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Research on the Constraints and Countermeasures for Low-Carbon Development of Port Logistics in Hebei under the Dual Carbon Goals

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Abstract: The proposal of the "dual carbon" goals has posed stringent emission reduction requirements for China's port logistics industry. As an important energy export hub in the Bohai Rim region, Hebei Province faces significant challenges in reducing carbon emissions from its port logistics sector due to its large total emissions and complex structure, coupled with multiple constraints in its low-carbon transition. This paper first reviews the current status of energy consumption and carbon emissions in Hebei's port logistics sector. It then identifies five major constraints to low-carbon development: reliance on fossil fuels in the energy structure, uneven coverage of shore power facilities, insufficient depth in the application of green technologies, the need for further improvement in the policy support system, and the necessity to enhance public awareness of low-carbon practices. Based on these findings, the paper proposes collaborative advancement paths from four dimensions—technology, industry, policy, and society—including optimizing carbon reduction technologies, accelerating the energy structure transition, increasing the utilization rate of shore power, improving green finance and carbon trading mechanisms, and strengthening public participation, to construct a support system for low-carbon development in port logistics. The research conclusions can provide references for formulating low-carbon policies for port logistics in Hebei Province and similar regions.

Keywords: Port logistics; Carbon emissions; Low-carbon development; Dual carbon goals; Hebei Province

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1. Introduction

The global climate governance situation is becoming increasingly urgent, prompting China to set the strategic goals of “achieving carbon peak before 2030 and carbon neutrality before 2060.” The transportation sector, as a crucial front in emission reduction efforts, faces severe challenges. As vital nodes in the comprehensive transportation system, ports undertake multiple functions such as cargo distribution, transshipment, and warehousing, with complex sources of carbon emissions covering various aspects, including ship berthing, port operations, and collection and distribution systems [1]. According to statistics, CO_2 emissions from international shipping account for approximately 3% to 4% of global total CO_2 emissions, and this proportion significantly increases when considering port operations and land-based collection and distribution, thereby elevating the carbon emissions associated with port logistics [2].

Hebei Province boasts three major ports: Qinhuangdao Port, Tangshan Port, and Huanghua Port, serving as important channels for China’s “coal transportation from west to east” and “coal transportation from north to south” [3]. In 2022, Hebei Port Group was reorganized and established, forming a new collaborative development pattern of “three ports and four districts.” In 2024, the cumulative cargo throughput of ports under the group reached 842 million tons, marking a year-on-year increase of 6.0% and setting a new historical record [4]. However, with the continuous growth in port throughput, the issue of carbon emissions has become increasingly prominent. Despite a series of breakthroughs in green port construction achieved by Hebei Port Group in recent years, the low-carbon transition still faces numerous challenges due to factors such as energy structure, infrastructure, technological level, and policy mechanisms [5].

Based on the actual situation of port logistics in Hebei Province, this paper systematically identifies the constraints to low-carbon development by analyzing the current status of energy consumption and carbon emissions. It then proposes corresponding countermeasures from four dimensions: technology, industry, policy, and society, aiming to provide theoretical support and practical guidance for the green and low-carbon transition of port logistics in Hebei.

2. Analysis of the current status of carbon emissions in Hebei port logistics

2.1. Overview of port development

Hebei Province has a mainland coastline of 487 kilometers, with approximately 126.8 kilometers of planned port coastline, accounting for more than a quarter of the province’s total coastline [6]. After the reorganization and establishment of Hebei Port Group in 2022, Qinhuangdao Port, Jingtang District of Tangshan Port, Caofeidian District of Tangshan Port, and Huanghua Port have formed a collaborative development pattern with complementary functions (**Table 1**): Qinhuangdao Port is being developed into an international tourism port and a modern comprehensive trade port, Jingtang District and Caofeidian District of Tangshan Port are focusing on building regional container shipping hubs and major hub ports for energy and raw materials, and Huanghua Port is striving to become a multifunctional, comprehensive, and modern large port [7].

