern conditions requires a comprehensive theoretical and methodological approach that integrates classical economic concepts with contemporary institutional and empirical research. The evolution of scientific thought demonstrates a gradual transition from viewing education as a factor in human capital accumulation to considering it a complex system encompassing financial, institutional, infrastructural, and digital components. In this context, education financing is considered not only a tool for providing resources, but also a key mechanism for generating long-term economic growth, social mobility, and sustainable development.

The classical starting point for the analysis of education financing is the theory of human capital, formed in the works of Gary Becker and Theodore Schultz. According to this theory, investments in education are a form of investment that brings economic returns in the form of increased labor productivity and income (Becker, 1964; Schultz, 1961). Empirical studies confirm that education is one of the most stable factors explaining income differences at both the individual and macroeconomic levels (Mincer, 1974).

In the macroeconomic context, economic growth models have integrated human capital into the production function, demonstrating its key role in explaining cross-country differences in levels of development (Mankiw et al., 1992). However, subsequent studies have shown that increases in education levels and related costs are not always accompanied by proportional increases in economic and educational outcomes (Devarajan et al., 1996; Krueger, 1999). Afonso (2006) showed that, at the same level of funding, countries and regions exhibit different efficiencies in converting resources into educational outcomes. An increase in costs leads to a decrease in the marginal effect, especially when a certain level of the education system's resource provision is reached (Barro and Lee, 2013). This indicates that the effectiveness of investments is determined not only by their volume, but also by the quality of the educational environment.

However, subsequent studies have significantly clarified this relationship. In particular, it has been shown that quantitative indicators of education are less significant than qualitative characteristics, particularly students' cognitive skills (Checchi, 2006; Rao and Jani, 2008; Hanushek and Woessmann, 2012). Moreover, research shows that the quality of education, rather than its duration, has a statistically significant impact on economic growth (Goczek et al., 2021; Hanushek and Woessmann, 2015). This indicates the need to rethink the role of education financing, shifting the focus from the number of resources to their effectiveness.

The next stage in the development of scientific thought concerns the analysis of the role of government spending in education. The results of empirical and generalizing studies show that increased spending on education does not always lead to improved educational outcomes or accelerated economic growth (Easterly, 2001; Pritchett, 2001). However, the key issue is not only the amount of funding, but also its effectiveness. A meta-analysis of empirical research shows that increased spending on education does not always lead to improved educational outcomes or economic growth (Benos, 2014). Thus, the quality of education is of key importance not only in terms of macroeconomic effects, but also at the

level of behavior of economic agents (Koning and Wiel, 2013).

This phenomenon is explained by the influence of institutional factors. In particular, it has been shown that the effectiveness of educational expenditures depends on the quality of management, the structure of resource allocation and the institutional environment (Churchill et al., 2015; Psacharopoulos and Patrinos, 2018). More recent research confirms that countries with comparable levels of funding exhibit significant differences in educational outcomes, pointing to the key role of institutional mechanisms and educational policies (Aghion et al., 2009; Woessmann, 2016; Schwerdt et al., 2020).

An important area of research is the analysis of the nonlinear nature of the impact of educational expenditure. Recent studies suggest that the relationship between spending and educational outcomes is heterogeneous and context-dependent, with additional investments not always leading to proportional improvements in performance (Schleicher, 2019; Carnoy et al., 2016). Moreover, recent cross-country analyses highlight that improvements in outcomes occur primarily when financial inputs are complemented by institutional reforms and system-level efficiency gains (Barrett et al., 2015; Kraft, 2019).

Modern research also highlights the role of infrastructure as one of the key factors of educational effectiveness. A well-developed material and technical base provides conditions for the implementation of educational programs and improving the quality of education (Goczek et al., 2021). Recent studies demonstrate that digital tools can significantly improve educational outcomes, especially in contexts with limited traditional resources, while also increasing flexibility and personalization of learning (Selwyn, 2019; Tran-Duong, 2022). Research showed that digitalization has a significant impact on educational outcomes, especially in conditions of limited traditional resources (Bulman and Fairlie, 2016; Winthrop et al., 2020). Moreover, contemporary empirical evidence suggests that digital technologies can amplify the impact of educational investments by serving as an efficiency multiplier when effectively integrated into teaching and learning processes (Reimers and Schleicher, 2020; Escueta et al., 2020; Zhao et al., 2021).

At the same time, the effectiveness of digitalization depends on the level of its integration and the availability of appropriate competencies among teachers. With insufficient training and infrastructure, digitalization may not lead to the expected results, which underscores the need for an integrated approach to reforming the educational system. A separate area of research is related to the analysis of educational inequality. It has been established that differences in access to educational resources lead to the reproduction of socio-economic inequalities (Blanden et al., 2022). Empirical evidence shows that unequal access to digital technologies and educational resources contributes to the persistence and reproduction of socio-economic disparities (Werfhorst et al., 2022). This is especially true in countries with economies in transition, where there is significant regional differentiation in funding levels, infrastructure, and the quality of education.

In the context of Kazakhstan, these problems are becoming particularly relevant. Modern research shows that the education financing system is characterized by high dependence on the state budget, as well as the presence of structural imbalances in the allocation of resources (Aryn and Issakhova, 2018; Zamirbekkyzy et al., 2024). At the same time, an increase in funding is not always accompanied by an increase in the quality of educational outcomes, which corresponds to the conclusions of international research. The effectiveness of the education system largely depends on the quality of implementation, the level of management practices and the institutional environment, which is especially typical for countries with economies in transition (Potluri and Mukashev, 2024). At the same time, research on the Kazakh education system highlights the influence of behavioral and structural factors,

including the choice of educational institutions and perceptions of their quality, which also reflect the system's heterogeneity and differences in access to educational resources (Jumasseitova et al., 2025).

Thus, modern scientific literature helped identify several key areas of analysis: (1) the role of education financing in the formation of human capital; (2) resource efficiency and institutional constraints; (3) the importance of infrastructure and digitalization; (4) the non-linear nature of the relationships; (5) regional differentiation of educational systems. Despite significant progress in the study of these issues, a scientific gap remains in the insufficient integration of financial, infrastructural, and digital factors into a single empirical model, especially in countries with economies in transition. In addition, there is a limited number of studies that take into account the spatial differentiation of the effectiveness of educational systems. Thus, the present study aims to fill this gap through a comprehensive analysis of the financing mechanisms of secondary education in the Republic of Kazakhstan using econometric methods, efficiency assessment and spatial approach.

3 | RESEARCH METHODS

In the context of the increasing burden on the secondary education system and the need to improve the efficiency of public resource use, a quantitative analysis of financing mechanisms is becoming particularly relevant. Unlike traditional approaches, which primarily focus on estimating budget expenditures, the modern scientific agenda focuses on the effectiveness and efficiency of allocating financial resources, as well as on identifying the relationship between investments in education and their final results.

The present study employs a comprehensive methodological approach that combines descriptive statistics, correlation analysis, econometric modeling, and performance evaluation. This approach makes it possible to account for both the temporal dynamics of indicators and interregional differences, and to identify structural relationships between financing and the quality of education.

The study's empirical base is panel data for 17 regions of the Republic of Kazakhstan for the period 2015–2025, yielding a balanced sample of 187 observations. Each observation is a region–year combination, which allows simultaneous analysis of temporal and spatial effects.

Within the framework of the study, the system of financing secondary education is considered a set of interrelated elements, including the number of financial resources, staffing, infrastructure, and the level of digitalization. Based on this concept, a system of variables has been developed to reflect the key characteristics of the educational system.

The dependent variable is an integral indicator of education quality, calculated as a composite index based on normalized components reflecting key educational outcomes by formula (1):

$$EduQuality_{\text{it}} = \frac{1}{n}\sum_{k=1}^{n} Z_{\text{kit}} \tag{1}$$

where:

$EduQuality_{\text{it}}$ – integral indicator of education quality in region i at time t;

Z_{kit} – normalized value of the k-th indicator included in the index;

n – number of indicators used to construct the index.

