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Dynamic Strategic Driving Model Construction: Systematic Pathway and Shaoxing Empirical Study on Low-Carbon Transportation Transition in Chinese Large Cities

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Abstract

Under the dual drive of the "dual carbon" goals and Chinese-style modernization, low-carbon transportation transition in megacities has become a key carrier for coordinating economic growth, social equity, and ecological governance. Taking Shaoxing, a node city in the Yangtze River Delta, as an empirical case, this paper innovatively proposes a "dynamic strategic driving model" to deconstruct the systematic implementation pathway of low-carbon transportation from five dimensions: top-level design synergy, technology response diffusion, infrastructure flexible support, policy-market optimization, and public behavior guidance. Research shows that institutional innovation is the core engine; Shaoxing has built a "carbon efficiency code" hierarchical governance system, linked with green finance, achieving an average annual reduction rate of transportation carbon intensity of 3.5%. Spatial reconstruction lays the low-carbon foundation; through the "three-network integration" (rail + bus + slow traffic) led by rail transit, private car travel is reduced by 35%, shaping a 15-minute low-carbon living circle. Technology empowerment enhances operational efficiency; integrated technologies such as BIM construction optimization, photovoltaic stations, and regenerative braking reduce rail transit unit energy consumption by 22%. Government-enterprise-public collaboration ensures sustainability; carbon account point exchange, special bond financing, and public "golden ideas" mechanisms form a multi-governance pattern. The Shaoxing experience demonstrates that modular toolkits (such as open-source

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carbon efficiency code systems) and the industry-transportation-energy synergy paradigm can provide megacities with transformation solutions that balance emission reduction effectiveness and economic feasibility, advancing the low-carbon process of regional transportation in Chinese-style modernization.

Keywords

Chinese-Style Modernization, Low-Carbon Transportation, Dynamic Strategy-Driven Model, Carbon Efficiency Code, Urban Transportation Transition

1. Introduction

Currently, China is at a critical stage of moving towards high-quality development, and promoting Chinese-style modernization has become a core proposition of national development. In this process, cities, as the intersection of economic, social, and ecological development, have seen the green transition of their transportation systems become a key lever for achieving sustainable development. Especially in megacities, transportation is not only the artery of economic operation but also the focus of environmental governance and a window to social equity. Therefore, exploring the strategic significance of Chinese-style modernization and low-carbon transportation development in megacities possesses not only theoretical depth but also practical urgency (Yao, Gao, & Yang, 2019).

On one hand, low-carbon transportation is an inherent demand of Chinese-style modernization. First, high-quality development in urban clusters imposes new requirements. Chinese-style modernization emphasizes a comprehensive, coordinated, and sustainable development model, and urban clusters, as important carriers of national spatial structure optimization, are becoming the main battlefield of regional coordinated development. Against this backdrop, the traditional urban transportation model dominated by expansion and motorization can no longer meet the new demands of high-quality development. The internal transportation systems of urban clusters need to shift from accessibility to integration, greenness, and intelligence, building multi-level, integrated, low-carbon transportation networks. For example, the Yangtze River Delta integrated development strategy requires interconnected urban transportation within the region, promoting the coordinated development of low-carbon transportation modes such as rail transit, bus priority, and slow-traffic systems. Inter-city transportation connections are no longer just about "roads open and people flowing" but emphasize "green sharing," aiming to reduce carbon emissions and enhance resource efficiency. This transformation reflects the structural demand for low-carbon transportation in Chinese-style modernization. Second, the carbon peak and carbon neutrality goals require transportation transition. The "dual carbon" goals are important levers for ecological environment governance in the process of Chinese-style modernization. The transportation sector is one of the main sources of carbon emissions, particularly in cities. According to data from the Ministry of Ecology and Environment, China's transportation sector accounts for about 10% of national carbon emissions, with urban transportation making a significant contribution. Therefore, the development of low-carbon transportation is a key pathway to achieving the carbon peak and carbon neutrality goals. This includes not only the promotion of new energy vehicles (such as electric and hydrogen-powered vehicles) but also the optimization of transportation structures (such as public transport priority and non-motorized system construction), guidance of travel modes (such as green travel incentive mechanisms), and low-carbonization of transportation infrastructure (such as green roads and energy-saving stations). These transition directions not only align with the national "dual carbon" strategy but also support the construction of a green urban system. Third, there is a need for coordinated development of common prosperity and green travel. Chinese-style modernization emphasizes that development achievements are shared by the people, which aligns closely with the concept of common prosperity. In the transportation field, the popularization of green travel concerns not only environmental protection but also travel equity and social inclusivity. Currently, there is an uneven distribution of urban transportation resources among different income groups: high-income groups rely more on private cars, while middle- and low-income groups depend more on public transportation and non-motorized systems. Therefore, promoting green travel is not only a technical issue but also a social equity issue. By improving public transport networks, enhancing the accessibility of slow-traffic systems, and providing green travel subsidies, more people can enjoy the convenience and benefits of low-carbon travel. This "green + fairness" development model is precisely the essence of transportation development in Chinese-style modernization (Xu & Geng, 2025).

On the other hand, low-carbon transportation has strategic value for urban sustainable development. First, it addresses the need to reduce pollution and carbon emissions while protecting the ecological environment. The construction of low-carbon transportation systems directly relates to urban air quality, carbon emission intensity, and ecological environment quality. Traditional transportation models rely on fossil fuels, emitting large amounts of carbon dioxide, nitrogen oxides, and particulate matter, severely threatening urban residents' health. Low-carbon transportation, by optimizing energy structures, improving transportation efficiency, and reducing empty driving rates, helps significantly reduce pollutant emissions in the transportation sector. For example, promoting electric buses, building bus-only lanes, and developing shared transportation not only reduce vehicle exhaust emissions but also enhance transportation operational efficiency. Additionally, green transportation infrastructure (such as photovoltaic stations and green pavement) is gradually becoming an important component of urban green renewal. The advancement of low-carbon transportation is a key support for achieving the goals of urban ecological civilization construction. Second, it meets the need to enhance urban operational efficiency and resident travel experiences. Low-carbon transportation is not only a symbol of environmental protection but also key to improving urban operational efficiency. By constructing diverse and integrated transportation networks (such as rail + bus + slow-traffic systems), urban congestion can be effectively alleviated, commute times reduced, and residents' quality of life improved. Moreover, the application of digital technologies in low-carbon transportation is increasingly widespread, such as intelligent scheduling systems, real-time traffic information services, and electronic ticketing systems, enhancing the intelligence level of transportation systems. Taking Hangzhou as an example, through its "City Brain" project for intelligent traffic signal control, road capacity has been greatly improved. This "green + smart" transportation model not only enhances residents' travel experiences but also strengthens urban livability and attractiveness. Third, it drives green upgrades in the transportation industry and the development of emerging business formats. The development of low-carbon transportation also promotes green transformation in the transportation industry and the growth of emerging business models. New fields such as the new energy vehicle industry chain, intelligent transportation systems, Mobility as a Service (MaaS) platforms, and shared bicycles are constantly emerging, becoming new growth points for urban economies. Taking new energy vehicles as an example, China's breakthroughs in batteries, motors, and electronic controls in recent years have driven the development of upstream and downstream industrial chains, creating many jobs. Meanwhile, with the introduction of policy tools like carbon trading and green finance, green investments and innovations in the transportation sector are increasingly active. Low-carbon transportation not only changes travel modes but also injects green momentum into urban economies (Wang, 2025).

