“The impact of transport routes on Kazakhstan’s agro-industrial complex considering ESG approaches”

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THE IMPACT OF TRANSPORT ROUTES ON KAZAKHSTAN'S AGRO-INDUSTRIAL COMPLEX CONSIDERING ESG APPROACHES

Abstract

This study aims to investigate the relationship between environmental sustainability, social development, and governance within Kazakhstan's agro-industrial complex. The paper applies econometric modeling and statistical analysis to assess these relationships and provide strategic recommendations for sustainable development. A dataset from 2013 to 2023, sourced from the Bureau of National Statistics of the Republic of Kazakhstan, was utilized to assess the influence of transit routes and agriculture on ESG performance. Principal component analysis (PCA) and regression modeling identified three key components – environmental (84.3%), social (98.4%), and governance (88.33%) – as significant contributors to ESG variability. The results demonstrate that transit flows positively affect environmental and governance indicators ($\beta = 0.266$, $p = 0.050$), while agro-industrial activity has mixed effects: improved social sustainability but increased environmental pressure. The combined impact of transit corridors and the agro-industrial complex provides a more comprehensive explanation of ESG variability ($R^2 = 0.998$), reinforcing the need for integrated policy approaches. The findings highlight the strategic importance of aligning transit infrastructure and agro-industrial development with ESG frameworks. This paper contributes to the discourse on sustainable development by offering practical insights for policymakers on optimizing logistics and agricultural strategies to promote ESG adoption, particularly in agriculture-dependent economies.

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INTRODUCTION

The agro-industrial complex influences economic growth and ensures social stability and ecological balance, which makes it a strategically important industry that determines food security, economic growth, and sustainability. The importance of the agro-industrial complex has been studied through various lenses, emphasizing the management and integration of resources to increase productivity and stimulate innovation, and has been more theoretical. Spatial planning and land use have been central factors in the development of the agro-industrial cluster.

Modern research should consider not only the production aspects of the agro-industrial complex but also its connection with global logistics systems and trade and sustainable development ecosystems, making the topic especially relevant for countries with high agrarian potential but with underdeveloped transport and trade infrastructure. Within the framework of international initiatives, the agro-industrial complex is one of the central mechanisms for achieving SDGs such as

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Zero Hunger and Decent Work and Economic Growth. In addition, the World Bank invests in projects to develop agrarian infrastructure, and today, special attention is paid to the development and improvement of transport networks in the agro-industrial complex. The EU is actively reforming the agro-industrial complex, focusing on sustainable production, logistics, and emission reduction. China's Belt and Road Initiative is creating new logistics routes for agricultural exports, connecting Asia, Europe, and Africa.

The development of the agro-industrial complex is inseparable from its integration into global logistics systems. Key international priorities now include reducing logistics costs, advancing sustainability, and embracing digitalization. The agro-industrial complex is increasingly viewed as a mechanism for ESG implementation, promoting green innovations and corporate social responsibility. For countries with high agrarian potential, aligning with international programs and adapting to global logistics standards is beneficial and essential for maintaining competitiveness. The global shift toward sustainability and ESG compliance emphasizes the interconnection between management, agriculture, and transit logistics. However, a significant gap remains in integrating agro-industrial development with transit corridors to drive ESG implementation, particularly in agrarian-dependent economies such as Kazakhstan.

1. LITERATURE REVIEW

The agro-industrial complex is vital to economic, social, and ecological development. It significantly contributes to GDP, job creation, and food security while improving rural living standards through employment and infrastructure. However, its environmental impact is twofold – both advancing sustainable resource management and causing ecological harm. This makes it particularly relevant in transitioning to a sustainable economy and implementing ESG.

In the traditional economy, the agro-industry development faced integration problems and weak vertical interaction chains. Coase (1937) even showed that transaction costs reduced market efficiency. Davis and Goldberg (1957) first proposed the concept of agribusiness, emphasizing the importance of vertical integration, while Schultz (1964) proved that the industrialization of agriculture was necessary for economic growth.

To enhance efficiency, the growth of the agro-industrial system must align with regional planning and environmental factors through context-specific hubs that optimize resource distribution (Richardson & Townpoe, 1987; Haila, 1990). The agro-industrial complex cannot function in isolation; it depends on integration with industry and services such as logistics, processing, marketing, and finance (Sonka & Hudson, 1990; Lerman & Parliament, 1990; Göbel, 1991). In economies reliant on traditional sectors, agro-industrial expansion triggers a multiplier effect – boosting demand for machinery, fertilizers, and transportation, which in turn stimulates industrial and service sectors (Page & Walker, 1991; Bagachwa & Stewart, 1992). This industrialization strengthens national economic competitiveness (Jelinek & Porter, 1992; Grant, 1991). Effective land, human capital, and technology management form the foundation of agro-industrial clusters (Palladino, 1994), where agro-hubs serve as innovation centers, leveraging regional advantages (Porter, 1998, 2000).

The agro-industrial system is increasingly recognized as a key driver of Sustainable Development Goals (SDGs), bridging environmental, social, and economic dimensions to ensure long-term sustainability. Elkington (1994) initially highlighted the private sector's role in industrial damage and proposed the triple bottom-line framework. Later, the UN institutionalized corporate social responsibility, consolidating ESG standards into a structured approach (Annan, 2004). While industrial agriculture supports economic growth, it also poses environmental and public health risks, such as pollution and chemical exposure (O'Mahony et al., 2013). ESG integration into investment decisions has since emerged as a strategy to enhance sustainability and governance transparency in agriculture (Schramade, 2016). Green technologies, in particular, offer pathways to reducing agricultural emissions and supporting a low-carbon transition (Okereke et al., 2019; Avenyo & Tregenna, 2022; Nchofoung et al., 2024; Castillo et al., 2024).