The constructed system of variables makes it possible to proceed to the analysis of their statistical properties and to assess the degree of variation. At this stage, descriptive statistics are applied to evaluate the range of indicator values, their dynamics, and interregional

differences. The results of the analysis indicate a steady increase in education expenditures and the level of digitalization, accompanied by a reduction in teacher workload and a gradual improvement in education quality. At the same time, significant regional disparities persist, indicating the heterogeneity of the secondary education system.

The correlation analysis is based on aggregated data for the period 2015–2025, which makes it possible to identify stable dependencies between financing, infrastructure, digitalization and the quality of education. However, this approach does not allow quantifying the impact of factors, which requires the use of econometric modeling.

To assess the impact of these factors on the quality of education, the following econometric model is specified by formula (2):

$$EduQuality_{it} = \alpha + \beta_1 EduExp_{it} + \beta_2 PTR_{it} + \beta_3 Infra_{it} + \beta_4 Digital_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

where:
$EduQuality_{it}$ – education quality indicator;
$EduExp_{it}$ – education expenditures;
PTR_{it} – teacher workload (pupil–teacher ratio);
$Infra_{it}$ – infrastructure level;
$Digital_{it}$ – the level of digitalization;
μ_i – region-specific effects;
ε_{it} – stochastic error term.

The model parameters are estimated using panel data regression techniques based on the least squares method for the period 2015–2025. The use of panel data allows controlling for unobserved regional heterogeneity and capturing both temporal dynamics and cross-regional differences, which improves the robustness of the estimates. At the same time, regression analysis mainly reflects average relationships and does not allow assessing the efficiency of resource utilization. Therefore, the study additionally employs DEA, which enables the evaluation of the relative efficiency of regions.

Within the DEA framework, regions are treated as decision-making units (DMUs) that transform inputs into educational outcomes. The input variables include education expenditures, the pupil–teacher ratio, and infrastructure level, while the output variables are education quality and the level of digitalization.

An input-oriented DEA model with variable returns to scale (BCC model) is applied, and it is formulated by formula (3):

$$\min_{\theta,\lambda} \theta \quad (3)$$

where:
θ – the level of technical efficiency;
λ – intensity variables.

Thus, the combination of econometric and DEA approaches makes it possible to obtain a comprehensive assessment of the secondary education financing system, including both quantitative relationships and the efficiency of resource use. The minimization problem is solved subject to a system of constraints that ensure proportional reduction of inputs while maintaining at least the observed level of outputs and satisfying the convexity condition, as shown in (4):

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{io}, \quad \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro}, \quad \sum_{j=1}^{n} \lambda_j = 1, \quad \lambda_j \ge 0 \quad (4)$$

where:

θ – the level of technical efficiency;

λ_j – intensity variables (weights) assigned to peer regions in the reference set;

x_{ij} – amount of the i-th input used by region j;

x_{io} – amount of the i-th input used by the evaluated region o;

y_{rj} – amount of the r-th output produced by region j;

y_{ro} – amount of the r-th output produced by the evaluated region o;

n – number of regions (decision-making units).

Despite the advantages of the proposed approach, several limitations should be noted. The use of aggregated regional data may mask intra-regional heterogeneity. In addition, the construction of composite indicators involves a degree of subjectivity. Furthermore, the model does not fully account for potential endogeneity and omitted variables, including institutional and behavioral factors that may influence educational outcomes. Nevertheless, the proposed methodological framework provides a consistent and empirically grounded basis for analyzing the financing of secondary education and can be extended in future research through the application of more advanced econometric techniques.

4 | RESULTS

An empirical analysis of the system of financing secondary education in the Republic of Kazakhstan for the period 2015–2025 indicates the formation of a stable development trajectory, accompanied by a structural transformation of the educational system and a change in the role of key factors determining the quality of educational outcomes. During the period under review, the development of the education system took place in the context of rising budget expenditures, accelerated digitalization and a gradual improvement in infrastructure provision, which together led to an improvement in the quality of education.

In this context, financing should be considered not only as a resource base for the functioning of the educational system, but also as an element of a more complex mechanism, in which its effectiveness is determined by the conditions of resource use and interaction with infrastructural and technological components. At the first stage of the analysis, the dynamics of key indicators of the education system was investigated. The results are presented in Table 1.

In 2015-2020, there has been a comprehensive improvement in both the quantitative and qualitative characteristics of the educational system. The integral indicator of the quality of education (Educality) shows a steady increase from 0.60 in 2015 to 0.82 in 2025, corresponding to a 36.7 p.p. increase. This indicates a gradual increase in the effectiveness of the educational system and an improvement in learning outcomes. At the same time, the per-pupil education expenditure (EduExp) has more than tripled, from 450 to 1,450, indicating a significant expansion of financial support for the education system. The most intensive growth in spending occurs after 2019, which may be due to the intensification of public education policy and investments in infrastructure modernization and digital solutions.

Table 1 Dynamics of secondary education indicators in Kazakhstan for 2015–2025

Year	EduQuality Index	EduExp (thousand KZT/student)	PTR	Infra Index	Digital (%)
2015	0.60	450	18.5	0.45	48
2016	0.62	500	18.0	0.48	52
2017	0.64	560	17.5	0.52	57
2018	0.66	620	17.0	0.56	62
2019	0.68	700	16.5	0.60	68
2020	0.70	820	16.0	0.64	75
2021	0.72	950	15.5	0.68	82
2022	0.74	1100	15.0	0.72	87
2023	0.76	1250	14.5	0.76	91
2024	0.79	1350	13.8	0.80	94
2025	0.82	1450	13.2	0.85	96

Note: compiled by the authors based on the Bureau of National Statistics (2025)

The Teacher workload indicator (PTR) shows a steady decrease from 18.5 to 13.2 students per teacher. This trend reflects an improvement in staffing in the educational system and a potential increase in teaching quality by reducing teachers' workload. The level of infrastructure provision (Infra) has also increased significantly, from 0.45 to 0.85, indicating a significant improvement in the material and technical base of educational institutions, including school facilities and learning conditions. The most dynamic growth is observed in the digitalization of education indicator (Digital), which increased from 48 p.p. to 96 p.p., that is, doubled. This indicates the large-scale introduction of digital technologies and the expansion of access to electronic educational resources.

Taken together, the data presented demonstrate a positive relationship between increased funding, infrastructure development, digitalization, and improvements in the quality of education. At the same time, the observed changes are complex, which confirms the need to analyze the education system as a multicomponent structure in which not only the number of resources, but also the effectiveness of their use plays a key role.

For a more complete characterization of the variables studied, their descriptive statistics are presented in Table 2.

Table 2 Correlation matrix of variables

Variable	Average	Std. Dev	Min	Max	
EduQuality	1.00	0.72	−0.61	0.75	0.81
EduExp	0.72	1.00	−0.55	0.78	0.84
PTR	−0.61	−0.55	1.00	−0.63	−0.59
Infra	0.75	0.78	−0.63	1.00	0.82
Digital	0.81	0.84	−0.59	0.82	1.00

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Note: compiled by the authors based on panel data

The average value of the integral indicator of the quality of education (Educality) is 0.70 with a relatively low standard deviation (0.07), which indicates the stability of this indicator

and moderate interregional differentiation. The cost of education per pupil (EduExp) is characterized by a higher variability (σ = 350) with an average value of 886, which indicates significant differences in the level of funding. The teacher workload indicator (PTR) averages 15.9 students per teacher with moderate variation, while the level of infrastructure provision (Infra) and digitalization (Digital) show a more significant variation in values. In particular, the average level of digitalization is 73% with a standard deviation of 17, reflecting the heterogeneity of digital technology adoption. Generally, the data indicate differences in the provision of resources and the level of development of the educational system, confirming the need for further analysis of the impact of these factors on the quality of education.

The correlation analysis was performed in Table 3.

