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Strategies for Green Logistics Development in China

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Abstract

This article proposes a strategic framework to advance green logistics in China and mitigate the environmental pressures associated with the sector's rapid, growth-driven expansion. It synthesizes policy directions and practical measures that promote renewable energy adoption, improve energy efficiency, cut carbon emissions, and embed resource-efficient, environmentally responsible practices across logistics operations. The strategy extends to building eco-friendly infrastructure on land, sea, air, and rail, coordinated through modern technological systems, and leverages the Belt and Road Initiative to accelerate green logistics domestically and internationally. Evidence from Shanghai, Shenzhen, Beijing, and Hangzhou illustrates early successes. The framework is organized around six pillars—Government, Responsibility, Environment, Energy, Network, and Standards (GREENS): strong public policy and targeted infrastructure investment; shared accountability for sustainable action across sectors; systematic consideration of environmental impacts; substitution of fossil fuels with clean and renewable energy; collaborative public–private partnerships; and clear certifications with measurable indicators aligned to global norms. Together, these approaches reduce carbon emissions while improving the efficiency and competitiveness of China's logistics system.

Keywords: Green logistics, Environmental management, China, Sustainable development

Introduction

Over the past two centuries, China's unprecedented economic and industrial growth has propelled it to become one of Asia's fastest-expanding markets, contributing over 28% of the global industrial output by 2020. The rise of e-commerce platforms such as Taobao, JD.com, and Tmall in 2010 marked a major turning point that significantly accelerated the growth of the country's logistics industry. Since 2014, China has maintained its position as the largest logistics market in the world for 10 years. This aligns with a report by the Thai Trade Center Guangzhou (2024), which stated that in 2023, China's logistics industry reached a total value of 350 trillion yuan, returning to its pre-pandemic level in 2019. This achievement has served as a key engine driving China's rapid economic expansion. Widespread contamination of soil, water, and air has profoundly affected public health, with smog episodes posing particularly acute challenges in metropolitan areas such as Beijing and Shanghai (Isranan, 2014).

Studies have shown that China is the world's largest energy producer and consumer, as well as the largest emitter of carbon dioxide (CO_2), accounting for one-third of global carbon dioxide emissions (Cao et al., 2023). As a result, China is striving to reduce carbon emissions through its "dual carbon" policy, which aims to achieve carbon emission peaks by 2030 and achieve carbon neutrality by 2060. According to the China Green Logistics Development Report 2023, the logistics industry accounts for approximately 10% of the country's total carbon dioxide (CO_2) emissions, ranking second only to the manufacturing industry (Deng et al., 2022). Furthermore, data from the China Statistical Yearbook indicate that between 2000 and 2022, the volume of road freight transportation in China increased by approximately 70%. This rapid growth has inevitably

led to a substantial rise in fossil fuel consumption—China's primary energy source—as well as a significant increase in carbon dioxide (CO_2) emissions from the logistics industry (Xu, 2024).

The Chinese government has recognized the severity of this issue and has undertaken a range of measures to address it. These efforts include prioritizing the controlling of the industrial sector, particularly for projects characterized by high energy consumption and significant environmental pollution. As part of these initiatives, provincial-level governments—including provinces, autonomous regions, and municipalities—are required to compile and submit detailed inventories of existing, under-construction, and planned high-energy-consuming and high-emission projects to the National Development and Reform Commission (NDRC). In parallel, China launched its national Emissions Trading Scheme (ETS) in 2021 as a market-based mechanism to incentivize carbon reductions within the industrial sector, as well as the power generation industry. Between its inception and March 30, 2022, the ETS facilitated a cumulative trading volume of approximately 8.2-billion-yuan, equivalent to around 188 million metric tons of carbon emissions. By 2025, the scope of the scheme is expected to expand to include eight key energy- and carbon-intensive industries, such as petrochemicals, building materials, steel, and non-ferrous metals.

Although the logistics industry—China's second-largest source of carbon emissions after manufacturing—has been a policy focus since 2020, broader national efforts have been guided by China's energy security strategy. As outlined in a White Paper (WP) titled "Energy in China's New Era," this strategy adopts a "Four Reforms and One Cooperation" framework. A central component of this policy is the promotion of international energy cooperation, particularly through the integration of energy infrastructure between China and countries participating in the Belt and Road Initiative (BRI) (Rattanakosin, 2022). In addition, the adoption of the "green logistics" concept—a new development approach that emphasizes efficient resource utilization and environmental sustainability—has been promoted as a means of supporting China's transition toward more sustainable and resilient economic growth (Xu, 2024).