Table 1. Functional positioning of “three ports and four districts” of Hebei Port Group

Port Area	Functional Positioning	Main Cargo Types
Qinhuangdao Port	International tourist port, modern comprehensive trade port	Coal, petroleum, grain
Tangshan Port Jingtang Port Area	Regional container shipping hub	Containers, steel, ore
Tangshan Port Caofeidian Port Area	Main hub port for energy and raw materials	Ore, coal, crude oil
Huanghua Port	Multifunctional, comprehensive, modern large port	Coal, ore, general cargo

In 2024, Hebei Port Group's cargo throughput exceeded 842 million tons, marking a year-on-year increase of 6.0%, while container throughput rose by 24.7% year-on-year, ranking third among major coastal port groups nationwide (**Figure 1**) [5]. As one of the world's largest bulk cargo ports, Qinhuangdao Port serves as a vital hub for the "north-to-south coal transportation." Leveraging the Caofeidian Circular Economy Demonstration Zone, Tangshan Port has evolved into a crucial component of China's specialized transportation system for bulk materials. Huanghua Port, located at the junction of Hebei and Shandong provinces, has witnessed the fastest growth in throughput in Hebei Province in recent years.

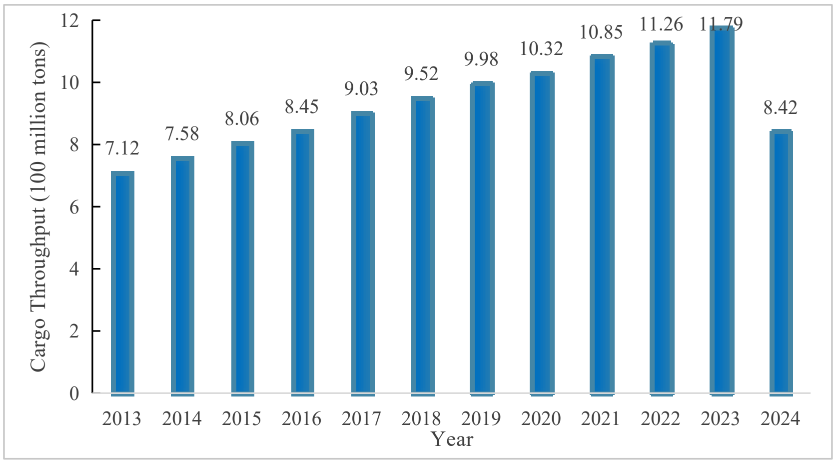

Figure 1. Trend of cargo throughput changes at Hebei Port Group from 2013 to 2024. Data Source: From 2013 to 2021, the data was obtained by summing up the throughput of Qinhuangdao Port, Tangshan Port, and Huanghua Port based on the China Port Yearbook and port statistics of Hebei Province; data for 2022–2023 was sourced from the annual reports and public reports of Hebei Port Group; data for 2024 was obtained from official announcements by Hebei Port Group

As shown in **Figure 1**, from 2013 to 2019, the cargo throughput of Hebei Port Group continued to grow steadily; after 2020, the growth rate significantly slowed down due to stricter environmental protection policies and adjustments in the transportation structure from road to rail. In 2024, under the dual effects of optimized statistical methods (eliminating double counting and empty container turnover) and continuous optimization of the bulk cargo transportation structure, the throughput decreased year-on-year to 842 million tons. This change does not represent a contraction in scale but rather a phased manifestation of the Group's transition from "scale expansion" to "quality improvement, efficiency enhancement, and green development", aligning with the continuous decline in carbon emission intensity.

2.2. Energy consumption structure

During the "14th Five-Year Plan" period, with the optimization of throughput structure and the continuous advancement of green development strategies, the energy consumption structure of Hebei Port Group has undergone significant changes—the proportion of electricity consumption has rapidly increased, while the dependence on fossil fuels has concurrently decreased. The main energy sources consumed by Hebei Port Group include diesel, gasoline, liquefied natural gas, natural gas, heat, electricity, etc. (**Table 2**) [8]. In 2024, notable changes occurred in the energy structure: the proportion of green electricity usage reached 51%, with installed capacity of completed and under-construction photovoltaic power generation reaching 23.2 MWp, and planned installed capacity of wind power generation at 33 MWp; three battery swap stations and 268 charging piles have been constructed (**Figure 2**) [11]. The duration and volume of ship shore power connections have approximately tripled compared to 2022, with nearly 700 new energy-powered internal transport vehicles and non-road mobile machinery added, and the commissioning of the first pure electric locomotive retrofitted from a "retired" locomotive in China and the first new energy tugboat in the Bohai Bay [9].