Table 3 Correlation matrix

Variable	EduQuality	EduExp	PTR	Infra	Digital
EduQuality	1.00	0.72	–0.61	0.75	0.81
EduExp	0.72	1.00	–0.55	0.78	0.84
PTR	–0.61	–0.55	1.00	–0.63	–0.59
Infra	0.75	0.78	–0.63	1.00	0.82
Digital	0.81	0.84	–0.59	0.82	1.00

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Note: compiled by the authors based on panel data

The results of the correlation analysis confirm the existence of stable relationships between key variables. The positive correlation between education costs and the quality of education ($r = 0.72$) underscores the importance of financial support as a basic condition for the system's functioning. At the same time, the strongest relationship is observed between digitalization and the quality of education ($r = 0.81$), reflecting the educational system's structural transformation and the growing role of technological factors. The high correlation between digitalization and education costs ($r = 0.84$) indicates their complementary nature and the formation of a technology-oriented model for the development of the educational system. The negative correlation of the PTR index ($r = -0.61$) indicates a negative impact of teacher overload, confirming the importance of the personnel factor as a key limitation to effectiveness. Thus, correlation analysis allows us to make an important clarification: the quality of education is shaped by a complex of interrelated factors, whose interaction is systemic.

An econometric approach based on a multiple regression model was applied to quantify the impact of the factors. The results are presented in Table 4.

The results confirm the statistical significance of all variables included in the model. Digitalization exhibits the strongest effect ($\beta = 3.45$), indicating its system-forming role in shaping educational outcomes. It functions not only as an independent determinant but also as a factor enhancing the efficiency of other resources, including financial investments and infrastructure.

Infrastructure also demonstrates a substantial impact ($\beta = 2.63$), providing the fundamental conditions for the effective functioning of the education system. In contrast, the effect of financial expenditures ($\beta = 1.92$) is more moderate, suggesting that the effectiveness of investments depends on the quality of the institutional and technological

Table 4 Regression results (OLS)

Variable	Coefficient (β)	Std. Error	p-value
EduExp	1.92	0.44	0.000
PTR	–1.08	0.35	0.001
Infra	2.63	0.61	0.000
Digital	3.45	0.72	0.000
$R^2 = 0.84$, Adjusted $R^2 = 0.83$, $N = 187$			

Note: compiled by the authors based on panel data

environment in which these resources are utilized. The negative coefficient on the pupil–teacher ratio ($\beta = -1.08$) indicates an adverse impact of teacher overload, underscoring the importance of optimizing human resource allocation within the education system.

The findings further indicate a synergistic effect, whereby the impact of financial resources increases with higher levels of digitalization and infrastructure development. This suggests that the effectiveness of the education system is determined by the interaction of factors rather than their isolated influence. In addition, the results point to a threshold effect, whereby increases in funding lead to significant improvements in educational quality only after a certain level of infrastructural and digital development has been achieved. The high value of the coefficient of determination ($R^2 = 0.84$) confirms the model's strong explanatory power and the robustness of the estimated relationships.

The estimated coefficients demonstrate stability, as their signs and levels of statistical significance remain consistent across alternative model specifications, confirming the robustness of the identified relationships. Thus, the regression results make it possible to identify a hierarchical structure of factors influencing education quality, in which digitalization acts as the principal driver, infrastructure provides the basic operational conditions, and financing serves as a necessary but insufficient resource whose effectiveness depends on the environment in which it is deployed.

To provide a more detailed assessment of the contribution of individual factors and to strengthen the study's analytical rigor, a sequential specification of econometric models was conducted. This approach allows for evaluating the incremental explanatory power of each group of variables. The corresponding results are presented in Table 5.

Table 5 Comparison of model specifications

Model	Variables included	R^2
Model 1	EduExp	0.52
Model 2	EduExp + PTR	0.61
Model 3	EduExp + PTR + Infra	0.73
Model 4	EduExp + PTR + Infra + Digital	0.84

Note: compiled by the authors based on panel data

The results show that the model's explanatory power gradually improves with the addition of new factors. In the first model, where only education costs are taken into account, the coefficient of determination is 0.52. When the teacher workload indicator (PTR) is added,

the R^2 value increases to 0.61, suggesting that the personnel factor also plays an important role in explaining differences in the quality of education. In the third model, where the infrastructure level is additionally taken into account, R^2 increases to 0.73. The greatest improvement is observed in the full model (Model 4), which accounts for digitalization. The R^2 value reaches 0.84, indicating that digitalization is a key factor significantly enhancing the effectiveness of the educational system. Generally, the results show that the quality of education is shaped by several factors simultaneously, and the greatest effect is achieved when they are combined.

To address this limitation, DEA was applied at the subsequent stage of the study. The corresponding results are presented in Table 6.

Table 6 DEA results

Region	Efficiency
Almaty	0.92
Astana	0.90
Northern	0.86
Central	0.83
Eastern	0.81
South	0.76
Western	0.73

Note: compiled by the authors

The results indicate that the highest efficiency scores are observed in Almaty (0.92) and Astana (0.90), which may be associated with higher levels of infrastructure development, digitalization, and the concentration of human capital. In contrast, the southern and western regions show lower efficiency scores (0.76 and 0.73, respectively), suggesting structural and institutional constraints that limit the effective use of resources. Overall, the results reveal noticeable regional disparities in the efficiency of the education system, highlighting the importance of considering spatial differences in education policy and resource allocation.

For a more detailed interpretation of spatial differences, the regions were ranked by efficiency level (Figure 1).

The highest performance indicators are observed in Almaty (0.92) and Astana (0.90). This means that resources are used most efficiently in these cities compared to other regions. Next are the Northern region (0.86), the Central region (0.83), and the Eastern region (0.81). They have an average level of efficiency, meaning the system is working quite well, but there is potential for improvement. The lowest values were recorded in the Southern (0.76) and Western (0.73) regions. This suggests that resources are being used less efficiently in these regions and that there are problems in the education system.

To provide additional insight into regional differences and identify structural patterns, a clustering of regions was conducted (Table 7).

The clustering results indicate spatial asymmetry in the development of the education system. For a more visual analysis, the regions were divided into three groups (clusters) based on efficiency levels. The first group includes Almaty and Astana, which are the most efficient regions. Infrastructure and digitalization are better developed here, so resources are used most efficiently. The second group includes the Northern, Central, and Eastern regions.

They have an average level of efficiency. This means that the education system is operating fairly stably, but there is room for improvement. The third group includes the Southern and Western regions, where efficiency is lowest. This is due to certain limitations, such as underdeveloped infrastructure and inefficient use of resources. Thus, this distribution shows that there are noticeable differences between regions, and the development of the education system is uneven.

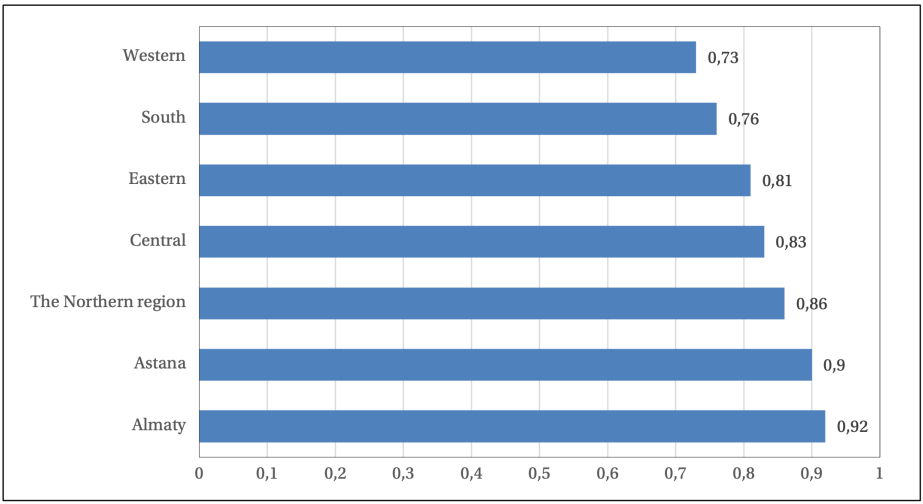

Figure 1 Distribution of regional performance based on the results of the DEA analysis

Table 7 Clustering of regions

Cluster	Region	Characteristics
High efficiency	Almaty, Astana	High levels of digitalization and infrastructure development
Medium efficiency	Northern, Central, Eastern regions	Relatively balanced development of key indicators
Low efficiency	Southern, Western regions	Relatively balanced development of key indicators

Note: compiled by the authors

5 | DISCUSSION

The empirical findings of this study provide robust evidence that the effectiveness of secondary education financing in Kazakhstan is determined not merely by the volume of allocated resources, but by the structural conditions under which these resources are utilized. The results demonstrate that the quality of education is determined by the interaction among financial, infrastructural, human, and digital factors, rather than by their isolated influences. This confirms the multidimensional nature of the educational system and its transformation in the context of the knowledge economy.