This paper takes Shaoxing, Zhejiang, as an example to explore the construction of a low-carbon transportation development model for megacities in Chinese-style modernization. Shaoxing is located in the core area of China's Yangtze River Delta, adjacent to Hangzhou and Ningbo, and is an important node city in Zhejiang Province's "One Bay, Two Belts, Three Zones" strategy. By 2024, Shaoxing's population reached 5.12 million and GDP reached 698 billion yuan, achieving leapfrog development and becoming a key support for the regional economy (Zhejiang Provincial Bureau of Statistics, 2025). Shaoxing has realized "expressways connecting all towns," with expressway mileage exceeding 480 kilometers. Relying on the powerful collection and distribution system of the Ningbo-Zhoushan Port, annual freight volume reached 190 million tons, making it an important node in the Yangtze River Delta port cluster. Its transportation system exhibits typical "regional coordinated development" characteristics, with strong regional connectivity in rail transit, road networks, and water transport systems. Shaoxing actively promotes integrated development with Hangzhou and Ningbo, enhancing its external transportation capacity through infrastructure interconnections such as rail transit and expressways. In low-carbon transportation, Shaoxing leverages regional synergy advantages to promote seamless integration between rail transit (e.g., Shaoxing Metro) and the Hangzhou metropolitan transportation network, reducing carbon emissions in cross-city commuting. Additionally, Shaoxing vigorously develops green water transport, integrating inland waterway shipping with new energy-powered vessels to achieve low-carbon transformation of urban logistics transportation. The core of Chinese-style modernization lies in unifying economic development, social equity, and ecological sustainability. Shaoxing innovates a "low-carbon transportation + urban renewal" integration model through regional coordination, policy innovation, and digital governance, providing valuable experience for low-carbon transportation development in megacities.

This study aims to construct a "Dynamic Strategic Driving Model" applicable to low-carbon transportation transformation in large Chinese cities, systematically analyzing the synergistic mechanisms among five dimensions: top-level design, technological response, infrastructure support, policy-market integration, and public behavior guidance. Taking Shaoxing as an empirical case, it seeks to explore replicable and scalable pathways for low-carbon urban transport development, providing theoretical support and practical paradigms for achieving the "dual carbon" goals and Chinese-style modernization.

2. Implementation of Low-Carbon Transportation Development Strategy Practices in Large City Systems

In the context of global climate governance, the transportation sector, as one of the major sources of carbon emissions, is becoming a key battlefield for urban green and low-carbon transformation. Especially under the impetus of the "dual carbon" goals, major cities in China are actively exploring development pathways for low-carbon transportation (Jin & Tian, 2025). As an important node city in the integrated development of the Yangtze River Delta, Shaoxing has undertaken systematic and innovative practices in advancing the construction of a low-carbon transportation system (Chen, 2025). Taking Shaoxing as an example, this article reveals the city's implementation paths and practical achievements in areas such as clean vehicle replacement, optimization of transportation structure, intelligent traffic management, green infrastructure upgrading, source governance of industrial clusters, and strengthening of policy regulation, highlighting its exemplary significance and replicable experience in the development of low-carbon transportation in large cities (Shaoxing Transportation Law Enforcement Branch, 2024; Yu, Yang, & Jin, 2023).

2.1. Vehicle Clean Replacement and New Energy Transportation System Creation

First, Shaoxing has taken the lead in achieving electrification transformation in the public transportation sector. By the end of 2024, the electrification rate of the city's buses had reached 100%, and the electrification rate of taxis exceeded 80%. This achievement is attributed to the government-led "electric bus first" strategy, which, through fiscal subsidies, infrastructure support, and operational model innovation, formed a comprehensive electric bus support system. It not only effectively reduced exhaust emissions but also improved the service quality and operational efficiency of public transportation. At the same time, Shaoxing optimized bus routes and station distribution based on urban spatial layout, promoting the integrated construction of a "bus + slow travel" system, providing citizens with greener and more convenient travel options. Additionally, Shaoxing explored seamless connections between buses and subways to enhance the overall accessibility of urban transportation. Second, the new energy penetration rate for private cars and taxis has steadily increased. In the private transportation sector, Shaoxing has continuously improved the market penetration of new energy vehicles through a dual-drive approach of policy incentives and market guidance. Data from 2024 show that the number of new energy private passenger vehicles in Shaoxing exceeded 150,000, accounting for nearly 10% of the city's total vehicles, with a trend of annual growth. The government introduced multiple encouraging policies, such as purchase subsidies, exemption from purchase taxes, priority license plate allocation, and parking discounts, to stimulate citizens' enthusiasm for buying new energy vehicles. Meanwhile, Shaoxing also guided citizens to actively participate in low-carbon travel through mechanisms like "trade-in" and "green travel points," fostering green consumption habits. Third, hydrogen-powered heavy truck pilots and multi-vehicle type coordination are advancing. As an extension of new energy transportation exploration, Shaoxing actively deployed the hydrogen energy industry, particularly promoting pilot projects for hydrogen-powered vehicles in the heavy truck sector. Leveraging local chemical industry foundations and hydrogen energy supply chain advantages, Shaoxing has launched hydrogen-powered heavy truck pilot transportation projects in some industrial parks and logistics parks, exploring commercialization pathways for hydrogen energy transportation. Additionally, Shaoxing promoted the coordinated application of various vehicle types, such as hydrogen fuel buses, sanitation vehicles, and engineering vehicles, gradually building a diversified new energy transportation system. This initiative not only helps alleviate carbon emissions pressure in transportation but also provides practical support for the popularization of hydrogen energy technology and the improvement of the industrial chain.

2.2. Optimization of Transportation Structure and Formation of Green Freight System through Multimodal Transport

First, the promotion of models such as rail-water intermodal transport and road-to-water shift. Located in the southern wing of the Yangtze River Delta, Shaoxing actively promoted green transportation models like "rail-water intermodal transport" and "road-to-water shift" by leveraging water transport resources from the Yangtze River system and the Beijing-Hangzhou Grand Canal. By integrating resources from railways, water transport, and road transport, it achieved efficient coordination of transportation modes, significantly reducing the carbon emission intensity per unit of freight. The Shaoxing government encouraged key logistics enterprises to conduct multimodal transport pilots through policy guidance, infrastructure construction, and enterprise support, especially promoting green logistics models like "water transport + distribution" in high-energy-consumption industries such as building materials, textiles, and chemicals. This not only improved transportation efficiency but also effectively alleviated urban traffic congestion and air pollution issues. Second, the upgrading of clean transportation standards for industrial enterprises. Shaoxing formulated and implemented stricter clean transportation standards for the raw material and product transportation processes of industrial enterprises. Key enterprises were required to adopt clean transportation tools such as new energy trucks and electric forklifts, with monitoring and management of carbon emissions during transportation. The government promoted enterprise-level transportation greening from the source through measures like "green factory" certification, "carbon account" management, and green supply chain construction. This initiative not only enhanced the environmental performance of enterprises but also helped build a green manufacturing system, promoting deep integration between industry and transportation. Third, the deep integration of rail transit and urban transportation networks. The construction and operation of Shaoxing's rail transit is a key driver for optimizing urban transportation structure. With the full opening of Shaoxing Metro Line 1, transportation links between Shaoxing's urban area and the Hangzhou metropolitan area were strengthened, providing strong support for integrated "commuting + travel." Simultaneously, Shaoxing emphasized seamless connections between rail transit and other transportation modes, such as the integrated design of subways with buses, bicycles, and pedestrian systems, building a multi-dimensional travel network of "rail + bus + slow travel." This multi-network integrated transportation structure not only improved urban accessibility but also significantly reduced urban transportation carbon emissions.

