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Analysis of the Impact of the Split Warehouse Distribution Model on Carbon Emissions Based on LMDI Modeling

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Abstract: To address the challenge of high carbon emission intensity in China's logistics industry, split warehouse distribution is used as an entry point to construct a transportation-warehousing coupling model to quantify the synergistic effect of multilevel warehousing networks on carbon emission reduction in the logistics industry. Based on the measured data of the industry, the Logarithmic Mean Divisia Index (LMDI) model is used to decompose the carbon emission drivers, and the difference in carbon footprints between the traditional direct distribution mode and the split warehousing mode is compared through the case of home appliance logistics in East China. The results show that the split warehouse model significantly reduces transportation carbon emissions by shortening the average transportation distance, but the warehouse scale expansion partially offsets some of the emission reduction benefits. The sensitivity analysis further reveals that the transportation distance is the core sensitive parameter and the penetration rate of new energy vehicles is the most potential emission reduction parameter among the secondary sensitive parameters, and that shortening the transportation radius and increasing the proportion of electric trucks can respectively increase the total emission reduction efficiency. To provide a systematic optimization path for the logistics industry to achieve the “dual-carbon” goal, intelligent scheduling, warehousing and sharing, and clean energy substitution are suggested to balance the network efficiency and economy of scale.

Keywords: split warehouse distribution model, carbon emissions, transportation-warehousing coupling, LMDI model.

1. Introduction

According to the China Green Logistics Development Report (2023), the total carbon emissions of China's logistics industry account for 9% of the country's total carbon emissions, of which 85% is contributed by the transportation link and 15% by the rest of the link, such as warehousing. At present, the traditional direct distribution model still dominates the logistics and distribution system. It relies on a single central warehouse for national radial distribution, and its limitations are further highlighted in the latest industry practice: Low transportation efficiency leads to an increase in the average transportation distance, storage energy consumption, rigid growth, and warehouse area growth but little reduction in unit energy consumption. Many improvement methods are emerging, such as the use of new energy vehicles for transportation [1]. Although the penetration rate of new energy logistics vehicles is increasing, the expansion of e-commerce scale and supply chain complexity leads

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to the logistics industry's overall carbon emission intensity still being high, and it is necessary to crack the contradiction between "growth and emission reduction" through systematic optimization.

In recent years, the current situation of carbon emissions in China's logistics industry has received increasing attention, and many scholars have adopted different methods to study it. Wang combines the hierarchical analysis method with data envelopment analysis to construct a comprehensive evaluation model for evaluating the performance of low-carbon logistics [2]; Zhang and Dong used visualization and analysis tool to construct a knowledge map to understand the research dynamics and future trends in the field of low carbon logistics at home and abroad, and to reveal the key information in the field of low carbon logistics [3]; Gu et al. measured and decomposed the carbon emissions of China's transportation industry through the IPCC Carbon Emission Factor Approach and the LMDI model [4]; Wang et al. used the combination of game theory and dynamic system analysis to construct a model [5]. Although a few scholars have also studied the split-warehouse stocking model, there are fewer related studies linking split-warehouse stocking and carbon emissions.

By constructing a three-level network of "central warehouse - regional warehouse - forward warehouse," the warehouse allocation model systematically shortens the transportation radius and optimizes the inventory distribution, which is significantly in line with the construction goal of "green logistics hub." However, this model lacks a quantitative assessment of carbon emissions and a rigorous system and methodology. Based on this, we intend to break through the limitations of traditional one-dimensional research and construct a transportation-storage coupling model for the first time to quantify the carbon emission reduction potential of the split-storage model, to provide logistics enterprises with low-carbon operation solutions that can be put into practice, and to promote the green transformation of the logistics industry to a new stage.

In this paper, our main contributions can be summarized as follows:

(1) Integrates the synergistic effect of transportation and warehousing into the analytical framework, quantifies the comprehensive impact of multilevel warehousing networks on carbon emissions under the split-warehousing mode, and provides systematic methodological support for the traceability of the carbon footprint of the logistics industry.

(2) The LMDI model is used to accurately decompose the carbon emission drivers, and the sensitivity analysis is used to identify the key parameters, which reveals the core emission reduction path of the split warehousing model.

