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THE ESG-ORIENTED APPROACHES TO DEVELOPING A SUSTAINABLE RAIL FREIGHT MARKET: METHODOLOGY AND EFFECTIVENESS ASSESSMENT

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Resume

In this paper, the sustainability of Kazakhstan's rail freight market was analyzed in the context of the influence of ESG (Environmental, Social, Governance) variables. The data used (secondary data 2018-2024) and the expert surveys (regression, SEM (Structural Equation Modelling), DEA (Data Envelopment Analysis)) revealed that ESG factors have a significant impact on performance ($R^2 = 0.85$), competitiveness ($R^2 = 0.82$), and stability ($R^2 = 0.84$). The most powerful factors were corridor efficiency ($\beta = 0.421$) and service quality ($\beta = 0.370$) with negative effects being energy consumption ($\beta = -0.312$) and emissions ($\beta = -0.275$). The SEM path coefficients ranged 0.597-0.652; DEA scores ranged 0.87-0.94.

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Nomenclature

AVE - Average Variance Extracted
CB-SEM - Covariance-Based Structural Equation Modelling
CE - Corridor Efficiency
CFA - Confirmatory Factor Analysis
CFI - Comparative Fit Index
CI - Community Impact
CR - Composite Reliability
DEA - Data Envelopment Analysis
EC - Energy Consumption
EFF - Efficiency Score
EM - Emissions
ESG - Environmental, Social, and Governance
IT - Investment Transparency
KPI - Key Performance Indicator
KTZ - Kazakhstan Temir Zholy (national railway operator)

LPI - Logistics Performance Index
LTS - Long-Term Stability
MC - Market Competitiveness
OECD - Organisation for Economic Co-operation and Development
PLS-SEM - Partial Least Squares Structural Equation Modelling
RC - Regulatory Compliance
RFP - Rail Freight Performance
RMSEA - Root Mean Square Error of Approximation
SEM - Structural Equation Modelling
SP - Strategic Planning
SQ - Service Quality
SRMR - Standardized Root Mean Square Residual
TBL - Triple Bottom Line
UIC - International Union of Railways
VIF - Variance Inflation Factor
WS - Workforce Safety

1 Introduction

The rail freight sector has seen rapid growth in Kazakhstan over the last decade, with the pace of growth being somewhat uneven. Although it carries a large amount of traffic in the transit between China and Europe, a lot of infrastructure is still aged and loaded with ESG obstacles. Major routes are under threat due to increasing stress on the environment and erratic investment cycles [1-2]. While numerous studies have shown that the current rail planning governance is inadequate and there is a need for new sustainability tools [3-4], only a few consider ESG evaluation methods for rail freight.

In the field of transport sustainability theory, attention is drawn to the issue of governance, environmental performance, network efficiency and community implications [5-7]. Experts believe that the ESG factors have an impact on rail performance, while the infrastructure sustainability has an impact on freight reliability [8-9]. The problems of governance impede improvement [10] and there is no public study of the sustainability of Kazakhstani rail infrastructure by ESG. An environmental scorecard without social and governance information [11] was suggested while other study concentrated on economic resilience [12] or could not find any safety risk-ESG association [13]. Whereas, with the competition from other transport corridors, the high efficiency of the corridor is crucial to maintain market share and to shift the traffic to the corridor [14]

This gap was addressed by presenting an ESG-based analysis model of the Kazakhstan rail freight market. The goals are to (1) assess the impact of ESG on market performance, competitiveness, and long-term stability; (2) assess the empirical validity of the proposed ESG methodology; and (3) develop a repeatable framework to incorporate ESG indicators in a rail corridor sustainability index. This study is an addition to the quantitative evaluation to the ESG integration in a rail project in Central Asia. In this paper, a unified analytical framework is introduced and empirically validated for the first time, integrating Structural Equation Modelling (SEM) and Data Envelopment Analysis (DEA) to assess sustainability performance of Kazakhstan's rail freight sector, as opposed to previous studies, which examined either one of these dimensions separately or generic frameworks. To our knowledge, this is one of the first studies to carry out such a methodological synthesis in the context of a transitional economy, providing an instrument which is replicable for policymakers and infrastructure managers...