2.3. Intelligent Transportation and Digital Transportation Empowering Comprehensive Transportation Efficiency Improvement

First, bottleneck transformation and application of intelligent signal control systems. Addressing urban traffic congestion, Shaoxing actively promoted "smart congestion management" projects, identifying and optimizing urban traffic congestion points through big data analysis and artificial intelligence algorithms. Using intelligent traffic signal control systems, it achieved dynamic adjustment of traffic signals, enhancing road network efficiency. Additionally, Shaoxing improved road capacity during peak hours through flexible traffic management methods like "tidal lanes" and "variable lanes." These measures not only reduced energy waste from traffic congestion but also enhanced the travel experience of urban residents. Second, pilot projects for new transportation tools such as unmanned minibuses. Shaoxing conducted several cutting-edge explorations in intelligent transportation, with the unmanned minibus pilot project being representative. Operating between some parks, communities, and transportation hubs, it utilized L4-level autonomous driving technology for all-weather, unmanned operation. The application of unmanned minibuses not only improved short-distance transfer efficiency but also provided technical validation and operational experience for future smart transportation development. Meanwhile, the promotion of such new transportation tools helped reduce operational costs and carbon emissions. Third, big data platforms enabling dynamic traffic monitoring and prediction. Shaoxing established an urban traffic operation monitoring and management platform, integrating multi-dimensional data such as traffic flow, weather, and incidents for real-time monitoring and traffic prediction. Through AI algorithms, the platform analyzed traffic trends, providing scientific basis for traffic management decisions. This intelligent transportation platform improved the precision and response speed of urban traffic scheduling and offered smarter travel services for enterprises and citizens. By accurately guiding travel behavior, Shaoxing effectively alleviated peak-hour traffic pressure, shifting traffic operations from "passive response" to "active regulation."

2.4. Continuous Upgrading of Green Infrastructure and Formation of Low-Carbon Transportation Space

First, comprehensive layout of supporting facilities such as charging piles and hydrogen refueling stations. To support the development of the new energy transportation system, Shaoxing actively promoted the construction of charging infrastructure. By 2024, the city had built over 12,000 public charging piles, covering major urban areas, towns, and highway service areas, essentially achieving the goal of "charging within 10 kilometers." Simultaneously, Shaoxing advanced hydrogen refueling station construction in key areas, providing infrastructure support for hydrogen energy transportation development. Currently, Shaoxing has 5 hydrogen refueling stations in operation, with 10 under construction, forming a "point-line-surface" integrated new energy transportation infrastructure network. Second, integration of green building and energy substitution technologies. In the process of transportation infrastructure construction, Shaoxing emphasized the incorporation of green building concepts. New bus depots, rail transit stations, parking lots, etc., all adopted energy-saving materials and photovoltaic power generation technologies, creating "zero-carbon transportation station" demonstration projects. Additionally, Shaoxing explored the integration of transportation stations with urban microgrids, achieving self-sufficiency of transportation facilities through distributed energy systems, further enhancing urban transportation's energy efficiency and environmental friendliness. Third, coordinated advancement of port shore power and zero-carbon waterways. As a major water transport city, Shaoxing prioritized the green transformation of ports and waterways. All major ports in the city have achieved full shore power coverage, allowing ships to use clean electricity instead of diesel power generation while docked, significantly reducing air pollutant emissions. Meanwhile, Shaoxing promoted "zero-carbon" pilot projects for waterways, creating green water transport corridors through measures like solar streetlights, electric patrol boats, and ecological slopes. This initiative not only improved water transport environmental quality but also provided replicable experience for national water transport green development.

2.5. Low-Carbonization of Transportation-Related Industries and Benign Governance of Industrial Clusters

First, VOCs emission control and application of green coatings. As a hub for traditional manufacturing industries such as textiles, chemicals, and printing in China, Shaoxing's transportation is closely linked to industrial emissions. To reduce transportation-related pollution at the source, Shaoxing strengthened VOCs (volatile organic compounds) control, particularly promoting green coatings and low-VOCs materials in industries like automotive repair, painting, and printing. Through technological upgrades, equipment improvements, and environmental regulation, Shaoxing's total VOCs emissions significantly decreased, effectively improving urban air quality. This measure also provided new ideas for green collaborative governance of transportation and industry. Second, rectification of high-emission industries and green industrial transformation. Shaoxing systematically rectified high-emission industries such as steel, cement, and building materials, encouraging enterprises to adopt clean production processes and low-emission technologies. Simultaneously, it promoted "green factory" construction among enterprises to enhance the overall green and low-carbon level of industries. Through linked governance of transportation and industry, Shaoxing achieved a shift from "end-of-pipe treatment" to "source control," offering a replicable model for low-carbon development in large cities. Third, enterprise carbon efficiency rating and green financial linkage mechanisms. Shaoxing explored the establishment of an enterprise carbon efficiency rating system, incorporating transportation carbon emissions into corporate environmental credit evaluations and linking it with green financial policies. Enterprises with higher carbon efficiency ratings gained easier access to financing support such as green loans and bond issuance. This mechanism not only stimulated corporate emission reduction enthusiasm but also guided social capital toward low-carbon transportation-related industries, promoting deep integration of green finance and low-carbon transportation.

2.6. Strengthening Policy Regulation to Achieve Dual Support from Systems and Funds

First, local fiscal subsidies and establishment of special funds. The Shaoxing municipal government attached high importance to low-carbon transportation development, setting up special funds to support areas like new energy transportation, infrastructure construction, and intelligent transportation applications. Through various means such as fiscal subsidies, tax incentives, and green procurement, it continuously guided the low-carbon transformation of transportation. Meanwhile, Shaoxing explored diversified financing models like "PPP + green bonds" to attract social capital into urban low-carbon transportation construction, forming a new pattern of government-market synergy. Second, improvement of regulatory standards and strengthening of law enforcement. To ensure the effective implementation of low-carbon transportation policies, Shaoxing continuously improved its regulatory standards system. It issued policy documents such as the "Shaoxing Green Transportation Development Plan," "Shaoxing New Energy Vehicle Promotion and Application Implementation Plan," and "Shaoxing Transportation Carbon Emission Control Management Measures," clarifying the goals, pathways, and responsible entities for low-carbon transportation development. Simultaneously, it strengthened law enforcement supervision, legally penalizing behaviors like illegal emissions, unlicensed operations, and non-compliant construction, forming a robust institutional guarantee. Third, goal-oriented policies and performance evaluation mechanisms. Shaoxing implemented a "goal-oriented + performance assessment" policy mechanism, incorporating low-carbon transportation development into the government's annual performance evaluation system and establishing a closed-loop management mechanism of "indicator decomposition—task implementation—effectiveness evaluation." Through regular assessments and feedback, Shaoxing continuously optimized policy implementation pathways, ensuring the sustained advancement and dynamic adjustment of the low-carbon transportation development strategy.