(3) The emission reduction path of "transportation optimization as the main focus and warehouse synergy as the supplement" is proposed, which provides a systematic optimization solution for the logistics industry to achieve the goal of "double carbon."

The rest of this paper is organized as follows. After describing the research methodology (Section II), the carbon footprint difference between the traditional direct distribution model and the split warehousing model is compared and analyzed with sensitivity analysis, taking the household appliance logistics in East China as a case study (Section III). Finally, some conclusions are given in Section IV.

2. Research methods

2.1. Problem description

The transportation and warehousing links in the logistics network are used as the object of study to focus on the mechanism of carbon emission by the warehouse preparation strategy. The Transportation-Warehousing Coupling (TWC) model is proposed to quantify the synergistic effect of transportation and warehousing in the logistics network and its comprehensive impact on carbon emission. The model considers the entire transportation and warehousing links of split-warehouse stocking. Among them, the transportation link covers the whole chain of trunk transportation, regional

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distribution, and terminal distribution from the warehouse to the consumer, and the key considerations include the transportation distance and the type of transportation vehicles, which excludes the carbon emission impact of transportation and reverse logistics at the production end. The warehousing link focuses on the area of warehousing as well as the energy consumption per unit, which specifically includes the energy consumption of lighting, refrigeration, and the operation of the equipment, and the energy consumption of the warehouse construction and packaging and storage is not included. This definition provides a systematic analytical framework for the traceability of the carbon footprint in the warehouse mode.

2.2. Transportation modes

We build a comparative analysis model of single-center direct distribution mode and multi-level warehouse mode. To be more specific, the single-center direct distribution model covers the East China region with a central warehouse in Shanghai. Specifically, the East China region includes six provinces and one city: Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Fujian, and Shandong provinces, respectively. The centralized storage and point-to-point transportation are adopted for all categories (see Figure 1).

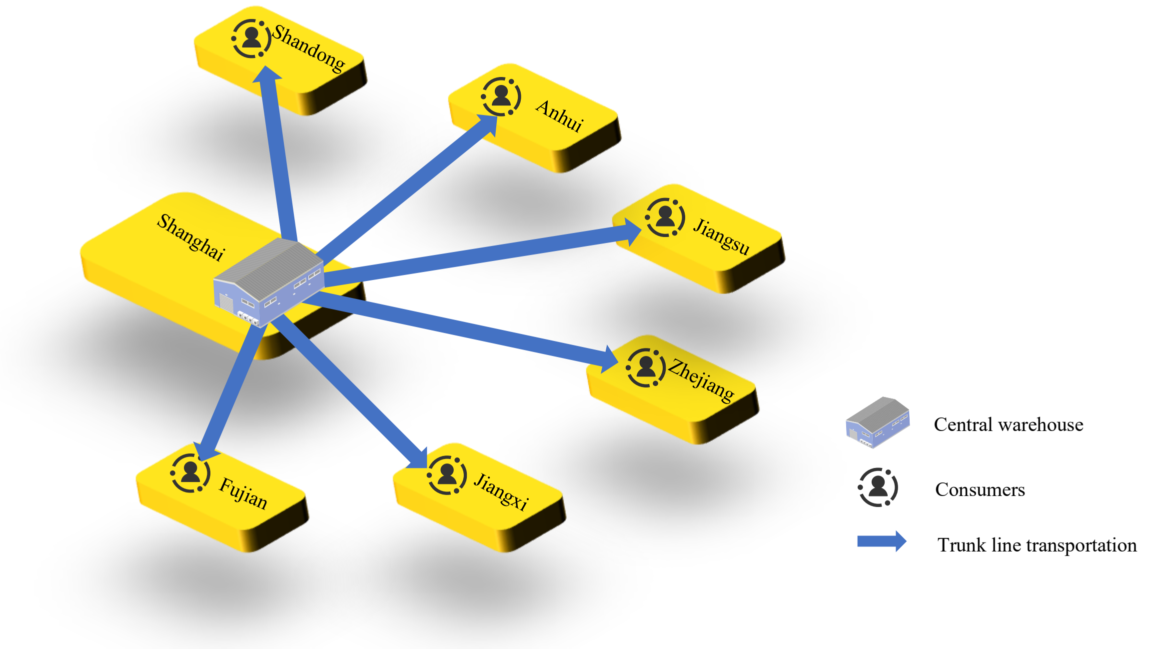

Figure 1: The single-center direct distribution model

The multi-level warehousing mode adopts a three-level structure of “one central warehouse + two regional warehouses + six front warehouses,” through the trunk line transportation (center-regional warehouse), branch line distribution (regional-front warehouses), and end distribution (front warehouses-consumers) links (see Figure 2) and the implementation of inventory hierarchical management. The difference between the transportation hierarchy and inventory space configuration of the two modes provides an empirical basis for the study of the carbon effect of the binning strategy.