2 Literature review

In this section, the theoretical and empirical literature on the link between ESG factors and rail freight sustainability is summarized. It starts with the

theoretical literature, continues with empirical evidence on the ESG performance and finally ends with the methods for sustainability assessment and the creation of analytical frameworks based on ESG principles. The section ends with the definition of the research gap addressed in this study.

2.1 Theoretical literature review

The theoretical basis is sustainable development theory, which focuses on economic development, social needs, and environmental conservation [15].

This balance is relevant to the rail systems with high externalities [16]. The Triple Bottom Line (TBL) is a relationship between the people, the planet and economic performance, forming an ESG-based index [17].

Stakeholder theory addresses workers, shippers, communities and regulators in relation to service quality and trust [18].

Planning stability has been shown to influence investment decisions by institutional theory and the resource-based view, which explain why safe, efficient assets contribute to competitiveness [19-20].

These theories support a model in which the relationships between the ESG indicators mediate freight performance and stability in Kazakhstan's rail market.

2.2 Empirical literature review

The empirical literature is reviewed in three subsections, each of which is relevant to one of the objectives of the study. In the first part, the evidence on the impact of ESG on rail freight performance and stability is discussed. In the second part, the current sustainability-assessment approaches and their efficacy are reviewed. In the third part, the empirical underpinnings for building an ESG-oriented analytical framework are examined.

2.2.1 Empirical evidence on how the ESG factors shape rail freight performance and stability (Objective 1)

A triple bottom line analysis [21] shows that environmental and social issues are influencing the efficiency of railways. The ESG related key performance indicator (KPI) based network reliability differences between countries were highlighted in the IRES report [22]. The polls revealed that the cargo density and environmental stress in Kazakhstan has increased [23], while results of Organisation for Economic Co-operation and Development (OECD) study suggest that governance effects the rail planning and funding

[24]. While in a number of studies was highlighted the rail performance in developed economies or individual ESG elements, ESG considerations influence the rail performance. The integrated environmental, social and governance implications of transitioning economies, such as Kazakhstan, are poorly researched. It is necessary to establish a broad ESG framework for the rail freight sector of Kazakhstan.

H_1: Higher ESG performance in rail operations and infrastructure improves performance, competitiveness, and long-term stability of the rail freight market in Kazakhstan.

2.2.2 Empirical studies on the effectiveness of sustainability-assessment methods (Objective 2)

It is known that the multi-indicator techniques can assess the performance of the rail freight, but need sufficient data [25]. Composite index research has shown that the weights of indicators do influence scores [26] and a systematic evaluation for the built environment has been developed for application in the rail sector [27]. A review of Kazakhstan's policy has shown that sustainability assessment tools remain underdeveloped and that local experimentation is needed [28]. Kazakhstan is in need of an ESG approach, but it is not structured and does not have institutions. There are general approaches to sustainability assessment that do not take into account operational conditions in a particular sector. Few empirical evidence exist on Central Asian rail networks about their usefulness in data-limited settings and institutional capacity limitations. Current sustainability assessment frameworks are largely based in mature economies where there is good data provisioning and institutional resources. Transitional economies (like Kazakhstan) have specific issues such as difficulty in accessing data, a lack of historical data, or developing regulatory frameworks. This opens up a disconnection between the general sustainability tools and real-world requirements of infrastructure managers and policy makers in the region. This gap is addressed by developing a context-sensitive ESG framework that takes these data and institutional realities into account. So, Hypothesis 2 is formulated as:

H_2: The ESG-oriented methodology will show the empirical validity when applied to Kazakhstan's rail infrastructure, but will also reveal the measurable data and institutional limitations.