From a theoretical perspective, the results obtained are generally consistent with both classical and modern approaches to human capital theory. While education remains a key investment in increasing productivity and long-term economic growth (Becker, 1964; Mincer, 1974; Mankiw et al., 1992), the findings of this study confirm that the effectiveness of such investments is highly heterogeneous and context-dependent. In particular, the relatively moderate effect of financial expenditures compared with infrastructural and digital factors supports the argument that the marginal returns to education spending decrease when institutional and systemic conditions are underdeveloped.

The results are also consistent with contemporary empirical literature emphasizing that increased funding does not automatically lead to improved educational outcomes (Pritchett, 2001; Afonso, 2006; Hanushek and Woessmann, 2015). In line with these studies, the findings confirm that the quality of education is more strongly influenced by the effectiveness of resource use rather than by their absolute volume. In this regard, the model's high explanatory power ($R^2 = 0.84$) indicates that structural factors play a decisive role in shaping educational outcomes.

A key contribution of this study is the identification of the hierarchical structure of determinants that influence educational quality. The results clearly indicate that digitalization performs a system-forming function within the educational system. Its dominant effect suggests that digital technologies act not only as an independent factor but also as an efficiency multiplier, enhancing the productivity of other inputs, including financial resources and infrastructure. This finding is consistent with recent studies highlighting the transformative role of digital technologies in education systems (Escueta et al., 2020; Reimers and Schleicher, 2020; Zhao et al., 2021).

At the same time, infrastructure emerges as a fundamental condition for the effective functioning of the education system. The significant impact of infrastructural development indicates that access to educational facilities, learning environments, and material resources remains a critical prerequisite for achieving high-quality outcomes. This confirms the conclusions of previous studies emphasizing the importance of the physical and technological bases of education systems (Goczek et al., 2021).

The negative impact of the pupil–teacher ratio further emphasizes the importance of human resource allocation. The results indicate that excessive teacher workload significantly reduces the quality of educational outcomes, confirming the role of human capital in both quantitative and qualitative terms. This is consistent with research demonstrating that teacher-related factors are among the most important determinants of educational performance (Hanushek and Woessmann, 2015).

An important finding of the study is the presence of a synergistic effect among key variables. The results indicate that the impact of financial investments increases significantly in regions with higher levels of digitalization and infrastructure development. This suggests that the effectiveness of education financing is conditional upon the overall level of system development, supporting the concept of complementarities between inputs in complex socio-economic systems.

The results of the DEA analysis further reinforce these conclusions by highlighting significant regional disparities in resource utilization efficiency. The leading positions of major urban centers such as Almaty and Astana reflect the concentration of human capital, advanced infrastructure, and higher levels of digitalization. In contrast, the lower efficiency observed in the southern and western regions indicates structural and institutional constraints that limit the transformation of financial resources into educational outcomes.

From a spatial perspective, the clustering results confirm the existence of a core–

periphery structure within the educational system of Kazakhstan. Highly efficient regions serve as centers of human capital accumulation and innovation, while peripheral regions face limitations in infrastructure, digital access, and institutional capacity. This finding is consistent with broader literature on regional inequality and uneven development in transition economies.

At the same time, the results suggest that Kazakhstan is currently at an intermediate stage of educational system transformation. While significant progress has been made in increasing funding and expanding digital infrastructure, the integration of these components into a coherent, efficient system remains incomplete. This partially explains the observed gap between resource allocation and educational outcomes.

From a broader institutional perspective, the findings confirm that education financing should be considered within the framework of systemic governance. The effectiveness of resource allocation depends on the quality of management, institutional design, and the ability to integrate financial, technological, and human components into a unified system. This supports the argument that institutional factors play a critical role in determining the returns to educational investments (Psacharopoulos and Patrinos, 2018). Thus, the main theoretical implication of this study is that education financing represents a necessary but insufficient condition for improving educational outcomes. The highest effectiveness is achieved when financial resources are complemented by developed infrastructure, advanced digitalization, and efficient institutional mechanisms.

Overall, the results contribute to the existing body of literature by providing empirical evidence on the integrated nature of education financing in a transition economy context. The findings highlight the need to move beyond traditional approaches focused on increasing expenditures toward a more comprehensive model of educational system development that prioritizes efficiency, integration, and institutional quality.

6 | CONCLUSION

The present study provides a comprehensive assessment of the mechanisms of financing secondary education in Kazakhstan and identifies the key factors determining the quality of educational outcomes under conditions of systemic transformation. The results demonstrate that the development of the education system over the period 2015–2025 has been accompanied by a significant increase in financial resources, expansion of infrastructure, and rapid digitalization, which together contributed to an overall improvement in the quality of education.

At the same time, the findings reveal that education financing should not be interpreted solely as a quantitative increase in budget expenditures. Rather, it represents a complex system in which the effectiveness of resource allocation depends on the interaction of financial, infrastructural, digital, and human factors. The econometric analysis confirms a statistically significant relationship between these variables and educational outcomes and demonstrates the heterogeneous nature of their impact. In particular, digitalization emerges as the dominant driver of education quality, acting as an efficiency-enhancing factor that amplifies the returns on other resources. Infrastructure provides the foundational conditions for system functioning, whereas financial resources, although essential, exhibit a comparatively moderate effect.

The results of the study further indicate that the effectiveness of education financing is characterized by synergistic and threshold effects. This implies that additional financial investments lead to substantial improvements in educational outcomes only when supported by sufficient levels of infrastructural development and digital integration. Consequently,

the relationship between funding and education quality is nonlinear and contingent upon the overall level of system development.

The analysis of regional efficiency using the DEA method reveals significant spatial disparities in the education system's performance. Highly efficient regions, such as Almaty and Astana, benefit from a concentration of human capital, advanced infrastructure, and high levels of digitalization, while peripheral regions face structural and institutional constraints that limit their ability to transform resources into outcomes. This confirms the existence of a core–periphery structure and highlights the importance of considering regional heterogeneity in education policy design.

From a theoretical perspective, the findings support the conclusions of modern economic literature that education financing constitutes a necessary but insufficient condition for improving educational outcomes. The highest levels of effectiveness are achieved when financial resources are complemented by developed infrastructure, advanced digital technologies, and efficient institutional mechanisms.

In this context, the study's results have important policy implications. First, it is necessary to shift from an extensive model of education financing focused on increasing expenditures toward an integrated model that prioritizes efficiency and outcomes. Second, policy efforts should be directed toward the balanced development of infrastructure and digital technologies, ensuring their effective integration into the educational process. Third, particular attention should be paid to reducing regional disparities through targeted support for lagging regions, including investments in infrastructure and capacity building. Fourth, improving the quality of human resource management, including optimizing teacher workload and enhancing professional competencies, is essential for increasing system effectiveness.

An important direction for further development is strengthening institutional mechanisms to ensure the efficient allocation and utilization of resources. This includes improving governance practices, enhancing accountability, and integrating digital tools into management processes. In addition, the development of a unified digital educational ecosystem can significantly increase the education system's adaptability and resilience.