The agro-industrial complex also plays a crucial role in ecological and economic resilience. Its efficiency depends on well-structured resource management that integrates economic, environmental, and social factors alongside institutional mechanisms (Tsani et al., 2020; Surya et al., 2021). Recent studies suggest various approaches to improving resource utilization. For example, Caixeta et al. (2022) developed a water-energy-food nexus model, enhancing agricultural sustainability, while Wang (2022) highlighted the need for effective monitoring in agro-industrial parks, noting disparities between developed and emerging economies. Yap and Leow (2023) suggested that less rigid regulatory environments in developing countries allow for innovative governance models. However, the absence of clear institutional frameworks can hinder long-term sustainability (Kuandykova et al., 2023; Abduvasikov et al., 2024). Thus, the agro-industrial sector is evolving from a resource-exploiting system into a platform for sustainable business practices, integrating energy and water management, emissions control, and social impact assessment. This transition is key to balancing economic growth with environmental and social responsibility, particularly in developing economies.

Recent studies highlight the growing importance of optimizing transit flows to enhance logistics efficiency and economic stability in agro-industrial systems. Beyond reducing costs, transit corridors shape agro-industrial expansion and trade dynamics. Stein and Kalina (2019) view agrarian corridors as spatial development tools where transport infrastructure attracts agricultural investment. Chen and Li (2021) demonstrated that well-developed corridors boost agro-exports by lowering logistics costs and expanding market access. Similarly, Datsii et al. (2021) emphasize that transport infrastructure and technology investments enhance trade competitiveness. Multimodal logistics, integrating various transport types, further improves efficiency and reduces storage and transportation costs (Zhou et al., 2021). Thus, infrastructure development, cost-efficient transport models, and multimodal logistics significantly enhance agro-industrial profitability and sustainability (Soliani, 2022; Sun et al., 2023).

International studies further show that effective logistics must balance cost efficiency with environmental and social responsibility. The Trans-European Transport Network, for instance, has contributed to reducing regional inequalities and fostering economic growth (Öberg et al., 2018). However, simply increasing transport accessibility may yield only short-term benefits. Sustainable growth requires integrating environmental and social considerations into transport development. Therefore, adopting green technologies and corporate sustainability initiatives is crucial (Zou & Feng, 2024).

Research in Kazakhstan primarily focuses on economic efficiency, often analyzing logistics and agriculture separately. Bazarbekova et al. (2018) and Taisarinova et al. (2020) explored Kazakhstan's potential as a transit hub due to its strategic location in Central Asia. Meanwhile, Kontrobayeva et al. (2023) and Tsoy and Nurbatsin (2024) examined local agricultural logistics and productivity challenges. Other studies address resource management issues, particularly land degradation, water scarcity, and outdated agricultural practices (Tokbergenova et al., 2018). Asperov et al. (2023) highlight financial support and innovation as key to increasing agro-industrial productivity and competitiveness.

While these studies offer valuable insights, they often overlook the interconnected role of transit routes and agrarian development in fostering ESG-oriented sustainable growth. Given Kazakhstan's reliance on both sectors, a more integrated approach is needed to assess how transit infrastructure and agro-industrial policies collectively shape economic, social, and environmental outcomes. Thus, this study aims to identify the relationship between developing transport routes, the agro-industrial sector, and ESG approaches in Kazakhstan. This analysis aims to fill this gap by examining the joint impact of transit corridors and agro-industrial development on ESG implementation, offering a comprehensive framework for sustainable growth in Kazakhstan.

The literature review showed that the agro-industrial complex has been traditionally studied through the lens of cluster development, logistics, and production processes. However, the role of transport routes and agriculture in transitioning

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to a sustainable economy has not been sufficiently explored. Specifically, there is a lack of studies analyzing the impact of transportation corridors on implementing ESG standards in agriculture. Based on this, three hypotheses are proposed:

H1: *Transportation infrastructure development significantly influences the adoption of environmental, social, and corporate governance practices.*

H2: *Agriculture plays a crucial role in implementing ESG approaches.*

H3: *The combined influence of transport corridors and the agro-industrial complex explains the variability in the implementation of ESG approaches.*

2. METHODS

The agricultural sector and transit logistics overlap in their dependence on ESG, which is key in ensuring long-term sustainability. The main goal is to quantify the impact of these factors on these two industries and identify the relationships between them, which will offer sound recommendations for strategic planning and management. Therefore, data analysis methods such as econometric modeling, statistical processing, and integral indices are used to reflect the cumulative impact of ESG on selected industries.

The study uses a structured methodology that includes research into transit routes and regression analysis to identify influential factors. This approach focuses on systematizing data in the context of Kazakhstan's national characteristics.

2.1. Composite freight volume index calculation

This analysis provides insight into the efficiency and sustainability of transit logistics and ESG dimensions, highlighting their contributions to sustainable development and governance frameworks. Data on freight flows were analyzed and integrated into the study to evaluate the role of transit logistics. The selection of countries was based on the four key metrics: total freight volume (tons), shipment frequency, receiving frequency, and freight volume by destination.

A composite freight volume index was aggregated for each country based on (1).

$$CFV_c = \omega_1 \cdot Z_1 + \omega_2 \cdot Z_2 + \omega_3 \cdot Z_3 + \omega_4 \cdot Z_4, \qquad (1)$$

where CFV_c – composite freight volume index for country c; Z_1, Z_2, Z_3, Z_4 – standardized values of the metrics; ω_1, ω_2, ω_3, ω_4, – weights assigned to each metric.

The transit analysis considered aggregated rankings of the top 20 countries in each category. Such categorization identifies key transit partners and evaluates their contribution to ESG governance.

