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Digital Empowerment, Geopolitical Adaptation and Green Transition: The New Path of High-Quality Development of China-Europe Railway Express under the Global Supply Chain Resilience Framework

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Abstract

Against the backdrop of frequent global supply chain disruptions, intensifying geopolitical games, and the global call for carbon neutrality, the China-Europe Railway Express (CER Express) has evolved from a "channel construction" stage to a critical period of quality improvement and efficiency optimization. As the core logistics carrier of the Belt and Road Initiative (BRI), it has become a key link in stabilizing Eurasian trade and enhancing supply chain resilience. Based on the analysis framework of "digital empowerment-geopolitical adaptation-green transition", this paper systematically explores the operation status, multi-dimensional challenges and development path of CER Express by integrating the latest industry data, typical cases and empirical analysis. The research shows that: by the end of 2024, the cumulative number of CER Express trains has exceeded 110,000, with a total cargo value of over 450 billion US dollars, covering more than 300 cities in 40+ countries; digital technology has improved the operation efficiency of CER Express by more than 30%, while certain geopolitical factors have increased the transportation cost by 15% - 25%; the green transformation represented by zero-carbon trains has become a new growth point, but it is constrained by inconsistent carbon accounting standards and high transformation costs. This paper proposes a high-quality development system of "digital drive + geopolitical coordination + green synergy", which provides theoretical support and practical reference for the sustainable operation of CER Express, the interconnection of Eurasian trade, and the construction of a low-carbon and resilient global supply chain.

Subject Areas

Transportation Engineering

Keywords

China-Europe Railway Express, Digital Empowerment, External Factor, Green Transition, Supply Chain Resilience, Belt and Road Initiative

1. Introduction

1.1. Research Background

Since the first CER Express train departed from Xi'an International Port Station in 2013, this land logistics corridor connecting Asia and Europe has achieved leap-frog development after more than a decade of construction. Unlike traditional maritime and air transportation, CER Express has the unique advantages of stability, efficiency, and low carbon emissions, which has become an important pillar for stabilizing the global supply chain under the impact of the COVID-19 pandemic, regional conflicts, and extreme weather. Based on the official statistical baseline of China State Railway Group Co., Ltd. (2024), by the end of 2024, the cumulative number of CER Express trains has exceeded 110,000, carrying more than 20 million TEUs of goods, with a total cargo value of over 450 billion US dollars, covering 128 cities in China and 229 cities in 26 European countries, forming a three-inland-channel (west, central, east) and three-overseas-line (north, central, south) network pattern [1]. By June 2025, the network coverage remains consistent with the end-2024 baseline, with operational adjustments only in train volume and route allocation due to geopolitical events.

However, CER Express faces unprecedented challenges in its high-quality development. Geopolitical games bring great uncertainties: in July 2025, Poland unilaterally suspended the railway freight passage of the key border port with Belarus (a key node of the northern line undertaking 35% of the transit volume), forcing CER Express to detour, extending one-way transportation time from 12 days to 18 - 22 days and increasing container detour cost by about 12,000 US dollars, leading to a 19% year-on-year decline in train volume from July to September 2025. After resumption, Poland added unreasonable requirements such as mandatory cabin space allocation and additional safety inspection fees, increasing operational risks and costs [2].

Meanwhile, the global demand for carbon neutrality and digital transformation put forward new requirements. Railway transportation itself has significant carbon advantages: a CER Express train carrying 55 40-foot containers emits far less carbon than trucks with the same volume. In 2024, the national railway electrification rate reached 75.8%, and green power application and carbon offset measures further enhanced its green attributes. Digital technologies such as big data and blockchain have been gradually applied, promoting logistics services

from "traditional transportation" to "intelligent integration"—for example, Chongqing's "channel brain" has collected over 340 million customs clearance and logistics data, shortening information inquiry time from half a day to a few seconds [3].

The 2024 "Action Plan for Effectively Reducing the National Logistics Costs" clearly proposed optimizing CER Express operation and capacity allocation, providing policy guarantee. Under this background, exploring CER Express's high-quality development path from digital empowerment, geopolitical adaptation and green transition is of great academic and practical significance [4].

Core Concept Definition and Measurable Indicators:

High-quality development: The sustainable development of CER Express in scale expansion, structure optimization and efficiency improvement, measured by cumulative train volume growth rate, high-value-added cargo proportion and inbound-outbound train balance ratio.

Digital empowerment: The improvement of CER Express operational efficiency and service level through digital technology application, measured by customs clearance time reduction rate and digital transformation rate of operation enterprises.