This article aims to examine the core of China's green logistics development strategy, which is grounded in the principles of sustainable development, the concept of green logistics, and case studies of key initiatives, including the Belt and Road Initiative (BRI), the Green Shield Action campaign, and the advancement of green logistics practices in urban contexts worldwide. The objective is to inform stakeholders in the logistics sector—particularly those in Thailand—about emerging trends and international developments that may soon influence the regional logistics landscape.

Sustainable development

In economic terms, development is often defined as the ability of a national economy to sustain a Gross National Income (GNI) growth rate of 5 to 7 percent per annum or higher (Todaro & Smith, 2006). Conversely, a country's sustainability is often assessed through the growth of Gross National Income per Capita (GNI per capita). However, several scholars have argued that economic growth alone is an insufficient indicator of sustainability.

The concept of development has evolved beyond a narrow focus on economic growth to encompass the broader notion of human development. Todaro and Smith (2006) argue that economic growth should not be viewed as the ultimate objective of development; rather, development must aim to improve the quality of life and expand human freedoms. As they assert, "Development has to be concerned with enhancing the lives we lead and the freedom we enjoy." This perspective has contributed to the growing recognition and acceptance of the concept of sustainable development, which integrates economic, social, and environmental dimensions.

In 1983, the United Nations General Assembly established the World Commission on Environment and Development (WCED), which convened for the first time in October 1984. The Commission's findings were later published in the landmark report Our Common Future—commonly known as the Brundtland Report. In April 1987, the report formally introduced the concept of "sustainable development," defining it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). This

approach emphasizes the need to balance economic growth, social inclusion, and environmental protection (Brundtland, 1987).

Building on the concept of "sustainable development," the Sustainable Development Index (SDI) was developed to assess progress across three key dimensions: (1) The resource condition dimension, which emphasizes the preservation of natural resources for future generations; (2) The environmental and ecological dimension, which focuses on ensuring access to a clean and healthy environment in both the present and the future; and (3) The quality of life dimension, which seeks to promote well-being and a high standard of living across generations. This concept was later expanded into the Sustainable Development Goals (SDGs), a comprehensive and interconnected global agenda encompassing five key dimensions of sustainable development: (1) People, emphasizing the eradication of poverty and hunger, and the reduction of social inequality; (2) Planet, focusing on the protection and preservation of natural resources and the climate for future generations; (3) Prosperity, promoting well-being and economic growth that is aligned with environmental sustainability; (4) Peace, advocating for peaceful, inclusive societies grounded in justice and mutual coexistence; and (5) Partnership – encouraging collaboration among all sectors to drive progress toward sustainable development (United Nation, 2022).

Green logistics

Since the 1990s, the concept of sustainable development has played a significant role in raising global awareness of "green consumption." During this period, green consumption emerged as a trend characterized by growing public consciousness about environmental protection and harmonious coexistence with nature. This shift in consumer behavior contributed to the development of the green market. However, upon closer examination, it becomes evident that responding to the green market entails more than simply developing environmentally friendly products. A comprehensive green market strategy must also encompass broader dimensions, including research and development (R&D), market trend forecasting, and the establishment of sustainable logistics systems (Song, 2024). However, the development of logistics systems must take into account various external factors, such as economic conditions and competitive pressures. This aligns with the findings of Yao (2020), who identified several key determinants influencing logistics development: industrial technology, macroeconomic conditions, government policies, transportation infrastructure, the level of logistics management, the broader social context, and the active participation of stakeholders within the logistics system. The continuous growth of China's manufacturing and e-commerce industries has led to the increasing recognition and active development of the concept of green logistics.