3. Key Challenges in Developing Low-Carbon Transportation in Major Chinese Cities

Driven by global climate governance and the carbon peaking and carbon neutrality goals ("dual-carbon" goals), major Chinese cities—areas with high population density and robust transportation demand—are at a critical stage of transitioning toward low-carbon transportation. However, this transformation faces a series of deep-rooted technological, policy, social, and economic challenges. These challenges not only constrain the efficiency of building low-carbon transportation systems but also spark multifaceted controversies and debates (Zhang, Weng, & Wen, 2025). The following analysis delves into the key challenges and contentious issues in developing low-carbon transportation in major Chinese cities from four perspectives: technological bottlenecks, policy coordination, social acceptance, and economic pressures.

3.1. Relative Technological Bottlenecks

The core of low-carbon transportation lies in the widespread adoption of new energy vehicles. Yet, the maturity and cost control of current new energy transportation technologies remain major barriers to their large-scale deployment. First, power battery endurance and charging infrastructure shortfalls. Despite significant advancements in lithium battery technology in recent years, issues such as energy density, cycle life, and low-temperature adaptability of power batteries remain unresolved. Especially in cold northern cities like Beijing, Shenyang, and Harbin, significant battery performance degradation affects the range and user experience of electric vehicles. Simultaneously, charging infrastructure development suffers from problems like "emphasizing quantity over quality" and "unreasonable spatial distribution." While the number of charging piles in major cities continues to grow, low coverage of fast-charging piles, uneven charging efficiency, and lagging operational management make "charging difficulty" a persistent issue. Second, hydrogen transportation and storage bottlenecks. Hydrogen, as a zero-emission energy source, is considered a vital component of future transportation energy systems. However, the promotion of hydrogen fuel cell vehicles in cities faces multiple technological hurdles. Hydrogen production, storage, transportation, and refueling involve high costs and significant safety risks. Currently, hydrogen production primarily relies on fossil fuels, leaving carbon emissions fundamentally unaddressed. Liquid hydrogen storage and transportation technologies are not yet mainstream, posing leakage and explosion risks during transit. Additionally, high construction costs and complex approval processes for hydrogen refueling stations limit hydrogen transportation to pilot stages in cities, hindering economies of scale. Third, implementation challenges for intelligent transportation systems (ITS). ITS, encompassing autonomous driving, vehicle-to-everything (V2X) communication, and traffic big data analytics, is a crucial enabling technology for low-carbon transportation. However, its practical application in urban settings faces numerous obstacles. On one hand, severe data fragmentation exists due to incompatible interfaces between different transportation management departments, impeding information interoperability. On the other, autonomous driving technology remains immature, particularly in perception, decision-making, and execution capabilities within complex urban road environments. Furthermore, public concerns about autonomous driving safety and lagging legal frameworks restrict ITS adoption.

3.2. Insufficient Policy Coordination

Developing low-carbon transportation relies not only on technological progress but also on systematic policy support. However, major Chinese cities currently exhibit inadequate interdepartmental coordination and institutional alignment in policy formulation and implementation. First, fragmented urban transportation, energy, and environmental policies. Achieving low-carbon transportation involves multiple sectors—transportation, energy, environmental protection, and urban planning—yet policies across these domains lack effective integration. For example, while transportation departments promote new energy vehicles, energy departments fail to synchronously optimize grid structures to support large-scale EV charging demand. Environmental authorities emphasize carbon reduction but lack unified standards for transportation carbon accounting. This policy fragmentation leads to resource waste and misaligned objectives. Second, central-local policy implementation gaps. Despite numerous national guidelines for low-carbon transportation development, local execution often reflects the adage "upper policies, lower countermeasures." Local governments may inadequately enforce central policies due to fiscal pressures or regional interests. For instance, some cities implement new energy vehicle subsidy policies inconsistently or lack detailed measures for transportation carbon control targets. Moreover, cumbersome local approval processes and lengthy cycles for new energy infrastructure projects delay implementation. Third, inadequate incentives and regulatory mechanisms. Current incentive mechanisms for low-carbon transportation remain underdeveloped. Financial subsidies often adopt a "one-size-fits-all" approach, failing to differentiate between high- and low-emission vehicle models, leading to inefficient resource allocation. Meanwhile, tax incentives, green credit, and other financial tools lack systematic frameworks. Regulatory oversight lags, lacking dynamic monitoring and evaluation mechanisms for actual emissions data and new energy vehicle performance. Some enterprises exploit policy loopholes for "subsidy fraud," undermining policy fairness and sustainability.

3.3. Limited Public Engagement

The ultimate success of low-carbon transportation depends on broad public participation and acceptance. Yet, residents in major cities still have significant room for improvement in green travel awareness and behavioral shifts. First, usage habits and cognitive barriers toward new energy vehicles. Despite ongoing subsidy policies, public misconceptions persist. Many consumers still worry about EVs' inadequate range, inconvenient charging, and low resale value. Others lack confidence in maintenance costs and after-sales services, dampening purchase intent. Poor liquidity in the second-hand market further heightens consumer hesitation. Second, public transit attractiveness and service quality issues. Public transit is a crucial low-carbon travel mode but remains insufficiently attractive in major cities. Limited rail coverage, long wait times, and inconvenient transfers reduce commuting efficiency. Severe overcrowding and inconsistent service quality on buses and subways during peak hours push residents toward private cars. Emerging green options like shared bikes and e-scooters face management, safety, and orderliness challenges that degrade user experience. Third, conflicts between economic rationality and environmental awareness. Daily travel choices often reflect tensions between cost efficiency and eco-consciousness. Some residents endorse low-carbon principles but prioritize cheaper, more convenient options. For example, lower fuel prices enhance the cost advantage of conventional vehicles over EVs. Others lack deep commitment to green travel, adopting low-carbon modes only under policy mandates or subsidies. Such "short-termism" impedes the cultivation of a lasting green travel culture.