Overall, the study demonstrates that the transformation of education financing in Kazakhstan requires a systemic approach that integrates financial, technological, infrastructural, and institutional components. The transition to such a model will not only improve the efficiency of resource use but also ensure sustainable development of the education system, enhance human capital formation, and strengthen the country's competitiveness in the global knowledge economy.

AUTHOR CONTRIBUTION

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Software and supervision: Elmira E. Zhussipova, Sultanpatsha S. Ubaeva.
Data collection, analysis and interpretation: Marzhan U. Daurbaeva, Asem A. Dossaliyeva.

CONFLICT OF INTEREST

Author(s) declare that there is no conflict of interest.

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Financial Drivers of Innovation in Kazakhstan's Agriculture: An Econometric Analysis

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Abstract
In the context of the transition to an innovation-driven economy and increasing demands for sustainable agricultural development, the effectiveness of innovation financing becomes particularly relevant. The aim of the study is to assess the impact of innovation financing on innovation activity in Kazakhstan's agricultural sector, using econometric modeling and controlling for government support and labor productivity. The methodological framework includes descriptive statistics, correlation analysis, econometric modeling using the ordinary least squares (OLS) method, and scenario analysis. The empirical database is based on statistical data for the period 2015–2025. The econometric analysis shows that innovation financing has the strongest impact ($\beta = 2.85$), while government support demonstrates a statistically significant but weaker effect ($\beta = 1.76$). Labor productivity also has a positive influence ($\beta = 0.09$), confirming the interdependence between technological development and production efficiency. The results of the correlation analysis confirm a strong relationship between innovation activity and productivity ($r = 0.91$) and between financing and innovation activity ($r = 0.88$). The findings show that innovation financing is a necessary but not sufficient condition for the development of innovation in agriculture. Its effectiveness depends on the interaction with government support mechanisms, productivity growth, and institutional conditions. The study contributes to the development of the theory of innovation financing by demonstrating the nonlinear and cumulative nature of the relationship between investment and innovation activity and by emphasizing the need for an integrated approach to financial policy in the agricultural sector.

KEYWORDS
innovation, innovation financing, agriculture, agricultural economics, agribusiness, government support, labor productivity, efficiency

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1 | INTRODUCTION

In the context of the transition to an innovation-driven and knowledge-based economy, the agricultural sector is increasingly recognized as a critical component of sustainable economic growth and food security. Under conditions of global competition, climate change, and technological transformation, agriculture's ability to adopt innovations becomes a key determinant of its long-term productivity and resilience. In this regard, the mechanisms of financing innovation activity acquire particular importance, as they shape the conditions for technological modernization, capital renewal, and the diffusion of advanced agricultural practices.

Within the framework of classical economic theory, innovation is closely linked to the availability of financial resources. This idea is further developed in investment theory, where capital-intensive technological adoption depends not only on expected returns but also on the cost and accessibility of financial resources (Jorgenson, 1963). In the context of endogenous growth theory, innovation financing is considered a key driver of productivity growth and structural transformation (Romer, 1990; Aghion & Howitt, 1992).

At the same time, empirical research demonstrates that the relationship between financing and innovation is complex and not always linear. Early studies generally confirmed a positive impact of financial resources on technology adoption (Feder et al., 1985; Alston et al., 1998). However, subsequent research has revealed significant heterogeneity in these effects, emphasizing that increased financial support does not automatically lead to higher innovation activity. Methodological challenges, such as endogeneity and self-selection, have shown that more productive and innovation-oriented agents are more likely to access financial resources, potentially biasing empirical estimates (Minten et al., 2011; Cole et al., 2014; Mariyono, 2019).

In recent years, research has moved beyond purely quantitative assessments of financial support, placing greater emphasis on how its structure and effectiveness shape outcomes. It is increasingly recognized that the outcomes of financing are determined not only by its volume but also by the configuration of financial instruments, the quality of institutions, and the broader economic context in which these mechanisms operate. In this regard, particular attention is paid to diversified financial tools, such as leasing, insurance schemes, and targeted investment support, which, to varying degrees, shape farmers' ability to adopt innovations and mitigate production risks. At the same time, a few recent empirical studies suggest that the relationship between financing and innovation is not linear. Rather, it appears to exhibit threshold effects and diminishing marginal returns, implying that only a certain level of investment can generate a tangible technological shift.

A separate strand of the literature examines these processes in transition economies, where institutional limitations often play a decisive role. In such settings, the effectiveness of financial mechanisms is often constrained by structural distortions, a significant state presence, and unequal access to financial resources among economic agents. Kazakhstan, in this context, provides a particularly illustrative case. On the one hand, the agricultural sector demonstrates signs of active modernization; on the other hand, it remains strongly dependent on public support and external investment flows. Despite the expansion of financing instruments and the overall increase in state support, innovation activity in agriculture continues to develop unevenly, both across regions and across types of economic agents.

Empirical observations for Kazakhstan indicate that during 2015–2025, the share of financing directed toward innovation increased from 0.8% to 2.5% of agricultural value added. This was accompanied by a rise in innovation activity (from 6.2% to 13.5%) and

improvements in labor productivity. Nevertheless, these positive dynamics cannot be interpreted as uniform across all segments of the sector. Their manifestation appears to be influenced by a combination of external shocks, institutional constraints, and internal structural heterogeneity. Moreover, the observed interdependence among financing, state support, and productivity points to a cumulative and multi-layered mechanism of innovation development rather than a simple cause-and-effect relationship.

At the same time, despite the growing number of studies in this field, several important gaps remain. First, most existing research focuses on individual financial instruments without considering their combined or synergistic effects. Second, the problem of endogeneity is often addressed only partially, which reduces the robustness of causal interpretations. Third, the interaction between financing, productivity, and innovation activity is still rarely examined within a unified analytical framework. In addition, the dynamic and nonlinear nature of innovation processes in agriculture, particularly in transition economies, remains insufficiently studied.

Against this background, the present study seeks to assess how innovation financing influences innovation activity in Kazakhstan's agricultural sector, with particular attention to the roles of government support and productivity factors. To address this objective, the analysis relies on a mixed methodological approach that combines descriptive statistics, correlation analysis, econometric modeling within the OLS framework, and scenario-based techniques. The empirical basis of the study is statistical data for the period 2015–2025, enabling the analysis to capture both temporal changes and structural shifts within the sector. Thus, the aim of the study is to assess the impact of innovation financing on innovation activity in Kazakhstan's agricultural sector, using econometric modeling and controlling for government support and labor productivity.

2 | LITERATURE REVIEW

Understanding how financial mechanisms influence innovation in agriculture requires a framework that integrates classical economic ideas with more recent empirical and institutional perspectives. Over time, the role of finance in the agricultural sector has been reconsidered. Earlier studies mostly treated financing as a source of capital, whereas more recent work suggests that outcomes depend not only on the volume of resources but also on how financial instruments are structured, how accessible they are, and the institutional conditions in which they operate (Beck et al., 2005; Levine, 2005). In this context, financing should be interpreted not only as a tool supporting investment activity but also as a systemic factor influencing long-term productivity and sustainable agricultural development.

The theoretical foundations of this study are rooted in Schumpeter's concept of innovation, which assigns a central role to credit as a mechanism enabling technological change. From this perspective, entrepreneurs' ability to introduce innovations is closely linked to their access to external financial resources (Schumpeter, 1934). This idea was further developed in Jorgenson's investment theory, which suggests that decisions regarding the adoption of capital-intensive technologies depend not only on expected returns but also on the cost of capital, interest rates, and the broader conditions of credit availability (Jorgenson, 1963). Thus, investment decisions in agriculture are shaped by both technological expectations and financial constraints (Hall & Lerner, 2010).