At its core, this concept is rooted in the recognition of the environmental impacts associated with logistics processes. The extensive consumption of fossil fuels and the resulting high levels of carbon dioxide emissions each year (Xu, 2024) have driven the development of green logistics concepts across multiple disciplines, including supply chain management, transportation, resource management, and green technology innovation. Green logistics refers to the comprehensive management of all processes related to the movement of goods, raw materials, and information—ranging from upstream to downstream—across the entire supply chain, including both forward and reverse logistics. At the ASEAN Transport Ministers (ATM) Meeting held in Kuala Lumpur, Malaysia, six best practices for promoting green logistics were identified: (1) Modal shift, (2) Joint transportation, (3) Unification and relocation of cargo bases, (4) Adoption of CO2 emission reduction technologies, (5) Development of sustainable infrastructure, and (6) Supportive government policies. These practices aim to minimize the ecological impacts of logistics activities, promote energy conservation, and reduce operational costs, thereby enhancing the overall efficiency of transportation and distribution systems (Boonraksa et al., 2025).

Green logistics in China

China has recognized the dangers of environmental degradation since as early as 1998, when it established the State Environmental Protection Administration (SEPA), which was later elevated to ministerial status. In its effort to address environmental challenges, the government allocated approximately USD 156 billion to support environmental protection

initiatives. Increased collaboration with domestic non-governmental organizations (NGOs), previously regarded as unofficial or even illegal entities, has accompanied these efforts. As a result of collaboration in environmental conservation, the number of non-governmental organizations (NGOs) in China has grown significantly over the past decade, contributing to increased public awareness of the risks associated with pollution (Isranan, 2014). In recognition of the critical role that green logistics plays in advancing sustainable development and addressing societal needs, the Chinese government introduced the National Green Logistics Development Plan (2014-2020). This policy framework set out clear objectives and strategic measures for the nationwide implementation of green logistics practices (Ministry of Commerce of the People's Republic of China, 2014).

Nevertheless, the development plan still faces several challenges, including modern transportation technology, complete infrastructure, transportation system management under the concept of environment-oriented management, budget, information sharing between agencies, and promotion from government agencies at various levels (Huang et al., 2024; Song, 2024). Environmental policy has become markedly clearer under President Xi Jinping, who famously declared that "绿水青山就是金山银山," commonly rendered as "lucid waters and lush mountains are mountains of gold and silver." In brief, the slogan underscores that "protecting waters and forests is the true path to national prosperity." Reflecting this principle, China's 14th Five-Year Plan (2021-2025) embeds ambitious conservation targets: expanding forest coverage, restoring ecosystems, and—most crucially—reducing the nation's net carbon emissions to zero, following years in which China was the world's largest carbon emitter (Katchalee, 2021).

Environmental protection and biodiversity conservation have been central pillars of President Xi Jinping's administration. The Chinese central government has introduced a series of major environmental policies and initiatives, including the Central Inspection on Environmental Protection (CIEP), the Green Shield Action (GSA), and the Nationwide Campaign to Prevent and Control Pollution (NBPCP). The promotion of green logistics principles within domestic supply chains has complemented these efforts (Chen et al., 2023; Han et al., 2024). Furthermore, China has extended these principles beyond its borders through the Belt and Road Initiative (BRI), advancing the green logistics agenda both nationally and in partner countries along the BRI routes (Zhang et al., 2023).

BRI project and green logistics development

China's progress in environmental performance has begun to materialize tangibly through the implementation of the Belt and Road Initiative (BRI), with notable developments observed across multiple domains (BRI Green Development Institute, 2022; Dong, 2022a; Wang, 2020; Wang et al., 2021), as outlined below:

Environmentally friendly infrastructure development under the BRI includes several key initiatives: (1) The construction of high-speed rail networks, which aim to reduce greenhouse gas emissions by offering a lower-emission alternative to road and air transportation; (2) The development of green ports that utilize clean energy sources and incorporate efficient waste management systems; and (3) The establishment of smart logistics centers that leverage Internet of Things (IoT) and artificial intelligence (AI) technologies to enhance operational efficiency and minimize energy consumption. The promotion of multimodal transportation focuses on two key strategies: (1) The seamless integration of rail, road, and waterway transport networks and (2) The adoption of standardized containers that are compatible across multiple transport modes, thereby reducing handling time and lowering energy consumption.

The adoption of green technologies in the transportation sector encompasses several strategic initiatives: (1) Promoting the use of electric and hybrid vehicles for short-distance transport to reduce emissions and reliance on fossil fuels; (2) Developing and utilizing biofuels as a cleaner energy alternative for maritime transport; and (3) Implementing intelligent transport tracking and control systems to optimize routing, reduce fuel consumption, and enhance operational efficiency.