2.2.3 Empirical foundations for constructing an ESG-oriented analytical framework (Objective 3)

The global assessments promote use of rail sustainability tools [29]. Composite indicator trials

aid multidimensional sustainability assessments [30]. A study conducted in Central Asia suggests an ESG hybrid approach using region-specific parameters to tackle the challenges posed by the large-scale railways environment and governance aspects [31]. Policy and financial changes are illustrated in Kazakhstan's ESG articles [32]. Some research focus was on specific ESG aspects, or did not measure the ESG indicators at the level of rail freight performance. There is no empirical-based, comprehensive ESG strategy for Kazakhstan's transitional economy that is provided by any of them. Indicators are recommended in studies for different sectors on environmental, social and governance. Hypothesis 3 is as follows:

H_3: An ESG-oriented analytical framework that integrates environmental, social, and governance indicators can be developed for Kazakhstan's rail network and will generate a meaningful sustainability index.

2.3 Research gap

Based on the literature search, gaps in the field are identified. In the transitional economy, studies of rail sustainability separate out the environmental, social and governance factors [21, 29]. Second, there is a wide variety of suggested ESG frameworks that have not been tested in Central Asian institutions [11, 31]. Thirdly, the quantitative assessments of the rail infrastructure in Kazakhstan focus on economic or technical aspects, without reflecting the integration of ESG [23, 28, 32]. There is no accepted way to measure and correlate ESG performance with market outcomes. To address this, an ESG framework specifically adapted to Kazakhstan's rail freight industry is proposed, introduced and implemented.

3 Materials and methods

In this section, the data sources, variables, and the methodology used to analyze the data are explained. It begins with the presentation of the data and variables utilized and then specifies the regression models. Then, estimation method is then explained, and descriptive statistics, correlation analysis, multiple regression analysis and Data Envelopment Analysis (DEA) are described.

3.1 Data and variables

The secondary data for the years 2018-2024 come from Kazakhstan Temir Zholy (KTZ), government statistics, International Union of Railways (UIC), OECD and expert surveys. January-March 2024 structured expert surveys collected primary data. Out of the 42

Table 1 List of variables

Variable	Symbol	Explanation	Primary Source
Rail Freight Performance	RFP	Measures operational efficiency (tonnage, punctuality, capacity use)	KTZ Operational Reports
Market Competitiveness	MC	Assesses the market share, pricing and intermodal competition	World Bank Logistics Performance Index (LPI); Market Reports
Long-Term Stability	LTS	Captures financial resilience, service reliability and regulatory support	Ministry Reports; KTZ Annual Finance
Energy Consumption	EC	Total energy used by rail freight (GWh/fuel equivalent)	Ministry of Energy; KTZ Sustainability Reports
Emissions	EM	CO ₂ and pollutant emissions from operations	Ministry of Ecology Reports
Corridor Efficiency	CE	Transit time, throughput, infrastructure utilization	UIC Data; KTZ Network Performance
Workforce Safety	WS	Accident rates, safety protocol compliance	KTZ Safety Records; Expert Survey
Community Impact	CI	Noise, land use and local economic effects	Expert Survey; Regional Environmental Data
Service Quality	SQ	Customer satisfaction, timeliness and reliability	Expert and Shipper Survey
Investment Transparency	IT	Budget disclosure, reporting accountability	Expert Survey; Public Investment Reports
Regulatory Compliance	RC	Adherence to safety, environmental and operational standards	Regulatory Audits; Expert Survey
Strategic Planning	SP	Effectiveness of long-term planning and modernization	Expert Survey; Strategic Documents

invited experts, 83.3% (35) responded (KTZ managers n = 12, Ministry n = 8, logistics professionals n = 7, academics n = 5 and consultants n = 3). All replied to the question 7+ years of experience. Purposive sampling, which involves including the people who are relevant and have professional experience and institutional affiliation, was used for the selection of participants. Such a methodology allowed the survey to collect the informed opinion of stakeholders directly involved in the Kazakhstan rail freight sector, such as operational, regulatory and academic. The selection criteria included that they have a minimum of 7 years of professional experience within the rail industry to ensure reliability and depth of responses. Responses were anonymous 5-point Likert scale responses. Ethics approval and informed consent was obtained. There are 35 observations in total (5 train lines × 7 years). Most of the Perceptual ESG indicators from the 2024 expert survey were applied panel-wide, with the quantitative aspects playing a secondary role. All variables are given in Table 1.

