Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 19 May 2025
DOI 10.3389/fenvs.2025.1534526

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RECEIVED 26 November 2024
ACCEPTED 24 March 2025
PUBLISHED 19 May 2025

CITATION
Yang S, Zhou Y and Meng Q (2025) Gift or gamble? Evaluating the impact of urban low-carbon governance on high-quality development in China.
Front. Environ. Sci. 13:1534526.
doi: 10.3389/fenvs.2025.1534526

Gift or gamble? Evaluating the impact of urban low-carbon governance on high-quality development in China

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Introduction: Climate change demands urgent action, and low-carbon urban governance has become crucial for sustainable development. China introduced the Low-Carbon City Pilot (LCCP) policy to reduce emissions and promote green growth. This study evaluates how LCCP affects high-quality development (HQD), providing insights for policymakers.

Methods: We measured HQD using the entropy weight method and employed the difference-in-differences (DID) approach with 2000-2021 panel data from 351 Chinese cities, treating the LCCP as a quasi-natural experiment. Analyses included baseline tests, robustness tests, mechanism tests, and heterogeneity analysis.

Results: The findings indicate that the LCCP significantly enhances HQD, thereby supporting the Porter Hypothesis within the context of China's environmental and economic policies. Robustness tests, including parallel trend test, propensity score matching-DID, expanded sample analysis and substituted the explained variable, confirm the reliability of these results. Mechanism analysis reveals that the improvements in HQD are driven by technological innovation, industrial upgrading, infrastructure development, and energy system transformation. Furthermore, heterogeneity analysis shows that the policy's impact is more pronounced in general cities and Han Chinese provinces.

Discussion: These results demonstrate that the LCCP functions as a "gift" for enhancing HQD, offering valuable insights for refining low-carbon governance policies and providing actionable lessons for other countries pursuing ecological environment with well-being growth.

KEYWORDS

low-carbon pilot cities, urban low-carbon governance, high-quality development, quasi-natural experiment, climate change, sustainable development

1 Introduction

As global warming intensifies, rising sea levels, the increased frequency of extreme weather events, and the loss of biodiversity have become pressing concerns. The international community increasingly recognizes the necessity of implementing low-carbon environmental governance strategies to tackle these severe challenges (Liu et al., 2023; Lu et al., 2023; Song et al., 2020). The State of the Climate 2024 Update for

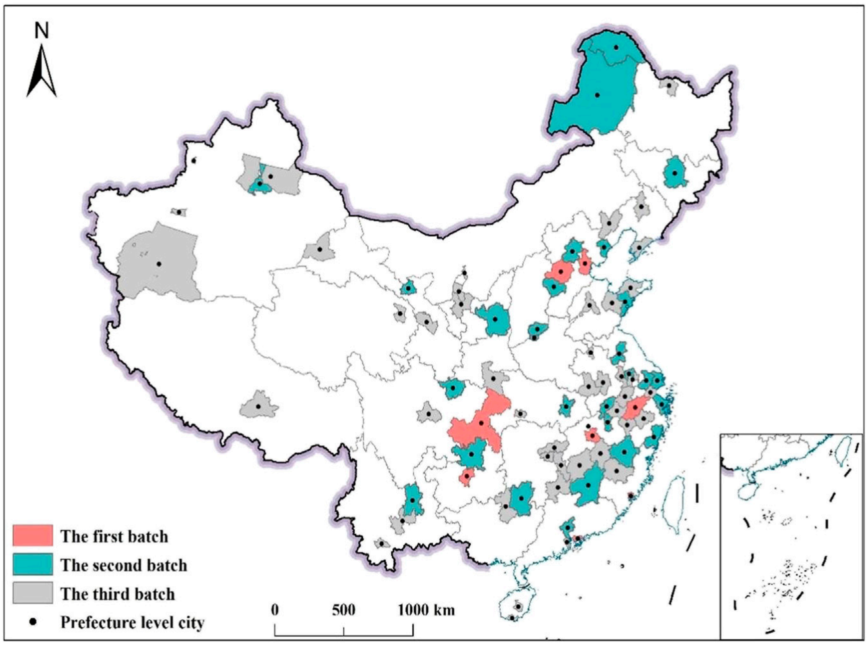

FIGURE 1
Spatial distribution of the LCCP in China.