3.4. Sustained Investment Pressures

Building low-carbon transportation systems requires substantial upfront investment—including R&D, infrastructure, and subsidies—but delivers long payback periods, creating funding pressures and profitability challenges for market entities. First, corporate transition costs and subsidy phase-out risks. Low-carbon transition demands massive capital from businesses. Automakers must develop new models and retool production lines; energy companies invest in charging/hydrogen infrastructure; logistics firms upgrade fleets and optimize operations. Yet, as fiscal subsidies gradually phase out, enterprises face heavy transition pressures without sustained funding. Small and medium-sized enterprises, with weaker risk resilience, are particularly vulnerable to cash-flow strains. Second, market participation willingness and profitability concerns. Although governments encourage private capital in low-carbon transportation, corporate engagement remains constrained by profitability. Related industries are nascent, featuring long investment returns and thin profit margins, fueling hesitation. Moreover, ambiguous local government support policies and unstable long-term expectations further deter investment. Third, difficulties quantifying long-term green benefits. Environmental benefits from low-carbon transportation—such as carbon reduction and air quality improvement—are long-term and externalized, rarely translating into immediate revenues. The absence of mature green benefit assessment mechanisms complicates corporate valuation of social and environmental impacts during investment decisions. Additionally, underdeveloped green finance instruments (e.g., carbon trading, green bonds) in major Chinese cities limit financing channels, hindering sustainable development of low-carbon projects.

4. Constructing the "Dynamic Strategy-Driven Model" for Low-Carbon Transportation Development in Major Chinese Cities under Chinese-Style Modernization

Under the guiding era of the "dual carbon" strategic goals, China's urban transportation, especially in major cities serving as the nation's core engines, shoulders the historic responsibility of transitioning from traditional high-carbon models to low-carbon greening. These urban transportation systems are characterized by massive scale, complex structures, and prominent energy consumption and carbon emission intensity. Their transformation urgently requires moving beyond fragmented measures and calls for a systematic, forward-looking, and highly adaptable strategic framework. To this end, this paper proposes and constructs the "Dynamic Strategy-Driven Model," aiming to provide the core driving force for the green and low-carbon development of transportation in China's major cities (As shown in Figure 1).

The "dynamic" nature of this model emphasizes its ability to keenly capture and respond to continuous changes in internal and external environments such as market supply and demand, technological iterations, policies and regulations, and public demands. "Strategy-driven" is deeply rooted in the essence of Michael Porter's strategic management thinking, emphasizing that all development pathways and strategies of the transportation system must achieve dynamic adaptation and drive with external environmental challenges (such as dual carbon constraints and urbanization pressures) and internal resource endowments (such as technological level, fiscal capacity, and governance structure) to build and maintain its competitive advantage and core capabilities for sustainable development (Porter, 2014). This paper explores the systematic pathways and innovative strategies for low-carbon transportation transition from five interconnected and co-evolving key dimensions: dynamic synergy of top-level design and strategic orientation; dynamic response to technological innovation and application diffusion; flexible support of infrastructure planning and construction; dynamic optimization of policy mechanisms and market incentives; dynamic guidance of public awareness and behavioral choices. This model is a qualitative framework employing innovative operating mechanisms to propel systemic transformation. This study explores systematic pathways and innovative strategies for low-carbon transportation transition through five interconnected and co-evolutionary key dimensions:

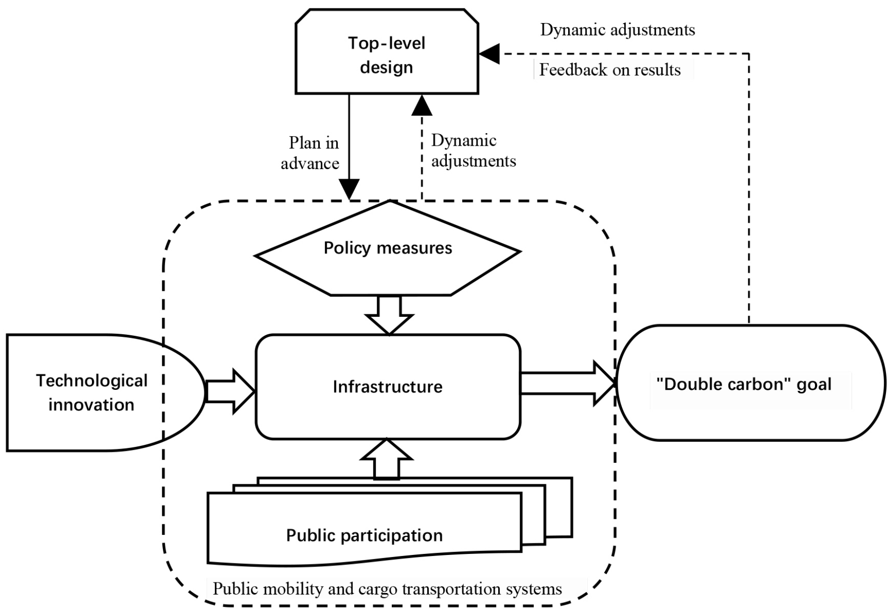

Figure 1. Dynamic strategic driving model for low-carbon transport development in large cities.

4.1. Dynamic Synergy of Top-Level Design and Strategic Orientation

Strengthen top-level design and formulate a systematic roadmap for low-carbon transportation development. First, clarify goal orientation and phased tasks. In low-carbon transportation construction, goal setting is the foundation for guiding direction, allocating resources, and measuring effectiveness. Major cities should establish clear low-carbon transportation development goals under the national "dual carbon" strategic framework, including the target year for peak carbon emissions, the reduction ratio of carbon emission intensity per unit of transportation, and the target proportion increase for new energy vehicles. Simultaneously, set short-term, medium-term, and long-term tasks in phases. For example, focus on optimizing the transportation structure and promoting new energy vehicles in the short term; concentrate on building intelligent transportation systems and deeply adjusting the energy structure in the medium term; and promote the comprehensive decarbonization of the transportation system in the long term. Second, establish a multi-departmental collaborative working mechanism. The low-carbon transition of the transportation system involves multiple departments, such as transportation, energy, environmental protection, housing and urban-rural development, finance, and public security. It is imperative to break down administrative barriers of "departmental segmentation" and establish efficient cross-departmental coordination mechanisms. This can be achieved by setting up a municipal-level special leading group for low-carbon transportation to coordinate policy arrangements in transportation, energy, urban planning, land use, and other fields, promoting the formation of a collaborative governance system characterized by "policy linkage, unified standards, and resource concentration." Third, construct a triple-driven mechanism of policy-market-society. The development of low-carbon transportation cannot rely solely on government promotion; it requires the joint participation of market mechanisms and social forces. At the policy level, introduce a series of incentive policies, such as vehicle purchase subsidies, tax reductions, and road priority access. At the market level, introduce social capital to participate in infrastructure construction and operation, and develop the green transportation industry. At the social level, stimulate public awareness of green travel through public education and social organization mobilization, thereby forming a triple-driven mechanism of policy guidance, market propulsion, and social co-governance.