Geopolitical adaptation: The ability of CER Express to respond to and mitigate external factors, measured by transportation cost change rate caused by certain geopolitical factors and train volume recovery rate after risk occurrence.

Green transition: The low-carbon transformation of CER Express's transportation links and operation mode, measured by green power application proportion and carbon emission reduction rate per TEU of goods.

1.2. Literature Review

Foreign research on CER Express focuses on three aspects: trade impact, operational efficiency optimization, and geopolitical influence. Li *et al.* (2019) evaluated CER Express's sustainable transportation competitiveness under the BRI, finding it significantly promoted China-Europe trade in mechanical equipment and electronic products. Foreign scholars also pointed out that border clearance coordination and loading rate optimization are key to improving efficiency, and geopolitical conflicts and institutional differences are major obstacles [5].

Domestic research shows a steady upward trend. CiteSpace analysis shows hotspots include BRI, railway transportation, international trade, development strategies, government subsidies, and optimization methods. Choi (2021) used a quasi-natural experiment to find CER Express significantly promoted agricultural product exports [6]. Xia *et al.* (2024) studied its role in leading Inner Mongolia's opening-up. With digitalization and green development, scholars began focusing on blockchain application in customs clearance and carbon emission reduction effects [7].

Existing research has deficiencies: most focus on a single dimension, lack sys-

tematic integration of digitalization, geopolitics and environment; geopolitical research is mostly qualitative, lacking quantitative analysis on cost and efficiency impact; green transition research is insufficient, especially on carbon accounting coordination and zero-carbon transformation feasibility; most use data before 2023, lacking analysis of 2024-2025 latest status (e.g., Poland border incident, zero-carbon trains). This paper fills these gaps with a multi-dimensional framework and latest data [8]-[10].

1.3. Research Methods and Technical Route

This paper adopts multiple methods to ensure scientificity, with clear differentiation between 2018-2024 dataset findings and 2025 case evidence in the research process:

Literature Research: Sort out relevant literature on CER Express, digital empowerment, external factor and green transition to clarify research status and lay a theoretical foundation.

Data Analysis: Collect 2018-2024 CER Express operational data from authoritative sources including China State Railway Group Co., Ltd., China Federation of Logistics and Purchasing, European Railway Agency and China Container Industry Association. The core variables include train volume, cargo volume, cargo value, loading rate, port operation data and digital transformation rate; the calculation rules for efficiency and cost are: operational efficiency = (cargo volume/train volume)/transportation time, transportation cost = container detour cost + additional inspection fees + infrastructure use fees. This part focuses on quantitative analysis of the long-term operational status and development trend of CER Express.

Case Study: Analyze 2025 typical cases including Wuhan zero-carbon train, Chengdu-Chongqing digital transformation and Poland border incident response. This part focuses on qualitative and supplementary quantitative analysis of the latest challenges and practical responses of CER Express.

Comparative Analysis: Compare CER Express's operational data in different regions/routes (east/central/west China, north/central/south overseas lines) and with other logistics modes (maritime, air transportation) to clarify its competitive advantages and disadvantages in efficiency, cost and carbon emissions.

The technical route is: clarify research background and core concept definition → put forward research questions based on literature review → analyze operational status (scale, route, cargo, industrial chain) with 2018-2024 quantitative data → explore multi-dimensional challenges combined with 2018-2024 data and 2025 case evidence → propose development paths and verify with typical cases → summarize conclusions and put forward policy suggestions.

1.4. Research Innovation and Significance

Research Innovation: Construct a "digital empowerment-geopolitical adaptation-green transition" framework with measurable indicators, breaking single-di-

mensional limitations; focus on 2024-2025 latest challenges (Poland border incident, zero-carbon trains) and distinguish between long-term dataset and latest case evidence; combine quantitative and qualitative analysis with the latest industry data and typical practical cases.

Research Significance: Theoretically, enrich Eurasian logistics corridor research and provide a new analytical framework with measurable indicators for CER Express research. Practically, put forward targeted suggestions to help all parties respond to external factors, promote digital and green transformation, and enhance supply chain resilience.