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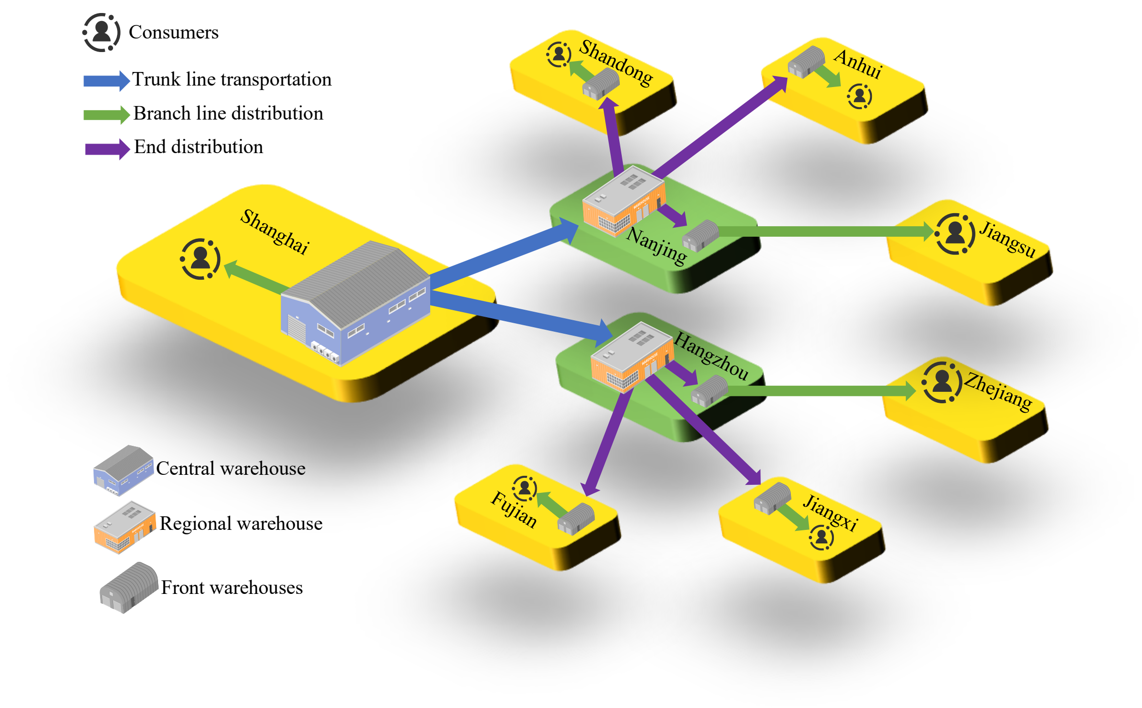

Figure 2: Multi-level warehousing mode

2.3. Carbon emission measurement methodologies

Carbon emission measurement is the technical basis of logistics decarbonization research, and the IPCC emission factor method (Tier 1) is widely used for its standardization and ease of operation [6]. Its core formula is equation (1):

$$C = \sum(AD \times EF) \tag{1}$$

where AD is the activity data (e.g., energy consumption volume) and EF is the emission factor. The specific equations for transportation carbon emissions are equations (2)-(3):

$$C_{transport} = FC \times EF_{transport} \tag{2}$$

$$FC = r \times D \tag{3}$$

The specific equations for carbon emissions from storage are equations (4)-(5):

