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Can green transport policy drive urban carbon emission reduction? Evidence from pilot cities of China's low–carbon transportation system

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Introduction: Amidst the global climate crisis and the urgent need for carbon reduction, the transportation sector, a critical source of carbon emissions, has become a focal point for low-carbon transformation.
Methods: This paper investigates the impact of China's Low-Carbon Transportation System (LCTS) pilot policy on urban carbon emissions using a difference-in-differences (DID) model and a panel dataset covering 242 Chinese cities from 2007 to 2022.
Results: We find that the LCTS pilot policy has significantly reduced urban carbon emission intensity by an average of 17.3%, highlighting its effectiveness in promoting urban carbon reduction. Mechanism analysis reveals that the LCTS pilot policy achieves emission reduction primarily by fostering green technological development, advancing the clean energy transition, and enhancing government environmental attention. Furthermore, heterogeneous analysis indicates that the policy's effectiveness is more pronounced in cities with higher public environmental awareness, denser road networks, and stronger public transportation service capabilities.
Discussion: These findings offer valuable insights for the future design and implementation of green transportation policies, providing both theoretical support and empirical evidence for advancing the low-carbon transition in urban transportation sectors. This research contributes to the global efforts in achieving carbon neutrality and offers a reference for other countries and regions aiming to reduce carbon emissions in the transportation sector.

KEYWORDS

low-carbon transportation system, carbon emissions, green technology, energy transition, government environmental concern

1 Introduction

As global warming intensifies, the cascading environmental, economic, and social consequences of greenhouse gas and carbon dioxide emissions have become increasingly severe. Mitigating these emissions is critical for maintaining global ecological balance and ensuring long–term economic stability (Tu et al., 2022; Zhao et al., 2023; Li et al., 2025a). Among various emission sources, the transportation sector stands out as a major contributor, accounting for approximately one–quarter of global carbon emissions (Li et al., 2021; Wang S. et al., 2023). With ongoing urban expansion and motorization, this proportion is likely to grow, posing a significant barrier to achieving the climate action goals of the Sustainable Development Goals (SDGs), particularly SDG 13 (Fan et al., 2018; Sun et al., 2023).

Exploring emission reduction measures in the transportation sector is thus imperative for addressing the climate crisis, as well as for achieving sustainable economic growth, ensuring energy security, and optimizing urban spatial layouts. These efforts are closely intertwined with multiple SDGs: SDG 13 (climate action) relies on transportation–related emission reductions; SDG 7 (affordable and clean energy) requires advancing the energy transition in transport; SDG 11 (sustainable cities) demands green transportation systems to alleviate congestion and pollution; and SDG 9 (industry, innovation, and infrastructure) encourages new energy transport technologies to drive low–carbon transformation (Lambrecht and Willeke, 2025). These interconnected goals provide a clear direction for research on transportation emission reduction.

In China, rapid economic growth and accelerated urbanization have led to a sharp expansion in transportation demand, increasingly highlighting the carbon emission problem in the transportation sector (Li et al., 2025b). Statistics indicate that in 2022, carbon emissions from transportation in China accounted for over 10% of the national total, with road transport constituting more than 80% of this share. As the urbanization rate continues to rise, the demand for motorized travel is expanding persistently (Guan and Huang, 2025). Against this backdrop, China's carbon – emission – reduction efforts in the transportation sector are vital for its sustainable development and play a crucial role in global climate governance. Confronted with mounting carbon emission pressure, China has actively fulfilled its responsibilities as a major country. It has integrated carbon emission reduction into its national development strategy and has been vigorously promoting the green and low – carbon transformation of its economy and society (Yuan et al., 2024). In the transportation field, building a green transportation system has become a key way to achieve carbon – emission – reduction targets (Lambrecht and Willeke, 2025). The green transportation system, a low – consumption, low – pollution, and high – efficiency transportation development model, involves various aspects such as giving priority to public transportation, encouraging walking and cycling, promoting new energy vehicles, building intelligent transportation systems, and greening transportation infrastructure. These initiatives offer new solutions for reducing urban carbon emissions (Zhao R. et al., 2024). By optimizing the transportation structure and enhancing transportation efficiency, the green transportation system can reduce dependence on conventional fossil fuels. Thus, it can significantly lower the carbon – emission intensity of the transportation sector while meeting people's growing travel demands, generating a far – reaching impact on urban sustainable development and environmental quality improvement (Tian et al., 2023).

In response to the carbon emission challenges in the transportation sector, China's Ministry of Transport launched a pilot policy for a Low–Carbon Transportation System (LCTS) between 2011 and 2012. The initial phase included ten cities: Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding, Wuhan, and Wuxi. In 2012, an additional 16 cities, including Beijing, were incorporated into the pilot program. Centered on road and waterway transportation as well as urban passenger transport, the policy encompasses various aspects such as the development of low–carbon cities, ports, waterways, and roads. Its objective is to explore viable models and effective pathways for promoting low–carbon development within the transportation sector. Theoretically, by advancing new energy transportation technologies, optimizing transportation organization and management practices, and strengthening carbon emission monitoring and evaluation systems, the policy is expected to significantly reduce transportation–related carbon emissions in the pilot cities and support their transition toward low–carbon development (Zhang et al., 2023).

However, existing research on green transportation systems has significant gaps in empirically evaluating China's LCTS policy. While some studies touch on related themes, they lack systematic assessments of LCTS implementation, in–depth analysis of its internal mechanisms, and exploration of heterogeneous impacts across cities. This leaves critical questions unanswered: Does China's LCTS pilot policy effectively reduce urban carbon emission intensity? Through what specific mechanisms—such as green technology development, energy transition, or enhanced government environmental attention—does the policy achieve emission reductions? And do these effects vary across cities with different characteristics, such as public environmental awareness, road network density, or public transportation service capability?

This study addresses these gaps by using a multi–period difference–in–differences (DID) model and panel data from 242 Chinese cities (2007–2022) to evaluate the LCTS policy's impact on urban carbon emissions. It makes three key contributions: First, while prior studies have primarily employed qualitative analyses or case studies to examine the emission–reduction effects of green transportation systems (Li et al., 2021; Liu and Ma, 2025), there remains a lack of systematic assessments of policy implementation and in–depth exploration of the internal mechanisms and heterogeneous impacts on urban carbon emissions. By employing a multi–period DID model and utilizing panel data from 242 Chinese cities (2007–2022), this paper investigates the impact of China's LCTS policy, thereby addressing this gap in the literature.

Second, this study extends beyond examining the direct effects of the LCTS pilot policy on urban carbon emissions. It further investigates potential underlying mechanisms by integrating green technology development, energy consumption structure, and government environmental attention into the analytical framework. The results demonstrate that the LCTS policy fosters green technological innovation and its application in the transportation sector, improves energy efficiency, optimizes the energy consumption structure by decreasing reliance on high–carbon energy sources, and reinforces policy enforcement and environmental oversight through increased governmental focus on environmental issues.

Third, this paper innovatively conducts heterogeneous analyses across three dimensions: public environmental awareness, road network density, and public transportation service capability. The results indicate that in cities with higher levels of public environmental awareness, residents are more receptive to low–carbon travel, thereby producing more pronounced policy effects. In cities characterized by dense road networks, well–developed infrastructure facilitates low–carbon travel and consequently enhances policy effectiveness. Similarly, in cities with efficient public transportation systems, residents are more inclined to use public transit rather than private vehicles, resulting in more substantial reductions in carbon emissions. These heterogeneous findings provide crucial theoretical support for the precise formulation and differentiated implementation of policies.

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature. Section 3 presents the policy background and proposes the hypotheses. Section 4 outlines the empirical strategy. Section 5 analyzes the regression results. Finally, Section 6 provides a summary of the conclusions and offers related policy recommendations.

2 Literature review

2.1 Transport decarbonization

A growing body of work highlights that deep decarbonisation of urban transport is achievable only through coordinated policy portfolios that synchronize demand–side restraint, supply–side restructuring, and externality pricing—all within a socio–technical transition framework. Such portfolios typically encompass land–use intensification to reduce travel distances, modal shifts toward public and active transport, and vehicle electrification, with their effectiveness hinging on local institutional capacities and behavioral norms (Lefèvre et al., 2021; Winkler et al., 2023). This emphasis on integration stands in contrast to fragmented approaches, as meta–reviews caution against mechanical policy transfer across contexts, given the variability in local governance structures and societal attitudes (Javaid et al., 2020; Borchers et al., 2024).

Empirical evidence from cities like London, Berlin, Vienna, and Melbourne reinforces these theoretical insights. Agent–based and system–dynamic simulations reveal that fleet electrification alone, without concurrent reductions in private car use and strengthened public/active transport systems, fails to keep cumulative emissions within Paris–aligned budgets. Even targeted infrastructure interventions, such as turbo–roundabouts, deliver only limited, site–specific abatement (Goehlich et al., 2021; Mądziel et al., 2021; Moffatt and Dia, 2021; Ribeiro et al., 2024). These findings underscore the need for holistic strategies that address both technological and behavioral dimensions of transport systems.