2. Operational Status of China-Europe Railway Express: Scale, Structure and Characteristics

2.1. Operational Scale: Steady Growth and Continuous Expansion

In recent years, CER Express operational scale has maintained steady growth. Based on 2018-2024 data from China State Railway Group and China Container Industry Association, the number of trains increased from 6,363 to 19,300 (CAGR 25.3%); cargo volume from 604,000 TEUs to 2,077,000 TEUs (CAGR 22.8%); total cargo value from 17.9 billion US dollars to 98.8 billion US dollars (CAGR 33.5%) (see Table 1). The time to operate 10,000 trains shortened from 90 months to 6 months, reflecting improved efficiency [11] [12].

Table 1. Operational scale indicators of China-Europe railway express (2018-2024).

Year	Number of Trains (Units)	Cargo Volume (10,000 TEUs)	Total Cargo Value (100 Million US Dollars)	Loading Rate (%)	Year-on-Year Growth Rate of Trains (%)
2018	636.3	60.4	179	90.1	24.5
2019	822.5	72.5	243	92.4	29.3
2020	1018.0	97.6	340	94.8	23.8
2021	1518.3	146.8	592	97.5	49.2
2022	1600.5	160.4	749	98.2	5.4
2023	1749.0	189.8	864	98.5	9.3
2024	1930.0	207.7	988	99.1	10.7

Note: Data sources include China State Railway Group Co., Ltd., China Federation of Logistics and Purchasing, and China Container Industry Association. The data for 2024 is the final statistical data; the loading rate refers to the comprehensive loading rate of inbound and outbound trains.

By the end of 2024, CER Express covers 128 Chinese cities (31 provinces) with Xi'an (over 20,000 cumulative trains), Chongqing (over 18,000, focusing on electronic products and auto parts), Zhengzhou as core hubs. Overseas, it covers over 300 cities in 40+ countries, forming a global network. In 2024, inbound-outbound train ratio was 0.84:1, cargo volume ratio 0.82:1, significantly improved from 2018

(0.52:1 and 0.48:1), transforming from "one-way transportation" to "two-way interactive".

2.2. Route Network: Diversified Layout and Continuous Improvement

CER Express has formed a network with three domestic channels and three overseas lines based on the end-2024 official baseline of China State Railway Group. Domestic channels: western (Xi'an, Chongqing → Alashankou, Horgos → Central Asia, Europe), central (Zhengzhou → Erenhot → Mongolia, Russia), eastern (Suzhou, Harbin → Manzhouli, Suifenhe → Russia, Europe). Overseas lines: northern (China-Kazakhstan-Russia-Belarus-Poland-Germany, undertaking 60% of transportation volume), central (China-Kazakhstan-Uzbekistan-Türkiye-Europe), southern (China-Vietnam-Laos-Thailand-Europe).

Certain geopolitical factors affected the northern line: the 2025 Poland-Belarus border closure caused a 42% drop in northern line trains. China accelerated southern and central line construction: 2024 southern line trains increased by 20% year-on-year, central line by 15%. China has upgraded five major ports (Alashankou, Horgos, Erenhot, Manzhouli, Suifenhe) and put Tongjiang North Port into use, with daily handover capacity of 184 trains. Alashankou handled 6797 trains in 2024 (35% of total, +34.9% year-on-year) (see Table 2).

Table 2. Operation data of key border ports of China-Europe railway express in 2024.

Port Name	Number of Trains Passed in 2024 (Units)	Year-on-Year Growth Rate (%)	Proportion of Total Traffic Volume (%)	Main Corresponding Routes
Alashankou	6797	34.9	35.0	Western channel, northern line, central line
Manzhouli	4387	−12.6	22.7	Eastern channel, northern line
Erenhot	3800	14.6	19.7	Central channel, northern line
Horgos	3370	4.1	17.5	Western channel, central line
Suifenhe	888	0.2	4.6	Eastern channel, northern line
Tongjiang North	858	56.3	4.5	Eastern channel, northern line

Note: Data source: China Container Industry Association, "2024 China Container Multimodal Transport Development Report".

2.3. Cargo Structure: Continuous Optimization and Upgrading of High-Value-Added Goods

CER Express transports 53 categories and over 50,000 commodities, covering electronic products, auto parts, machinery, light industry, agriculture, and medical supplies. In 2024, high-value-added goods (auto parts, machinery) accounted for over 60% (+25 percentage points from 2018): electronic products 28% (mobile phones, notebooks, lithium batteries), auto parts 22% (exported to Germany, Poland), machinery 12% (engineering machinery, precision instruments) (see Figure 1). Inbound goods are mainly European characteristic products (food, wine, cosmetics), accounting for 45% of inbound volume.