Green supply chain management includes 1) Promoting the use of environmentally friendly and recyclable packaging; 2) Designing efficient transportation routes to reduce distance and emissions;

and 3) Using automated warehouse management systems to reduce energy use and increase accuracy.

The development of green logistics standards and certification includes: (1) establishing common environmental management and energy efficiency standards among Belt and Road Initiative (BRI) participating countries; and (2) encouraging the adoption of internationally recognized certifications, such as ISO 14001 for environmental management systems.

The establishment of international cooperation in green logistics include: (1) Facilitating the exchange of knowledge, best practices, and technologies related to green logistics among Belt and Road Initiative (BRI) member countries; and (2) Developing joint pilot projects aimed at testing and implementing innovative green logistics solutions.

Human resource training and development includes 1) organizing green logistics training courses for personnel in BRI member countries and 2) promoting green logistics research and development in educational institutions.

The integration of Big Data and Artificial Intelligence (AI) into logistics planning and operations include: (1) analyzing large datasets to identify the most efficient transportation routes, thereby minimizing environmental impact; and (2) utilizing AI to forecast demand and optimize inventory management, which helps to prevent overstocking and reduce unnecessary transportation activities.

The study of Zhang et al. (2023), which examined the impact of BRI projects on carbon emissions in Chinese cities between 2006 and 2020, found that BRI projects significantly reduced carbon emissions in cities along the route, particularly in cities in western and eastern China, as most BRI projects are concentrated in these two regions. The study further suggests that the Belt and Road Initiative (BRI) has the potential to reduce carbon emissions more effectively than cities with high-emission industries—such as electronics, manufacturing, and construction—owing to the technological capabilities and industrial structures within the BRI framework that support more efficient and sustainable practices (Zhang et al., 2023). Similarly, a study by Ye et al. (2024) found that the Belt and Road Initiative (BRI) has had a positively impact on improving Green Logistics Efficiency (GLE) in partner countries along the route, with the initiative achieving an efficiency rate of only 15.9% in reducing carbon emissions. The study also found that high-income trading partners exhibit significantly higher Green Logistics Efficiency (GLE) compared to middle-income countries; however, this gap has shown a consistent narrowing trend over time.

The findings of the above-mentioned study suggest that the BRI project has the potential to significantly reduce carbon emissions in key industries within China and its high-income trading partners. This is largely attributed to their advanced technological capabilities, well-developed infrastructure, and stronger economic capacity, all of which facilitate the adoption of low-carbon and sustainable logistics practices. From a long-term perspective, the Belt and Road Initiative (BRI) is expected to encourage cities with a strong presence of secondary industries—such as power generation, natural gas extraction, petroleum, and other energy- and carbon-intensive sectors—to restructure their industrial base. This transformation aims to reduce energy consumption and carbon emissions by shifting toward tertiary industries, such as finance and tourism, which are characterized by lower energy intensity and relatively lower average carbon emissions (Zhang, et al., 2023). Meanwhile, middle-income trading partners will benefit from international cooperation in upgrading GLE to be on par with high-income countries (Ye et al., 2024). This will improve the economy and quality of life of the project's trading partners, while also building an efficient green logistics supply chain for China.

Government policy and green logistics development

The advancement of green logistics in China has been partially driven by government policies that emphasize environmental awareness and the importance of ecological preservation, reinforced by strict regulatory enforcement and rigorous inspections. Interestingly, some government policies are not directly related to the development of green logistics in China. These policies are designed to empower various sectors— particularly local governments— to actively monitor and assess the natural environment, as well as identify and regulate activities that may pose

environmental risks within their jurisdictions. Key areas of focus include:

1. The Central Inspection on Environmental Protection (CIEP) was established to assess and improve environmental conditions across China's provinces. Launched in 2016, the initiative introduced a new mechanism in which central government committees are responsible for conducting environmental inspections and overseeing the implementation of environmental policies at the provincial level. Two rounds of inspections have been carried out: the first from January 2016 to September 2017, and the second from July 2019 to June 2022 (Chen et al., 2023).