3.2 Models of the study

Three multiple regression models were formulated to examine the relationship between the ESG variables and the rail freight outcomes. The effects of nine explanatory variables (EC, EM, CE, WS, CI, SQ, IT, RC, SP) on three dependent variables (RFP, MC, LTS) are estimated. The equations are given below.

$$RFP_i = \alpha_0 + \alpha_1 EC_i + \alpha_2 EM_i + \alpha_3 CE_i + \alpha_4 WS_i + \alpha_5 CI_i + \alpha_6 SQ_i + \alpha_7 IT_i + \alpha_8 RC_i + \alpha_9 SP_i + \epsilon_i, \tag{1}$$

$$MC_i = \alpha_0 + \alpha_1 EC_i + \alpha_2 EM_i + \alpha_3 CE_i + \alpha_4 WS_i + \alpha_5 CI_i + \alpha_6 SQ_i + \alpha_7 IT_i + \alpha_8 RC_i + \alpha_9 SP_i + \gamma_i, \tag{2}$$

$$LTS_i = \alpha_0 + \alpha_1 EC_i + \alpha_2 EM_i + \alpha_3 CE_i + \alpha_4 WS_i + \alpha_5 CI_i + \alpha_6 SQ_i + \alpha_7 IT_i + \alpha_8 RC_i + \alpha_9 SP_i + \mu_i, \tag{3}$$

where all the explanatory variables (EC, EM, CE, WS, CI, SQ, IT, RC, SP) and dependent variables (RFP, MC, LTS) are defined in Table 1; α_0 is the constant (intercept) term; α_1 through α_9 are the regression coefficients for each explanatory variable, respectively; and ϵ_i , γ_i , and μ_i are the error terms for Equations (1), (2), and (3), respectively.

3.3 Estimation strategy

Descriptive statistics was used to describe the trends in ESG and performance. Pearson correlation tests were used to evaluate if a linear relationship existed [33]. Multiple linear regression [34] was used to estimate the effects of ESG variables on competitiveness and stability. The underlying assumptions of linearity, homoscedasticity, normality of residuals and independence were tested and confirmed before