2.2. Principal component analysis

This analysis provides insight into the intricate relationships between key factors influencing the implementation of the ESG framework. This approach, encompassing data standardization, composite indicator development, and regression analysis, offers a robust framework for assessing ESG implementation and identifying strategic areas for policy intervention. For the development of composite indicators through principal component analysis (PCA), Z-scores were applied for data standardization. The Z-score standardization was calculated using (2):

$$Z = \frac{X - \mu}{\sigma}, \qquad (2)$$

where Z – standardized value; X – the original value of the indicator; μ – mean of the indicator; σ – standard deviation of the indicator.

PCA was applied to reduce the dimensionality of the ESG indicators while preserving as much variance as possible. The first principal component (PC1) was selected as the aggregated indicator for each dimension and was calculated according to (3):

$$PC1 = \omega_1 \cdot Z_1 + \omega_2 \cdot Z_2 \ldots\ldots + \omega_n \cdot Z_n, \qquad (3)$$

where $PC1$ – first principal component; ω_2. – weights (loadings) of the variables; Z_n – standardized indicators.

2.3. Regression analysis

This analysis provides insight into the influence of agriculture and transit routes on implementing the ESG framework. This stage builds on the primary components developed in the previous step, using them as dependent variables in the regression model. To evaluate the influence of agriculture and transit routes on the implementation of the ESG framework, linear regression analysis was performed according to (4)

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

where Y – dependent variable; X_1, X_2, X_3 – aggregated indicators (environmental, social, governance); β_0 – intercept, representing the baseline value of Y; β_1, β_2, β_3 – coefficients for each ESG dimension; ε – error term.

The developed methodology comprises a set of methods that enable data integration and the composition of ESG components, taking into account key indicators within the context of Kazakhstan. Brief descriptive statistics, summarized in Table 1, provide an overview of the two groups of selected variables.

To ensure complex analysis, a data set covering three main dimensions, environmental, social, and governmental, was selected. The data were collected from the Bureau of National Statistics and the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan for the period between 2013–2023. The environmental (E) component included variables reflecting the resource management system and emission intensity. The social (S) component is evaluated through variables analyzing human capital and agriculture. The governance (G) component covers economic efficiency and logistics performance variables and reflects resource and transit routes management.

3. RESULTS

3.1. Analysis of transit route

The first stage of the analysis is focused on assessing the management of transit logistics dynamics through Kazakhstan. Data on the diversity of countries were based on the categories: the total weight sent through and to the Kazakhstan transit route, the number of shipments, and destinations, covering the period from 2013 to 2022.

Based on the conducted analysis, the key partner countries with economic contributions to the transit networks of Kazakhstan were assessed through the analysis of shipment and weight volumes passing through the country. The development of customs unions and the removal of trade

Table 1. Overview of measurement variables

ESG Category	Component	Sub-component variable	Code	Measurement Unit
Environmental	E_Water_Management	Water Exploitation Index	E1	Percentage
		Water Resource Load Level	E2	Index
		Freshwater Withdrawal	E3	Million cubic meters
	E_Carbon_Sustainability	Carbon Productivity	E4	USD per kg CO_2 eq.
		CO_2 Emission Intensity	E5	Tons per capita
Social	S_Employment	Average Annual Population	S1	Thousand
		Employment in Agriculture	S2	Thousand
		Gross Value Added per Employed Person	S3	KZT
	S_Economic_Activity	Gross Output of Agricultural Products	S4	KZT
		GDP by Production Method	S5	KZT
		Gross Crop Production	S6	KZT
		Gross Livestock Production	S7	KZT
Governance	G_Energy Intencity	Transport and Storage Energy Intensity	G1	Tons per 1,000 USD
		Accommodation and Food Services Energy Intensity	G2	Tons per 1,000 USD
	G_Market_Power	Herfindahl-Hirschman Index	G3	Index
		Diversification Index	G4	Index
	G_Transit _Flow	Annual Transit Volume	G5	Tons
		Total Weight of Shipments	G6	Tons
		Number of Shipments	G7	Thousand

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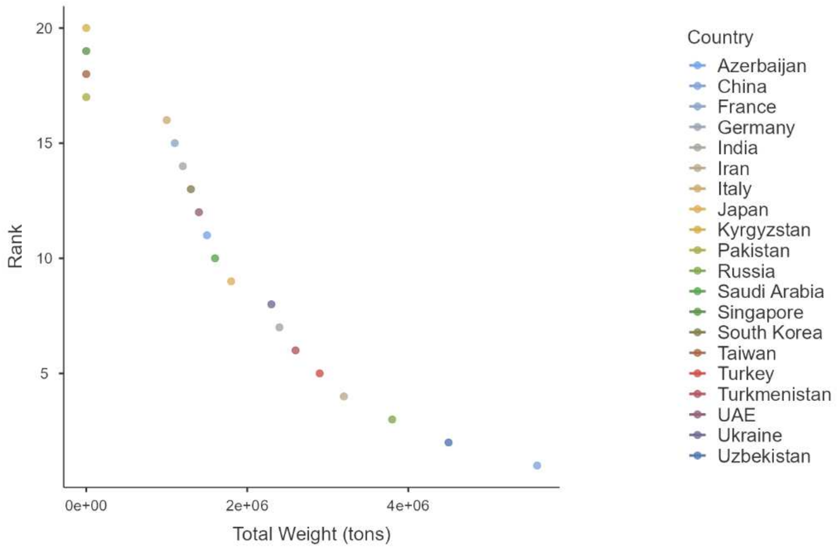

Figure 1. Trans-Eurasian trade and logistics network

barriers (within the Eurasian Economic Union) have strengthened Kazakhstan's position in the international integration of transport flows, including those of its European, Central Asian, and East Asian neighbors. Kazakhstan plays a crucial role in global transport corridors, including the Trans-Eurasian trade and logistics network that connects Europe, Central Asia, East Asia, the Middle East, and South Asia and highlights the qualitative economic significance of Kazakhstan's transit system (Figure 1).