Table 2. Changes in the energy consumption structure of Hebei Port Group (2020–2024)

Energy Type	Share in 2020	Share in 2022	Share in 2024
Diesel	42%	38%	28%
Electricity	38%	42%	51%
Natural Gas	8%	10%	12%
Other Clean Energy	2%	5%	9%

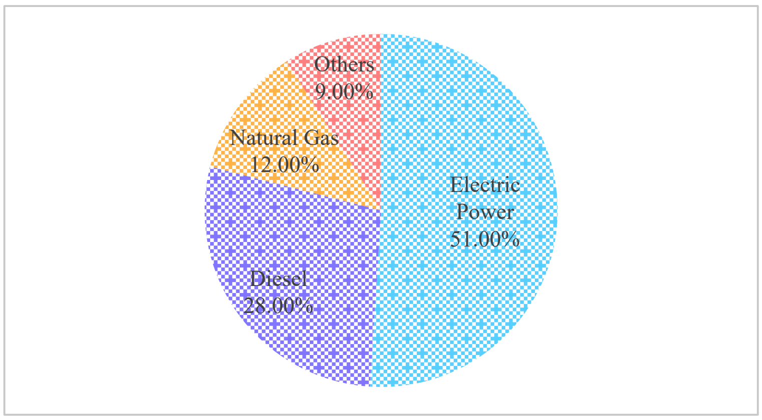

Figure 2. Energy Consumption Structure of Hebei Port Group in 2024. Data Source: Hebei Port Group's 2024 Social Responsibility Report, official news releases, and green development statistics

In 2024, electricity was the primary source of energy consumption for Hebei Port Group, accounting for 51%, followed by diesel at 28%, natural gas at 12%, and other energy sources at 9%. Electricity holds a dominant position in the port's energy mix.

Regarding energy conservation, in 2024, the proportion of green transportation for iron ore reached 82.4%, an increase of 20 percentage points from 2022; the proportion of green transportation for bulk cargo reached 90%, an increase of approximately 14 percentage points from 2022 [10]. A hydrogen-powered zero-carbon transportation route from "Huanghua Port-Wu'an-Changzhi" was launched, establishing a new pattern for hydrogen energy transportation at Huanghua Port [9]. By the end of 2024, the group had completed and put into operation 12 iron ore evacuation railway loading buildings with an annual loading capacity exceeding 100 million tons; 25.8 kilometers of enclosed belt conveyor corridors were constructed in the "three ports and four districts," along with over 330 charging stations and 3 battery swap stations [10]. The specific construction achievements are shown in **Table 3**.

Table 3. Construction achievements of the green transportation system of Hebei Port Group in 2024

Indicator	Value	Change Compared to 2022
Proportion of green transportation for iron ore	82.4%	+20 percentage points
Proportion of green transportation for bulk cargo	90%	+14 percentage points
Proportion of new energy vehicles in port collection and distribution road transport	73.5%	+25 percentage points
Length of enclosed belt pipe gallery	25.8 km	+8.2 km

2.3. Carbon emission characteristics

From the perspective of carbon emission composition, over 95% of Hebei Port Group's carbon emissions originate from indirect emissions generated by purchased electricity and heat, while direct carbon emissions from the combustion of fossil fuels such as diesel and gasoline account for less than 5% and exhibit a year-on-year declining trend [11]. In 2024, with the proportion of green electricity usage increasing to 51%, the intensity of indirect carbon emissions further decreased.

In terms of carbon emission intensity, the CO_2 emissions per unit of cargo turnover at Hebei Port demonstrated a fluctuating yet continuously declining trend from 2013 to 2024. Specifically, there was a downward trend from 2013 to 2016, followed by a rebound from 2017 to 2019, and then a renewed decline after 2020. The declining trend further solidified from 2023 to 2024, showcasing a phased characteristic of "initial decline, subsequent rebound, further decline, and sustained reduction." Details are shown in **Table 4** and **Figure 3**.