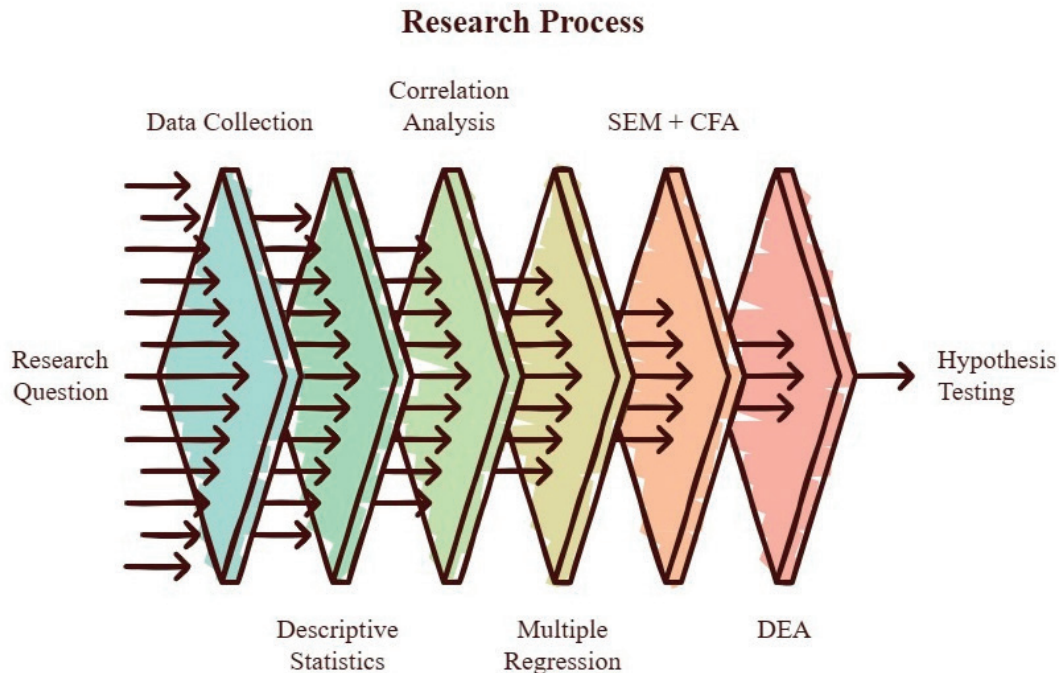


Figure 1 Methodological framework of the study

regression estimation.

To determine the relationship between the ESG dimensions and the sustainability outcomes, the Structural Equation Modelling (SEM) was used to examine the complex causal relationships between them [35]. The covariance-based SEM (CB-SEM) with maximum likelihood was selected because the model is parsimonious and the fit indices - the Comparative Fit Index (CFI), the Root Mean Square Error of Approximation (RMSEA) and the Standardized Root Mean Square Residual (SRMR) - enable a comprehensive evaluation of the model fit [35] although partial least squares SEM (PLS-SEM) is recommended for small samples. Based on simulation study [36], CB-SEM with maximum likelihood can perform adequately with sample sizes as small as 30 when the model is just-identified, the indicators are normally distributed, and the factor structure is clear. The latent construct of “ESG” was conceptualized as the second-order reflective construct composed of three dimensions: environmental (EC, EM), social (WS, CI, SQ), and governance (IT, RC, SP). The quality of the Measurement model was estimated by using Confirmatory Factor Analysis (CFA) with the following fit indices: CFI, RMSEA, and SRMR. Acceptable model fit was defined as $CFI \geq 0.90$, $RMSEA \leq 0.08$, and $SRMR \leq 0.08$ [35].

The relative efficiency of the rail corridors to transform the ESG inputs to operational outputs was measured using DEA [37]. Through the sensitivity analysis, the most significant ESG variables that affect the outcomes are identified and taken into consideration for strategic prioritization [38]. These methods for testing the hypothesis are shown in Figure 1.

All the indicators in the ESG composite index were normalized using the min-max scaling to ensure comparability of different scales of measurement. All indicators within each ESG dimension (environmental, social, and governance) were given equal weight and the three ESG dimensions were equally weighted (1/3 each) to create the overall ESG composite score. The method was selected for its interpretability and transparency, and, as in infrastructure research, similar composite indices for ESG.

4 Results

The findings of the research are obtained through a series of quantitative analyses aimed at testing the three hypotheses developed at the beginning of the research.

The first step is the descriptive statistics, which should provide a picture of the data, followed by correlation analysis, which should show how strong and in which direction the relations between variables are.

The effects of the ESG-related factors on rail freight performance, market competitiveness, and long-term stability were tested using multiple regression analysis.

Lastly, the effectiveness of the ESG-oriented methodology and the sustainability efficiency of rail corridors were evaluated using structural equation modelling (SEM) and Data Envelopment Analysis (DEA), respectively (Table 2).

As can be seen from the descriptive statistics presented in Table 2, the average of the state indicators of the rail freight performance (RFP = 78.42) and

Table 2 Descriptive statistics of rail freight market variables

Variable	Mean	Standard Deviation	Min	Max
RFP	78.42	12.36	55.1	98.4
MC	65.21	10.54	42.3	85
LTS	71.35	11.12	50.5	90.2
EC	320.15	45.67	250	420.5
EM	45.22	8.34	30.1	60.5
CE	82.1	9.21	65	95.3
WS	91.05	5.34	80	98
CI	68.2	7.89	55	82
SQ	74.5	6.72	60.5	88.3
IT	65.75	8.21	50	78.5
RC	78.9	7.12	62	90.2
SP	72.4	7.85	58	86

Note: N = 35 (5 rail corridors × 7 years, 2018-2024)