$$C_{warehouse} = E \times EF_{warehouse} \tag{4}$$

$$E = u \times A \tag{5}$$

2.4. LMDI model

The LMDI model is an improved tool for decomposing carbon emission influences based on Kaya's constant equation [7], which breaks down influences into multiple independent drivers by decomposing changes in aggregate variables (e.g., carbon emissions). Common forms include the additive form (LMDI-I) and the multiplicative form (LMDI-II). The results of the multiplicative and additive decompositions are consistent with each other; the decomposition process does not change the overall results of the analysis. According to the needs of this study, it is more appropriate to use additive decomposition to clarify the absolute value contribution of each factor. Combined with the research cases in related literature [8-10], the LMDI factor decomposition method is utilized to classify the influencing factors into four types: transportation distance, transportation vehicle type, storage size, and storage energy consumption, and construct the additive decomposition formula, which is shown in equations (6)-(7):

$$\Delta C = C^{T} - C^{0} = \Delta C_{D} + \Delta C_{S} + \Delta C_{A} + \Delta C_{E} \tag{6}$$

$$L(a, b) = \begin{cases} \frac{a-b}{\ln a - \ln b} & a \neq b \\ a & a = b \end{cases} \tag{7}$$

where L (a, b) is the log-mean weight function; ΔC is the total amount of change in carbon emission intensity; ΔC_D and ΔC_S are the contribution values of transportation distance and transportation model type to the change in carbon emission intensity, respectively; and ΔC_D and ΔC_S are calculated by the following equations (8)-(9):

$$\Delta C_{D} = L(C^{T}, C^{0}) \cdot \ln\left(\frac{D^{T}}{D^{0}}\right) \tag{8}$$

$$\Delta C_{S} = \sum_{k} L\left(C_{k}^{T}, C_{k}^{0}\right) \cdot \ln\left(\frac{S_{k}^{T}}{S_{k}^{0}}\right) \tag{9}$$

ΔC_A and ΔC_E are the contribution values of warehouse scale and unit energy consumption to the change of carbon emission intensity, respectively. ΔC_A and ΔC_E are calculated by the following equations (10)-(11):

$$\Delta C_{A} = L(C^{T}, C^{0}) \cdot \ln\left(\frac{A^{T}}{A^{0}}\right) \tag{10}$$

$$\Delta C_{E} = L(C^{T}, C^{0}) \cdot \ln\left(\frac{E_{u}^{T}}{E_{u}^{0}}\right) \tag{11}$$

Table 1: Parameter symbol definition

Parameter symbol	Clarification
$C_{transport}$	Carbon emissions from transportation (kg)
$C_{warehouse}$	Carbon emissions from warehousing (kg)
$EF_{transport}$	Carbon emission factor of transportation energy ($kgCO_2/kg$)
$EF_{warehouse}$	Carbon emission factor of electricity ($kgCO_2/(kW \cdot h)$)
FC	Total fuel consumption (kg)
r	Vehicle fuel consumption per 100 kilometers (kg/km)
D	Total mileage traveled (km)
E	Total warehousing energy consumption (kW·h)
u	Energy consumption per unit area (kW·h/m²)
A	Warehousing Total area (m²)
C^{T}	Total carbon emissions in split warehouse mode (kg)
C^{0}	Total carbon emissions in direct distribution mode (kg)
ΔC_i	Contribution of the ith driver (kg)
D^{T}	Total transportation distance in split warehouse mode (km)
D^{0}	Total transportation distance in direct distribution mode (km)
S_k^{T}	Transportation share of vehicle model k in split warehouse mode (%)
S_k^{0}	Transportation share of vehicle model k in direct distribution mode (%)
A^{T}	Total warehousing area in split warehouse mode (m²)
A^{0}	Warehousing area in direct distribution mode (m²)
E_u^{T}	Energy consumption per unit area in split warehouse mode (kWh/m²)
E_u^{0}	Energy consumption per unit area in direct distribution mode (kWh/m²)