The analysis revealed that Kazakhstan is crucial among primary connecting transit routes. The Kazakhstani segment of the transit route ensures faster delivery, lower transaction costs, and improved competitiveness for transported goods. China was identified as the key partner in East Asia, making the most significant contribution, driven by China's Belt and Road Initiative. Active engagement was observed between Central Asia and Kazakhstan, as neighboring countries rely on overland routes to access global markets. Thus, East Asia and Central Asia were identified as the primary sources of transit flows through Kazakhstan.

Based on the analysis, East Asia is regarded as the most significant contributor to Kazakhstan's transit flows. China holds the dominant role and accounts for 22.73 billion units of total shipment weight, representing more than 60% of the overall volume for the period considered. Apart from China, South Korea and Japan also made a significant contribution. South Korea accounts for 757.65 million units, while Japan adds 112.77 million units for the considered period. The next countries with prominent contributions despite smaller volumes were Taiwan (71.76 million units) and Hong Kong (17.39 million units). Therefore, Kazakhstan is a central link in the global supply chains that connect East Asian production hubs with European consumer markets.

Central Asia provides the second largest contribution to Kazakhstan's transit network. The analysis revealed Uzbekistan and Turkmenistan as key partners. The potential of Kazakhstani transit routes as international transport corridors builds a high reliance on Uzbekistan. The results also revealed Kazakhstan's strategic role in terms of Turkmenistan exports (406.39 million units). The involvement of the following two countries, Tajikistan (1.40 billion units) and Kyrgyzstan (12.46 million units), in the logistic system of Kazakhstan confirmed its role in regional integration.

There was a less prominent contribution to transit flows from Europe. In particular, Germany accounts for 34.79 million units, making it one of Kazakhstan's key European partners. Italy and France were the subsequently identified most active participants, with 18.08 million units and 10.17 million units, respectively. Other countries, such as Spain, Belgium, and the Netherlands, also

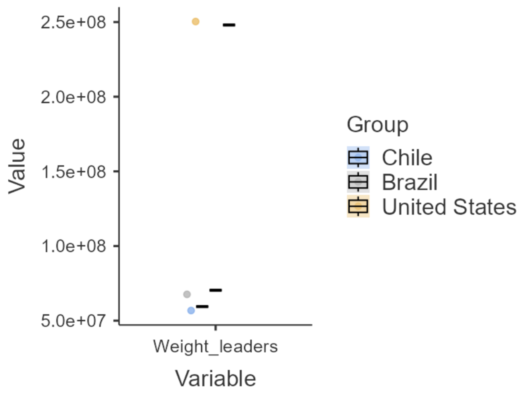

Figure 2. North and Latin America's collective shipment weight volume

participate, though to a lesser extent (less than 10 million units for the period). In the Middle East, the position of bridging countries between Europe, Central Asia, and South Asia, the corridor from Russia through Kazakhstan and Turkmenistan, is given to Turkey (565.88 million units) and Iran (445.27 million units). Iran's objective is to ensure a seamless shipment process between Central Asia and the Middle East. Despite the low weight volume transported through the Kazakhstani transit route, the North-South Transport Corridor is focused on the flow of high-value goods (such as industrial equipment or advanced technology) and therefore requires higher logistics standards. Kazakhstan's transit route appears to be an opportunity to reduce shipping times and avoid maritime routes, especially for India (177.39 million units). Another emerging participant is Pakistan (74.91 million units), which serves as a connecting block between Central and South Asia. The most prominent participants and contributors are China, Uzbekistan, and Turkey, which account for a significant portion of the overall transit volumes. Additionally, driven by China's Belt and Road Initiative, East and Central Asia are the leading regions.

North and Latin America are emerging markets for Kazakhstan in terms of international transit logistic network development (Figure 2).

First, the collective shipment weight volume for North and Latin America is smaller than that of East Asia. In particular, the participation of the United States, Brazil, and Chile must be included in Kazakhstan's transit flows. Additionally, the nature of the transit logistic relationship is different for these countries, which reflects the comprehensive nature of the transit route in Kazakhstan. Brazil and Chile, based on the nature of their shipments as raw materials, are more sensitive to transportation cost changes. At the same time, the United States focused more on individual posts or specialized goods such as industrial machinery, electronics, or mining equipment. It focuses on the speed of delivery or goods transportation. Thus, Kazakhstan provides more stable and available policies for North and Latin America.

The inclusion of countries from Latin and North America represents a shift from Kazakhstan's traditional dependence on East Asia, Central Asia, and Europe. This diversification marks the formation of new trade corridors, especially with Brazil and Chile, suggesting the market is still developing. The presence of Mexico and Argentina, albeit with smaller contributions, further supports the argument for an emerging market, as these countries have the potential to increase their share in future trade flows.

Emerging markets are characterized by untapped potential for expansion. The logistical link between South America, North America, and Eurasia is still underdeveloped. As trade agreements, digitalization of customs processes, and logistics infrastructure improve, the flow of goods from the Americas to Eurasia is likely to increase. Kazakhstan, in the position of a central and flexible international transit, can leverage existing and emerging connections to become a Central Eurasian Logistic Hub in an expanding transit market.

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3.2. Analysis of relationships between key factors

At the second stage, the paper conducted principal component analysis (PCA) to identify key indicators influencing sustainable economic development. Based on the methodological approach, the main objective was to develop aggregated components for further analysis.

Seven subcomponents were developed for principal component analysis provision and composition of main ESG components. Table 2 shows the validity of all subcomponents.