Against this rich international backdrop, research on urban transport decarbonisation in China remains comparatively nascent, with critical gaps in both scope and methodology. Spatial–panel analyses of 284 prefecture–level cities have documented that road–area expansion can curb emissions during early stages of motorisation but becomes counterproductive once car ownership peaks, while high urban density and effective public transit consistently mitigate emissions (Zhao P. et al., 2024). However, rigorous causal identification of policy impacts remains scarce; most domestic studies rely on static correlations or forward simulations, rarely leveraging the staggered rollout of China's Low–Carbon Transportation System (LCTS) pilots as a natural experiment to isolate policy effects.

Freight–sector measures—now recognized globally as a major gap in urban carbon governance—have received only conceptual attention in China, with few empirical assessments of interventions like consolidation centres, curb–space pricing, or electric last–mile logistics (Maxner et al., 2025). Similarly, marginal–abatement estimates from meta–regressions, which inform policy prioritization, are limited to a handful of global studies with wide confidence intervals for tools like congestion pricing and low–emission zones, reflecting both context dependence and data deficiencies (Bencekri et al., 2023). Perhaps most notably, while international case studies repeatedly highlight multi–level governance misalignment and fiscal disincentives as binding constraints on urban transport decarbonisation, analogous political–economy analyses are largely absent from Chinese discourse (Butterfield and Low, 2017; Gray et al., 2017; Colombo and Dijk, 2023; Black and Nakanishi, 2024).

Within the emerging literature on China's LCTS pilots, recent studies have begun to address these gaps but remain incomplete. Zhao et al. (2024) and Zhang et al. (2023) confirm that LCTS enhances carbon emission efficiency and generates spatial spillovers, attributing these effects to green innovation, energy efficiency, and public transit infrastructure. Wang J. et al. (2024) further link LCTS to improved green total factor productivity through industrial optimization and technological progress. However, these works rarely engage with the international emphasis on integrated policy portfolios or the nuanced interplay of demand–side and supply–side measures. They also lack critical analysis of how local institutional capacities—such as public environmental awareness, road network density, or public transit service capability—mediate policy effects, a dimension that international scholarship identifies as central to success.

By employing a multi–period difference–in–differences model to exploit the staggered LCTS rollout, this study seeks to advance the literature in three key ways: first, by providing rigorous causal evidence of policy impacts, addressing the dearth of quasi–experimental analyses in Chinese transport decarbonisation research; second, by unpacking mechanisms that bridge demand–side (e.g., public behavior) and supply–side (e.g., green technology, energy transition) factors, aligning with international calls for integrated strategies; and third, by examining heterogeneous effects across cities with varying institutional and infrastructural endowments, responding to concerns about context dependence in policy transfer. In doing so, it aims to connect Chinese empirical insights to global theoretical frameworks, enhancing both the generalizability of domestic findings and their relevance to international climate governance.

2.2 Environmental regulations and China's carbon emissions

As the global climate crisis intensifies, urban carbon–emission governance has become a key topic in academic and policy circles, with a growing body of literature exploring the effectiveness of low–carbon policies across diverse contexts (Li et al., 2022; Qin and Gong, 2022). China, as the world's largest developing country, has emerged as a critical case study for examining low–carbon pilot policies, given its scale of urbanization and commitment to carbon neutrality (He and Song, 2022). Existing research on China's low–carbon initiatives can be synthesized around three interrelated themes: the multifaceted impacts of low–carbon city policies, the role of supporting mechanisms such as technology and finance, and the emerging focus on transportation–specific measures—yet these strands remain insufficiently integrated, leaving critical gaps in understanding how policies translate to tangible emission reductions.

Studies on low–carbon city pilot policies have predominantly focused on their effects on land use, energy structures, and digital integration, with methodological approaches varying in rigor and scope. Liu et al. (2022) provide a foundational analysis of how such policies enhance urban land use efficiency, arguing that optimized land utilization contributes to emission reductions, though their work relies on aggregate data that may mask localized variations. Chen (2023) advances this by employing high–resolution emission data and a combination of difference–in–differences (DID) and propensity score matching, offering more precise evidence that low–carbon city policies lower carbon intensity. However, both studies primarily assess direct policy effects without fully exploring how contextual factors—such as urban density or governance capacity—mediate outcomes, a limitation highlighted by Guo (2023), who emphasizes that policy effectiveness hinges on local adaptation and coordination.

Beyond direct emission reductions, research has increasingly explored synergistic environmental benefits and spatial dynamics. Wang H. et al. (2024) use a Spatial Durbin Model combined with DID to show that low–carbon city policies generate spillover effects on air quality, underscoring the need for regional coordination. Similarly, Wang H. et al. (2023) link digital technologies, such as e–commerce policies, to enhanced green development, though their focus on digital transformation leaves underexamined how these technologies interact with traditional transportation systems. These studies collectively highlight the complexity of policy impacts but often overlook the specific role of transportation infrastructure in amplifying or constraining such synergies.

Technological innovation and financial mechanisms have emerged as key drivers in the literature, though their application to transportation remains underexplored. Song et al. (2022) demonstrate that low–carbon policies boost energy efficiency through technological progress, using data from 281 cities to support their claims, while Luo et al. (2023) and Wan et al. (2023) highlight the role of financial reforms and green finance in enabling emission reductions. These works establish that technology and finance are critical enablers, yet they rarely focus on how these mechanisms specifically affect transportation sectors—a gap that becomes more pronounced when examining the intersection of digitalization and smart transportation, as noted by Liu and Zhang (2023) and Zheng et al. (2023), whose analyses of intelligent urban development touch on transportation but stop short of detailed examination.

Research specifically on transportation has begun to address this gap, with a growing focus on China's Low–Carbon Transportation System (LCTS) pilot policy. Wang Q. et al. (2024) find that low–carbon city pilots improve energy efficiency in transportation infrastructure, while Zhao R. et al. (2024) use a multi–period DID model to show that LCTS enhances carbon emission efficiency through green innovation and financial technology. Zhang et al. (2023) further identify spatial spillover effects of LCTS, attributing improved carbon performance to enhanced energy efficiency, green technology, and public transit infrastructure. Wang J. et al. (2024) extend this by linking LCTS to green total factor productivity, emphasizing industrial optimization and technological progress. These studies collectively confirm that LCTS has tangible benefits, but they lack critical engagement with how transportation planning—such as road network design, public transit coverage, or land–use integration—shapes these outcomes.

In conclusion, the existing literature consistently demonstrates that environmental policies under China's dual carbon targets framework significantly contribute to urban carbon emission reduction. The effectiveness of these policies stems not only from direct advancements in technology and infrastructure but also from synergistic effects that involve land use optimization, digital transformation, financial innovation, and integrated urban planning. However, despite the extensive research on the impact of China's environmental policies on carbon emissions, studies that specifically focus on the influence of green transitions in the transportation sector on carbon emissions remain relatively scarce. The existing literature paid limited attention to the unique mechanisms and implementation paths of transportation–oriented green policies. This gap is particularly evident in the context of China's low–carbon transportation system pilot policies, where the specific role of transportation infrastructure upgrades, energy structure adjustments, and technological innovations in driving emission reductions has not been systematically explored. Consequently, this paper aims to bridge this research void by conducting a comprehensive analysis of how green transition policies in the transportation sector influence urban carbon emissions.

3 Institutional background and research hypotheses

3.1 Institutional background

As the world's largest developing country, China bears significant responsibility in global climate governance. Reducing carbon emissions from the transportation sector is essential for achieving national low–carbon development goals (Jing et al., 2022; Liu et al., 2023). To tackle this challenge, China's Ministry of Transport initiated the Low–Carbon Transportation System (LCTS) pilot policy during 2011–2012. The first batch of pilot programs was launched in 2011 across ten cities: Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding, Wuhan, and Wuxi. In 2012, a second batch expanded the initiative to an additional sixteen cities, including Beijing, Kunming, Xi'an, Ningbo, Guangzhou, Shenyang, Harbin, Huai'an, Yantai, Haikou, Chengdu, Qingdao, Zhuzhou, Bengbu, Shiyan, and Jiyuan. The distribution of LCTS pilot cities is shown in Figure 1. This policy primarily focuses on road transport, waterway transportation, and urban passenger transport. Its objective is to develop low–carbon models tailored to China's national conditions and to provide replicable experiences and demonstrations for the broader low–carbon transformation of the country's transportation industry (Zhang et al., 2023).