Table 4. Changes in carbon emission intensity of Hebei Port Group (2013–2024)

Year	CO_2 Emissions per Unit Turnover of Goods (tons/10,000 ton-km)	Year-on-Year Change
2013	15.2	—
2015	13.8	-9.2%
2018	14.5	+5.1%
2020	13.2	-8.9%
2022	11.6	-12.1%
2024	9.8	-15.5%

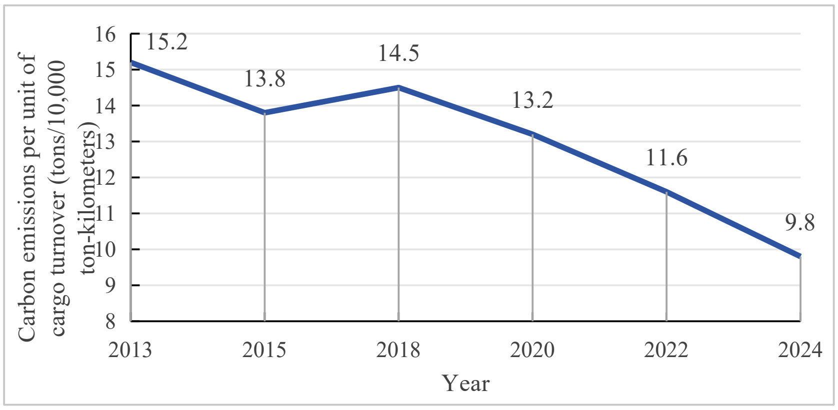

Figure 3. Trend of carbon emission intensity changes in Hebei Port Group from 2013 to 2024

Carbon emission intensity is defined as CO_2 emissions per unit of cargo turnover (tons/10,000 ton-kilometers). Overall, it exhibits a phased characteristic of initial decline, subsequent rebound, further decline, and sustained reduction, dropping to 9.8 tons/10,000 ton-kilometers in 2024, indicating significant carbon reduction achievements.

In 2024, Hebei Port Group achieved remarkable accomplishments in green and low-carbon development: Seven terminal companies under the group were awarded the title of "Green Port" by the China Port Association, and two terminal companies were recognized as "Asia-Pacific Green Ports." The Coal Terminals III, IV, and V in the eastern port area of Qinhuangdao Port became the first "five-star" green port area in the country [9]. Details are shown in **Table 5**. The first digital carbon efficiency system for equipment in domestic ports was launched and put into operation, enabling statistical analysis, quantitative evaluation, and coded inquiry of carbon emission information from port handling equipment [12]. The shore power system for Jin-Tang container terminals achieved 100% coverage across all berths, with 475 vessel connections and 452,200 kWh of shore power supplied from January to August 2024, resulting in a carbon reduction of approximately 399.74 tons [13].

Table 5. Green Port construction achievements of Hebei Port Group in 2024

Honor/Certification	Quantity	Remarks
China Ports Association "Green Port"	7 facilities	Covering "three ports and four areas"
Asia-Pacific Green Port	2 facilities	Internationally certified
"Five-Star" Green Port Area	1 area	Qinhuangdao Port East Port Area

3. Constraints on the low-carbon development of port logistics in Hebei

3.1. Short-term conflicts between corporate objectives and environmental goals

Logistics enterprises primarily aim to achieve profitability, whereas low-carbon logistics emphasizes resource conservation and environmental protection alongside economic benefits [14]. In the absence of effective external constraints and incentive mechanisms, some port enterprises still tend to opt for lower-cost but higher-carbon-emission operational methods in the short term [15]. This conflict of objectives relegates carbon emission governance to a relatively peripheral position in corporate development [16].

Although Hebei Port Group has made substantial investments in green port construction, some small and medium-sized ports and shipping enterprises face shortages in funding and technology, resulting in insufficient motivation for low-carbon transformation. Data from 2024 indicates that new energy vehicles accounted for 73.5% of the total automobile transportation volume for iron ore collection and distribution at the group's ports, while approximately 26.5% of automobile transportation still relied on traditional fuel vehicles [10]. This gap reflects the uneven progress of low-carbon transformation among enterprises (**Figure 4**).

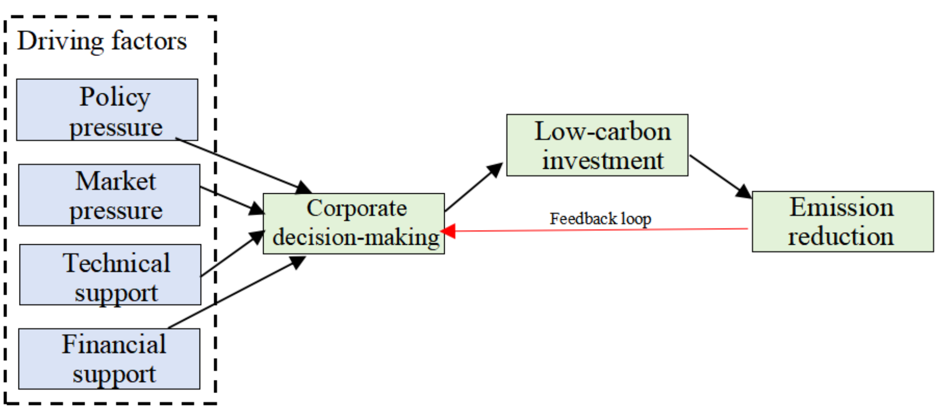

Figure 4. Analysis of the dynamic mechanism for low-carbon transformation in port enterprises