The results for Chi-squared showed that the subcomponents were identified and four needed further justification. First group of environmental subcomponents showed the following results. The E_Water model is exactly identified and the factor structure of the model fits well and no additional subcomponent specification is required. The E_Carbon Sustainability subcomponent is unidentified based on the degrees of freedom of –1.

Secondly, the results of the social subcomponents revealed the following. The S_Employment subcomponent is exactly identified. Therefore, specification is not required, as all parameters are fully utilized to explain the variance of the variables. The S_ Economic Activity results (degree of freedom = 2) indicated that the model does not fit perfectly.

Thirdly, the results for governmental subcomponents showed that the selected variables exactly identified the G_Transit Flow subcomponent. The next two, G_Energy Intensity and G_Market Power, subcomponents had negative degrees of freedom and thus required deeper analysis.

To justify developed subcomponents and check the validity of variables, an analysis of subcomponent loadings was conducted and provided separately. Table 3 presents the results for environmental subcomponent validation.

The loadings of the environmental component confirmed the validity of both models: E_Water management and E_Carbon Sustainability. For E_Water management subcomponent, the analysis observed a strong relationship of both variables. E1 and E3 showed positive relationship with 98% and 92.5% of variance respectively explained by the model. On the contrary, E2 showed negative relationship.

The loadings of the E_Carbon Sustainability model showed strong relationship with 70.7% of the variance explained by the variables. The results indicated strong negative relationship with E4 with 70.7% of variance, thus reflecting that an increase in E4 reduces the overall subcomponent score. E5 showed positive strong relationship with the model that as E5 increases, the overall subcomponent score increases as well.

Table 2. Chi-squared test of ESG subcomponents

ESG Category	Model Subcomponents	Value	Degrees of freedom	P
Environmental	E_Water Management	1.673	0	
	E_Carbon Sustainability	2.211	–1	
Social	S_Employment	2.094	0	
	S_ EconomicActivity	62.569	2	< .001
Governmental	G_Energy Intencity	2.103	–1	
	G_Market_Power	2.097	–1	
	G_Transit Flow	119.530	0	

Table 3. Component loadings for the environmental component

Model Subcomponents	Variables	Rotated Loading Coefficient	Uniqueness	Explained Variance (%)
E_Water management	E1	0.990	0.020	98.0
	E2	–0.972	0.055	94.5
	E3	0.962	0.075	92.5
E_Carbon Sustainability	E4	–0.841	0.293	70.7
	E5	0.841	0.293	70.7

Table 4. Component loadings for the social component

Model subcomponents	Variable	Rotated Loading Coefficient	Uniqueness	Explained Variance (%)
S_Employment	S1	0.974	0.051	94.9
	S2	0.963	0.073	92.7
	S3	–0.897	0.195	80.5
S_Economic Activity	S4	0.998	0.003	99.7
	S5	0.987	0.026	97.4
	S6	0.977	0.046	95.4
	S7	0.932	0.131	86.9

Table 5. Component loadings for the governmental component

Model subcomponent	Variable	Rotated Loading Coefficient	Uniqueness	Explained Variance (%)
G_Energy Intencity	G1	–0.959	0.081	91.9
	G2	0.959	0.081	91.9
G_Market_Power	G3	–0.994	0.012	98.8
	G4	0.994	0.012	98.8
G_Transit Flow	G5	0.990	0.020	98.0
	G6	0.990	0.020	98.0
	G7	0.957	0.085	91.5

To sum up, the results showed that there is good resource management reflected in the reduction (negative loading) of E1, which represents a positive environmental impact. The E5 management system is under control, confirmed by the (negative loading) increase in production efficiency (carbon productivity) with lower emissions. Both models are accepted for further analysis.

Next, Table 4 shows the validity of social subcomponents. The analysis of the S_Employment subcomponent showed S1 and S2 variables with 94.9% and 92.7% variance, confirming strong positive relationships. At the same time, economic output in agriculture per employee showed negative loading with an 80.5% variance. Overall, the results align with the structural transformation of the economy. As the S3 variable increases, it affects the S_Employment subcomponent and defines low economic diversification. Otherwise, there is an increase in employment in other fields of the economy. S_ Economic Activity, including S4 (99.7%), S5 (97.4%), S6 (95.4%), and S7 (86.9%), showed strong positive relationship. Both models' subcomponents were accepted for further analysis.

Table 5 presents governmental subcomponent validation. G5, G6, and G7 showed a strong positive relationship with 98%, 98%, and 91.5% variance, respectively. G1 and G2 showed a strong relationship with 81% of the variance, but with negative for G1 and positive for G2. G3 variable showed a strong negative relationship while G4, on the contrary (98.8%), is positively related to the subcomponent. All three subcomponents are accepted.

According to the analysis conducted, all subcomponents were justified in further composing the primary components of ESG. Table 6 presents the PCA for three components of ESG.

Table 6. Chi-squared test for ESG

Model	Value	df	p
Environmental	2.123	–1	–
Social	2.097	–	–
Governmental	1.605	0	–

The social and governmental components are well-defined for analysis and require no re-specifications. The social component showed a stable and well-defined structure. The governmental component, with a Chi-squared value of 1.605 and a *p*-value of 0, requires closer attention. As for the environmental component with a Chi-squared value of 2.123 and a degree of freedom of –1, the subcomponent is not identified. Nevertheless, a degree of freedom of –1 is acceptable.