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3. Case study

3.1. Setting parameters

The household appliance industry is used as an object to simulate 1000 order delivery scenarios in East China to compare and analyze the carbon emission reduction efficacy of the traditional direct distribution versus the split warehouse model (comparing only the carbon emissions generated in the process of processing these 1000 orders). As an economically active region with a dense logistics network, the order decentralization in East China provides a typical scenario for verifying the applicability of the split warehouse model [11]. In the parameter setting, the direct distribution mode takes Shanghai as the central warehouse, reflecting the limitation of a single central warehouse; the split warehouse mode realizes the compression of transportation radius through the three-level warehouse network layout of "Shanghai + Nanjing + Hangzhou." Different models of trucks vary; in order to control a single variable, the heavy diesel truck with a fuel consumption of 20 liters per 100 kilometers (about 0.17kg) is used throughout. The area of the direct distribution warehouse is 5000m², the area of the center warehouse in the split warehouse model is 5000m², and the areas of the regional warehouse and the front warehouse are 3000 m² and 300 m², respectively. To ensure the accuracy of the results, 1,000 orders were stored in the center warehouse for 8 hours in the direct distribution mode and in the regional warehouse for 8 hours in the split warehouse mode. According to the data from the National Greenhouse Gas Emission Factor Database [1] and the conversion, the carbon emission factors of diesel and electricity are 3.1863 $kgCO_2/kg$ and 0.5617 $kgCO_2/(kW\cdot h)$ in that order.

Assuming that the energy consumption of warehousing in this case is electricity energy consumption, 1000 orders stored for eight hours, then each square meter lighting 0.8 $(kW\cdot h)/m^2$, refrigeration 32 $(kW\cdot h)/m^2$, and equipment operation 3 $(kW\cdot h)/m^2$, the total unit of energy consumption is 35.8 $(kW\cdot h)/m^2$.

In order to ensure the accuracy of the distance data, the distances between the two provinces are used to represent the average distance between the corresponding provincial capitals of the two provinces. Based on the data from the GOD Maps navigation and calculations, Table 2 was summarized to show the average distances between different regions:

Table 2: Distance between the two places

Area	Average distance (km)
Shanghai-Hangzhou (Zhejiang)	180
Shanghai-Nanjing (Jiangsu)	300
Shanghai-Hefei (Anhui)	480
Shanghai-Nanchang (Jiangxi)	750
Shanghai-Jinan (Shandong)	830
Shanghai-Fuzhou (Fujian)	800
Hangzhou (Hangzhou (Zhejiang) - Nanchang (Jiangxi)	550
Hangzhou (Zhejiang) - Fuzhou (Fujian)	600
Nanjing (Jiangsu) - Hefei (Anhui)	180
Nanjing (Jiangsu) - Jinan (Shandong)	620

According to the data in the chart, we can calculate the following: The average distance from Shanghai to the other six provinces is 557 km; the average distance from Shanghai to Hangzhou and

[1] https://data.ncsc.org.cn/factoryes/index.

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Nanjing is 240 km; the average distance from Hangzhou to Jiangxi and Fujian is 575 km; and the average distance from Nanjing to He'anhui and Shandong is 400 km.

The direct distribution mode adopts centralized storage of the whole category and point-to-point direct transportation, and its total transportation distance is 557*1000 = 557000 km; the multi-level warehouse mode uses a three-tier structure, and trunk transport (center-regional warehouse) is mainly used to replenish the regional warehouse. Assuming that there is a one-time replenishment of 500 orders to each regional warehouse, the total transport distance is 240*2 + 575*500 + 400*500 = 487980 km.

The data for the above parameters are summarized in Table 3:

Table 3: Comparison of the parameters of the two modes

Parameters	Direct distribution model	Split warehouse model
Central warehouse location	Shanghai	Shanghai+Nanjing+Hangzhou
Total distance traveled	557000 km	487980 km
Number of orders	1000 orders	1000 orders
Warehouse area	5000 m^2	5000*1+3000*2+500*6=14000 m^2
Heavy-duty diesel truck fuel consumption per 100 km	0.2 L/km (0.17 kg/km)	
Energy consumption per unit area	35.8 (kW·h)/m^2	
Transportation emission factor	3.1863 $kgCO_2$/kg (diesel truck)	
Electricity emission factor	0.5617 $kgCO_2$/(kW·h)	
Parameters	Direct distribution model	

3.2. Calculation results

The resultant data calculated from the above model and the data provided are shown in Tables 4 and 5. The analysis results show that the carbon emission reduction effect of the split warehouse distribution model is mainly driven by the transportation distance reduction (216.4% contribution), which significantly reduces fuel consumption by compressing the average transportation distance through the construction of a multilevel warehousing network. However, the expansion of warehousing scale (+20108.9 $kgCO_2$) offsets part of the emission reduction gain, highlighting the potential contradiction between the densification of end-of-line distribution and the growth of warehousing area.