As shown in **Figure 4**, four external factors—policy pressure, market pressure, technological support, and financial support—collectively act on the decision-making level of enterprises, forming the driving force for low-carbon transformation. Among them, policy pressure primarily manifests in mandatory institutional arrangements such as the constraints of the "dual carbon" goals, stricter environmental regulations, and mandatory requirements for shore power utilization. Market pressure originates from the demands of cargo owners for a green supply chain, expectations of international shipping carbon taxes, and shifts in consumer environmental preferences. Technological support encompasses the maturity and availability of low-carbon technologies, including new energy equipment, digital carbon efficiency management systems, and shore power facilities. Financial support covers economic incentives such as government subsidies, green financial products, and carbon trading revenues. After being transmitted internally within the enterprise, these four types of driving forces are transformed into specific low-carbon investment decisions, including equipment upgrades, energy substitution, and process optimization. The implementation of low-carbon investments directly yields emission reduction effects, which not only improve the environmental performance of ports but also benefit enterprises by reducing costs, enhancing brand image, and generating carbon revenues, thereby forming a positive feedback loop. Meanwhile, emission reduction effects also bolster the confidence of policymakers, market participants, and financial institutions in low-carbon transformation, further strengthening the input of external driving forces and forming a closed-loop mechanism of "driving force input—enterprise decision-making—low-carbon investment—emission reduction effect—feedback reinforcement." This mechanism reveals that the low-carbon transformation of port enterprises is not a linear process driven by a single factor but rather a systematic evolutionary process involving the coordinated action of multiple driving forces and the reinforcement of positive feedback loops. It also explains the internal logic behind why some enterprises can continue to advance low-carbon transformation despite facing short-term cost pressures in the initial stages.

3.2. Energy structure reliance on fossil fuels

Despite significant progress in the application of clean energy in Hebei Province's ports, traditional fuels such as diesel and gasoline still account for a certain proportion [17]. LNG, as an important transitional energy source in the global energy transition, is still in its infancy in the application of Hebei Province's ports, with some ports lacking complete LNG refueling infrastructure [18]. Although notable achievements have been made in energy structure transformation, sustained efforts are still required to completely eliminate reliance on fossil fuels [19].

3.3. Uneven coverage of shore power facilities

Shore power technology is an effective means of reducing carbon emissions during ships' berthing [20]. Currently, Jingtang Container Terminal has achieved 100% shore power coverage, but shore power coverage in other port areas remains uneven (**Figure 5**) [16]. Specialized berths at Qinhuangdao Port and Tangshan Port, for example, have shore power coverage rates ranging from 50% to 80%, with some berths still lacking shore power facilities [21]. Furthermore, issues such as non-uniform shore power interface standards and high costs for retrofitting ships with shore power equipment also somewhat constrain further improvements in shore power utilization rates [22].