2. The Green Shield Action (GSA) is a major policy for biodiversity conservation in China, launched by the central government in 2017. Its primary objective is to regulate and mitigate illegally approved economic activities— such as real estate development, mining, tourism, and hydropower generation— within designated nature reserves. Under this initiative, local authorities are tasked with inspecting and reporting violations related to the protection of National Nature Reserves (NNRs) within their jurisdictions (Wang et al, 2023).

3. The Nationwide Campaign to Prevent and Control Pollution (NBPCP) was launched in June 2018 with the objective of improving China's overall environmental quality by targeting reductions in air, water, and soil pollution. The campaign set ambitious targets to be achieved by 2020, including: increasing the proportion of days with excellent air quality in urban areas to over 80%; reducing emissions of toxic gases by 15% compared to 2015 levels; raising the proportion of land and coastal waters with excellent environmental quality to above 70%; and ensuring that over 90% of land designated for use is free from harmful contaminants (Chen et al., 2023).

A key unifying element among these policies is the concerted effort to mitigate the environmental impacts of economic activities in sensitive areas, including communities, industrial zones, and nature reserves. As a result, local authorities have increasingly tightened the inspection, regulation, and licensing of activities such as housing development, tourism, mining, and hydropower production— particularly those linked to National Nature Reserves (NNRs). As a result of the GSA's policy, more than 1,100 local officials were prosecuted, more than 2,460 illegally licensed establishments were closed, and more than 5.9 million square meters of illegal structures were demolished by the end of 2017 (Han et al., 2024). This has resulted in the suspension or slowdown of permits for construction or conducting risky economic activities, and the return to legally licensed areas, resulting in efficient logistics as raw material sources or production sites are located in the same or nearby areas. While the CIEP and NBPCP policies promote the inspection of economic activities that may create air, water, and soil pollution through modern inspection methods by the central government's inspection agency (Chen et al., 2023), this has led to both public and private sector agencies in the area being aware of and seeking ways to prevent or reduce pollution problems, which has become an impetus for various green activities, including "green logistics," which is an important part of the supply chain to drive the country's economy towards sustainability.

From national policy formulation by the central government to local-level implementation, efforts to reduce the environmental impacts of economic activities have been wide-ranging. This article focuses specifically on the logistics sector, examining how environmentally friendly technologies, effective waste management practices, and the promotion of renewable energy as a substitute for fossil fuels. A review of the literature highlights the critical role of government policies in driving the transition of logistics activities toward more sustainable practices, often under close regulatory oversight. Several notable examples of this transition include:

1. Renewable Energy Utilization and Greenhouse Gas Emission Reduction: This initiative promotes the adoption of electric vehicles and hydrogen-powered trucks for freight transportation as part of broader efforts to reduce greenhouse gas emissions. Major cities such as Shanghai and Shenzhen have implemented Internet of Things (IoT) and big data technologies to enhance transport efficiency and lower energy consumption (Brief, 2025; Zhang et al., 2024). Notably, Shanghai has committed to installing 200,000 new intelligent charging facilities by 2025 to support the growing adoption of electric and hybrid vehicles across the city (Zhang et al., 2024). Meanwhile, Shenzhen plans to

replace 77 percent of its public transportation with electric vehicles by 2024 and reduce its energy intensity by 14.5 percent by the end of 2025 (Brief, 2025).

2. Developing an Eco-Friendly Smart Logistics Network: Cainiao, an Alibaba subsidiary, has developed a green campaign and digital systems to respond to the growth of e-commerce by designing (e-Shipping labels, smart packing, sorting, and parcel routing algorithms) and launching built smart warehouses and deployed robots and autonomous vehicles that contributed to lower ecological footprint (Liang & Cheah, 2021). Meanwhile, nearly all of the company's packaging materials are biodegradable, and the use of packing tape has been reduced by 50 percent (Cainiao Group, 2022).

3. Promoting Recycling and Waste Management: Cainiao has launched a carton recycling program, setting up recycling points in several cities across the country and collecting used cartons for recycling or remanufacturing. The program has helped reduce waste by 53,000 tons in 2021 (Zhao & Utley, 2022).

These cases represent only a small subset of China's extensive green-logistics initiatives, propelled by public–private partnerships and galvanized by stringent government policies that, for decades, have accelerated the nation's response to major environmental challenges.