Table 4: Relevant parameter result data

Relevant parameters	Results data	
	Transportation link	
$C^{T}_{transport}$	264324.6 $kgCO_2$	/
$C^{0}_{transport}$	301710.7 $kgCO_2$	/
$\Delta C_{transport}$	-37386.1 $kgCO_2$	/
$L(C^{T}_{transport}, C^{0}_{transport})$	/	282605.3
	Warehousing link	
$C^{T}_{warehouse}$	120653.2 $kgCO_2$	/
$C^{0}_{warehouse}$	100544.3 $kgCO_2$	/
$\Delta C_{warehouse}$	1102.2 $kgCO_2$	/
$L(C^{T}_{warehouse}, C^{0}_{warehouse})$	/	110293.4

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Table 5: Comparative results of cases

Driving forces	Contribution value($kgCO_2$)	Percentage(%)
	Transportation link	
Transportation Distance (ΔC_D)	-37386.1	216.4
Transportation Vehicle Type (ΔC_S)	0	0
	Warehousing link	
Storage Size (ΔC_A)	20108.9	-116.4
Unit Energy Consumption (ΔC_E)	0	0
Total Change	-17277.2	100

3.3. Sensitivity analysis

Sensitivity analysis is used to verify the robustness of the carbon emission model of the split warehouse distribution model and identify the mechanism of key parameters on the emission reduction effect. Still based on these 1,000 orders, the transportation distance, new energy vehicle penetration rate, storage area, and unit energy consumption are taken as core variables, and their values are adjusted respectively (±10%~20%), and the results are shown in Table 6:

Table 6: Sensitivity analysis data sheet

Parameters	Adjustments	Change in carbon emissions ($kgCO_2$)	Change in total emission reductions (%)
Transportation distance	-20% (+97,596 km)	-52864.9	-306
	-10% (-48,798 km)	-26432.5	-153
	+10% (+48,798 km)	+26432.5	+153
	+20% (-97,596 km)	+52864.9	+306
Penetration rate of new energy vehicles (Based on the current industry data, the power consumption of 100km is taken as 0.5 (kW·h)/km)	5% electric van replacement	-6363.7	-36.8
	10% electric van replacement	-12727.4	-73.7
	15% electric van replacement	-19091.1	-110.5
	20% electric van replacement	-25454.8	-147.3
Warehouse area	-20% (-1200 m^2)	-24130.6	-139.7
	-10% (-600 m^2)	-12065.3	-69.8
	+10% (+600 m^2)	+12065.3	+69.8
	+20% (+1200 m^2)	+24130.6	+139.7
Unit energy consumption	-20% (-7.16 (kW·h)/m^2)	-24130.6	-139.7
	-10% (-3.58 (kW·h)/m^2)	-12065.3	-69.8
	+10% (+3.58 (kW·h)/m^2)	+12065.3	+69.8
	+20% (+7.16 (kW·h)/m^2)	+24130.6	+139.7

Sensitivity analysis shows that transportation distance is the core sensitive parameter affecting the emission reduction effect of the warehouse-sharing model. The penetration rate of new energy vehicles, storage area, and unit energy consumption are the secondary sensitive parameters affecting the emission reduction effect of the warehouse-sharing model, and controlling the storage scale can

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reduce the increment of carbon emissions, but the scale change is limited. It is worth noting that the penetration rate of new energy vehicles is the parameter with the most potential to increase the emission reduction effect among the secondary parameters, and future research can dynamically incorporate the optimization of vehicle model structure to more accurately quantify the synergistic emission reduction potential.

4. Conclusions

This study reveals the key role of the split warehousing and distribution model in carbon emission reduction in the logistics industry through model construction and case study analysis. The results show that the split warehousing model drives down carbon emissions in the transportation chain by constructing a three-tier warehousing network and shortening the average transportation distance, making it a core driver of emission reduction. However, the increase in carbon emissions due to the expansion of warehousing area offsets part of the emission reduction gains, highlighting the potential contradiction between the densification of the end distribution network and the growth of warehousing scale. Although the model does not dynamically incorporate the penetration rate of new energy vehicles, which may underestimate the actual potential of energy structure optimization, the decomposition results still validate the emission reduction path of "transportation optimization as the mainstay and warehousing synergy as a supplement."

