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Research on green logistics transformation and carbon emission reduction paths of Sino-Russian cross-border e-commerce under the background of digital economy

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Abstract. The growth of Sino-Russian cross-border e-commerce increases the demand for long-distance logistics services and strengthens the environmental pressure associated with transport, warehousing, packaging and customs procedures. This article examines the main sources of carbon emissions in Sino-Russian cross-border e-commerce logistics and assesses how digital technologies can support the transition to greener logistics models. The study focuses on four problem areas: inefficient transport routing, empty return trips, excessive packaging waste and the absence of unified carbon accounting mechanisms. The analysis shows that big data-based route planning, intelligent capacity allocation, paperless customs clearance, smart warehouse management and digital carbon accounting can reduce unnecessary transport operations and improve energy efficiency across the logistics chain. At the same time, the transition is constrained by differences in Chinese and Russian environmental standards, uneven digital infrastructure at border points, limited recycling systems and insufficient coordination between logistics companies and public authorities. The paper proposes a set of carbon reduction measures, including a joint digital logistics platform, cross-border packaging recycling, energy-efficient warehouse modernization and harmonization of green logistics standards. The findings provide a structured framework for reducing the carbon intensity of Sino-Russian cross-border e-commerce logistics under the conditions of digital economic transformation.

1. Introduction

As global climate governance deepens, energy conservation, emission reduction and green infrastructure construction have become mainstream norms in international trade. Driven by increasingly close Sino-Russian strategic cooperation, cross-border e-commerce has gained rapid development thanks to its flexible trading modes. Meanwhile, border logistics, China-Europe freight trains and sea-land combined transportation have laid solid foundation for cross-border commodity circulation [1-3].

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However, the logistics model used in Sino-Russian cross-border e-commerce remains relatively carbon-intensive. Long-distance transport increases fuel consumption, while insufficient coordination between orders, vehicles and routes contributes to empty mileage and low loading efficiency. The widespread use of disposable packaging further increases the environmental footprint of parcel delivery. In addition, differences between Chinese and Russian approaches to green logistics regulation, carbon accounting and environmental certification complicate the implementation of common low-carbon standards [4]. These factors limit the ability of logistics operators to reduce emissions throughout the cross-border supply chain.

Digital technologies can help address these limitations by improving the transparency, coordination and controllability of cross-border logistics operations. Intelligent scheduling can reduce empty mileage and improve vehicle loading, digital supply-chain management can shorten storage and delivery cycles, and paperless customs procedures can reduce administrative delays and resource consumption. On this basis, the article examines the mechanisms through which the digital economy supports energy saving and emission reduction in Sino-Russian cross-border logistics. The purpose of the study is to identify practical carbon reduction paths that combine economic efficiency with environmental performance in bilateral e-commerce trade [5–7].

2 Current situation and ecological deficiencies of Sino-Russian cross-border e-commerce logistics

2.1 Development status

The trade volume of Sino-Russian cross-border e-commerce keeps rising, forming a comprehensive transportation network composed of railway, sea and highway transport. Different from traditional foreign trade logistics, it features scattered orders, frequent delivery and numerous small parcels, which set higher requirements for warehousing, customs clearance and terminal distribution. At present, digital order management, online settlement and automatic sorting have been gradually applied, laying a foundation for logistics digitalization [8].

Nevertheless, Sino-Russian cross-border logistics involves multiple links such as port inspection, cargo transshipment and multimodal transport. Its long industrial chain and wide coverage make energy consumption control and low-carbon management much more difficult than domestic logistics [9-10].

2.2 Main existing problems

First, transportation energy utilization is low with excessive carbon emissions. Most logistics enterprises follow fixed delivery routes without dynamic capacity allocation, resulting in serious empty return trips. Road transportation consumes large amounts of fuel, and outdated transport equipment further raises energy cost and pollutant emission.

Second, packaging waste is serious without complete recycling mechanisms. Multi-layer and plastic packaging are commonly used for cross-border parcels. Package damage during transit and lack of unified cross-border recycling standards make resource reuse difficult, which is inconsistent with sustainable development concepts.

Third, smart logistics construction lags behind with backward energy consumption control. Many border warehouses lack energy-saving facilities such as intelligent temperature control and photovoltaic power supply, resulting in unnecessary energy waste. Besides, there is no unified digital carbon footprint statistics platform, making it impossible to achieve precise low-carbon management.

Fourth, bilateral policy differences hinder green logistics cooperation. The two countries hold different standards in carbon emission assessment, environmental inspection and low-carbon incentive policies. Inconsistent certification and customs procedures greatly increase the institutional cost of green logistics transformation.