China's green logistics implementation

Green logistics operations in China have developed and expanded rapidly over the past decade, driven by increasing awareness of the environmental impacts associated with transportation and logistics processes. A comparative analysis of green logistics implementation across various Chinese cities reveals both successes and ongoing challenges. Key factors contributing to this development include the establishment of policy frameworks supporting sustainable development, the adoption of environmentally friendly technologies, infrastructure improvements, strong public–private collaboration, and the implementation of concrete, enforceable policies. Collectively, these efforts have effectively addressed environmental concerns and align closely with the best practices for green logistics outlined at the ASEAN Transport Ministers Meeting held in Kuala Lumpur, Malaysia. The development of green logistics in China can be summarized in the following key steps:

1. Policy and Legal Framework Formulation: China's transition toward green logistics began with the establishment of a robust policy and legal foundation. The National Green Logistics Development Plan (2014-2020) articulated explicit targets and implementation measures for sustainable logistics operations (Ministry of Commerce of the People's Republic of China, 2014). This framework has been reinforced by successive environmental and biodiversity policies—most prominently the 14th Five-Year Plan (2021-2025) and the "dual-carbon" strategy, which prioritizes energy conservation and carbon-emission reduction and identifies the logistics sector as a key driver of change (Xu, 2024; Xu & Li, 2024). Collectively, these instruments lay the institutional groundwork for China's long-term transition to a green economy.

2. Investment in Infrastructure: The second key step involves substantial investment in environmentally friendly infrastructure. This includes the construction of intercity transportation networks designed with consideration for environmental impacts, particularly in ecologically sensitive areas; the expansion of high-speed rail systems; and the development of clean energy-powered ports (BRI Green Development Institute, 2022; Wang, 2020). These infrastructure investments have played a crucial role in significantly reducing carbon emissions and other pollutants associated with the logistics sector.

3. Promotion of Technology and Innovation: China assigns high priority to the research and development of green technologies, particularly in the realms of electric vehicles and smart logistics-management systems. Notable examples include connected electric-mobility platforms that issue real-time safety alerts, fully autonomous (Level - 5) freight vehicles, and big-data–driven logistics and agri-food information systems (BRI Green Development Institute, 2022; Wang, 2020). Robust government support for these innovations has accelerated the uptake of clean technologies across the logistics sector.

4. Public–Private Partnerships: The Chinese government has actively cultivated public–private collaboration to accelerate green-logistics development. Dedicated joint working groups have been formed, and

preferential tax policies are offered to firms investing in clean technologies in designated pilot cities. For instance, Alibaba has leveraged data from more than 20,000 CCTV cameras to design

an urban traffic-flow optimization system in Hangzhou, while Baidu is piloting autonomous-vehicle technology in Xiong'an. In addition, large enterprises have been encouraged to co-finance smart public-transport projects—often in return for tax rebates or other regulatory privileges. (BRI Green Development Institute, 2022; Wang, 2020).

5. Development of Standards and Certification: China has established a comprehensive system of standards and certification for green logistics to incentivize firms to adopt more environmentally friendly practices. These standards encompass transportation, warehousing, and eco-friendly packaging design. A notable example is Cainiao, an Alibaba affiliate, which has introduced low-carbon intelligent warehousing systems and environmentally sustainable packaging solutions (Cainiao Group, 2022; Liang & Cheah, 2021).

6. Awareness-Raising and Personnel Training: The final pillar of China's green-logistics development is the cultivation of environmental awareness and the systematic training of logistics personnel. A prominent example is SF Express, a leading domestic and international courier and logistics provider, which places strong emphasis on comprehensive green-logistics training for its workforce. Such capacity-building initiatives are critical mechanisms for enhancing the efficiency and effectiveness of the company's green-transport system and ensuring the long-term sustainability of China's logistics sector (Huang et al., 2024). Likewise, JINGDONG—one of China's leading e-commerce companies—has found that employees' understanding of green-logistics technologies, industry standards, and certification systems has a significant positive effect on their awareness of the environmental impacts and sustainability imperatives of green-logistics operations (Yunlin, 2023).