In terms of the policy's core content, it addresses several key areas. Regarding transportation equipment, the policy strongly

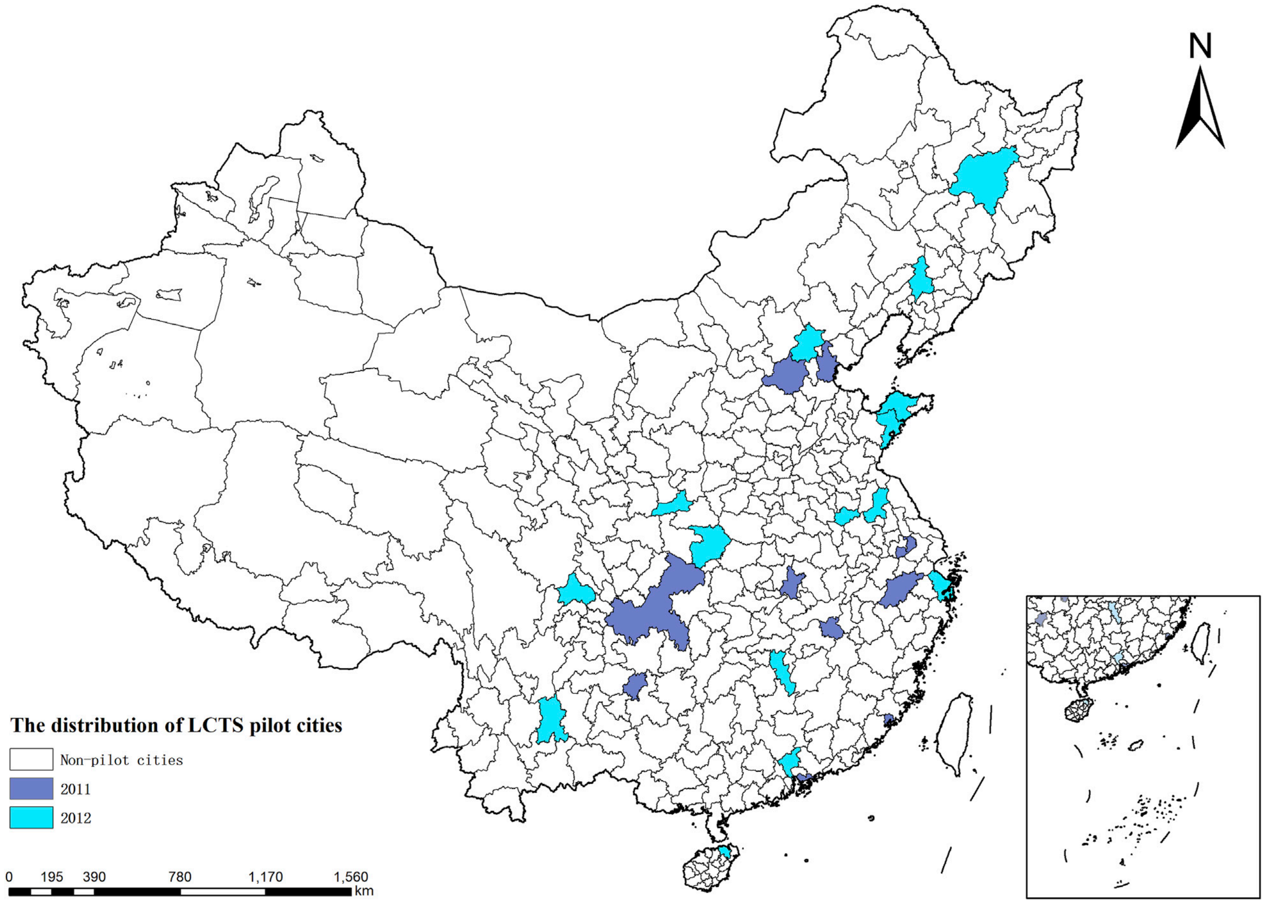

FIGURE 1
The distribution of LCTS pilot cities.

encourages transportation enterprises to adopt new energy and clean energy vehicles. For example, to promote the adoption of new energy buses, many pilot cities provide vehicle purchase subsidies and operational incentives. These measures accelerate the electrification of bus systems and reduce carbon emissions during vehicle operation. In the area of transportation organization, the policy actively promotes multimodal transport by integrating the advantages of various transportation modes, such as railways, roads, and waterways. By optimizing transportation routes and transfer processes, these initiatives help reduce detours and empty–load occurrences, thereby improving transportation efficiency and lowering carbon emissions.

In terms of transportation infrastructure development, the policy emphasizes the use of low – carbon technologies. Some pilot cities have employed new environmental materials in road construction to enhance road durability and energy efficiency. In port construction, shore – power technology has been promoted to reduce fuel consumption and emissions from ships when they are in port. Moreover, the policy focuses on establishing and improving carbon emission monitoring and evaluation systems. It requires pilot cities to set up robust carbon emission monitoring systems and conduct quantitative evaluations of transportation enterprises' carbon emissions. This provides data support and managerial basis for the policy implementation.

From the perspective of policy objectives, LCTS aims to promote a green and low–carbon transformation of the transportation industry through a series of policy measures, support China in achieving its national carbon reduction targets, and contribute Chinese efforts to global climate governance. During the implementation phase, each pilot city has formulated clear and phased goals and tasks based on local conditions, such as increasing the proportion of new energy vehicles, optimizing the transportation structure, and improving public transportation service quality, thereby ensuring effective policy implementation and tangible outcomes.

3.2 Research hypotheses

3.2.1 LCTS and carbon emissions

The LCTS policy, as a key initiative for promoting low–carbon transformation in the transportation sector, is designed to reduce carbon emissions by encouraging low–carbon practices in transportation activities through a variety of policy instruments. In terms of implementation, the policy has introduced a series of targeted measures across core areas such as transportation equipment, transportation organization, and infrastructure development—each closely aligned with the goal of reducing carbon emissions. Specifically, in the area of transportation equipment, the policy actively promotes the adoption of new energy and clean energy vehicles among transportation enterprises. For instance, the promotion of new energy buses demonstrates a significant shift toward sustainable urban transport. Compared to traditional fuel–powered buses, new energy buses generate almost no carbon emissions during operation (Zhang et al., 2023).

Regarding transportation organization, the LCTS policy strongly advocates for efficient transportation models such as multimodal transport. By integrating the advantages of various transportation modes—including railways, roads, and waterways—and optimizing transportation routes and transfer procedures, multimodal transport effectively minimizes detours and empty–load transportation during cargo movement, thereby significantly reducing carbon emissions.

The LCTS policy also prioritizes accelerating low – carbon technology R&D and application. By supporting green technology innovation, it enhances energy efficiency and reduces carbon intensity per unit of transportation activity, offering technological support for urban carbon – emission reduction. Moreover, the policy promotes establishing and improving low – carbon transportation management systems. Through strengthened supervision and guidance, it regulates the behavior of transportation enterprises and individuals, further curbing unnecessary carbon emissions (Zhao R. et al., 2024).

China faces severe environmental and climate challenges, particularly in terms of carbon emissions. As a major source of emissions, the transportation sector holds significant potential for low–carbon transformation, which is of substantial practical importance (Li Y. et al., 2025). The LCTS policy offers policy support and resource allocation to designated pilot cities, enabling them to develop more effective low–carbon transportation systems. Under this policy framework, these cities have increased investment in public transportation optimization, enhancing service quality and attractiveness, thereby reducing reliance on private vehicles and cutting transportation–related carbon emissions. Meanwhile, pilot cities are actively promoting new energy vehicles—such as electric and hybrid cars—and constructing the necessary charging and energy supply infrastructure, further accelerating the low–carbon transition of the transportation industry (Wang et al., 2022). Furthermore, the LCTS policy promotes low–carbon travel through public awareness campaigns and educational initiatives, fostering greater environmental consciousness among the public and encouraging willingness to adopt low–carbon travel behaviors, thus mitigating carbon emissions at the behavioral source.

In summary, we propose the hypothesis H1:

The Low – Carbon Transportation System (LCTS) pilot policy can reduce urban carbon emissions.

3.2.2 LCTS, green technology development and carbon emissions

The implementation of the LCTS pilot policy has provided comprehensive support and incentives for the development of urban green technologies in a broad sense, thereby contributing to the reduction of urban carbon emissions through both direct and spillover effects. From a policy guidance perspective, while the LCTS policy is rooted in the transportation sector, it explicitly promotes green technological innovation across multiple linked domains by increasing financial subsidies and offering tax incentives for R&D in low-carbon technologies—creating a favorable policy environment for enterprises and research institutions engaged in green innovation (Zhang et al., 2023). With this support, pilot cities have advanced the development of green technologies not only for transportation equipment (e.g., new energy vehicles) and operational processes (e.g., energy-saving and emission-reduction techniques in logistics) but also for related industrial chains, such as battery manufacturing, smart infrastructure, and clean energy supply systems. These technologies, though initially driven by transportation needs, extend beyond the sector itself, enhancing energy efficiency and reducing carbon emissions across interconnected economic activities.

During the stage of technology application and diffusion, the LCTS policy facilitates the widespread adoption of green technologies by reshaping market incentives, a dynamic aligned with industrial organization theory, which highlights how regulatory frameworks and market structure drive technology diffusion. By establishing stringent carbon emission standards for transportation, the policy raises the cost of high-carbon technologies while lowering barriers for green alternatives. This not only accelerates the replacement of traditional transportation assets (e.g., fossil fuel vehicles) with green alternatives but also stimulates demand for upstream and downstream green technologies—such as charging infrastructure, low-carbon materials for road construction, and intelligent traffic management systems. This market transformation drives economies of scale in green technology production, making them more accessible for application in non-transportation sectors (e.g., municipal energy systems and urban construction), thereby amplifying their emission reduction impact.