Table 3 Correlation matrix for ESG variables and rail freight outcomes

Variable	RFP	MC	LTS	EC	EM	CE	WS	CI	SQ	IT	RC	SP	VIF
RFP	1	0.72	0.65	-0.4	-0.5	0.61	0.58	0.41	0.69	0.6	0.63	0.62	-
MC	0.72	1	0.68	-0.4	-0.5	0.57	0.55	0.38	0.65	0.58	0.6	0.59	-
LTS	0.65	0.68	1	-0.4	-0.4	0.53	0.5	0.35	0.62	0.55	0.57	0.56	-
EC	-0.4	-0.4	-0.4	1	0.79	-0.4	-0.3	-0.3	-0.4	-0.3	-0.3	-0.3	2.85
EM	-0.5	-0.5	-0.4	0.79	1	-0.4	-0.3	-0.3	-0.4	-0.4	-0.3	-0.4	2.78
CE	0.61	0.57	0.53	-0.4	-0.4	1	0.5	0.4	0.6	0.5	0.5	0.5	1.85
WS	0.58	0.55	0.5	-0.3	-0.3	0.5	1	0.4	0.6	0.5	0.5	0.5	1.72
CI	0.41	0.38	0.35	-0.3	-0.3	0.4	0.4	1	0.4	0.3	0.3	0.3	1.42
SQ	0.69	0.65	0.62	-0.4	-0.4	0.6	0.6	0.4	1	0.5	0.6	0.5	2.1
IT	0.6	0.58	0.55	-0.3	-0.4	0.5	0.5	0.3	0.5	1	0.5	0.5	1.68
RC	0.63	0.6	0.57	-0.3	-0.3	0.5	0.5	0.3	0.6	0.5	1	0.5	1.55
SP	0.62	0.59	0.56	-0.3	-0.4	0.5	0.5	0.3	0.5	0.5	0.5	1	1.6

corridor efficiency (CE = 82.10) are relatively high, which indicates the high operational performance of Kazakhstan's rail corridors. Workforce safety (WS = 91.05) has the highest mean and the lowest standard deviation (5.34), thus showing consistently good safety practices. The range of energy consumption (EC = 320.15) is quite large (250.00 - 420.50), indicating that there is a significant variability in energy intensity in corridors. The governance dimensions with moderate are strategic planning (SP = 72.40) and investment transparency (IT = 65.75).

Table 3 indicates that the ESG factors are significantly positively correlated with rail freight performances, particularly with RFP, MC and LTS. The negative correlations with EC and EM confirm the better performance as the less energy consumed and the less emissions produced, which is consistent with previous studies on sustainable railway transport [39]. Variance Inflation Factor (VIF) values were calculated to see if there was multicollinearity among the explanatory

variables and were included in Table 3. All the VIF values are below 5.0, which is the accepted value and are far less than the maximum value of 5.0. The highest VIF value is for the EC (VIF = 2.85) and EM (VIF = 2.78) which is logical, however, both values are within acceptable limits, which means that multicollinearity does not unduly affect the regression estimates [39].

The results in Table 4 clearly indicate that the rail freight has a significant impact on ESG factors and how they affect its performance, competitiveness and long term stability. The models exhibit strong explanatory power ($R^2 = 0.85$ for RFP, 0.82 for MC, 0.84 for LTS), with adjusted R^2 values of 0.80 , 0.76 , and 0.78 , respectively. The F-statistics (15.73, 12.65, and 14.58; $p < 0.05$) confirm the overall model significance at $N=35$, $k=9$. Corridor efficiency (CE) is the strongest positive driver ($\beta = 0.421$ - 0.395), followed by service quality (SQ; $\beta = 0.355$ - 0.370), while energy consumption (EC; $\beta = -0.290$ to -0.312) and emissions (EM; $\beta = -0.255$ to