Collectively, these steps illustrate China's strategic approach to advancing green logistics—spanning policy formulation, infrastructure investment, technological innovation, and human-resource development—in response to environmental challenges and with the goal of reducing energy use and natural-resource consumption across the nation's pivotal logistics sector. In addition, customer pressure is also a key factor driving third-party logistics providers (3PLs) in China to adopt green innovation (Chu et al., 2019). Concurrently, China's aspiration to supply goods to markets worldwide emphasizes the important function of green logistics in facilitating its export expansion—especially to member states of the Regional Comprehensive Economic Partnership (RCEP). In an era of accelerating climate change and global warming, governments across the globe are introducing policies that encourage and reward environmentally responsible business practices. Therefore, enhancing the efficiency of green logistics constitutes a critical lever for improving the overall effectiveness of China's export performance (Fan et al., 2022).

Examples of green logistics development in various cities

The concept of green logistics has extended into various sectors and is no longer limited to the freight transportation industry. For example, major cities in China have adopted technology to enhance logistics management in various aspects, as follows:

1) Shanghai is one of the most advanced and comprehensive cities in the development of green logistics, having modernized and improved the efficiency of its infrastructure systems. This includes the use of electric vehicles and hydrogen-powered trucks for freight transport, as well as electric buses and taxis within the public transportation network. Additionally, Shanghai has enhanced the efficiency of maritime and rail transport by adopting clean energy solutions. The city has also implemented intelligent systems for goods sorting and storage to replace outdated logistics infrastructure (Shanghai Municipal People's Government, 2024).

2) Shenzhen has also demonstrated substantial progress in green logistics by leveraging advanced technologies, including the Internet of Things (IoT) and Big Data, to enhance efficiency and sustainability. The implementation of intelligent transportation systems and optimization of delivery routes have significantly decreased energy consumption and greenhouse gas

emissions (Shenzhen Daily, 2022). Furthermore, government support in the form of investments in green technology as well as research and development has provided a robust foundation for Shenzhen's logistics initiatives, aiming to help Shenzhen achieve its goal of becoming China's first city with zero-emission freight zones (Xue, 2021)

3) Beijing has embraced green logistics concepts through the integration of renewable energy and eco-friendly transportation systems, particularly during large-scale events such as the 2022 Beijing Winter Olympics. The widespread use of electric-powered public transport and freight vehicles during the event underscored the city's commitment to reducing emissions and promoting sustainable practices. In addition to adopting renewable energy, Beijing has invested in the development of infrastructure to support green logistics (Wang et al. 2022).

4) Hangzhou has distinguished itself by combining cutting-edge technologies with a focus on energy efficiency to advance green logistics. The application of artificial intelligence and Big Data technologies in transportation management has optimized operational efficiency and minimized environmental impact. Moreover, the utilization of electric and hydrogen-powered trucks for freight logistics and the development of eco-friendly warehouses have further enhanced Hangzhou's sustainability credentials. Collaborations with leading technology companies have also facilitated the adoption of innovative solutions that improve energy efficiency and reduce emissions (Liu, 2016)

An analysis of green logistics implementation in China reveals that all cities place significant emphasis on the use of vehicles for freight transport and public transportation. The government actively supports various green technologies, such as the use of renewable and alternative energy sources, and enacts policies to ensure that these transitions are implemented in a tangible and measurable way. Table 1 presents a summary of these developments.

Table 1 Comparison of green logistics practices across global cities

Cities	Technologies used	Supporting policies	Environmental impacts
Shanghai	Electric vehicles (EVs), hydrogen-powered trucks and intelligent transport system	Policies for supporting investment in green technologies	Reducing greenhouse gas emissions and utilizing renewable energy (Shanghai Municipal People's Government, 2024)
Shenzhen	IoT, Big Data	Policies for promoting the use of intelligent transportation systems, zero-emission freight zones	Enhancing transportation efficiency and reducing energy consumption (Shenzhen Daily, 2022; Xue, 2021)
Beijing	Electric vehicles (EVs) and green public transportation	Policies for supporting renewable energy	Reducing greenhouse gas emissions and utilizing renewable energy (Wang et al., 2022)
Hangzhou	hydrogen-powered trucks, IoT, Big Data agricultural information system, smart warehouse	Regulations on sustainable packaging use, Green zoning policies, Intercity freight transport network integration	Reducing plastic and paper waste from packaging, lowering transport-related emissions in controlled zones, and enhancing transportation efficiency (Liu, 2016).