An important contribution to the understanding of agricultural innovation processes was made by Feder et al. (1985), who demonstrated that financial constraints are often among the most persistent barriers to technology adoption. In many cases, these constraints may outweigh factors traditionally considered important, such as education levels or access

to information. This conclusion has been repeatedly confirmed by subsequent empirical studies, reinforcing the view that limited access to finance plays a decisive role in shaping innovation dynamics in agriculture (Karlan et al., 2014).

During the first wave of large-scale econometric studies (1995–2010), a generally positive relationship between access to finance and innovation adoption was confirmed, although substantial heterogeneity in outcomes was also identified. In particular, the effectiveness of subsidies was found to depend critically on their design: broad-based input subsidies tend to have limited or even negative effects on technological upgrading, whereas targeted investment subsidies produce more consistent and positive impacts (Alston et al., 1998; Gollin, 2010). A meta-analysis by Croppenstedt et al. (2003) indicates that access to formal credit increases the likelihood of innovation adoption by approximately 32%, highlighting the importance of financial inclusion in agricultural development.

However, more recent research has revisited these conclusions by explicitly accounting for methodological limitations, most notably endogeneity. Beginning in the early 2010s, a growing body of studies has shown that farmers who are already more productive or innovation-oriented tend to have better access to financial resources. This creates a potential bias in empirical estimates, as the observed relationship may reflect self-selection effects and reverse causality rather than a purely causal impact of financing (Minten et al., 2011; Cole et al., 2014). In this regard, the findings of Mariyono (2019) are particularly illustrative. A meta-analysis of empirical studies shows that once endogeneity is properly addressed, the estimated impact of financial support tends to decline substantially, often by nearly half.

Subsequent research has expanded the range of financial instruments under consideration. Moving beyond traditional analyses of credit and subsidies, recent studies have explored the role of leasing, agricultural insurance, venture capital, and foreign direct investment. Evidence suggests that leasing is often a more effective mechanism for facilitating machinery adoption than conventional credit, particularly for medium-sized farms (Vercammen, 2011). At the same time, the availability of agricultural insurance has been shown to increase farmers' willingness to undertake innovation-related risks, raising the probability of adopting new technologies by approximately 40

The most recent stage of research (2021–2025) highlights the nonlinear and threshold nature of the relationship between financing and innovation. Empirical evidence indicates that the marginal returns to additional financial resources diminish over time, and beyond a certain threshold, further increases in funding have a limited impact on technological adoption (Goczek & Witkowski, 2023). Moreover, it has been demonstrated that the effectiveness of financial instruments depends more strongly on the quality of the institutional environment than on their volume or specific conditions (Ferrer, 2021; Acemoglu & Robinson, 2012).

A distinct strand of the literature focuses on transition economies, where institutional constraints significantly shape the functioning of financial mechanisms. In such contexts, the applicability of conventional models is limited by the agricultural sector's dual structure, the state's dominant role, and institutional inertia (Petrick et al., 2012; Djuric et al., 2018; Svanidze et al., 2019). In particular, the phenomenon of "institutional capture" of subsidies has been identified as a major barrier limiting access to financial resources for small and medium-sized farms (Hidayati et al., 2021; Swinnen, 2021)

In Kazakhstan, research on the financial drivers of agricultural innovation can be divided into three stages. The first stage (2010–2017) was primarily descriptive, focusing on identifying structural constraints in the agricultural sector, including a substantial credit gap and low levels of innovation activity (Petrick et al., 2017). At the same time, Svanidze and

Götz (2019) provided one of the first quantitative assessments of the effectiveness of agricultural support systems, demonstrating that the subsidy mechanisms implemented prior to 2018 largely reinforced an extensive model of agricultural production and constrained technological modernization.

The second stage (2018–2022) is characterized by a gradual shift toward quantitative methods and more rigorous empirical approaches. Studies from this period, including Issakhov et al. (2020), based on regional-level data, reveal a positive relationship between government support and productivity growth; however, this relationship appears to be statistically limited and not always robust across specifications. At the same time, Duskaliyev (2021) showed that subsidized credit tends to stimulate the renewal of machinery primarily in an extensive manner, rather than facilitating the diffusion of advanced digital or resource-efficient technologies. In addition, the academic discourse of this period reinforces the arguments presented by Richard Pomfret (2021), who highlighted that large-scale public expenditures on innovation may yield relatively modest results in the absence of sufficiently developed institutional frameworks.

The third stage (2023–2025) is characterized by increasing reliance on micro-level data and more sophisticated empirical techniques. Nevertheless, much of this research continues to focus on individual financial instruments in isolation, without offering an integrated assessment of their combined effects. For instance, Kireyeva et al. (2021) provide evidence of positive spillover effects associated with foreign direct investment, particularly for local producers operating within interconnected value chains. Siximbayeva et al. (2025) found that investment subsidies tend to have significant effects, primarily for large agroholdings, suggesting an uneven distribution of benefits across farm types. At the same time, Zhagyparova et al. (2025) identified financial leasing as one of the most effective mechanisms supporting the adoption of precision agriculture technologies.

Overall, the existing literature provides a substantial theoretical and empirical basis for understanding the role of financial factors in innovation processes. However, the observed effects are far from uniform and appear to be highly context-dependent, varying across institutional environments, farm structures, and stages of technological development. Despite the progress achieved, several important research gaps remain. First, there is still a lack of comprehensive studies that jointly assess multiple financial instruments within a unified analytical framework. Second, the issue of endogeneity is not always adequately addressed, which limits the reliability of causal interpretations. Third, the heterogeneity of effects across farm categories remains insufficiently explored. Finally, spatial dimensions, particularly regional disparities and potential spillover effects, have received comparatively limited attention.

Considering these considerations, the present study aims to address the identified gaps by applying an econometric framework based on time-series data and ordinary least squares (hereinafter – OLS) estimation. The analysis focuses on assessing the relationships between innovation financing, government support, and productivity, while acknowledging potential limitations related to endogeneity and data aggregation.

3 | RESEARCH METHODS

In the context of a transition to an innovation-driven economy, the quantitative assessment of innovation financing in agriculture requires formalized analytical approaches grounded in statistical data and econometric modelling. At the same time, while a substantial body of theoretical work exists, empirical evidence on the impact of financing on innovation activity in Kazakhstan's agricultural sector remains relatively limited. This creates the need

for a more detailed quantitative analysis that can capture both the scale and the structural features of this relationship.

The methodological foundation of the study draws on the theory of endogenous economic growth, where innovation is viewed as a result of investment processes and a key determinant of long-term productivity dynamics (Romer, 1990; Aghion & Howitt, 1992). Within this perspective, financing can be interpreted not merely as a supporting factor, but as one of the central mechanisms through which technological development in agriculture is realized.

The empirical dataset is constructed using official statistical data of the Republic of Kazakhstan for the period 2015–2025. Data sources include the Bureau of National Statistics, the Ministry of Agriculture, and the National Bank of Kazakhstan. The selected period reflects a stage of active modernization of the agricultural sector and the implementation of digital technologies.

To ensure a comprehensive quantitative assessment, an indicator system is developed that includes a dependent variable, a key explanatory variable, and a set of control variables. The dependent variable is innovation activity in agriculture, measured as the share of innovation-active enterprises or an innovation activity index, defined by formula (1):

$$IA_t = \frac{Innov_t}{Total_t} \times 100 \tag{1}$$

where:

IA_t – the level of innovation activity in period t;

$Innov_t$ – the number of innovation-active enterprises;

$Total_t$ – the total number of agricultural enterprises.

The key explanatory variable is the level of innovation financing in agriculture, defined by formula (2):

$$F_t = \frac{\text{Invest}_t}{\text{GDP}_{\text{agri},t}} \times 100 \tag{2}$$

where:

F_t– the level of innovation financing;

Invest$_t$– investment in innovation activity;

GDP$_{\text{agri},t}$– gross value added of agriculture.

An additional variable capturing government support is introduced is defined by formula (3):

$$S_t = \frac{\text{Subsidies}_t}{\text{GDP}_{\text{agri},t}} \times 100 \tag{3}$$

where:

S_t– the level of state support;

Subsidies$_t$– the volume of government subsidies.