4.2. Dynamic Response to Technological Innovation and Application Diffusion

Promote technological innovation to build a core technology system for new energy transportation. First, strengthen research and development in batteries, hydrogen energy, and intelligent systems. Technological innovation is a key engine for achieving low-carbon transportation. In the field of new energy transportation, battery technology, hydrogen energy technology, and intelligent transportation systems constitute the three core technological directions. Major Chinese cities should increase R&D investment in high-energy-density batteries, solid-state batteries, and hydrogen fuel cells to overcome range and charging bottlenecks. Simultaneously, advance the construction of intelligent transportation systems, improving transportation operational efficiency and reducing unnecessary travel and energy waste through vehicle-infrastructure coordination, autonomous driving, and big data analytics. Second, promote green transportation technology standards and demonstration projects. To ensure technological achievements translate into practical productivity, accelerate the establishment of a green transportation technology standard system covering technical specifications for new energy vehicles, charging facilities, hydrogen energy supply, and intelligent transportation equipment. Concurrently, implement green transportation demonstration projects in major cities, such as pilot intelligent bus systems, construction of hydrogen-powered heavy-duty truck transportation corridors, and zero-carbon transportation hub trials, to drive the nationwide application and diffusion of green transportation technologies. Third, build low-carbon transportation industry innovation platforms. Major cities should leverage universities, research institutions, and leading enterprises to establish low-carbon transportation industry innovation platforms, creating an integrated innovation ecosystem encompassing technology R&D, achievement transformation, enterprise incubation, and talent cultivation. By setting up special funds, building industrial parks, and promoting industry-university-research collaboration, cultivate emerging industrial chains in new energy vehicles, intelligent transportation, and green energy, forming globally competitive low-carbon transportation industry clusters.

4.3. Dynamic Support of Infrastructure Planning and Construction

Develop green infrastructure to construct a low-carbon transportation spatial support network. First, improve the integrated layout of urban transportation, energy, and information infrastructure. Achieving low-carbon transportation relies on efficient, clean, and intelligent infrastructure support. Major cities should strengthen the integrated planning and construction of transportation, energy, and information infrastructure. For example, co-locate renewable energy power supply systems, intelligent charging piles, and 5G communication networks around transportation hubs to achieve deep integration of transportation facilities with energy and information systems, enhancing the greening and intelligence level of infrastructure. Second, promote the integrated development of rail transit, public transport, and slow-moving systems. Constructing a multi-level green travel system with rail transit as the backbone, public transport as the main body, and slow-moving systems as the supplement is an effective path to reduce transportation carbon emissions. Major cities should accelerate the construction of rail transit networks, improve the service quality and coverage density of public transport systems, and simultaneously enhance slow-moving systems such as bicycle lanes and pedestrian walkways, creating an integrated travel network of "rail + bus + slow mobility" to improve the convenience and comfort of residents' green travel. Third, implement full-life-cycle low-carbon management of infrastructure. During infrastructure construction, adopt the concept of full-life-cycle low-carbon management, controlling carbon emissions throughout the entire process from planning and design, construction, operation and maintenance, to decommissioning and demolition. For example, prioritize the use of low-carbon materials and green construction techniques during the construction phase, employ intelligent monitoring and energy-saving operation strategies during the operation phase, extend facility lifespan, reduce carbon footprint, and achieve sustainable development of transportation infrastructure.

4.4. Dynamic Optimization of Policy Mechanisms and Market Incentives

Innovate policy mechanisms to build incentives and constraints for low-carbon transportation. First, improve green finance and carbon trading mechanisms. Financial instruments are important levers for promoting low-carbon transportation development. Major cities should advance the construction of a green financial system, establish special funds for green transportation, and encourage financial institutions such as banks, insurance companies, and securities firms to develop green transportation financial products. Simultaneously, actively participate in the national carbon market construction, explore carbon trading mechanisms in the transportation sector, and guide enterprises to proactively reduce emissions through carbon quota trading and carbon credit incentives, driving the transition of the transportation system towards low-carbonization. Second, promote the application of digital regulatory tools such as carbon efficiency codes and carbon accounts. Digital regulation is a crucial means to enhance transportation carbon emission management. Major cities can pilot the implementation of a "carbon efficiency code," which evaluates the carbon emissions of transportation vehicles, transport enterprises, and individual travel behaviors, linking it to the credit system to form a quantifiable, traceable, and incentivized management mechanism. Concurrently, establish "transportation carbon accounts" to record the carbon emissions and reduction behaviors of individuals or organizations, providing data support for their participation in carbon trading or access to policy incentives. Third, establish a statistical, monitoring, and assessment system for transportation carbon emissions. A scientific statistical, monitoring, and assessment system is the foundation for formulating policies and evaluating effectiveness. Major cities should build a carbon emission monitoring system covering the entire transportation industry chain, utilizing big data, the Internet of Things, and other technological means to conduct real-time monitoring and dynamic analysis of transportation energy consumption and emission levels. Simultaneously, establish a comprehensive transportation carbon emission assessment mechanism, regularly publishing low-carbon transportation development reports to provide a basis for policy adjustment and public supervision.

4.5. Dynamic Guidance of Public Awareness and Behavioral Choices

Guide public participation to cultivate a green travel culture and social consensus. First, strengthen green transportation publicity, education, and public participation. The transformation of public awareness and behavior is the fundamental driving force for green transportation development. Major cities should enhance the promotion and popularization of green transportation concepts, disseminating green travel knowledge through diverse channels such as media, communities, schools, and enterprises to raise public environmental awareness. Simultaneously, encourage public participation in transportation policy formulation and evaluation, such as conducting public hearings on transportation planning and organizing signature campaigns for green travel initiatives, to enhance social recognition and participation in low-carbon transportation. Second, promote incentive mechanisms such as green travel points and carbon inclusion. To increase the appeal of green travel, major cities can explore establishing green travel point systems or "carbon inclusion" mechanisms. For example, citizens can earn points through low-carbon behaviors like walking, cycling, and using public transport, which can be exchanged for benefits such as public transport cards, parking discounts, and cultural/tourism consumption. Such positive incentive mechanisms can not only guide residents to form low-carbon travel habits but also help foster a culture of green consumption throughout society. Third, build a green travel-friendly urban spatial environment. The urban spatial environment significantly influences residents' travel choices. Major cities should optimize urban spatial layouts to create green travel-friendly cities. For instance, reduce vehicle lanes and widen sidewalks and bicycle lanes, establishing pedestrian-priority blocks; construct 15-minute living circles between office areas, commercial districts, and residential zones to shorten travel distances; promote the "park + transportation" integrated model, enhancing the synergy between urban greenway systems and transportation networks, creating a walkable, enjoyable, and livable urban environment.

5. Empirical Study of Shaoxing's "Dynamic Strategic Driving Model" for Low-Carbon Transportation Development

Driven by the dual goals of global climate governance and urban sustainable development, Shaoxing has adopted institutional innovation as a breakthrough. By reconstructing the operational logic of the transportation system through a "Carbon Efficiency Code" hierarchical governance system, the city has established a comprehensive "Dynamic Strategic Driving Model" for low-carbon transportation covering top-level design, technological innovation, infrastructure, policy mechanisms, and public participation (As shown in **Figure 2**). Centered on the "Green Intelligent Rail System," this model reshapes spatial patterns through three-network integration (rail transit, bus system, and slow-travel system) (Liu, Mao, 2025). Combined with digital governance tools and market-oriented incentive mechanisms, it pioneers a new pathway for synergistic development between transportation emission reduction and urban quality enhancement among small and medium-sized cities in the Yangtze River Delta (Liu, Chen, Wu, & Cheng, 2016).