Moreover, the LCTS policy boosts market demand for green products and technologies more broadly, prompting firms to increase investment in green R&D to gain competitive advantage. As public awareness of low-carbon mobility grows, demand for green transportation services (e.g., new energy vehicles and optimized public transit) rises, but this also spill over to drive demand for green technologies in related fields (e.g., renewable energy generation to power electric vehicles). Such cross-sectoral demand stimulates innovation in a range of green technologies, which then diffuse through industrial linkages—for example, battery technology developed for electric vehicles may improve energy storage systems for buildings, while smart traffic management algorithms can optimize energy use in urban grids (Lu and Lu, 2024). Supported by innovation diffusion theory, these spillover effects mean that green technologies initially driven by transportation needs contribute to emission reductions across multiple urban systems.

Notably, while the transportation sector alone accounts for a significant share of urban carbon emissions (over 10% of China's national total, with road transport contributing over 80% of this share), the green technologies promoted by LCTS exert influence beyond this sector. Their diffusion into related industries and urban systems creates a cumulative effect on overall urban carbon emissions.

Based on the above theoretical analysis and existing research conclusions, this paper proposes Hypothesis H2a:

The LCTS pilot policy reduces urban carbon emissions by promoting the development of green technologies.

3.2.3 LCTS, energy transition and carbon emissions

From the perspective of policy objectives, the LCTS policy aims to establish a green, low–carbon, and circular transportation system. At its core, it seeks to optimize the energy structure within the transportation sector through a series of targeted measures. Specifically, the policy mandates that pilot cities promote and adopt new energy and clean energy transportation equipment, such as natural gas–powered buses and new energy taxis, while also increasing the use of alternative fuels in operating vehicles and ships (Zhang et al., 2023). These initiatives help reduce reliance on traditional high–carbon energy sources and directly contribute to lowering carbon emissions in the transportation sector.

At the industrial policy level, the LCTS policy promotes the clean energy transition through planning and entry–standard guidance. According to the theory of industrial structure optimization, policies can guide resource allocation across sectors. The LCTS policy explicitly encourages the research, development, and production of new energy transport equipment by offering incentives such as production qualifications and subsidies for low–carbon–standard vehicles and ships. This drives the transport equipment manufacturing industry toward green and low–carbon development. It enhances the market supply of clean–energy–powered transport equipment, lowers procurement costs, and incentivizes transport enterprises to modernize their fleets, thereby increasing the share of clean energy in transport energy consumption. For example, purchase subsidy policies for new energy buses have enabled urban bus systems to rapidly phase out diesel buses and widely adopt electric buses, directly reducing carbon emissions in the transportation sector (Ke et al., 2024).

The LCTS policy can effectively address the "last mile" challenge in the application of clean energy within the transportation sector through strategic infrastructure investments, thereby accelerating the transformation of the energy structure. A well–developed infrastructure system serves as a critical foundation for industrial growth. Under the LCTS policy, significant efforts have been made to construct clean energy facilities such as charging stations and hydrogen refueling stations, which have improved the accessibility and usability of clean energy in transportation. For instance, as the number of charging stations has increased and their spatial distribution has been optimized, the "range anxiety" experienced by new energy vehicle users has been notably reduced, leading to a significant rise in the market acceptance of such vehicles. The advancement of new energy infrastructure not only facilitates the widespread adoption of new energy vehicles but also promotes the broader use of clean energy sources like electricity in the transportation sector. This, in turn, supports the transition of energy consumption from traditional fossil fuels to cleaner alternatives (Wang K. et al., 2023).

Based on the above analysis, this paper proposes Hypothesis H2b:

LCTS can reduce carbon emissions by promoting the clean transformation of energy.

3.2.4 LCTS, government environmental concerns, carbon emissions

Government conduct plays a critical role in determining the effectiveness of environmental governance. The LCTS policy enhances governmental attention to environmental issues and strengthens governance capacity by establishing a mechanism for transmitting policy pressure and reallocating resources, thereby effectively constraining carbon emissions. Grounded in principal–agent theory, the central government—acting as the principal in environmental governance—institutionalizes low–carbon transportation goals into local government performance evaluations through the LCTS policy framework. This process reshapes the incentive structure of local governments. When carbon emission control targets are tied to official promotions and fiscal transfers, local governments transition from a GDP–centric development model to a dual–objective strategy that balances economic growth with environmental sustainability (Hu and Li, 2025). This transformation in incentives leads to increased investment and stricter enforcement in environmental governance at the local level (He and Zhou, 2024). Motivated by central government directives, local authorities now integrate considerations of both economic expansion and long–term carbon emission impacts into urban transportation infrastructure planning. They prioritize investments in low–carbon facilities such as rail transit and bus rapid transit systems, which are complemented by land–use policies. These policies facilitate the optimization of urban functional layouts, reduce travel distances, and ultimately lower energy consumption in the transportation sector (Long et al., 2024).

The LCTS pilot policy supplies local governments with a defined green – governance goal and action framework. During implementation, pilot – city governments must continuously learn from advanced domestic and international environmental – management practices. They need to integrate cross – departmental administrative resources and strengthen environmental monitoring and data – statistical capabilities. Consequently, governments can formulate and execute environmental policies more precisely and effectively. They can better identify key areas and weak links in urban carbon emissions, thereby devising more targeted emission – reduction measures. By precisely monitoring and analyzing carbon emission sources in the transportation sector, governments can impose supervision and transformation on high – emission freight – logistics segments, optimize urban traffic – flow distribution, and enhance the overall energy efficiency of transportation systems (Zhao et al., 2022).

From the perspective of optimizing environmental regulations, the LCTS policy encourages local governments to enhance their environmental – regulation systems. In practice, pilot – area governments have explored more flexible and effective regulatory tools, such as emission – trading mechanisms and green – finance incentives. These innovative approaches not only boost regulatory effectiveness but also cut firms' emission – reduction costs, strengthening their willingness and initiative to participate in carbon – emission reduction (Wang Y. et al., 2024).

Based on the above analysis, this paper proposes Hypothesis H2c:

The LCTS pilot policy can reduce carbon emissions by enhancing local governments' environmental concerns.

4 Research design

4.1 Empirical strategy

This paper treats the LCTS as an exogenous shock. It assigns pilot cities as the experimental group and non – pilot cities as the control group. Then, it establishes a multi – period DID model to evaluate the emission – reduction effect of this green transportation policy. The econometric model is shown in Equation 1.

$$CI_{it} = \beta_0 + \beta_1 LCTS_{it} + \beta_c Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \qquad (1)$$

In Equation 1, CI_{it} represents a city's carbon dioxide emission intensity. $LCTS_{it}$ is a dummy variable for the green transport policy. For city i, if it becomes a pilot city in year t, $LCTS_{it}$ is set to 1 for that year and all subsequent years; otherwise, it remains 0. $Controls_{it}$ denote a set of control variables. μ_i and λ_t respectively indicate city and time fixed effects. ε_{it} stands for the random error term. Also, this study clusters standard errors at the city level.

4.2 Variables

4.2.1 The explained variable (*CI*)

Following the methodology of Lyu et al. (2025), this paper estimates each city's total carbon dioxide emissions based on electricity use, artificial gas, natural gas, and liquefied petroleum gas consumption:

$$CO_2 = \left(EC \times \delta_{ec} + NG \times \delta_{ng} + LPG \times \delta_{lpg}\right) \times 0.67 \times (44/12)$$

EC is electricity consumption; *NG* is artificial gas and natural gas consumption; *LPG* is liquefied petroleum gas consumption. δ_{ec}, δ_{ng}, and δ_{lpg} are the coefficients for converting electricity, natural gas, and *LPG* to standard coal, respectively. 0.67 is the carbon – emission factor for standard coal, and 44/12 is the oxidation factor for carbon dioxide. After calculating total CO_2 emissions for each city, we divide it by the city's GDP and take the logarithm to obtain carbon emission intensity (*CI*).

4.2.2 Explanatory variable (*LCTS*)

The core explanatory variable is the green transportation policy, which is operationalized as a dummy variable. Specifically, if a city is designated as a pilot city in the Low–Carbon Transportation System (LCTS) initiative in year *t*, the *LCTS* indicator for that city takes a value of 1 from year *t* onward; otherwise, it remains 0.

4.2.3 Mediating variables

Green technology development (*Gtec*). Referring to the research of Liu and Wan (2025), we use the logarithm of the *per capita* number of green invention patent applications in each city to represent it.

Energy consumption structure (*Egys*): According to the research of Fan et al. (2023), this paper uses the proportion of non–fossil energy consumption to represent the cleanliness of a city's energy structure.

Government environmental concern (*Gov*). Following the research design of Ren (2024), we employed a text analysis method to count the total frequency of words related to environmental protection in the government work reports of various cities. We then divided this by the total number of words in the government work reports to obtain a proxy variable for the intensity of government environmental concern (*Gov*). The specific word frequencies are presented in Table 1. Previous studies have shown that government work reports, as annual summaries and outlooks of local governments on their past year's work, directly reflect the government's concern for environmental protection in their descriptions. This measurement method has also been widely applied (Yu et al., 2023).