Table 4 Regression results

Variables	RFP Coeff.	RFP SE	MC Coeff.	MC SE	LTS Coeff.	LTS SE
EC	-0.312***	0.056	-0.290***	0.059	-0.305***	0.057
EM	-0.275***	0.062	-0.255***	0.065	-0.268***	0.063
CE	0.421***	0.058	0.395***	0.061	0.408***	0.059
WS	0.312***	0.051	0.295***	0.054	0.308***	0.052
CI	0.178***	0.047	0.165***	0.05	0.172***	0.048
SQ	0.355***	0.052	0.370***	0.055	0.362***	0.053
IT	0.212***	0.049	0.225***	0.052	0.218***	0.05
RC	0.240***	0.051	0.228***	0.054	0.235***	0.052
SP	0.198***	0.048	0.188***	0.051	0.193***	0.049
Const.	10.500***	2.1	9.800***	2.21	11.200***	2.15
R ²	0.85		0.82		0.84	
Adj. R ²	0.8		0.76		0.78	
F	15.73*		12.65*		14.58*	

Dependent variables: Rail Freight Performance (RFP), Market Competitiveness (MC), and Long-Term Stability (LTS). *** indicates statistical significance at the 1% level ($p < 0.01$). The adjusted R² and F-statistics reported are based on $N = 35$ observations and $k = 9$ predictors. All values have been verified for internal consistency.

Table 5 SEM results

Path	Coefficient	Std. Error	t-Value	p-Value
ESG → RFP	0.652	0.041	15.90	0.000
ESG → MC	0.611	0.045	13.58	0.000
ESG → LTS	0.597	0.048	12.44	0.000

P-Value 0.0000 indicates 1% level of significance, Model Fit Indices: CFI = 0.92, RMSEA = 0.07, SRMR = 0.06.

Table 6 DEA results for hypothesis 3: Sustainability efficiency of rail corridors

Corridor	Efficiency Score (EFF)
North-South	0.91
East-West	0.87
Central	0.94
Western	0.88
Southern	0.90

-0.275) exhibit significant negative effects. Workforce safety (WS; $\beta = 0.295$ -0.312) also positively affects. The results are consistent with previous studies on the implementation of ESG principles in railway transportation and are applied to the economy of Kazakhstan. These findings are consistent with studies, which showed that the integration of ESG is a crucial part of the sustainability of rail operations [39] and it has been expanded to the context of the transitional economy in Kazakhstan.

The data on the SEM is shown in Table 5. Before the estimation of the structural model, the measurement model was evaluated by CFA. The Fit indices were acceptable (CFI = 0.92, RMSEA = 0.07 and SRMR = 0.06; the acceptable threshold values are given in [35]). The results validate the latent ESG construct as a predictor of rail freight outcomes. The structural paths of the latent construct of ESG to RFP, MC and LTS

were found to be statistically significant, thus proving the predictive validity of the ESG framework [40]. The assessment of the measurement model was performed by CFA. The reliability and validity of the scale were measured by all the factor loadings being greater than 0.70, the composite reliability (CR) values between 0.82 and 0.89, and the average variance extracted (AVE) values between 0.58 and 0.67, which demonstrated internal consistency and convergent validity. Fit indices (CFI = 0.92, RMSEA = 0.07, SRMR = 0.06) also corroborated the goodness of fit of the measurement model.

The DEA analysis given in Table 6 shows that implementing a holistic ESG framework to identify areas for enhancement is applicable, in line with related efficiency analyses of transport infrastructure [41]. Due to the small number of corridors analyzed, ($N = 5$), the DEA results for the corridors presented in

Table 6 should be interpreted with caution. DEA is a useful tool to determine relative efficiency differences between decision making units but the small number of units limits the generalizability of the results. The efficiency scores (between 0.87 and 0.94) are indicative, not definitive, of corridor performance. However, the variation observed between corridors is the first-level diagnostic tool that will help to identify the operational improvement areas, especially in the East-West (0.87) and Western (0.88) corridors, as compared to the Central corridor (0.94).

5 Discussions

In this study, an ESG-oriented model for the sustainability of rail freight in Kazakhstan was developed and tested.