Table 7 shows factor loadings for a deeper analysis. The results demonstrated the strength and consistency of the subcomponents for the ESG model. First, the environmental component is well-

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Table 7. Component loadings of ESG

Model components	Subcomponent	Rotated Loading Coefficient	Uniqueness	Explained Variance Subcomponent (%)	Explained Variance Component (%)
Environmental	E_Water	–0.918	0.157	84.3	84.3
	E_Carbon_Sustainability	0.918	0.157	84.3	
Social	S_Employment	0.992	0.016	98.4	98.4
	S_Economic_Activity	0.992	0.016	98.4	
Governmental	G_Transit_Flow	0.976	0.047	95.3	88.33
	G_Market_Power	0.930	0.135	86.5	
	G_Energy_Intencity	–0.912	0.168	83.2	

defined. E_Water and E_Carbon_Sustainability showed 84.3% of variance for both subcomponents. The uniqueness values of 0.157 for both variables are within acceptable limits.

The social component showed high values for explained variance of 98.4% for each subcomponent, indicating that the social component is statistically well-defined. The uniqueness values are also within acceptable limits.

The governmental component is also well-structured, as shown by the loadings for G_Transit_Flow (95.3%), G_Market_Power (86.5%), and G_Energy_Intensity (83.2%). The uniqueness values are 0.047, 0.135, and 0.168, respectively. While the uniqueness for G_Energy_Intensity is slightly higher, it remains within an acceptable range, ensuring that the component retains explanatory power. The overall strength of the loadings for the governmental component showed the validity for further use.

Figure 3 provides network models for subcomponents and the aggregated primary ESG components, revealing key relationships, strengths, and economic significance.

The results for structural relationships among subcomponents showed seven nodes and 15 non-zero edges, resulting in a sparsity of 0.286. The relationships for ESG components showed three nodes with full linkage (sparsity 0.000).

Among all subcomponents, the node G_Transit_Flow (6) emerges as a central one, showing a relationship with the majority of the subcomponents in the system. The first strongest connection is observed between S_Economic_Activity (4) and S_Employment (3), indicating a strong interdependence between economic activity and employment levels. This demonstrates that an increase in economic activity directly contributes to higher employment.

The second strongest connection is shown between G_Energy_Intensity (7) and S_Employment (3), thus showing the critical role of energy efficiency in maintaining high employment levels, in particular in energy-intensive sectors. The third significant positive relationship is revealed between E_Carbon_Sustainability (2) and G_Transit_Flow (6), thereby marking the significance of carbon sustainability in transport infrastructure.

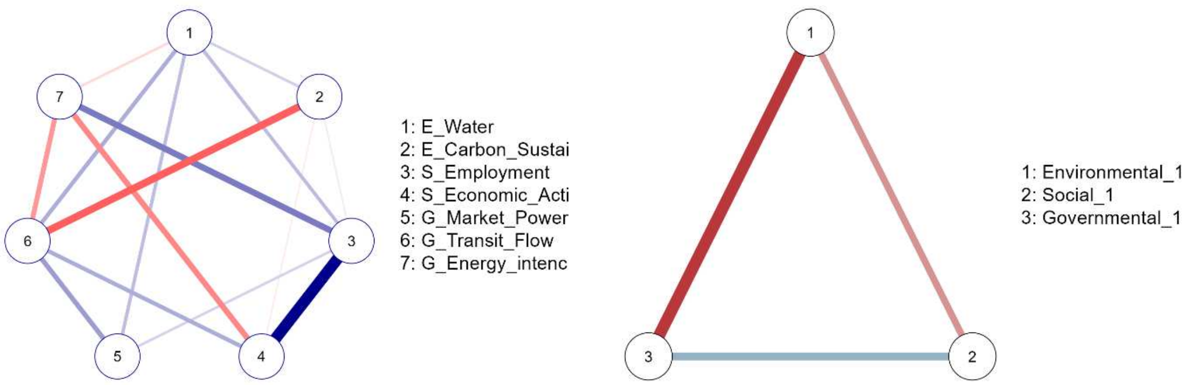

Figure 3. Network of PCA components/subcomponents

A moderate relationship was observed between G_Energy_Intensity (7) and S_Economic_Activity (4), confirming that energy efficiency has an impact on economic activity. Such dependence is revealed through cost reduction (IEA, 2014). Moreover Sun et al. (2023) revealed a positive relationship between G_Energy_Intensity (7) and G_Transit_Flow (6), marking a lack of energy-efficient solutions for improving the capacity of the transportation systems. The next moderate connection was observed between G_Market_Power (5) and G_Transit_Flow (6). According to Rodrigue and Notteboom (2013), the transport infrastructure strongly impacts market power, especially in enhancing regional competitiveness.

The next group shows a weak relationship between subcomponents. The relationship between E_Water (1) and G_Transit_Flow (6), according to Hoekstra et al. (2011), showed that water resource management affects the efficiency of transit flows management, especially in water-dependent sectors. The second relationship, between G_Transit_Flow (6) and S_Economic_Activity (4), signifies the part of transport infrastructure management in promoting economic activity, which, based on Holl and Rama (2014), is achieved by reducing logistical costs. The relationship between subcomponents E_Water (1) and S_Employment (3) showed that water resources influence employment in agriculture and water management systems (Molden, 2007).

Based on the revealed relationships, access to water resources is another mechanism for strengthening market positions in strategically important sectors (Wichelns, 2010). Therefore, the relationship between E_Water (1) and G_Market_Power (5) could be marked as high priority. Secondly, integrated management of water and energy resources (Perry et al., 2009) is required based on the weak relationship between E_Water (1) and G_Energy_Intensity (7). G_Transit_Flow (6) stands out as a central bridge within the network, ensuring interaction between economic activity, energy consumption, and environmental sustainability.