4.2.4 Control variables

Based on the existing relevant research works (Gu, 2022; Xiao et al., 2023; Xing et al., 2024; Wei and Wan, 2025), we also incorporated some other elements that might influence urban carbon emissions. These include: (1) industrial structure (*Is*), measured by the proportion of the output value of the tertiary industry; (2) economic development level (*Pgdp*), expressed as the logarithm of *per capita* GDP; (3) degree of openness to the outside world (*Open*), indicated by the ratio of total trade volume to GDP in each city; (4) number of motor vehicles (*Cars*), represented by the logarithm of the total number of motor vehicles in the city; (5) urbanization level (*Urban*), calculated as the ratio of the population in urban districts to the city's total population; and (6) population size (*lnPop*), expressed as the logarithm of the city's permanent resident population.

4.3 Data sources

Considering the availability of data and the robustness of the difference–in–differences model estimation, this paper retains 242 Chinese cities from 2007 to 2022 as the research sample, after removing observations with severe missing values. The primary data sources include the "China Urban Statistical Yearbook," the "China Urban Construction Statistical Yearbook," and the EPS database. To address minor missing data in certain variables, linear interpolation is employed. Ultimately, a total of 3,872 observations are obtained. Descriptive statistics for all variables are presented in Table 2.

5 Empirical results

5.1 Benchmark regression analysis

Table 3 presents the benchmark regression results of LCTS on urban carbon emissions. The coefficient of the core explanatory variable, *LCTS*, is significantly negative across different model specifications, indicating that the pilot LCTS policy has a significant inhibitory effect on urban carbon emission intensity. Specifically, in Column (1), where no control variables or fixed effects are included, the coefficient of LCTS is −0.251, which is significant at the 1% level. In Column (2), after controlling for both city and time fixed effects, the coefficient remains significantly negative at −0.269. Models (3) and (4) present regression results without and with control variables, respectively, yielding *LCTS* coefficients of −0.140 and −0.173, both statistically significant at

TABLE 1 Environmental word set.

Low–carbon, Carbon emission, Environmental protection, Air pollution, Green, PM2.5, PM10, Chemical Oxygen Demand (COD), Carbon dioxide (CO_2), Ecology, Pollution discharge, Emission reduction, Pollution, Environmental protection, Energy consumption

TABLE 2 Descriptive statistics.

Variable	N	Mean	SD	Min	Max
CI	3,872	2.821	0.759	0.354	6.841
LCTS	3,872	0.062	0.242	0	1
Is	3,872	38.458	9.713	11.220	83.870
Pgdp	3,872	10.403	0.735	4.595	13.06
Open	3,872	0.327	0.783	0	24.877
Cars	3,872	5.566	1.128	2.129	8.942
Urban	3,872	52.466	15.839	6.491	100.000
lnPop	3,872	5.900	0.691	2.868	8.136
Gti	3,872	3.300	1.910	0	9.868
Egys	3,872	0.246	0.233	0	0.919
Gec	3,872	3.253	1.407	0	12.389

the 1% level. These findings suggest that the negative impact of the LCTS policy on urban carbon emission intensity persists even after accounting for other influencing factors. According to the results in Column (4), the implementation of the LCTS pilot policy is associated with an average reduction of approximately 17.3% in urban carbon emission intensity, thereby supporting Hypothesis H1. While Sun and Zhao (2024) focus on data up to 2019, our study extends the sample period to 2007–2022, incorporating both earlier policy rollouts and post-pandemic dynamics (2020–2022).

5.2 Parallel trend test

The parallel trends test serves as a fundamental prerequisite for ensuring the validity of the difference–in–differences (DID) method. This test is designed to verify that the treatment group and the control group exhibit similar trends prior to the policy intervention. When this assumption is satisfied, any observed differences between the groups following the implementation of the policy can be more confidently attributed to the policy itself, thereby strengthening the reliability and credibility of the causal inference.

According to the parallel trend test results presented in Figure 2, prior to the policy implementation (from *pre5* to *current*), the estimated coefficients fluctuate around zero, and the corresponding confidence intervals include zero. This suggests that there was no significant difference in carbon emission trends between the treatment group cities and the control group cities before the pilot policy was introduced, thereby satisfying the parallel trend assumption. This consistency provides a solid foundation for employing the DID method to evaluate the impact of LCTS pilot policies on urban carbon emissions. Starting from the second year after the policy implementation, all estimated coefficients are significantly negative, indicating that the LCTS has had a strong carbon reduction effect.

From the perspective of possible underlying factors, the implementation of the LCTS pilot policy may have encouraged cities to increase investments in optimizing public transportation systems, promoting the adoption of new energy vehicles, and adjusting the energy structure within the transportation sector. These efforts likely contributed to a reduction in carbon emissions from urban transportation, thereby influencing the overall carbon footprint of the city. Furthermore, as the policy continued to be implemented and complementary measures were progressively advanced, the inhibitory effect on carbon emissions became increasingly pronounced over time. This trend suggests that the policy may have generated cumulative emission reduction benefits in the long run.

5.3 Robustness test

5.3.1 Placebo test

To ensure the robustness of the research results, we conducted a placebo test. This test breaks the connection between the original policy variables and actual policy implementation by randomly generating virtual policy variables, thereby verifying whether the policy effects identified in the original study originate from the policies themselves rather than other potential confounding factors. As can be seen from the Figure 3, the coefficient distribution presents a symmetric bell–shaped curve centered around 0. The red vertical bar represents the real estimate (−0.173), which shows the most noticeable deviation, and the corresponding p–value is greater than 0.1. This indicates that in the randomly generated virtual policy scenarios, there is no significant correlation between the policy variables and urban carbon emissions. Specifically, when policy variables are randomly assigned, their impact on urban carbon emissions is virtually zero and statistically insignificant. These results further confirm the robustness and reliability of the original findings, suggesting that the observed changes in urban carbon emissions following the implementation of the LCTS pilot policy are unlikely to be driven by unobserved confounding factors or random noise.

5.3.2 PSM–DID

To further enhance the robustness of research findings, this paper employs the Propensity Score Matching (PSM) method to match samples, eliminating potential endogeneity issues, and combines the Difference–in–Differences (DID) approach to reassess the impact of the LCTS pilot policy on urban carbon emissions. Specifically, we use all control variables in the benchmark regression—such as industrial structure and economic development level—as covariables for urban individual characteristics. The propensity scores for cities to be included in LCTS are estimated through a Logit model, and the radius matching method (with a radius set to 0.05) is applied to match the treatment

TABLE 3 Benchmark regression results.

Variables	(1)	(2)	(3)	(4)
	CI	CI	CI	CI
LCTS	−0.251***	−0.269***	−0.140***	−0.173***
	(0.047)	(0.045)	(0.053)	(0.041)
Is			0.004***	0.008***
			(0.002)	(0.002)
Pgdp			−0.303***	−0.181***
			(0.032)	(0.042)
Open			−0.054***	−0.069***
			(0.014)	(0.012)
Cars			0.030	0.103***
			(0.023)	(0.035)
Urban			0.029***	0.013***
			(0.001)	(0.002)
lnPop			−0.274***	−0.561***
			(0.028)	(0.120)
_cons	2.909***	2.930***	5.737***	6.442***
	(0.012)	(0.007)	(0.327)	(0.871)
City FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES
N	3,872	3,872	3,872	3,872
R−squared	0.127	0.752	0.280	0.834

Note: Standard errors clustered at the city level are reported in parenthesis; ***, ** and * indicate statistical significance at the levels of 1%, 5%, and 10% respectively, same below.

and control groups. The matching results show that the standardized deviations of all covariables are reduced to within 10% (see Figure 4), indicating that the characteristic balance between the treatment and control groups before policy implementation has significantly improved, effectively mitigating sample selection bias.

The regression results in column (1) of Table 4 show that the coefficient of *LCTS* is −0.072, significant at the 1% level. This indicates that after effectively controlling for sample selection bias through PSM, the LCTS policy still has a significant negative impact on urban carbon emission intensity.

5.3.3 Entropy balancing

In evaluating the impact of LCTS on carbon emissions, sample selection bias may compromise the accuracy of estimation results. While traditional PSM effectively selects urban samples with similar characteristics, it heavily relies on the Logit model specified in the first stage and may lead to sample attrition (Hu et al., 2023). To address potential endogeneity, this paper further employs the entropy balancing method proposed by Hainmueller (2012). This approach reweights the control group to achieve covariate balance, specifically matching the means, variances, and skewness of covariates between treatment and control groups (Godsell, 2022). By preserving the full sample and enforcing higher−order moment matching, entropy balancing ensures comparability while mitigating information loss.

Table 5 presents the results of entropy balancing. Prior to adjustment, there were significant differences in the distribution of covariates between the treatment and control groups. However, after balancing, the control group demonstrates nearly identical statistical characteristics to those of the treatment group. Column (2) in Table 4 reports the PSM−DID regression results following entropy balancing, showing that the LCTS coefficient is −0.180 and statistically significant at the 5% level. These findings are consistent with both the PSM−DID and the benchmark regression results.

5.3.4 Bacon decomposition

To further evaluate the robustness of our multi−period DID estimates and address potential threats to the parallel trends assumption arising from heterogeneous treatment timing across cities, we implement the Bacon decomposition (Bacon, 2015), which decomposes the overall policy effect into three distinct components: comparisons across timing groups ("Timing groups"), comparisons between never−treated and treated cities ("Never v timing"), and within−group comparisons ("Within").