The policy level suggests that the construction of a warehousing network should be included in the carbon trading system [12], and carbon quota incentives should be given to quantifiable emission reduction behaviors such as optimization of transportation distance and improvement of energy efficiency of warehousing. At the same time, it is necessary to enhance the penetration rate of new energy vehicles and promote new warehousing models [13] and reduce indirect emissions through intelligent temperature control and dynamic inventory management. It is worth noting that this study did not consider the impact of differences in packaging materials on carbon emissions, which can be expanded to the packaging link in the future to construct an all-link carbon footprint model to provide a more comprehensive decision-making basis for the green transformation of the logistics industry. In addition, future research still needs to deepen the development of intelligent warehouse location algorithms, combining real-time road condition data and order distribution characteristics to dynamically optimize the storage tier and layout [14], in order to balance network efficiency and economies of scale and further release the low-carbon potential of the warehouse mode.

Refereces

[1] *Mo C ,J. X R L ,Chaochao L .How to Improve the Market Penetration of New Energy Vehicles in China: An Agent-Based Model with a Three-Level Variables Structure[J].Sustainability,2021,13(21):12307-12307.*

[2] *Jinjuan W .Evaluation of Logistics Development Under the Visual Field of Low-Carbon Environmental Protection Based on Hierarchical Methods[J].International Journal of Ambient Computing and Intelligence (IJACI),2024,15 (1):1-16.*

[3] *Zhang J ,Dong B .A Review of Research in the Field of Low Carbon Logistics based on the Cite-Space Tool[J].Academic Journal of Management and Social Sciences,2024,8(2):48-56.*

[4] *Gu J ,Jiang S ,Zhang J , et al.An analysis of the decomposition and driving force of carbon emissions in transport sector in China.[J].Scientific reports,2024,14(1):30177.*

[5] *Wang Y ,Luo H ,Zhang X , et al.Research on evolutionary game of low-carbon logistics in two-level supply chain under carbon tax policy[J].Sustainable Futures,2024,8100387-100387.*

[6] *Ouatahar L ,Amon B ,Bannink A , et al.An integral assessment of carbon and nitrogen emissions in dairy cattle production systems: Comparing dynamic process-based greenhouse gas emissions factors with IPCC Tier 1 and Tier 2 approaches in confinement and pasture-based systems[J].Journal of Cleaner Production,2025,486144479-144479.*

[7] *Li Y ,Chen H ,Yu P , et al.The Application and Evaluation of the LMDI Method in Building Carbon Emissions Analysis: A Comprehensive Review[J].Buildings,2024,14(9):2820-2820.*

DOI: 10.54254/2755-2721/164/2025.23534

[8] Wang J ,Dai H ,Feng H , et al.Carbon emission of urban vehicles based on carbon emission factor correlation analysis[J].Scientific Reports,2025,15(1):2037-2037.

[9] Sun ,Ying,Qian , et al.The carbon emissions level of China's service industry: an analysis of characteristics and influencing factors[J].Environment, Development and Sustainability,2021,24(12):1-26.

[10] Li G ,Wang Z ,Wen Z .Decomposition of Energy Carbon Emission Factors and Scenario Prediction Based on Multiple Models[J].International Journal of Frontiers in Sociology,2024,6(9):

[11] Fan Z ,Fan J .Measurement Research of High-Quality Economic Development of East China Based on Critic Weight and Comprehensive Index Method[J].The Frontiers of Society, Science and Technology,2023,5(4):

[12] Yulu W ,Shenji G .Harmonizing the Digital Economy and Green Development: Challenges, Strategies and Pathways to Achieve the Double-Carbon Goal[J].Journal of Economics and Management Sciences,2024,7(3):p56-p56.

[13] Ricardo F ,Bruno R ,Calvin G , et al.Multi-agent based energy community cost optimization considering high electric vehicles penetration[J].Sustainable Energy Technologies and Assessments,2023,59

[14] Wu T ,An R .Study on the Optimization of X Warehouse Layout Based on SLP and Flexsim[J].Journal of Engineering System,2024,2(4):