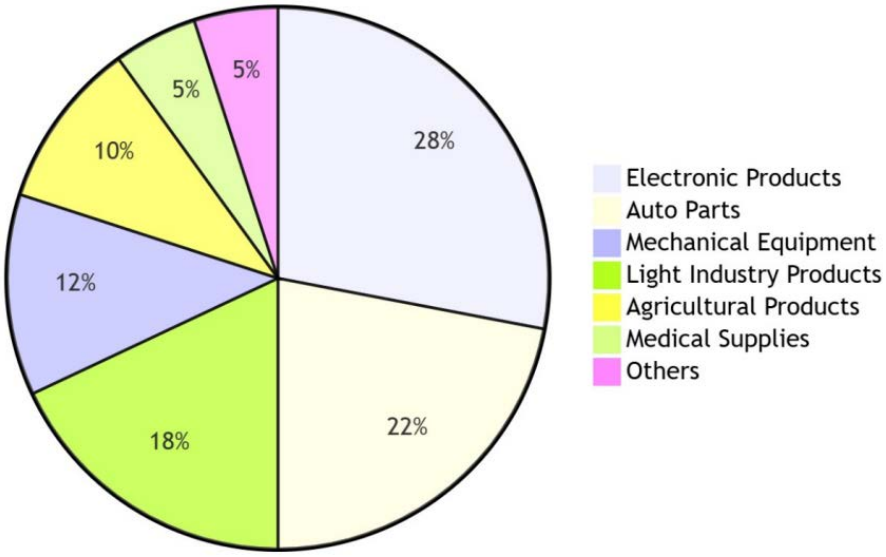

Figure 1. Cargo structure of China-Europe railway express in 2024.

Green product transportation grew rapidly: 2024 green product (electric vehicles, lithium batteries, photovoltaic modules) volume increased by 45% year-on-year, accounting for 15% of total. For example, a 2023 Xi'an-Tashkent train carried 20MW photovoltaic modules for a 1GW Uzbekistan project, reducing annual natural gas consumption by 588 million cubic meters.

2.4. Industrial Chain: Continuous Improvement and Increasing Synergy

CER Express has formed a complete industrial chain: upstream (railway infrastructure, locomotive/container manufacturing, logistics equipment), midstream (train operation, transportation, customs clearance), downstream (cargo distribution, warehousing, logistics finance). CRRC achieves over 95% localization of CER Express locomotives and containers. Key operation enterprises include China Railway Container Transport, Han'ou International Logistics. CER Express integrates deeply with cross-border e-commerce and industrial parks: Qingdao SCO Demonstration Zone realizes seamless connection between CER Express and e-commerce, shortening logistics cycle by 30%.

Policy support is improving: the "Action Plan for Effectively Reducing the National Logistics Costs" supports inland port construction; Shaanxi, Chongqing, Henan provide subsidies to encourage enterprises to use CER Express.

3. Multi-Dimensional Challenges Faced by the High-Quality Development of China-Europe Railway Express

3.1. Digital Empowerment: Insufficient Depth and Unbalanced Development

Digital application is superficial: mainly concentrated in information inquiry, online customs clearance, and route scheduling, lacking in-depth application of

AI, big data, and blockchain. Most enterprises rely on manual experience for capacity allocation and loading, and blockchain is only used for cargo information verification. Regional digital development is unbalanced: 2024 digital transformation rate of eastern China operation enterprises is 75%, central 45%, western 38%. Data disconnection exists between China and European countries, and between enterprises and government departments, leading to repeated declarations and inefficient monitoring.

3.2. Geopolitical Adaptation: Frequent Frictions and Unclear Rules

Border closures and restrictions are frequent: the 2025 Poland-Belarus border closure caused a 19% year-on-year decline in CER Express trains (July-September) and 25% higher transportation costs; border clearance time extended from 24 hours to 48 - 72 hours. Some countries add transit requirements: Poland requires 25% cargo space for local enterprises, 200 euros/container safety inspection fee, and detailed goods lists, adding 37.4 million euros annual cost. Institutional rule differences (customs clearance, technical standards, tax policies) cause obstacles, such as equipment modification needs and inconsistent tax policies.

3.3. Green Transition: High Transformation Costs and Inconsistent Standards

Carbon-Accounting Boundary Clarification: This paper defines the carbon accounting boundary of CER Express's green transition as the entire transportation link of the train, including traction power consumption, container transportation and train operation; "zero-carbon" refers to net-zero carbon emissions after carbon offset, that is, the remaining carbon emissions after reducing operational emissions through green power application and energy-saving technology are offset by carbon sink projects; the carbon emission comparison covers the whole logistics chain of CER Express (from departure port to destination port) compared with traditional railway transportation.