Table 6 presents the decomposition results, where each component is characterized by an *Estimator* (the coefficient for

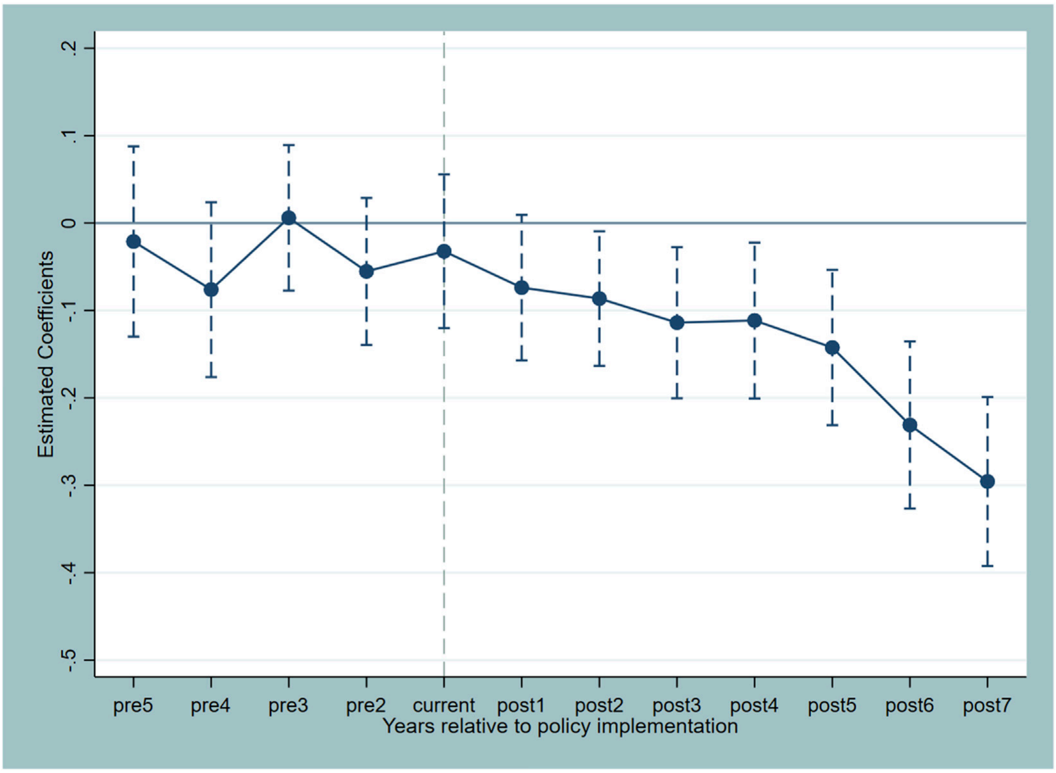

FIGURE 2
Parallel trend test.

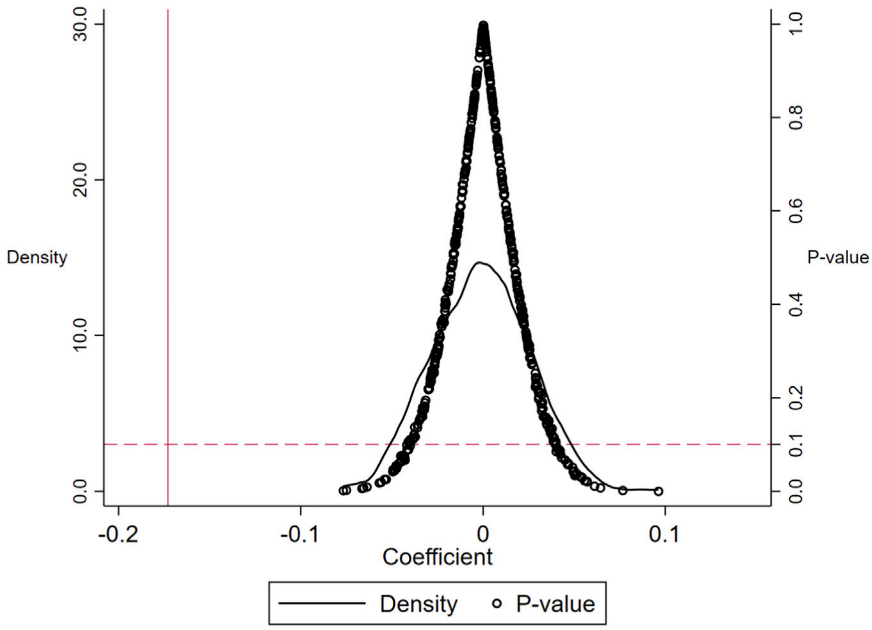

FIGURE 3
Placebo test.

that specific comparison) and a *Total Weight* (the proportion of the overall effect attributed to that component). Specifically, the "Timing groups" component—capturing differential effects between cities with different policy adoption timings—yields an estimator of 0.0937 with a total weight of 0.0080. The "Never v timing" component, which contrasts never-treated cities against all

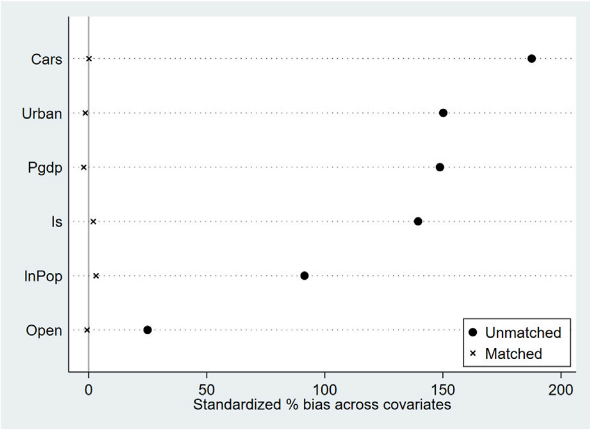

FIGURE 4
Results of balance test for covariates.

treated cities (regardless of adoption year), shows an estimator of −0.1732 and accounts for 0.9734 of the total weight, representing the dominant source of variation. Lastly, the "Within" component—reflecting within–group variation in treatment timing—has an estimator of −0.2612 and a total weight of 0.0186.

To assess consistency with our baseline findings, we compute the weighted average of these three components. This calculation yields: (0.0937*0.0080) + (−0.1732*0.9734) + (−0.2612*0.0186) ≈ −0.1727.

Notably, this weighted average (−0.1727) closely aligns with our benchmark DID estimate of −0.173, confirming that the core conclusion—that the LCTS policy reduces urban carbon emission intensity—remains robust to dynamic treatment effects and heterogeneous adoption timing. The overwhelming weight of the "Never v timing" component (0.9734) further indicates that the policy's emission–reduction impact is primarily driven by the contrast between treated cities (across all adoption periods) and never–treated cities, rather than by differential timing among treated groups.

TABLE 4 Results of robustness test.

Variables	(1)	(2)	(3)	(4)
	PSM–DID	Entropy balance	Replace the dependent variable	Exclude observations from the pandemic period
	CI	CI	PCI	CI
LCTS	−0.072***	0.180**	−0.071**	−0.1236***
	(0.016)	(0.077)	(0.032)	(0.0385)
Is	0.005*	0.004	0.003	0.0080***
	(0.003)	(0.004)	(0.012)	(0.0021)
Pgdp	−0.351***	−0.514***	−0.411**	−0.1279***
	(0.060)	(0.114)	(0.187)	(0.0423)
Open	0.057	0.094	−0.071**	−0.0738***
	(0.042)	(0.069)	(0.032)	(0.0114)
Cars	0.175***	0.180**	0.212**	0.0638*
	(0.055)	(0.077)	(0.104)	(0.0346)
Urban	0.013***	0.020***	−0.007	0.0109***
	(0.003)	(0.005)	(0.008)	(0.0022)
lnPop	−0.725***	−0.841***	−0.270	−0.2890**
	(0.154)	(0.206)	(0.380)	(0.1268)
_cons	8.918***	9.122***	5.912*	4.6031***
	(1.165)	(1.821)	(3.415)	(0.9064)
Controls	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	2,206	3,872	3,872	3,146
R–squared	0.832	0.765	0.714	0.764

TABLE 5 Results of entropy balance.

Variables	Treatment group			Control group (before entropy balancing)			Control group (after entropy balancing)		
	Mean	Variance	Skewness	Mean	Variance	Skewness	Mean	Variance	Skewness
Is	52.020	134.800	0.532	37.590	79.240	0.5808	52.010	127.4	0.131
Pgdp	11.240	0.265	−0.200	10.320	0.510	−0.253	11.240	0.309	−0.754
Open	0.499	0.294	1.988	0.327	0.671	12.860	0.499	0.319	1.928
Cars	7.215	0.750	−0.548	5.408	1.106	−0.015	7.214	0.740	−0.746
Urban	72.000	168.700	−0.116	50.790	230.500	0.6390	71.990	221.500	−0.407
lnPop	6.465	0.415	0.2741	5.861	0.458	−0.7039	6.464	0.339	−0.696

TABLE 6 Bacon decomposition weight results.