The second network includes three key relationships between major aggregated components: Environmental_1 (1), Social_1 (2), and Governmental_1 (3). The relationship between Environmental_1 (1) and Governmental_1 (3) is marked as the strongest one. However, a negative relationship, especially based on a detailed analysis of subcomponents, indicates the vulnerability of the resources management system. Ultimately, negative correlation highlights that with environmental indicators improvement, which require more stringent measures, there will be tensions in aligning environmental objectives with governance structures. A moderately strong negative relationship is observed between Environmental_1 (1) and Social_1 (2) subcomponents, indicating challenges in balancing environmental priorities with social issues. Thus, integration of ESG standards may have a negative impact on employment (particularly in agriculture) and escalate into a reduction of population well-being. Therefore, weak management is the primary stumbling block to ESG standards integration. The weakest positive relationship is observed between Social_1 (2) and Governmental_1 (3), showing that social indicators align positively with governmental actions or policies. Both networks are suitable for further analysis, as the significance of the components is evident.

3.3. Regression analysis

Table 8 depicts the fitness of all three models. The results showed that all three models demonstrated a strong fit. The transit routes model showed that the predictors explain 91.2% of the variation in the environmental component, with an adjusted R^2 of 0.868. Similarly, the environmental (agriculture) model exhibits an R^2 of 0.931, with an adjusted R^2 of 0.911, confirming the robustness of the model.

The ESG model has an exceptionally high R^2 of 0.998, suggesting that 99.8% of the variance in the combined ESG index is explained by its predictors, with an adjusted R^2 of 0.995. The root mean squared error for all models is low, indicating high predictive accuracy. Based on these results, all three models are accepted as valid for further analysis. The results of the hypothesis testing are presented in Table 9.

The ANOVA results confirmed that all three models are statistically significant, with a p-value of 0.001 (less than $\alpha = 0.005$), indicating that independent components have a significant

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Table 8. Model fitness

Model	R	R²	Adjusted R^2	Root Mean Squared Error
Environmental Transit routes _M_1	0.955	0.912	0.868	0.363
Environmental Agriculture _M_1	0.965	0.931	0.911	0.298
ESG_M_1	0.999	0.998	0.995	0.070

Table 9. ANOVA results

Model		Sum of Squares	df	Mean Square	F	P
Environmental Transit routes _M_1	Regression	8.208	3	2.736	20.727	0.001
	Residual	0.792	6	0.132	–	–
	Total	9.000	9	–	–	–
Environmental Agriculture _M_1	Regression	8.380	2	4.190	47.297	< .001
	Residual	0.620	7	0.089	–	–
	Total	9.000	9	–	–	–
ESG_M_1	Regression	8.980	5	1.796	367.724	< .001
	Residual	0.020	4	0.005	–	–
	Total	9.000	9	–	–	–

Note: The intercept models are omitted, as no meaningful information can be shown.

effect on the dependent variables. Thus, all hypotheses were accepted. Further, Table 10 provides the contributions of individual components to each model.

In the Transit Routes model, G_Transit_Flow emerges as the only significant predictor, with a p-value of 0.041. Thus, transit flows have a considerable impact on the environmental component. In the agriculture model, there are two components with significant contributions: E_Carbon_Sustainability with a strong positive impact (p = 0.015) and S_Economic_Activity with a strong negative impact (p = 0.020). In the ESG model, all components showed a statistically significant impact. Nevertheless, S_Employment (p = 0.004) and E_Carbon_Sustainability (p = 0.026) outstand all the rest of the components, predicting that employment and carbon sustainability have a crucial impact on integration and compliance with the ESG framework.

Table 11 presents the results of hypotheses testing. The analysis supported all the hypotheses. Thus, transit routes and the agricultural sector play key roles in implementing the ESG framework.

Table 10. Coefficients

Model		Unstandardized	Standard Error	Standardized	t	P
Environmental Transit routes _M_0	(Intercept)	1.018×10^{-15}	0.316	–	3.220×10^{-15}	1.000
Environmental Transit routes _M_1	(Intercept)	1.345×10^{-15}	0.115	–	1.171×10^{-14}	1.000
	G_Energy intencity_1	–0.008	0.235	–0.008	–0.035	0.974
	G_Market_Power _1	–0.012	0.278	–0.012	–0.043	0.967
	G_Transit_Flow_1	–0.331	0.127	–0.951	–2.594	0.041
Environmental Agriculture _M_0	(Intercept)	1.018×10^{-15}	0.316	–	3.220×10–15	1.000
Environmental Agriculture _M_1	(Intercept)	9.537×10^{-16}	0.094	–	1.013×10–14	1.000
	E_Carbon_Sustainability_1	0.526	0.164	0.526	3.203	0.015
	S_Economic_Activity	–0.492	0.164	–0.492	–3.000	0.020
ESG_M_0	(Intercept)	1.053×10^{-16}	0.316	–	3.331×10^{-16}	1.000
ESG_M_1	(Intercept)	-4.954×10^{-17}	0.022	–	-2.241×10^{-15}	1.000
	E_Water	0.179	0.059	0.179	3.021	0.039
	E_Carbon_Sustainability	–0.173	0.050	–0.173	–3.454	0.026
	G_Energy_Intencity	–0.143	0.047	–0.143	–3.071	0.037
	G_Transit_Flow_1	0.093	0.033	0.266	2.781	0.050
	S_Employment	0.324	0.054	0.324	6.011	0.004

Table 11. Hypotheses results

Hypothesis	Statement	Result
H1	Transit routes have a significant impact on the environmental component.	Accepted
H2	The agricultural sector significantly influences the environmental component.	Accepted
H3	The combined influence of transit routes, agriculture, and other predictors significantly explains variations in the ESG index.	Accepted

4. DISCUSSION

This study confirmed previous studies that there is a strong correlation between transport corridor development and agro-industrial complexes. The results showed that the development of transit flows has a significant positive impact on economic efficiency and ESG indicators. Thus, integrated transit systems can contribute to the overall sustainable development. Therefore, developing logistics infrastructure helps reduce logistics costs and increase agro-exports' profitability, which is consistent with the findings of Chen and Li (2021). In addition, Zhou et al. (2021) noted the importance of multimodal logistics in optimizing transport costs and improving the efficiency of agro-industrial supply chains.