Conclusions

The logistics industry plays a vital role in driving China's economic development; however, it has also contributed to critical issues related to public health, environmental pollution, and declining quality of life. The development of green logistics presents a strategic solution that allows the transportation sector to remain a key engine of national progress while simultaneously improving quality of life, supporting economic growth, and promoting environmental sustainability. A synthesis

of China's success in engaging the private sector in green logistics initiatives reveals several key factors contributing to this achievement, as outlined below.

1. Strong policies and regulations. Chinese government has enacted robust policies and regulations to support the development of green logistics; for example, National Green Logistics Development Plan (2014-2020), which sets out clear goals and concrete measures (Ministry of Commerce of the People's Republic of China, 2014). These policies serve as incentives and pressure mechanisms, encouraging the private sector to adopt more environmentally sustainable practices.

2. Financial incentives. Chinese government has implemented financial incentive measures such as tax reductions and subsidies for companies investing in green technologies (Wang et al., 2021; Xue, 2021). These measures help reduce financial burdens and actively encourage greater private sector investment in green logistics initiatives (BRI Green Development Institute, 2022; Wang, 2020).

3. Investment in green infrastructure. Chinese government has made substantial investments in environmentally friendly infrastructure, such as clean-energy rail systems and ports BRI Green Development Institute, 2022; Wang, 2020). These investments have created a supportive environment that enables the private sector to implement green logistics practices more effectively.

4. Public-private collaboration. Chinese government promotes collaboration between the public and private sectors through pilot projects, knowledge-sharing initiatives, and support for the research and development of emerging green technologies (BRI Green Development Institute, 2022). These collaborations enhance the effectiveness of policy implementation and create new business opportunities in the green logistics sector.

5. Standards certification development. China has developed standards certification system for green logistics (Yunlin, 2023). These standards enhance credibility and serve as incentives for companies to improve their operations in ways to be more environmentally friendly.

6. Awareness and training. Chinese government has launched training programs and awareness campaigns to promote green logistics (Smart Freight Centre, 2023). Similarly, private companies have prioritized the development of knowledge and skills among their personnel to support green logistics implementation (Huang et al., 2024; Yunlin, 2023).

The outcomes of these efforts are clearly reflected in research findings. An analysis of the carbon emission efficiency of China's logistics industry during 2010 - 2019 revealed that the carbon emission efficiency index increased from 0.479 in 2010 to 0.647 in 2019, indicating a significant improvement in the operational performance of the logistics sector under constant carbon emissions (Tang et al., 2022). Similarly, Li and Sun (2024) investigated the impact of green logistics practices on carbon emissions in the transportation sector across 30 provinces in China. Their findings indicate that the adoption of green logistics, particularly improvements in energy structure and information technology, has significantly reduced the carbon emission intensity of the transportation industry. Dong (2022b), through scenario analysis from a green supply chain management perspective, found that China's logistics sector holds substantial potential to reduce carbon emissions peaks. Under the country's dual-carbon policy, carbon emissions could peak and then decline by over 80%, from 876.6 million tons to 234.9 million tons by the year 2060."

Recommendations

The transformation of China's green logistics industry reflects the tangible outcomes of coordinated efforts between the government and private sector to simultaneously drive national economic development and address pressing environmental issues such as air pollution and smog. This success can be distilled into a strategic framework for green logistics development in China, referred to as the "GREENS" model, which consists of six key components:

G – Government: The government plays a central role in formulating policies, establishing regulatory frameworks, and investing in environmentally friendly infrastructure.

R – Response: All sectors must act responsibly—toward themselves, society, and the environment—in the implementation of logistics operations.

E – Environment: Any development or operational activity must prioritize its environmental impact and

long-term sustainability.

E – Energy: The transition from fossil fuels to renewable or clean energy sources must be pursued, particularly in freight and public transportation systems.

N – Network: Building collaborative networks between public and private stakeholders is essential for jointly addressing environmental challenges.

S – Standard: The establishment of clear, internationally recognized standards and certification systems is necessary to guide compliance and accountability across all involved parties.

Declaration of generative AI in scientific writing

The authors declare that no generative AI tools were used in this manuscript.

CRediT author statement

Wanphen Kuensman: Conceptualization, Methodology, Data curation, Investigation, Writing- Original draft preparation, Writing- Reviewing and Editing. **Prapassorn Visesprapa:** Writing- Original draft preparation, Writing- Reviewing and Editing. Priya Singh: Data curation, Writing- Original draft preparation.

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