Control group classification	Estimator	Total weight
Timing_groups	0.0937	0.0080
Never_v_timing	−0.1732	0.9734
Within	−0.2612	0.0186

5.3.5 Replace the explained variable

In the benchmark regression analysis, this paper defines the dependent variable as the logarithmic form of urban carbon dioxide emission intensity (*CI*). To ensure the robustness of the research results, we further replace the dependent variable with *per capita* carbon dioxide emissions (*PCI*) and re−run the regression analysis. The results are presented in column (3) of Table 4, where the estimated coefficient of *LCTS* on *PCI* is −0.071, significant at the 5% level. This indicates that LCTS also has a suppressive effect on urban *per capita* carbon dioxide emissions, further validating the carbon emission reduction effect of the LCTS policy.

5.3.6 Exclude observations from the pandemic period

To further ensure the robustness of our findings against potential confounding effects from the COVID-19 pandemic, we conduct an additional test by excluding observations from the pandemic period (2020–2022). The COVID-19 outbreak and subsequent control measures (e.g., lockdowns, travel restrictions) drastically altered transportation patterns and carbon emission dynamics globally, which might introduce spurious correlations into our baseline estimates. By removing this period, we aim to isolate the intrinsic impact of the LCTS policy from the exogenous shocks induced by the pandemic.

Column (4) of Table 4 presents the regression results after excluding 2020–2022 data. The core explanatory variable LCTS retains a statistically significant negative coefficient (−0.1236) at the 1% level, which is consistent in direction with our baseline estimate. This indicates that the emission-reduction effect of the LCTS policy remains robust even when accounting for the abnormal fluctuations in transportation and carbon emissions during the pandemic.

TABLE 7 Mechanism test results.

Variables	(1)	(2)	(3)
	Gtec	Egys	Gov
LCTS	0.132**	0.223***	0.637***
	(0.065)	(0.066)	(0.145)
Is	−0.005	−0.001***	0.011
	(0.003)	(0.000)	(0.007)
Pgdp	0.223***	0.011	0.637***
	(0.066)	(0.007)	(0.145)
Open	−0.014	0.002	0.146**
	(0.019)	(0.003)	(0.060)
Cars	0.318***	−0.016	0.231**
	(0.056)	(0.010)	(0.108)
Urban	0.012***	−0.001	0.014
	(0.003)	(0.000)	(0.009)
lnPop	1.106***	−0.043**	−0.885**
	(0.191)	(0.021)	(0.373)
_cons	−7.828***	0.558***	−0.656***
	(1.386)	(0.150)	(0.190)
Controls	YES	YES	YES
City FE	YES	YES	YES
Year FE	YES	YES	YES
N	3,872	3,872	3,872
R−squared	0.732	0.766	0.438

5.4 Mechanism test

In Section 3.2, we hypothesized that LCTS may achieve urban carbon emission reduction by promoting green technology development, optimizing energy consumption structure, and enhancing government environmental attention. To validate these three mechanisms, this study employs a mediation analysis framework with green technology development (*Gtec*), energy consumption structure (*Egys*), and government environmental attention (*Gov*) as mediating variables. The regression results are reported in Table 7.

Column (1) presents the result that the coefficient of *LCTS* on *Gtec* is 0.132, significant at the 5% level. This indicates that the LCTS policy effectively facilitated the development of urban green technologies. This outcome may be attributed to policy incentives that encouraged pilot cities to increase their R&D investment in green technologies, attract relevant enterprises and talent, and consequently accelerate the innovation and application of environmentally friendly technologies, thereby contributing to carbon emission reduction. Hypothesis H2a is therefore supported.

Column (2) presents the results for the energy consumption structure (*Egys*), where the coefficient of *LCTS* is 0.223 (significant at the 1% level). This indicates that the policy contributes to the optimization of urban energy consumption patterns by increasing the share of non–fossil energy sources. Specifically, the implementation of LCTS has prompted cities to tighten regulation on traditional fossil fuels while encouraging the adoption of new and renewable energy in transportation—such as through electric vehicle deployment and the expansion of charging infrastructure—thereby shifting the sector toward cleaner, low–carbon energy use. The growing reliance on non–fossil fuels reduces the transportation sector's dependence on high–carbon energy sources, thereby lowering total emissions and helping to mitigate urban carbon intensity. Hypothesis H2b is therefore supported.

Column (3) reveals a positive coefficient of LCTS on government environmental attention (*Gov*) at the 1% significance level, indicating that the pilot policy significantly enhanced local governments' focus on environmental issues. This can be partially attributed to pilot cities' imperative to comply with policy mandates, prompting them to formulate and implement low–carbon transportation measures proactively. The heightened environmental attention translates into stricter enforcement of emission regulations and more effective implementation of green transportation policies in the transportation sector, directly contributing to reduced urban carbon emissions. Hypothesis H2c is therefore supported.

Our study and Sun and Zhao (2024) both provide empirical evidence confirming that the LCTS pilot policy contributes to urban carbon emission reduction, underscoring the policy's effectiveness in promoting low-carbon transportation. Where our work diverges is in the exploration of underlying mechanisms: Sun and Zhao (2024) highlight industrial structure optimization as a key pathway, focusing on how the policy indirectly drives emission reductions through shifts in economic sectors. In contrast, our research emphasizes three transportation-specific mechanisms—green technology development, clean energy transition, and enhanced government environmental attention—delving into how the policy directly acts on technological innovation, energy structure adjustment, and governance practices within the transportation sector. These distinct perspectives together enrich the understanding of LCTS's emission reduction pathways, reflecting different dimensions of the policy's impact.

TABLE 8 Heterogeneity analysis based on public environmental awareness.

Variables	(1)	(2)
	High PEC	Low PEC
	CI	CI
LCTS	−0.151***	−0.087
	(0.055)	(0.063)
Is	0.017***	−0.003
	(0.005)	(0.004)
Pgdp	−0.097	−0.173
	(0.061)	(0.127)
Open	−0.090***	0.084
	(0.013)	(0.079)
Cars	0.225**	−0.045
	(0.112)	(0.085)
Urban	0.011	0.016**
	(0.008)	(0.006)
lnPop	−0.680*	−0.247
	(0.381)	(0.188)
_cons	5.365**	5.597***
	(2.689)	(1.685)
Controls	YES	YES
City FEs	YES	YES
Year FEs	YES	YES
Test for group differences	0.064***	
N	1929	1932
R–squared	0.842	0.843

5.5 Heterogeneity analysis

The benchmark regression results confirm that the Low–Carbon Transportation System (LCTS) pilot policy significantly promotes urban carbon emission reduction, and this conclusion is supported by multiple robustness tests, including parallel trend and placebo tests. However, Chinese cities exhibit substantial heterogeneity in terms of public environmental awareness, infrastructure development, and public service capacity. A more academically meaningful question, therefore, concerns whether the emission–reduction effects of the LCTS policy vary across cities with different characteristics. To explore these differential mechanisms of policy effectiveness, this paper conducts a heterogeneity analysis from three perspectives: public environmental awareness, road network density, and public transportation service efficiency. The objective is to provide both practical insights and theoretical support for the precise formulation and differentiated implementation of carbon–reduction policies.

5.5.1 Public environmental awareness

Public environmental awareness not only reflects residents' concern for environmental issues but also directly influences their acceptance and participation in low–carbon policies (Shen and Wang, 2023). This study utilizes search data provided by Baidu, Inc., where the ratio of the search frequency of the keyword "carbon dioxide" in each city to the total population is used as a proxy variable for public environmental awareness (*PEC*). Based on this indicator, sample cities are categorized into groups with higher and lower levels of public environmental awareness. The regression results presented in columns (1) and (2) of Table 8 indicate that in cities with higher public environmental awareness, the coefficient of *LCTS* is significantly negative. This suggests that the emission reduction effect of the LCTS policy is more pronounced in these cities. In contrast, in cities with relatively lower public environmental awareness, the LCTS coefficient is not statistically significant. Moreover, the intergroup differences are significant at the 1% level.

This result suggests that public environmental awareness has significantly influenced the effectiveness of the LCTS pilot policy in reducing emissions. In cities with relatively high levels of public environmental awareness, residents demonstrate greater concern for carbon emission issues and are more likely to support and engage in low–carbon initiatives, thereby strengthening the implementation outcomes of the LCTS policy. This may be attributed to the fact that in such regions, a low–carbon lifestyle is more prevalent, individuals respond more proactively to policy initiatives, and there is greater acceptance of green transportation options (Wang et al., 2025). Conversely, in areas where public environmental awareness is lower, limited resident engagement and attention to carbon issues hinder the full realization of the LCTS policy's emission reduction potential.

5.5.2 Road density

Urban road density serves as a critical indicator for assessing urban transportation infrastructure, directly influencing the efficiency and structure of transportation systems while exerting a significant impact on carbon emissions (Ghannouchi et al., 2023). In cities characterized by high road density, the transportation network tends to be more comprehensive, with greater coverage of public transit and non–motorized vehicle lanes. This facilitates low–carbon commuting options for residents and creates favorable conditions for the implementation of Low–Carbon Transportation Strategies (LCTS), thereby supporting the achievement of emission reduction goals. In contrast, cities with low road density may face limitations in transportation infrastructure, which can hinder the adoption and effectiveness of low–carbon transportation solutions, ultimately compromising policy outcomes.