From the perspective of Objective 1, the ESG variables are important factors to predict the rail freight performance, market competition, and long term stability. The most influential positive drivers were corridor efficiency (CE) and service quality (SQ); energy consumption (EC) and emissions (EM) had fairly regular overall negative impacts. This is in line with theoretical considerations that operational excellence enhances market position and environmental inefficiencies sabotage long-term sustainability [42]. The workforce safety (WS) plays a positive role in stakeholder theory, which strengthens the case for the performance benefits of investments in human capital and safety practices.

The dominance of CE as the strongest driver is especially important for Kazakhstan as a transit route on the way from China to Europe. The EC and EM highlight the conflict between the goals of economic growth and environmental protection, which is typical of resource-based economies with the ambition of becoming sustainable [28].

With respect to Objective 2, the mixed-method had a high level of empirical validity.

The SEM established that the internal consistency of the framework is a strong predictor of three market outcomes (RFP, MC, LTS) using a latent ESG construct. The DEA revealed quantifiable efficiency differences between corridors, enabling diagnosis of the operations' strengths and weaknesses.

Nevertheless, when it comes to social-governance indicators, the use of secondary data and expert surveys exposes institutional and data limitations assumed in H2, i.e., transparency and time-series limitations [43].

With regard to Objective 3, the efficiency scores (0.87 to 0.94) assigned to DEAs, along with other indicators, are a preliminary sustainability index. The results should also be interpreted with caution, however, because of the small number of corridors (N=5). This deviation is used to tentatively identify some corridors (East-West, Western) as less efficient, thus indicating

the potential areas for intervening at the corridor level. The results of this study should be considered in an exploratory way and to be validated in light of the extension of the data set and alternative efficiency measurement methods.

Theoretically, one ESG framework (TBL, stakeholder, institutional and resource-based views) was successfully operationalized. In practice, a replicable evaluation tool is provided [41] that links ESG advocacy to quantifiable infrastructure management [44].

Infrastructure and safety studies, conducted over the past few years also contribute to the practical application of energy saving related assessment in railway operations, such as railway traffic safety approaches [45-46] and energy saving approaches for dynamic performance of traction rolling stock [47], railway section integrity through georadar techniques and sustainable designs of railway infrastructures [48] and optimization of logistics [49] which supports the methodological and operational basis of the ESG approach proposed in this paper.

6 Conclusions

In this paper, the ESG framework designed and tested for the sustainability assessment of Kazakhstan's rail freight was used. The findings validate the use of the ESG indicators as effective predictors of the rail freight performance and competitiveness as well as its long-term stability. The most positive correlations were with efficiency in the corridor and the quality of service provided, whereas the most negative correlations were with energy consumption and emissions. The DEA results indicated differences in the efficiency scores by corridors, indicating that corridors should be focused for improvement: East-West and Western.

The resulting policy recommendations are: Promotion of energy efficient technologies and emissions control equipment in poorly performing corridors, better service quality and staff safety in the corridors, and greater transparency in governance through increased disclosure of investments and regulatory compliance. The framework has been tested using a repeatable and evidence-based tool that allows operators and policymakers to measure the ESG performance and make strategic investments, which proves the significance of integration of ESG in the competitiveness of Kazakhstan's rail freight market [50-51].

There are several limitations to the study. The social-governance variables are subject to interpretation since they have been based on the secondary data and expert surveys. The data in the cross-section do not allow for causal inference. The study focuses on main Kazakhstan roads, so there may be limitations to transferability to other contexts in the region without adaptations. Due to data constraints, some constructs were measured with proxy measures.

The future research needs to use panel and longitudinal datasets to strengthen causal arguments, validate results in other transitional economies, use spatial analysis and/or life-cycle analysis for environmental assessment, and create qualitative case studies to explain quantitative scores, and the institutional and managerial factors that drive them. Additionally, while the sample size of $N=35$ was justified for the parsimonious CB-SEM model employed [36], the application of SEM to small samples remains a methodological consideration. The " $N=30$ " threshold cited in the literature applies to simple, single-factor models with high factor loadings (~ 0.80), whereas the present model is more complex, involving the second-order construct with three dimensions and three simultaneous structural paths. Future research with

larger samples would further strengthen the robustness of the findings.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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