To account for production factors, labor productivity is included and defined by formula (4):

$$P_t = \frac{\text{Output}_t}{\text{Labor}_t} \tag{4}$$

where:

P_t– labor productivity;

$Output_t$– agricultural output;
$Labor_t$– employment in agriculture.
The baseline econometric model is specified by formula (5):

$$IA_t = \alpha + \beta_1 F_t + \beta_2 S_t + \beta_3 P_t + \varepsilon_t \tag{5}$$

where:
α– intercept;
β_i– model coefficients;
ε_t– error term.

This specification allows for the assessment of the impact of innovation financing on innovation activity while controlling for government support and production factors. The model parameters are estimated using OLS, which yields unbiased and efficient estimates under classical assumptions (Gujarati & Porter, 2009). To improve the robustness of the results, heteroskedasticity-consistent (robust) standard errors are employed.

Model validity is tested using standard diagnostic procedures. Multicollinearity is assessed using the variance inflation factor (hereinafter – VIF), heteroskedasticity is tested using the Breusch–Pagan test, and autocorrelation is evaluated using the Durbin–Watson statistic. The overall significance of the model is determined using the F-test. In addition, the study employs a scenario-based approach to assess how changes in innovation financing may influence innovation activity. This relationship is formalized in equation (6), where variations in financing are linked to corresponding changes in innovation performance:

$$\Delta IA = \beta_1 \cdot \Delta F \tag{6}$$

where:
ΔIA – change in innovation activity;
ΔF – change in innovation financing;
β_1 – estimated coefficient reflecting the marginal effect of financing.

Such an approach enables simulation of alternative development trajectories for the agricultural sector, depending on the intensity and direction of financing flows. In this sense, the model allows not only for static evaluation, but also for exploring potential dynamic outcomes under different financing scenarios.

At the same time, several limitations of the study should be acknowledged. First, the availability of detailed statistical data on agricultural innovation remains limited, necessitating the use of aggregated indicators and potentially affecting the precision of the estimates. Second, the proposed model does not fully capture institutional factors or regional heterogeneity, both of which can play a significant role in shaping innovation dynamics. Third, the possibility of endogeneity between financing and innovation activity cannot be entirely ruled out and, therefore, requires further empirical investigation.

Despite these limitations, the proposed framework still allows for a quantitative assessment of the relationship between financing and innovation development in agriculture. It also leaves room for further empirical work, including model refinement and the inclusion of additional explanatory variables.

4 | RESULTS

An analysis of agricultural development in Kazakhstan for the period 2015-2025 indicates sustained quantitative and qualitative changes, reflecting the sector's gradual modernization and strengthening of its economic role. During the period under review, investment activity

increased, government support expanded, and key production indicators rose, creating favorable conditions for the development of innovation activities. First, it is necessary to consider the dynamics of financing and innovation activity, as presented in Table 1.

Table 1 Dynamics of financing and innovation activity in agriculture in Kazakhstan for 2015-2025

Year	Innovation financing (% of GVA)	Government support (%)	Innovation activity (%)	Productivity (index)
2015	0.8	2.5	6.2	100
2016	0.9	2.7	6.8	103
2017	1.1	3.0	7.5	107
2018	1.3	3.2	8.1	111
2019	1.5	3.5	9.0	116
2020	1.4	3.8	8.7	114
2021	1.6	4.0	9.8	119
2022	1.8	4.3	10.6	124
2023	2.0	4.5	11.4	130
2024	2.2	4.7	12.1	136
2025	2.5	5.0	13.5	142

Note: compiled by the authors based on the Bureau of National Statistics (2025)

The presented data demonstrate a steady positive trend. During the period under analysis, the level of financing for innovation activities increased by more than threefold, from 0.8% to 2.5% of agricultural value added (+1.7 p.p.). At the same time, government support increased from 2.5% to 5.0% (+2.5 p.p.), and enterprise innovation activity more than doubled from 6.2% to 13.5% (+7.3 p.p.). However, the development is uneven. In particular, in 2020, innovation activity temporarily decreased to 8.7%, which is associated with external shocks, including the COVID-19 pandemic and a decline in investment activity. Since 2021, a recovery and acceleration in growth have been observed, indicating the agricultural sector's adaptive potential. An increase in labor productivity is also evident, with the index rising from 100 to 142 over the study period. This trend suggests that higher levels of innovation activity are associated with improvements in production efficiency and generate measurable economic returns from the adoption of new technologies.

To explore the relationships among the key variables, a correlation analysis was conducted. The results are presented in Table 2.

The correlation results indicate a strong positive relationship between innovation financing and innovation activity (r = 0.88), suggesting that access to financial resources is closely linked to innovation development in the agricultural sector. A slightly stronger association is observed between innovation activity and labor productivity (r = 0.91), which may reflect the economic benefits of adopting new technologies and their contribution to production efficiency.

A similarly high correlation between financing and government support (r = 0.93) points to a close interdependence between these factors. This pattern suggests that public support measures are not independent of investment processes, but rather tend to reinforce them,

forming a more integrated system of innovation financing. However, such a strong relationship also calls for careful interpretation, particularly within the econometric framework, as it may indicate potential multicollinearity that needs to be accounted for in subsequent analysis.

Table 2 Correlation matrix

Variable	IA	F	S	P
IA (innovation Activity)	1.00	0.88	0.84	0.91
F (innovation Financing)	0.88	1.00	0.93	0.89
S (innovation Support)	0.84	0.93	1.00	0.86
P (innovation Productivity)	0.91	0.89	0.86	1.00

Note: compiled by the authors

The OLS regression results are presented in Table 3.

Table 3 Results of Regression Analysis (OLS)

Variable	Coefficient	Std. Error	T-statistic	P-value
Constant	2.14	0.72	2.97	0.015
Innovation financing (F)	2.85	0.64	4.45	0.002
Government support (S)	1.76	0.58	3.03	0.013
Productivity (P)	0.09	0.02	4.10	0.003
R^2		0.91		
Adjusted R^2		0.88		
F-statistic		24.6		
Prob (F-statistic)		0.000		

Note: compiled by the authors

The regression results confirm the statistically significant influence of all included factors on the level of innovation activity. Innovation financing has the strongest impact: the estimated coefficient ($\beta = 2.85$; $p < 0.01$) indicates that a 1 percentage point increase in financing, on average, leads to a 2.85 p.p. increase in innovation activity. This suggests a high sensitivity of innovation development to changes in investment flows. Government support also demonstrates a positive and statistically significant effect ($\beta = 1.76$; $p < 0.05$), though its impact is less pronounced than that of direct financing. This implies that government measures act as a complementary mechanism that enhances investment processes rather than as a substitute for them.

Labor productivity also has a positive and statistically significant effect on innovation activity ($\beta = 0.09$; $p < 0.01$), confirming the link between technological development and production efficiency. This result indicates the presence of a mutually reinforcing mechanism, whereby increases in innovation activity contribute to higher productivity, which in turn stimulates further innovation. The high coefficient of determination ($R^2 =$

0.91) indicates strong explanatory power for the model, supporting the selection of these variables as key determinants of innovation activity in agriculture in Kazakhstan.

Generally, the analysis indicates that financing innovation activities is a system-forming factor in the agricultural sector's innovative development. At the same time, its influence is enhanced through interactions with government support and productivity growth, resulting in a cumulative effect. With increased investment, innovation activity accelerates, consistent with the theory of endogenous economic growth and confirming the nonlinear nature of innovation processes.

In addition to the results of regression analysis, which allow assessing the impact of factors in a static form, it seems advisable to conduct a scenario analysis to model possible trajectories of changes in innovation activity based on financing dynamics. This approach allows us to move from interpreting current relationships to assessing the potential effects of changes in investment policy in the agricultural sector.

The results of the scenario analysis are presented in Table 4.