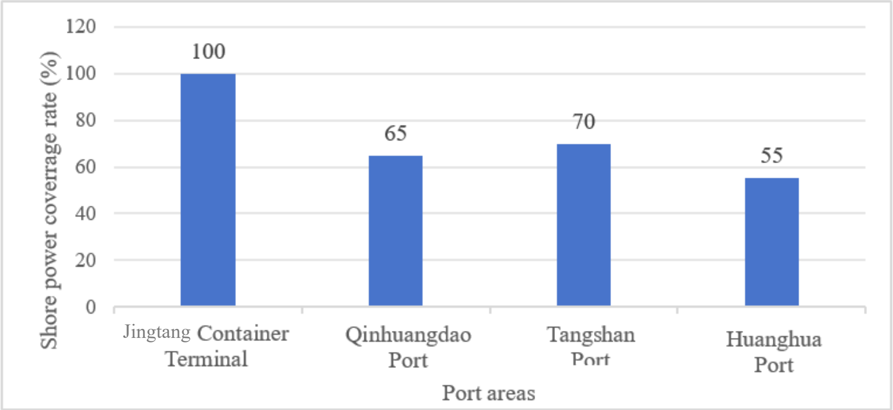

Figure 5. Comparison of Shore Power Coverage Rates Across Various Port Areas in 2024. Data Source: Hebei Port Group's 2024 Annual Report on Green Port Construction, Hebei Provincial Department of Transport, and public data from the governments of Tangshan and Cangzhou (2024). Note: The coverage rate is calculated on a comprehensive basis for the entire port area (including all berths for containers, bulk cargo, general cargo, etc.)

To further reflect the actual effectiveness of shore power promotion and avoid duplicating the content of **Figure 5**, the shore power usage volumes of various port areas are listed separately, as shown in **Table 6**.

Table 6. Shore power usage volumes across various port areas in 2024

Port Area	2024 Shore Power Usage (10,000 kWh)
Jintang Container	45.22
Qinhuangdao Port	28.6
Tangshan Port	31.2
Huanghua Port	12.5

Data sources: 2024 Green Port Construction Report of Hebei Port Group and public data from the Hebei Provincial Department of Transport

The difference in shore power usage is not only influenced by coverage but is also closely related to factors such as vessel berthing frequency, vessel type structure, and willingness to connect to shore power. The highest shore power usage in the Jin-Tang container terminals is attributed to their 100% coverage rate, the high degree of standardization of container vessels, and strong willingness to connect to shore power.

3.4. Insufficient depth in the application of green technologies

The low-carbon transformation of port logistics relies on the support of green technologies such as handling equipment, transportation tools, and energy management systems [23]. Currently, Hebei's ports have made initial progress in the application of electric mobile machinery, intelligent access control systems, and energy management platforms, with some areas reaching leading domestic levels. However, the overall technological system remains incomplete. Data from 2024 shows that the number of intelligent upgrades to the Group's main handling equipment reached 102 units, accounting for 49%, leaving more than half of the equipment yet to undergo intelligent transformation (**Table 7**) [9].

Table 7. Current status of green technology applications in ports in 2024

Technology Type	Application Ratio	Comparison with Domestic Advanced Level	Existing Issues
Electric mobile machinery	35%	60%	Insufficient charging facilities
Smart access control system	100%	100%	System integration needs improvement
Equipment digital carbon efficiency system	Operational	First of its kind in China	Requires time for promotion
New energy tugboat	1 vessel	First in Bohai Bay	Limited quantity

As shown in **Table 7**, the application ratio of electric mobile machinery in the Group in 2024 is relatively low, primarily due to the following reasons: Firstly, there is insufficient supporting charging infrastructure, with the layout of charging stations in some port areas still being inadequate, making it difficult to meet the daily operational needs of large-scale electric mobile machinery. Secondly, the single-charge endurance of electric mobile machinery still lags behind that of traditional diesel machinery, making it challenging to adapt to continuous high-intensity operational scenarios. Thirdly, the initial purchase cost is relatively high, posing practical financial pressures for some small and medium-sized port enterprises. Fourthly, the existing equipment inventory is still within its service life, and premature retirement would increase operational costs, limiting the willingness of enterprises to upgrade. These factors collectively constrain the rapid promotion of electric mobile machinery in port operations.

Figure 6 clearly illustrates the changing trend in the progress of intelligent transformation of main handling equipment from 2020 to 2024, showing a consistent and steady upward trajectory overall. In 2020, the proportion of intelligent transformation of main handling equipment was only 15%, reflecting the late start and limited investment in intelligent transformation by enterprises at the initial stage, with equipment intelligence levels remaining low. As enterprises increasingly emphasized intelligent transformation, they increased investment in technology research and development, equipment upgrades, and capital, leading to a steady year-by-year increase in the transformation proportion, reaching 49% by 2024, with nearly half of the main handling equipment having undergone intelligent transformation. From a trend perspective, the transformation proportion increased by 34 percentage points over five years, with an average annual increase of approximately 6.8 percentage points. The transformation progress was balanced overall, without significant fluctuations, indicating that enterprises' intelligent transformation plans were scientific and orderly, gradually achieving the transition of handling equipment from traditional manual operations to automation and intelligence. This change not only reflects the effectiveness of enterprise equipment upgrades but also the overall trend of intelligent development in the logistics industry, laying a solid equipment foundation for subsequent improvements in handling efficiency, reductions in labor costs, and ensuring operational safety.