Green transformation costs are high: single locomotive electrification costs 5 million US dollars, green power charging station 2 million US dollars [CRRC, 2024]; Wuhan 2025 zero-carbon train increases transportation cost by 10% per container via carbon offset [Wuhan International Port Group, 2025]. Carbon accounting standards are inconsistent: China's emission factor is 0.085 $kgCO_2/kWh$ [China National Greenhouse Gas Inventory Guide], EU's 0.055 $kgCO_2/kWh$ [EU Emissions Trading System (ETS) Guidelines], making emission reduction verification difficult; CER Express emission reduction is not connected to global carbon trading market. Green power supply is insufficient: 2024 green power accounts for only 38% of CER Express power [China State Railway Group, 2024], with backward green power facilities along the route. The green power application proportion is calculated by the ratio of green power consumption to total power consumption of CER Express in 2024.

3.4. Other Challenges: Unbalanced Regional Development and Insufficient Marketization

Regional development is unbalanced: 2024 eastern China trains account for 45%, central 35%, western 20%, due to differences in economic level, industrial foundation, and infrastructure. Marketization is insufficient: 2024 government subsidies account for 30% of operation costs; insufficient competition and homogeneous competition exist. Zhang Jingrong, Ma Fangyuan, and Zhou Yanjie (2024) found that enterprise cooperation can improve freight rate balance and market share.

4. The New Path of High-Quality Development of China-Europe Railway Express: Digital Empowerment, Geopolitical Coordination and Green Synergy

4.1. Accelerate Digital Transformation and Improve Operational Efficiency

Deepen emerging digital technology application: promote AI, big data, blockchain, and IoT, build intelligent systems for scheduling, loading, and customs clearance. Big data optimizes capacity allocation, blockchain realizes full-chain traceability, AI achieves automatic scheduling, which can improve efficiency by over 30%. Promote data standard unification and information interconnection: strengthen China-Europe cooperation to formulate unified cross-border railway data standards, build a global CER Express digital platform, and promote public data sharing. Promote balanced regional digitalization: increase central and western policy support and investment, carry out digital training, and narrow the digital gap.

4.2. Strengthen Geopolitical Coordination and Reduce Operational Risks

Strengthen multilateral negotiations: communicate with Poland, Belarus and other countries, establish a "CER Express Transit Coordination Mechanism" to resolve disputes through consultation. Promote unified transit rules: participate in international cross-border railway rule formulation, promote China-Europe rule convergence, and realize customs clearance document mutual recognition. Optimize route network: accelerate southern and central line construction, upgrade Almaty-Istanbul trunk line, open "China-St. Petersburg-Helsinki" cold chain train, and reduce single route dependence.

4.3. Promote Green Transition and Build a Low-Carbon Logistics Corridor

Reduce green transformation costs: government provides subsidies and tax incentives for locomotive electrification and green power facilities; enterprises strengthen technological innovation to reduce costs. Unify carbon accounting standards: cooperate with EU and route countries to formulate unified standards,

connect CER Express emission reduction to global carbon trading market (EU ETS, China National Carbon Market). Increase green power supply: build "photovoltaic + charging" stations, increase green power proportion to over 70% by 2030, promote new energy vehicles in collection and distribution links.

4.4. Promote Balanced Regional Development and Improve Marketization Level

Strengthen western region support: increase infrastructure investment, build operation hubs, support characteristic industries, and promote inbound-outbound balance. Improve market-oriented mechanism: gradually reduce government subsidies, encourage enterprise competition and integration, cultivate large professional operation enterprises, and establish market-oriented pricing standards based on supply and demand and costs.

5. Case Analysis: Typical Practices of CER Express in Digital Empowerment, Geopolitical Adaptation and Green Transition

Case Selection Basis: The three cases of Chengdu-Chongqing digital transformation, Poland external factor response and Wuhan zero-carbon train are selected because they are typical representative practices of CER Express in the three core dimensions of the research framework (digital empowerment, geopolitical adaptation, green transition) in 2024-2025, covering the key hub regions (Chengdu-Chongqing, Wuhan) and the major external factor events of CER Express, and the case data is complete and available from official sources (local port groups, China State Railway Group).

Case Limitation: The three cases are single-region or single-event practices, and the conclusions drawn from them cannot be fully generalized to the entire CER Express system; the effect of the practices is affected by regional economic foundation, policy support and other factors, and there may be differences in the promotion effect in other regions/routes.