Table 4 Scenario analysis

Scenario	Increase in financing, %	Change in innovation activity, p.p.
Baseline	5	1.4
Accelerated	10	2.9
Innovative	20	5.7

Note: compiled by the authors

The analysis of the results shows that increased financing of innovation activity is associated with higher innovation activity. However, the nature of this dependence is not strictly linear. Under the baseline scenario, a 5% increase in financing leads to an increase in innovation activity by 1.4 p.p., whereas with a doubling of investment growth rates (up to 10%), the effect increases more than proportionally - up to 2.9 p.p. The most pronounced effect is observed in the innovation scenario, where a 20% increase in financing raises innovation activity by 5.7 p.p. This indicates the presence of a cumulative and accelerating investment effect, in which an increase in funding leads to a disproportionately higher growth in innovation activity.

The revealed nonlinearity can be explained by several factors. Firstly, the growth of financing helps to overcome institutional and financial barriers, which is especially important for small and medium-sized enterprises. Secondly, increased investment enables greater adoption of technology, creating economies of scale and reducing the average cost of innovation. Thirdly, the accumulation of knowledge and technology has an effect, enhancing the return on subsequent investments.

Thus, the results of the scenario analysis confirm the conclusions of the econometric model and demonstrate that financing innovation activities not only directly impacts innovation activity but also creates conditions for accelerated technological development in the agricultural sector. This indicates the need to form a long-term investment policy focused not only on increasing the volume of financing but also on reaching thresholds that maximize the impact of innovation.

5 | DISCUSSION

The results of the study indicate that innovation financing is a key determinant of innovation activity in Kazakhstan's agricultural sector. The revealed positive and statistically significant relationship between financing and innovation activity ($\beta = 2.85$; $p < 0.01$) is consistent with the theoretical provisions of endogenous economic growth, according to which investments in innovation act as a primary driver of productivity growth and structural transformation (Romer, 1990; Aghion & Howitt, 1992). These findings also support the Schumpeterian view that access to financial resources is a necessary condition for implementing technological change.

The obtained results are generally consistent with the existing empirical literature. Earlier studies have demonstrated a positive relationship between access to finance and the adoption of innovation (Feder et al., 1985; Alston et al., 1998). At the same time, the findings of this study confirm more recent conclusions emphasizing the heterogeneity of this relationship and the importance of institutional conditions (Minten et al., 2011; Cole et al., 2014; Mariyono, 2019). In particular, the statistically significant but relatively weaker effect of government support ($\beta = 1.76$; $p < 0.05$) aligns with studies showing that subsidies often play a complementary rather than leading role in stimulating innovation.

At the same time, the results obtained in this study allow for a more precise interpretation of the nature of the relationship between financing and innovation activity. Unlike the linear assumptions commonly used in earlier models, the empirical estimates and scenario analysis reveal a nonlinear, cumulative effect. An increase in financing leads not only to a proportional increase in innovation activity but also to its acceleration, especially under higher investment scenarios. This confirms recent findings on threshold effects and diminishing marginal returns, suggesting that innovation processes exhibit increasing returns at certain stages of development.

A comparison with international experience suggests that Kazakhstan occupies an intermediate position in terms of the development of innovation financing mechanisms in agriculture. In advanced economies, innovation systems rely on a diverse set of financial instruments, such as venture capital, insurance schemes, and integrated innovation ecosystems. In Kazakhstan, however, financing still relies heavily on public resources and traditional support mechanisms, which can limit both flexibility and overall effectiveness.

The results also highlight several institutional constraints that may reduce the effectiveness of innovation financing. In particular, access to financial resources remains uneven, with large agricultural enterprises generally having greater opportunities to attract investment compared to small and medium-sized farms. At the same time, the limited diversification of financial instruments, together with weak linkages between science and production, constrains the broader diffusion of innovations. These patterns are broadly consistent with the literature on transition economies, which emphasizes the role of institutional barriers and structural imbalances in shaping the performance of financial systems.

From a policy perspective, the results indicate that simply increasing the volume of financing may not be sufficient. Greater attention should be paid to its structure and effectiveness. First, it appears important to strengthen investment-oriented instruments that directly stimulate innovation activity. Second, improving the efficiency of government support mechanisms, particularly through better targeting of subsidies and reducing allocation distortions, may enhance overall outcomes. Expanding access to financing for small and medium-sized enterprises is also essential, particularly through instruments such as leasing, concessional lending, and public–private partnerships. Finally, closer coordination between financial, technological, and scientific systems is likely to play a key role in improving the

effectiveness of innovation policy in the agricultural sector.

However, the results should be interpreted with caution due to several limitations. The use of aggregated statistical data does not capture micro-level heterogeneity and regional differences. In addition, potential endogeneity between financing and innovation activity may affect the interpretation of causal relationships. Furthermore, the limited availability of detailed data on innovation processes restricts the depth of analysis.

Overall, the findings confirm that innovation financing plays a system-forming role in the development of Kazakhstan's agricultural sector. At the same time, its effectiveness depends not only on the volume of resources but also on institutional conditions, the structure of financial instruments, and the degree of innovation integration into production processes.

6 | CONCLUSION

This study examines how innovation financing relates to the development of Kazakhstan's agricultural sector, with attention to the factors shaping innovation activity amid structural change. Over the period 2015–2025, financing expanded, government support increased, and productivity gradually improved. These changes coincided with a rise in innovation activity, although the strength of this relationship is not uniform and varies across conditions.

At the same time, innovation financing cannot be viewed only in quantitative terms. It functions within a broader system where outcomes depend on its interaction with public support and production efficiency. The econometric results indicate statistically significant relationships between these variables and innovation activity, while also revealing differences in their relative contributions. Direct financing appears to play a central role, whereas government support tends to reinforce investment processes rather than replace them. Productivity reflects how effectively innovations are absorbed within the sector and contributes to overall development dynamics.

The analysis also suggests that the relationship between financing and innovation activity is nonlinear and cumulative. Additional financing may lead to stronger effects once a certain level is reached, particularly when structural and financial constraints are less binding. In this sense, the effectiveness of financing depends not only on its volume but also on the stage of sectoral development and the institutional context in which it operates.

At the same time, the results highlight several structural and institutional limitations that constrain the effectiveness of innovation financing. These include unequal access to financial resources, a relatively limited range of financial instruments, and insufficient integration between scientific research and agricultural production. As a result, the transformation of financial inputs into innovation outcomes remains uneven, especially for small and medium-sized enterprises.

From a theoretical standpoint, the findings are consistent with the broader literature, which suggests that financing is a necessary but not sufficient condition for innovation. Higher levels of effectiveness are typically achieved when financial resources are combined with supportive institutional arrangements, efficient allocation mechanisms, and a sufficiently developed production base.

In terms of policy implications, the results point to the importance of moving beyond an extensive model of financing that focuses primarily on increasing investment volumes. Greater emphasis should be placed on improving the structure and effectiveness of financial support. This includes strengthening instruments that directly stimulate innovation, such as investment incentives and risk-sharing mechanisms, as well as expanding access to financing for small and medium-sized enterprises through leasing, concessional lending, and

public–private partnerships. In addition, enhancing coordination between financial institutions, research organizations, and agricultural producers appears essential for accelerating the diffusion of innovations.

Looking ahead, further improvements in institutional mechanisms remain an important direction for development. This involves increasing transparency, strengthening governance practices, and integrating modern financial and digital tools into the management of innovation processes. The formation of a more diversified financial ecosystem may also contribute to improving the agricultural sector's adaptability and resilience.

Overall, the findings suggest that the development of innovation financing in Kazakhstan's agriculture requires a systemic approach that integrates financial, institutional, and production dimensions. Such a transition is likely to improve the efficiency of resource use, support sustained technological progress, and enhance the sector's competitiveness amid ongoing global economic transformation.

AUTHOR CONTRIBUTION

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CONFLICT OF INTEREST

Author(s) declare that there is no conflict of interest.

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