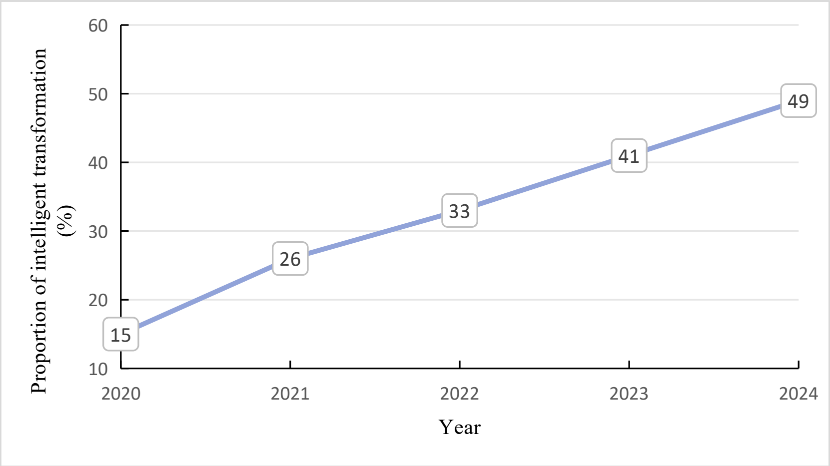

Figure 6. Progress of intelligent transformation of main handling equipment (2020–2024)

3.5. Policy support and market mechanisms need further improvement

Currently, the policy system for low-carbon development of port logistics in Hebei Province is relatively complete, but mandatory constraints and market-based incentive mechanisms still need strengthening [24]. The carbon trading mechanism has not yet covered port enterprises, the supply of green financial products needs further enrichment, and incentive measures such as environmental subsidies and tax incentives require further refinement and implementation [25]. In 2024, the Hebei Maritime Safety Administration issued the "Ten Measures to Support the Cost Reduction, Quality Improvement, and Efficiency Enhancement of Hebei Maritime Logistics", explicitly proposing to "promote pollution reduction and carbon reduction in ports", providing policy support for the low-carbon development of ports [26].

4. Countermeasures for low-carbon development of port logistics in Hebei Province

4.1. Optimize carbon reduction technology pathways

4.1.1. Promote the application of alternative fuels

Ports in Hebei Province should accelerate the layout of refueling facilities for decarbonized fuels such as liquid hydrogen and LNG, and encourage the use of clean energy by port operation vessels and collection and distribution vehicles [27]. Drawing on the experience of hydrogen energy transportation line construction in Huanghua Port, expand the application scope of hydrogen energy and electric heavy trucks. By 2030, strive to achieve a green vessel proportion of over 50% among vessels registered in Hebei Province [9, 28].

4.1.2. Increase shore power utilization

Promote the experience of 100% full coverage of shore power in Jin-Tang container terminals, establish unified general standards for shore power interface equipment, and improve the performance evaluation mechanism for shore power utilization. Drawing on experience from the Yangtze River Basin, shore power utilization can be incorporated into port operation permits and vessel berthing management requirements, with clear targets for shore power utilization proportions. The practice of reducing carbon emissions by approximately 399.74 tons through shore power in Jin-Tang container terminals from January to August 2024 demonstrates the significant emission reduction effects of shore power promotion [13].

Shore power promotion should set phased targets. In the near term (by 2025), focus on overcoming key berths to achieve 100% shore power coverage, ensuring that main operation berths have power supply capabilities. In the medium term (by 2030), complete full coverage of shore power facilities across the entire port area, increase utilization to over 60%, and simultaneously establish supporting management mechanisms. In the long term (by 2050), focus on intelligent upgrades—through intelligent scheduling, load forecasting, dynamic optimization, and other technological means, ultimately achieving zero carbon emissions during vessel berthing.

4.1.3. Implement speed restrictions

Set speed restrictions during vessel entry and exit from ports to reduce fuel consumption and carbon emissions by lowering navigation speeds. This measure has been verified in some international ports, demonstrating good emission reduction effects and cost-effectiveness [29].