Based on this, the paper classifies the full sample into two groups—cities with high road density and cities with relatively low road density—according to the median value of urban road density. The regression results presented in columns (1) and (2) of Table 9 indicate that, in cities with high road density, the coefficient of *LCTS* is −0.130 and statistically significant at the 1% level. This suggests that the LCTS pilot policy has a more pronounced emission reduction effect in such cities. In contrast, in cities with relatively low road density, the *LCTS* coefficient is not statistically significant. Furthermore, the difference between the two groups is significant at the 1% level. These findings demonstrate that urban road density significantly influences the effectiveness of the LCTS pilot policy. Specifically, in cities with higher road density, transportation infrastructure is more developed, public transit networks are better established, and residents have access to more low–carbon travel options, all of which contribute to a stronger policy implementation outcome.

TABLE 9 Heterogeneity analysis based on road density.

Variables	(1)	(2)
	High road density	Low road density
	CI	CI
LCTS	−0.130***	−0.033
	(0.037)	(0.049)
Is	0.005	0.003
	(0.006)	(0.005)
Pgdp	−0.080	−0.503***
	(0.072)	(0.117)
Open	−0.097***	−0.018
	(0.005)	(0.034)
Cars	−0.097	0.341***
	(0.072)	(0.119)
Urban	0.010	0.012**
	(0.006)	(0.006)
lnPop	0.316	−0.754***
	(0.696)	(0.160)
_cons	1.380	10.013***
	(4.233)	(1.530)
Controls	YES	YES
City FEs	YES	YES
Year FEs	YES	YES
Test for group differences	0.097***	
N	1931	1935
R–squared	0.819	0.863

5.5.3 Public transport service capacity

Urban public transport, as a key component of urban transportation systems, directly influences residents' travel choices and carbon emissions (Jing et al., 2022). Cities with high public transport service availability (PTSA) provide more convenient and efficient mobility options, which encourage residents to choose public transport over private vehicles, thereby achieving greater reductions in carbon emissions. In contrast, cities with low PTSA may fail to attract significant public transit usage due to insufficient coverage or infrequent services, thus limiting the emission–reduction potential of the Low–Carbon Travel Subsidy (LCTS) policy.

We classify the sample cities into high– and low–PTSA groups based on the median value of public transport passenger volume. As shown in Table 10, columns (1) and (2), the *LCTS* coefficient in

TABLE 10 Heterogeneity analysis based on public transport service capacity.

Variables	(1)	(2)
	High PTSA	Low PTSA
	CI	CI
LCTS	−0.217***	−0.128*
	(0.078)	(0.075)
Is	−0.001	0.014***
	(0.005)	(0.005)
Pgdp	−0.133*	−0.249**
	(0.079)	(0.111)
Open	0.703	−0.080***
	(0.902)	(0.018)
Cars	−0.098	0.322***
	(0.078)	(0.116)
Urban	0.012*	0.011*
	(0.007)	(0.006)
lnPop	0.453	−0.880***
	(0.585)	(0.178)
_cons	1.389	7.723***
	(3.336)	(1.723)
Controls	YES	YES
City FEs	YES	YES
Year FEs	YES	YES
Test for group differences	0.089**	
N	1934	1930
R−squared	0.843	0.836

high−PTSA cities is −0.217, statistically significant at the 1% level, indicating a substantial reduction in emissions. In low−PTSA cities, the coefficient is −0.128, significant only at the 10% level. The difference between the two groups is statistically significant at the 5% level. These findings confirm that PTSA plays a crucial role in determining the effectiveness of the LCTS policy. In high−PTSA cities, residents have access to more low−carbon travel alternatives, which aligns with the objectives of the LCTS policy and enhances its emission−reduction impact. Conversely, in low−PTSA cities, unmet travel demands and higher reliance on private cars weaken the policy's effectiveness.

6 Conclusion and policy recommendations

6.1 Conclusion

Based on a panel dataset covering 242 Chinese cities from 2007 to 2022 and a multi − period DID model, this paper evaluates the impact of the LCTS pilot policy on urban carbon emissions and explores its mechanisms and heterogeneous effects. The key findings are as follows.

1. The LCTS pilot policy has significantly reduced urban carbon intensity. The benchmark regression results indicate that after the implementation of the LCTS pilot policy, the average urban carbon emission intensity decreased by approximately 17.3%, demonstrating that the policy has played a significant role in promoting urban carbon reduction.
2. The LCTS policy achieves emission reductions through multiple pathways. Empirical analysis reveals that the LCTS pilot policy reduces carbon emissions by promoting green technological development, facilitating clean energy transition, and enhancing governmental environmental concern. Specifically, the policy has effectively stimulated the growth of green technologies in cities, advanced the innovation and application of new energy vehicle technologies, optimized the energy consumption structure, increased the proportion of non−fossil energy use, and notably enhanced local governments' attention to environmental issues, thereby strengthening policy enforcement and environmental regulatory efficiency.
3. The policy effect exhibits heterogeneity. Heterogeneity analysis shows that the emission reduction effect of the LCTS pilot policy is more pronounced in cities with higher public environmental awareness, greater road network density, and more efficient urban public transportation services. This suggests that the effectiveness of the policy is significantly influenced by the specific characteristics of individual cities.

6.2 Policy recommendations

First, it is essential to enhance the intensity and precision of policy implementation. Local governments should develop differentiated implementation plans tailored to the specific characteristics of each city. For example, in cities where public environmental awareness is relatively low, efforts should focus on increasing investment in publicity and education through community activities, media campaigns, and other outreach initiatives to raise residents' awareness of low−carbon travel. In cities with low road density, priority should be given to improving transportation infrastructure, rationally planning urban layouts, and expanding road networks to create favorable conditions for low−carbon mobility. Furthermore, governments should strengthen interdepartmental coordination and collaboration to foster policy synergy and jointly advance the development of green transportation.

Second, there is a need to reinforce support for the research, development, and promotion of green technologies. Governments must continuously increase financial subsidies and tax incentives to encourage enterprises and research institutions to engage in green technology innovation, particularly in key areas such as new energy vehicles and intelligent transportation systems. Establishing platforms for industry−academia−research collaboration on green technologies can accelerate the transformation and practical application of technological achievements. Taking new energy vehicle technology as an example, governments can establish special funds to support cutting–edge research in fields like battery technology and autonomous driving. At the same time, policy guidance can facilitate the widespread adoption of new energy vehicles in urban areas.

Third, urban transportation infrastructure and public services should be improved. Increased investment in the public transportation system is necessary to enhance service quality and expand its coverage. The supply of high–capacity transit options such as subways and light rails should be increased, while bus routes and schedules should be optimized to encourage more residents to choose public transportation for their daily commutes. For example, subway lines and station placements should be strategically planned based on population distribution and travel demand patterns. At the same time, efforts should focus on strengthening the construction of non–motorized vehicle lanes and pedestrian pathways to establish a safe and convenient slow traffic system. Urban planning should allocate sufficient space to create continuous and comfortable environments for walking and cycling, thereby reducing residents' reliance on private vehicles and lowering carbon emissions. Additionally, the government should implement intelligent transportation systems to optimize traffic flow distribution and improve overall traffic efficiency, further mitigating the increase in carbon emissions caused by traffic congestion.

6.3 Limitations and future research

This study provides empirical evidence for the carbon reduction effects of China's LCTS pilot policy, but several limitations remain, offering avenues for future research. First, the measurement of transportation carbon emissions in this paper mainly relies on energy consumption data (e.g., electricity, natural gas), which may not fully capture the entire life cycle of transportation activities—such as carbon emissions from vehicle manufacturing, maintenance, and infrastructure construction. Future studies could integrate life cycle assessment (LCA) methods with high–resolution data to refine carbon emission accounting.

Second, while this study identifies three key mechanisms (green technology, energy transition, and government environmental concern), the interactive effects between these mechanisms remain underexplored. For instance, does green technology innovation accelerate energy transition more significantly in cities with strong government oversight? Or do improvements in energy structure amplify the emission reduction effects of green technology? Future research could adopt structural equation models or moderated mediation analysis to unpack these complex interactions, enhancing the understanding of policy transmission chains.

Third, the heterogeneity analysis in this paper focuses on public environmental awareness, road density, and public transport capacity, but other contextual factors—such as fiscal capacity, marketization level, and intergovernmental coordination—may also shape policy effectiveness. For example, cities with stronger fiscal support might invest more in charging infrastructure, thereby strengthening the energy transition mechanism. Exploring these dimensions could provide a more nuanced understanding of how local contexts moderate policy impacts.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: Data available on request from the corresponding author. Requests to access these datasets should be directed to g20203408@xs.ustb.edu.cn.

Author contributions

JS: Methodology, Funding acquisition, Software, Supervision, Formal Analysis, Writing – review and editing, Visualization, Data curation, Project administration, Conceptualization, Writing – original draft, Validation, Resources, Investigation.

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The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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