As a crucial node city in the Yangtze River Delta integration, Shaoxing has conducted systematic exploration in low-carbon transportation transition. Its policy practices multidimensionally validate the applicability and operability of the Dynamic Strategic Driving Model, delivering empirical support for low-carbon development in large cities.

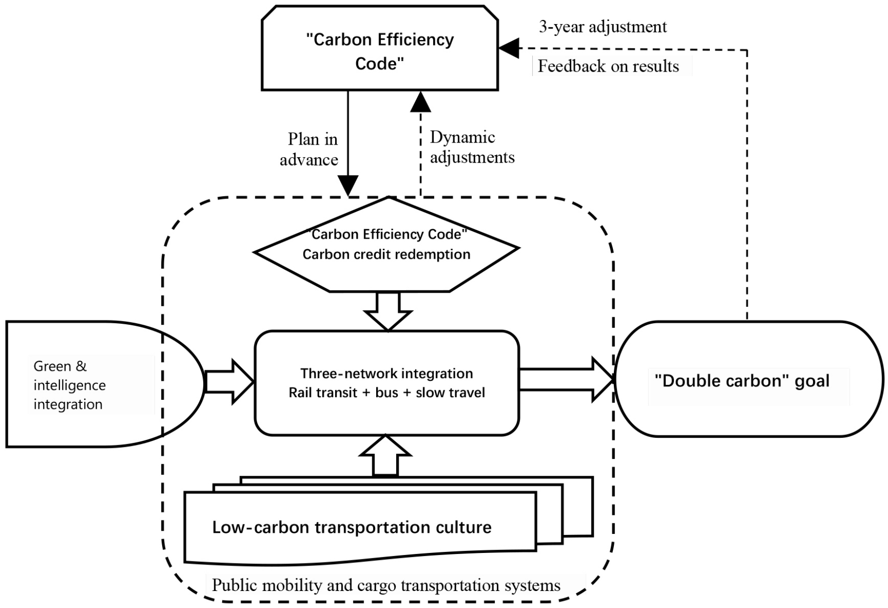

Figure 2. Dynamic strategic driving model for low-carbon transport development in Shaoxing city.

5.1. Dynamic Synergy in Top-Level Design

Shaoxing strengthens institutional innovation to lead systemic transformation in low-carbon transportation. First, it constructs a "Carbon Efficiency Code" hierarchical governance system, converting carbon emission indicators into quantifiable, manageable dynamic credit assets. This system covers three major entities—bus enterprises, logistics companies, and ride-hailing platforms—implementing differentiated management through green/yellow/red codes: Green-code enterprises receive incentives such as low-interest loans, government interest subsidies, and priority in transportation project bidding; yellow-code enterprises must rectify within deadlines under intensified environmental supervision; red-code enterprises face constraints including financing restrictions and operational route adjustments. This "positive incentives + reverse constraints" mechanism reduces annual average transportation carbon intensity by over 3.5%, achieving 40% higher efficiency than traditional administrative controls. Second, the "Carbon Efficiency Loan" product innovation, developed in collaboration with financial institutions, further bridges emission reduction value with financial capital. By linking corporate carbon efficiency ratings to loan interest rates, a "reduction-credit enhancement-financing convenience" closed loop emerges: One logistics company secured a green loan at a 3.2% annual interest rate—1.8 percentage points lower than standard commercial loans—due to its upgraded carbon efficiency rating, enabling the purchase of 20 new-energy trucks that reduce annual emissions by 1200 tons of CO_2. Such market-driven approaches significantly boost corporate emission reduction initiatives, with data showing participating enterprises increasing emission reduction investments to 5.2% of revenue, far exceeding industry averages. Third, the "1-4-6-4-N" strategic framework ensures sustainable low-carbon transition at the systemic level: Focusing on the Green Intelligent Rail System as the core objective, it spans four phases (planning, construction, operation, maintenance), integrates six key technologies (photovoltaic power generation, intelligent dispatching, regenerative braking energy recovery), establishes four management platforms (carbon emission monitoring, credit evaluation, financial support, public participation), and implements N application scenarios (hydrogen-powered bus demonstration lines, community micro-circulation buses). This framework combines technological integration with scenario implementation, avoiding fragmentation from single-technology promotion. For example, the Rail Line 1 project simultaneously applied BIM construction optimization, station photovoltaic power generation, and rainwater recycling, reducing energy consumption per kilometer by 22% compared to conventional subways. Fourth, a multi-departmental coordination mechanism provides critical implementation safeguards. The municipal low-carbon transportation task force coordinates 12 departments (transportation, environment, finance, etc.) through a "weekly meetings + monthly briefings + quarterly assessments" workflow, enabling horizontal linkage between the "Carbon Efficiency Code" and urban planning/industrial policies. For instance, in an industrial park plan, the task force mandated rail transit station coverage within 500 meters as a land-use red line, compelling companies to adjust logistics plans and reducing private car commuting from 38% to 19%.

5.2. Dynamic Response in Technological Innovation

Shaoxing advances technological innovation to drive low-carbon transition through green-intelligent integration. First, full-lifecycle rail transit technology integration serves as the core approach. In green construction, BIM technology reduced material waste from 8% to 2.3% while increasing recycled material usage to 32%. For intelligent operations, photovoltaic panels on 70% of station rooftops supply 30% of annual electricity needs, and intelligent dispatching systems decreased train idling rates from 15% to 6%. In energy-saving maintenance, regenerative braking energy recovery reached 20% efficiency, and rainwater recycling systems saved 4000 m^3 per station annually. These integrations reduced rail energy consumption to 0.05 kWh per passenger-kilometer—82% lower than private vehicles. Second, the three-network integrated smart service system enables data interoperability via the "Shaoxing Travel" APP, offering one-click intermodal services ("rail + bus + shared bike"). Integrating real-time data from 21,000 shared bikes, 1200 buses, and 86 rail trains, the system automatically plans optimal routes with promotional offers. During trials, bus punctuality rose from 82% to 95%, shared bike usage tripled daily, and short-distance private car travel decreased by 18%. Third, technological spillover effects enhance industrial synergy. The Carbon Efficiency Code compelled logistics upgrades: One courier company invested ¥120 million in new-energy heavy trucks and three photovoltaic charging stations, creating a "transportation-charging-PV" loop that cuts 5000 tons of emissions annually. Rail transit-oriented development (TOD) spurred PV industrial parks along rail corridors, with a 10 MW rooftop PV project generating enough electricity for 200 trains annually—achieving spatial alignment between transportation energy use and green power.

5.3. Dynamic Infrastructure Support

Shaoxing prioritizes infrastructure planning to reshape low-carbon spatial patterns through three-network integration. First, integrating rail, bus, and slow-travel systems establishes a multi-dimensional "rail-led, bus-supported, slow-travel-supplemented" mobility framework. Line 1 connects downtown with Keqiao and Shangyu industrial parks, replacing 21,000 daily private car trips and slowing car ownership growth along the corridor from 12% to 3%. Customized buses serve 12 industrial parks via 36 dedicated routes, while community micro-circulation lines cover 90% of residential areas, reducing private car commuting by 12%. New 180-km bike lanes and greenways decreased short-distance motorized trips by 35%, with slow-travel systems serving 450,000 daily users. Second, spatial optimization strategies reconfigure functions by "narrowing vehicle lanes + widening slow-travel space." In pilot old-town sections, vehicle lanes shrank from four to two, adding 2.5 m bike lanes and 1.5m sidewalks to create "15-minute low-carbon life circles," boosting nearby commercial traffic by 25%. The "park + transportation" model fully connects greenways to rail entrances, with five pocket parks built within 300 m of one station, cutting slow-travel transfer time from 15 to 5 minutes. Third, infrastructure enhances land-use efficiency: Within 500 m of rail stations, commercial development intensity increased 40%, residential density rose 25%, and GDP output per land unit grew 38%. This "rail + property" model shifts urban expansion from horizontal sprawl to vertical intensification, offering a template for compact development in small-medium cities.