4.2. Optimize the industrial structure of port logistics

4.2.1. Strengthen the construction of offshore wind power mother ports

Leveraging Hebei Province's location advantage around the Bohai Sea, promote the integrated development of the entire industrial chain of wind power port equipment research and development, wind farm development, installation, and maintenance, and create a wind power equipment operation mother port combining "production, learning, port, research, and services." In 2024, Hebei Port Group planned to construct a wind power with an installed capacity of 33MWp, laying the foundation for further development of the offshore wind power industry [9].

4.2.2. Develop multimodal transport

Optimize the collection and distribution system, increasing the proportion of low-carbon transportation methods such as railways and waterways in port collection and distribution. Reduce carbon emissions from road transportation through "road-to-rail" and "road-to-water" shifts. In 2024, Hebei Port Group collaborated with 20 steel enterprises to create 20 "zero-emission corridors" for iron ore collection and distribution, with all iron ore collection and distribution adopting new energy vehicles or "new energy vehicles + belt conveyor corridor" transportation methods [10].

4.3. Improve policy and market mechanisms

4.3.1. Establish a financial incentive and green finance system

Set up special funds for the low-carbon transformation of ports, providing subsidies to enterprises adopting clean energy, constructing shore power facilities, and implementing energy-saving transformations. Encourage financial institutions to develop green credit, green bonds, and other financial products to provide financing support for low-carbon port projects. In 2024, Hebei Port Group completed and was constructing a photovoltaic power generation with an installed capacity of 23.2MWp, providing a good example of green finance support [9].

4.3.2. Promote the inclusion of port enterprises in the carbon trading market

Draw on international experience to gradually include port enterprises in the national carbon emissions trading system. Form market-based emission reduction incentives through carbon quota allocation and trading mechanisms, encouraging enterprises to actively reduce carbon emissions. The equipment digital carbon efficiency system, launched in 2024, laid the data foundation for port enterprises to participate in carbon trading.

4.4. Enhance public awareness of low-carbon and social participation

4.4.1. Strengthen low-carbon propaganda and education

Integrate green and low-carbon concepts into national economic and social activities, raising public awareness of port carbon emission issues through media propaganda and community activities. The experience of Qinhuangdao Port's Donggang District becoming the first "five-star" green port in the country is worth promoting and publicizing.

4.4.2. Conduct community communication and public supervision

Port enterprises should regularly conduct visits to surrounding communities, inviting resident representatives and public interest organizations to inspect port operation environments, enhancing public participation and supervision capabilities. Form a good atmosphere for the whole society to jointly promote the low-carbon development of ports.

4.5. Construct internal low-carbon transformation motivation mechanisms for enterprises

To address the conflict between enterprises' short-term profit goals and low-carbon transformation, it is recommended to form long-term incentive and restraint mechanisms by incorporating carbon reduction into enterprise performance evaluation systems, establishing internal carbon pricing mechanisms, and promoting green supply chain management models. Port groups can take the lead in piloting "carbon performance" linked to operator salaries internally, guiding subsidiary enterprises to actively reduce carbon emissions. At the same time, encourage large port enterprises to play a leading role, incorporating low-carbon indicators into supplier admission and evaluation standards, driving coordinated transformation of the entire industrial chain.

5. Conclusion

Port logistics in Hebei Province face multiple challenges in energy structure transformation, infrastructure upgrades, technology application promotion, and policy mechanism improvement under the "dual carbon" goals. Based on a systematic analysis of the current situation of carbon emissions and constraints on low-carbon development, this paper proposes countermeasures and suggestions covering four dimensions: technology, industry, policy, and society. The main understandings are as follows:

First, carbon emissions from port logistics in Hebei Province show a phased characteristic of "initial decrease-subsequent increase-further decrease-sustained decrease." In 2024, the proportion of green electricity usage reached 51%, and the proportion of green transportation for iron ore reached 82.4%, marking a breakthrough progress in green port construction.

Second, low-carbon development faces five major constraints: short-term conflicts between enterprise goals and environmental goals, dependence on fossil fuels in the energy structure, uneven coverage of shore power facilities, insufficient depth of green technology application and the need for improvement in policy support and market mechanisms.

Third, it is necessary to promote coordinated progress from four dimensions: technology, industry, policy, and society, accelerating the decoupling of economic growth and carbon emissions in port logistics, providing beneficial references for the green and low-carbon transformation of the port industry in Hebei Province and across the country.

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The authors declare no conflict of interest.

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