3 Core mechanism of digital economy empowering logistics carbon reduction

Digital technologies influence the carbon intensity of cross-border logistics through several mechanisms: optimization of transport capacity, reduction of warehouse energy consumption, dematerialization of customs procedures, and improvement of carbon accounting. These mechanisms are especially important for Sino-Russian e-commerce logistics, where long transport distances and fragmented parcel flows increase the need for coordinated management.

3.1 Optimize transportation efficiency via big data intelligent scheduling

Big data-based scheduling can generate more efficient delivery routes by combining information on real-time orders, road conditions, vehicle availability, border-crossing capacity and port congestion. Intelligent capacity matching makes it possible to consolidate fragmented parcel flows and increase vehicle loading rates. As a result, logistics operators can reduce empty return trips, lower fuel consumption and decrease transport-related carbon emissions.

3.2 Reduce fixed energy consumption through smart warehouse digital management

The Internet of Things and sensing devices realize automatic regulation of warehouse environment and operating equipment, replacing inefficient manual management modes. Digital inventory management shortens goods storage cycle, reduces cargo loss and realizes energy-saving operation of logistics infrastructure.

3.3 Realize green and low-carbon customs clearance in paperless form

Traditional customs clearance relies on paper documents and repeated manual verification, which increases administrative costs and slows down cross-border delivery. Digital single-window systems and electronic declarations can reduce paper consumption, accelerate information exchange between customs authorities and logistics operators, and improve the predictability of border procedures. In environmental terms, faster and more transparent clearance also helps reduce vehicle waiting time at border checkpoints and the associated fuel consumption.

3.4 Implement refined low-carbon governance by digital carbon accounting system

Th A digital carbon accounting platform can record emissions generated at the main stages of cross-border logistics, including transportation, warehousing, packaging and last-mile distribution. Such a system can combine data on transport distance, vehicle type, fuel consumption, electricity use and packaging materials. More accurate carbon data would provide a basis for harmonizing low-carbon standards and coordinating emission reduction measures between China and Russia.

4 Green logistics transformation and carbon emission reduction paths

4.1 Build integrated intelligent logistics scheduling platform

A unified Sino-Russian digital logistics platform should be developed to integrate information on orders, vehicles, warehouses, border checkpoints and transport routes. Such a platform would support intelligent matching between parcel flows and available transport capacity. Priority should be given to lower-carbon transport modes, especially railway services and multimodal schemes combining rail, sea and road transport. This would reduce dependence on long-distance road delivery and lower the overall carbon intensity of cross-border logistics.

4.2 Establish cross-border green packaging recycling system

China and Russia should develop compatible green packaging requirements for cross-border e-commerce parcels. These requirements may include limits on excessive packaging, wider use of recyclable and biodegradable materials, and standardized labelling for packaging recovery. Digital traceability tools can be used to monitor packaging flows and support the creation of recycling points at warehouses, border logistics hubs and return-processing centres. This would reduce the volume of disposable packaging waste and improve material reuse in cross-border trade.

4.3 Accelerate the upgrading of green and intelligent logistics infrastructure

Promote energy-saving renovation of border ports and cross-border warehouses, popularize new energy power supply and intelligent energy-saving equipment. Establish a real-time carbon data monitoring system to realize dynamic supervision of logistics energy consumption and promote standardized low-carbon operation of logistics enterprises.

4.4 Eliminate institutional barriers and deepen bilateral policy coordination

Promote docking and unification of carbon accounting standards, green logistics certification and environmental supervision policies between the two countries. Establish long-term bilateral green logistics cooperation mechanisms, encourage low-carbon technology exchanges and capacity sharing, reduce policy barriers, and build a complete sustainable cross-border trade ecological system.

5 Conclusion

The transition to low-carbon development requires a revision of the traditional logistics model used in Sino-Russian cross-border e-commerce. The main environmental problems of this model are associated with long-distance transport, empty mileage, excessive packaging, insufficient warehouse energy management and the absence of unified carbon accounting. Digital technologies can reduce these problems by improving route planning, vehicle loading, customs clearance, warehouse control and emission monitoring. The proposed carbon reduction paths include the creation of a joint digital logistics platform, development of cross-border packaging recycling mechanisms, modernization of logistics infrastructure and coordination of Chinese and Russian green logistics standards. These measures can help reduce energy consumption and carbon emissions while maintaining the efficiency of bilateral e-commerce trade. The study confirms that digital transformation should be considered not only as a tool for improving logistics productivity, but also as a mechanism for achieving environmental performance goals in cross-border supply chains.

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