5.4. Dynamic Optimization of Policy Mechanisms

Shaoxing leverages policy tools to enable digital empowerment and market incentives. First, Carbon Efficiency Code 2.0 extends governance to individual "transportation carbon accounts," where points redeem 12 benefits like bus passes and attraction tickets. In one community trial, 500,000 residents earned points via cycling/walking/public transit (1 km cycling = 1 point = ¥0.20 voucher), redeeming ¥12 million annually. Corporate carbon efficiency links to land approvals and subsidies: One logistics company gained priority approval for 50-acre warehouse land, saving ¥2 million annually after rating upgrades. Second, green finance innovations overcome funding barriers with a ¥2 billion "Low-Carbon Transportation Special Bond" (China's first) and a "Carbon Emission Reduction Risk Compensation Fund." The bond financed 500 hydrogen buses, raising their share from 5% to 25%. The fund subsidizes 30% financing costs for green-code firms, with one new-energy automaker saving ¥15 million annually on a ¥500 million loan. Third, a digital supervision system—featuring a cloud platform monitoring 2000+

transport vehicles—ensures data authenticity via third-party audits and public oversight. One logistics firm downgraded to yellow-code for data fraud lost government procurement eligibility, driving monitoring improvements that lifted data accuracy to 98%.

5.5. Dynamic Guidance for Public Participation

Shaoxing cultivates low-carbon travel culture through education and engagement. First, the Carbon Inclusion Initiative spurs participation via "cycling points for vouchers" and "community low-carbon rankings." In one district, 500,000 residents' cycling activities cut 24,000 tons of CO_2 yearly; TOP100 families in community rankings received free annual bus passes, with top 10 trying hydrogen buses—boosting green travel from 65% to 82% through "honor + benefit" incentives. Second, immersive education expands reach via "Carbon Neutral Theme Pavilions" and school curricula. Station-based pavilions attract 100,000 visitors yearly, teaching low-carbon practices through VR and games; the "Water Town Green Journey" curriculum (100% coverage) incorporates student-designed "low-carbon travel maps" into city navigation, creating an "educate children, influence families" ripple effect. Third, public decision-making mechanisms enhance transparency through "low-carbon transportation ideas" campaigns and project hearings. Over three years, 127 citizen proposals were adopted (e.g., optimizing bus stops, adding bike parking). For one rail line, online consultations/hearings/satisfaction surveys adjusted five station locations, improving 30% of residents' travel convenience.

This study argues Shaoxing's standardized toolkit offers "plug-and-play" solutions for other cities. The open-source Carbon Efficiency Code system includes data collection, coding rules, and finance modules tailored for medium cities; coding templates set industry/size-specific standards to avoid one-size-fits-all; financial tools provide 10 options (loan discounts, risk compensation, special bonds) for flexible fiscal adaptation. The industry-transportation-energy synergy paradigm achieves multiplicative effects: The Code drives logistics firms to buy new-energy trucks, boosting local battery/motor industries; rail TOD attracts PV firms to corridor industrial parks, closing "green power production-transport consumption" loops. This synergy cuts transportation carbon emissions per GDP by 45% versus conventional models. Gradual implementation mitigates transition risks: Phase 1 pilots three-network integration in old towns/hi-tech zones to refine standards over 1 - 2 years; Phase 2 replicates the Code to manufacturing/construction; Phase 3 establishes inter-city carbon trading markets within five years to form regional reduction networks. This "local-to-global, sector-to-region" approach spreads costs over a decade, limiting annual investment to 0.8% of GDP. Shaoxing's success stems from its "institutional innovation-spatial restructuring-technological empowerment" triangle: Institutions provide governance frameworks, spatial restructuring optimizes resource allocation, and technology enhances operational efficiency. This systemic approach particularly suits Yangtze

River Delta small-medium cities, with modular, standardized solutions offering turnkey implementation blueprints to accelerate regional low-carbon transportation transitions (Sun, 2019).

6. Conclusion

In the context of Chinese-style modernization, the low-carbon transportation transition in large cities is a core proposition that integrates economic development, social equity, and ecological sustainability. This study takes Shaoxing as a sample, revealing the strategic value and practical pathways for low-carbon transportation development: On one hand, the necessity of systemic change. Traditional fragmented governance models struggle to address high-carbon lock-in effects. Shaoxing, through a "dynamic strategy-driven model," achieves synergistic breakthroughs in five dimensions: top-level design (carbon efficiency code hierarchical governance), technological innovation (green-intelligent rail integration), spatial restructuring (three-network integration), policy incentives (carbon account financialization), and public participation (carbon inclusiveness), demonstrating that systemic solutions can overcome technological bottlenecks and institutional barriers. On the other hand, the universal value of the Shaoxing model. Its "institutional innovation-spatial restructuring-technological empowerment" triangular model provides a standardized toolkit; the open-source carbon efficiency code system is adaptable to medium-sized cities' governance scenarios, driving a 40% increase in corporate emission reduction efficiency; the industry-transportation-energy synergy paradigm (e.g., rail transit TOD development coupled with photovoltaic industry) reduces transportation carbon emissions per unit GDP by 45%; the incremental promotion path (pilot → industry replication → regional networking) controls annual investment below 0.8% of GDP, reducing transition risks. This study provides an effective demonstration for the implementation of the national standard—Carbon Emission Accounting Method for Road and Waterway Commercial Transport Vehicles.

However, the model's promotion requires localization. For major cities in China's central and western regions (e.g., Xi'an, Urumqi) and northeastern region (e.g., Harbin, Shenyang), where sustained intensive fiscal investment is limited, the transition and adjustment period needs to be appropriately extended, and greater emphasis must be placed on the resilience and execution capacity of long-term planning. Simultaneously, deep integration with local natural resource endowments is essential, prioritizing the development and application of more cost-effective and operationally simpler economic technological innovation solutions to achieve the sustainable advancement of the low-carbon transition.

Simultaneously, future challenges and directions for low-carbon transportation require deepening breakthroughs in hydrogen energy storage and transport technologies, building cross-regional carbon sink markets, and safeguarding the mobility rights of vulnerable groups. Low-carbon transportation is not merely a technological substitution but a restructuring of urban governance paradigms—driving complex system changes under the "dual carbon" goals through dynamic strategies, providing a replicable "green artery" solution for Chinese-style modernization (Yao, Gao, Zhou, & Gu, 2025).

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Conflicts of Interest

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