Furthermore, the positive effect of employment (β = 0.324, p = 0.004) confirms the findings of Richardson and Townpoe (1987) and Castillo et al. (2024). Thus, employment in the agro-industrial sector plays an important role in ensuring social sustainability. In addition, Stein and Kalina (2019) considered agricultural corridors as investment hubs that stimulate regional development. The results showed a significant impact of logistics on environmental indicators (Environmental Transit Routes Model (R^2 = 0.912)). Moreover, transit flows have (G_Transit_Flow (β = 0.266, p = 0.050)) a positive impact on ESG. Soliani (2022) noted that logistics plays a key role in the competitiveness of the agribusiness sector, but its development should be accompanied by measures to reduce the negative environmental impact. Therefore, investments in transit route infrastructure contribute to the expansion of agribusiness operations, especially the efficiency of transport networks to maintain the economic sustainability of rural areas. However, some discrepancies were identified. Datsii et al. (2021) and Sun et al. (2023) argued that the growth of transit flows can exacerbate environmental problems. Zou and Feng (2024) attributed the negative impact to the adverse effect of infrastructure upgrades and the resulting fluctuations in energy consumption, which was reflected in the results of this study (G_Energy_Intensity (β = –0.143, p = 0.037)).

The findings also challenge the hypothesis of Okereke et al. (2019) that carbon sustainability always has a positive effect on ESG performance. At the same time, the results of the study showed a negative impact of carbon sustainability (E_Carbon_Sustainability (β = –0.173, p = 0.026), which may indicate significant regional differences in the regulation of CO_2 emissions and the effectiveness of policies to reduce them. Therefore, the results confirm the findings of Kuandykova et al. (2023) regarding the necessity of considering local characteristics when developing sustainable resource management strategies. This aligns with their conclusion that the agro-industrial sector in Kazakhstan lacks structured ESG mechanisms, highlighting the need for more comprehensive regulatory frameworks and implementation strategies. From the point of view of social and institutional governance, the study's results confirm the findings of Porter (1998, 2000) that the development of clusters and logistics systems increases regional competitiveness.

The governance model demonstrates that the development of transit infrastructure explains 95.3% of the variations in the regional economy, which is consistent with Porter's hypothesis on the formation of competitive advantages through the integration of logistics and agro-industrial clusters. Datsii et al. (2021), Kuandykova et al. (2023), and Pradhan et al. (2024) argued that the development of logistics systems automatically leads to increased regional competitiveness; the results partially confirmed these assumptions. The current results identified limitations related to regulatory barriers and resource management and pointed to the need for an integrated institutional approach to developing logistics and the agro-industrial complex. Thus, the study confirms the key role of

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transit infrastructure, employment, and logistics in the agro-industrial sector's development and identifies trade-offs that need to be considered when developing sustainable development policies. Although the positive impact of transit flows on economic and social sustainability, environmental and governance aspects require further improvement, including introducing energy-efficient technologies and improved institutional regulation.

In conclusion, this study combined economic, social, and environmental effects, showing that the agro-industrial complex and infrastructure should develop together, not separately. The study's results generally determined the balance that logistics contributes to sustainable development, but energy consumption and CO_2 emissions can reduce ESG indicators. Previous studies emphasized that logistics and clusters increase competitiveness. However, they did not consider that the effect highly depends on regional conditions. Thus, logistics works differently in different regions: somewhere, it strengthens the domestic market and significantly impacts foreign trade. Therefore, logistics and the agro-industrial complex cannot develop separately. Their integration reduces costs, increases exports, and creates jobs. However, logistics does not continually improve sustainability indicators; environmental risks and resource management require control. Thus, for the long-term development of the agro-industrial complex, it is important not only to develop transit routes but also to strategically integrate them into agro-industrial clusters, considering economic, social, and environmental factors.

CONCLUSION

This study aims to investigate the relationship between three main categories, including environmental sustainability, social development, and governance, within Kazakhstan's agro-industrial complex. The findings confirmed that both sectors play a significant role in advancing ESG standards and are critical to the transition toward a sustainable economy.

The results revealed that transit routes have a dual impact: they enhance economic activity while also strengthening governance structures. However, inefficiencies in energy intensity and market power indicate weaknesses in governance, highlighting areas that require policy improvements. The principal component analysis identified carbon sustainability and employment as the most influential ESG subcomponents, underlining the importance of balancing environmental and social priorities.

The regression analysis validated the proposed hypotheses. First, the results showed that transit routes significantly influence environmental sustainability, as transit flow was identified as an acritical factor. Second, the agricultural sector showed a significant impact on environmental sustainability. Moreover, the dual role of agricultural factors was revealed. AIC focus on improving carbon sustainability positively impacts the environment. However, rapid economic activity growth includes increased production or exports, causing more pollution and inefficient resource consumption. Therefore, balanced management in agricultural development with sustainability goals is particularly challenging in agriculture-dependent economies. Third, the combined effects of transit routes and agriculture were strongly supported. The combined approach is predicted to provide long-term improvements with stronger rural economies, improved agricultural practices, and responsible resource management, leading to reduced environmental degradation.

From a practical perspective, these findings highlight the need for policy strategies that align transport and agro-industrial development with ESG objectives. Investments in multimodal logistics, green technologies, and regulatory frameworks are essential to mitigate environmental risks while maximizing economic and social benefits. Future research should focus on refining ESG assessment models for the agro-industrial sector, incorporating real-time data on logistics efficiency, and evaluating the long-term socio-economic impacts of ESG-oriented policies.

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