5.1. Case 1: Digital Transformation of CER Express (Chengdu-Chongqing)—"Channel Brain" Empowers Intelligent Operation

By 2024, Chengdu-Chongqing CER Express has operated over 30,000 cumulative trains. Chongqing built a "1 + 4 + N" digital channel system: "1" is the "channel brain" integrating port logistics data and algorithms; "4" focuses on channel expansion, logistics organization, port services, and industrial development; "N" covers intelligent rail-sea intermodal and other scenarios. The system collected over 340 million data pieces, shared 77 million times, integrating national, cross-international, cross-provincial, and local data.

Results: logistics information inquiry time shortened from half a day to a few seconds; "intelligent rail-sea intermodal" opened 26 data blockages, realizing "one-code connection" and full-chain traceability. 2024 operational efficiency in-

creased by 45% compared with 2020, customs clearance time shortened by 60%.

5.2. Case 2: Response to External Factors—China's "Dialogue Consultation + Channel Backup" Strategy

In response to the 2025 Poland-Belarus border closure, China adopted a dual strategy. On one hand, China State Railway Group held a video meeting with Polish Ministry of Infrastructure on September 28, 2025, advocating equal negotiation and opposing unreasonable conditions, proposing a "China-Poland CER Express Cooperation Mechanism" to coordinate cabin space and fees. On the other hand, China accelerated southern line construction: increased China-Kazakhstan-Türkiye line capacity, opened 12 new trains monthly, offsetting northern line losses. By November 2025, CER Express train volume recovered to pre-closure level, with detour costs reduced by 30% through route optimization.

5.3. Case 3: Green Transition Practice—Wuhan Zero-Carbon CER Express Train

In August 2025, Wuhan opened the first zero-carbon CER Express train to Hamburg, Germany [Wuhan International Port Group, 2025]. Based on the carbon accounting boundary defined in this paper, the train uses electric locomotives, 100% green power (wind and solar), and adopts lightweight containers and energy-saving braking to reduce operational emissions; the remaining emissions are offset through Hubei forest carbon sink projects (Hubei Provincial Forestry Bureau, 2025). The train reduces carbon emissions by 80% compared with traditional trains [Wuhan International Port Group, 2025], measured by the carbon emission per TEU of goods of the zero-carbon train and the average carbon emission of traditional CER Express trains in 2024; and transportation cost increased by only 8% (lower than the 10% average) through government subsidies and technological optimization [Wuhan International Port Group, 2025]. It has operated 45 trains by December 2025, transporting 2475 TEUs of goods, gaining recognition from European enterprises.

6. Conclusions and Policy Suggestions

6.1. Research Conclusion

CER Express has achieved steady development, forming a large-scale, diversified network with optimized cargo structure and improved industrial chain. However, it faces digital empowerment insufficiency, certain geopolitical factors, high green transformation costs, unbalanced regional development, and insufficient marketization. The "digital drive + geopolitical coordination + green synergy" system can effectively promote its high-quality development, which is verified by typical cases.

6.2. Policy Suggestions

(1) Strengthen digital infrastructure construction: increase investment in digital

platforms and emerging technologies, formulate unified data standards, and promote regional digital balance by increasing central and western training and investment.

(2) Improve geopolitical coordination mechanism: strengthen multilateral cooperation with route countries, participate in international cross-border railway rule formulation, and optimize route network resilience by accelerating the construction of southern and central lines.

(3) Increase green transition support: provide subsidies and tax incentives for locomotive electrification and green power facilities, cooperate with EU to unify carbon accounting standards, and expand green power supply by building "photovoltaic + charging" stations.

(4) Promote regional coordinated development: strengthen western infrastructure and industrial support, build regional operation hubs, and narrow regional gaps by supporting characteristic industry transportation.

(5) Deepen market-oriented reform: gradually reduce government subsidies, encourage enterprise competition and innovation, and improve market operation efficiency by establishing market-oriented pricing standards.

6.3. Research Prospects

Future research can focus on three aspects: 1. Quantitative analysis of the economic and environmental effects of digital and green transformation of CER Express with panel data of multiple years and multiple routes. 2. In-depth research on the external factor early warning and response mechanism of CER Express, and construct a quantitative risk assessment model. 3. Research on CER Express's role in global supply chain restructuring under the BRI 2.0 framework, and explore its cooperation mode with other international logistics corridors.

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Conflicts of Interest

The authors declare no conflicts of interest.

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