COP29 paints a grim picture of the Earth, portraying it as teetering on the brink of collapse due to pollution from fossil fuels, which is driving climatic disturbances to unprecedented levels. The report highlights that the average near-surface global temperature is now 1.54°C (±0.13°C) above the pre-industrial baseline (1850–1900). These dire environmental conditions jeopardize the stability of natural ecosystems and species survival and severely threaten human quality of life and economic development (Lakner et al., 2024). Consequently, deploying low-carbon governance models characterized by reduced energy consumption, pollution, and emissions is urgently required globally (Bosah et al., 2023; Caglar and Yavuz, 2023). As critical regional economic and social development centers, cities are increasingly considered vital players in adopting low-carbon initiatives (Muñoz-Erickson et al., 2016). Responding to its status as the world's largest consumer of energy and emitter of greenhouse gases, the Chinese government proactively initiated the low-carbon city pilot policy (LCCP) in 2010, 2012, and 2017. The policy launched three batches of pilots involving 81 cities (see Figure 1) to foster economic growth, improve public welfare, and effectively control greenhouse gas emissions (Li et al., 2024b; Pan et al., 2022; Song et al., 2020; Wang and Yao, 2024). The 2023 National LCCP Assessment Report shows that pilot cities have achieved significant economic growth and effectively managed carbon emissions under the LCCP.

The United Nations Agenda 2030 outlines 17 Sustainable Development Goals (SDGs), encompassing a broad spectrum of economic, social, environmental, and ecological policy objectives (Biggeri et al., 2023; Salman et al., 2024). This framework signals a departure from the traditional quantitative model of economic growth, which no longer satisfies societal demands for improved environmental quality and life quality. Instead, the global trend in sustainable development now prioritizes an integrated approach that harmonizes economic development, environmental protection, and people's wellbeing (Agbedahin, 2019; Holden et al., 2017). China's development trajectory aligns closely with SDGs (Bei, 2018). In 2017, China issued an ambitious declaration on high-quality development (HQD), signaling a shift from a phase of rapid economic growth to one focused on HQD (Pan et al., 2021). This declaration serves as a milestone and a strategic guide for China's ongoing development efforts. HQD emphasizes the importance of maintaining economic growth while enhancing the quality and efficiency of development efforts. It aims for a balanced and sustainable progression across economic, social, and environmental dimensions (Pan et al., 2021; Zhao et al., 2019). Establishing a comprehensive assessment indicator system is imperative to effectively implement and assess the HQD level in China. Within this framework, the success of the LCCP in promoting HQD is critical for accurately measuring the effectiveness and outcomes of policy implementation and reform efforts.

Scholars hold differing views on the effectiveness of environmental policies. The traditional view suggests that ecological protection policies increase private production costs and reduce corporate competitiveness, thus negating their positive effects on society and adversely affecting economic growth (Adam, 1995). However, scholars like Porter and Van der Linde argue that the relationship between environmental protection and economic development cannot be dichotomized into opposition (Porter and Van der Linde, 1995). They believe appropriate environmental regulations can stimulate businesses to engage in more innovative activities. These innovations can enhance productivity, offset the costs associated with environmental protection, and improve corporate profitability in the market, thereby fostering economic growth. This topic has sparked a debate in the academic community, and more empirical research is needed to resolve these disputes (Benatti et al., 2024). The LCCP in China serves as a conventional administrative tool for environmental governance and manifests rational environmental regulation, aligning with the foundational premises of the Porter hypothesis (PH) (Yu et al., 2023). Accordingly, employing the PH as theoretical guidance, this study investigates whether the LCCP facilitates HQD as a beneficial gift or represents a precarious gamble.

Previous research has extensively examined the differential impacts of LCCP. However, these analyses have primarily focused on individual aspects such as environmental (Liu et al., 2022; Wen H. et al., 2022; Zeng et al., 2023), economic (Jiang et al., 2024; Wang S. S. et al., 2024), social (Fu et al., 2024; Zhang and Zheng, 2023), or business impacts (Chen et al., 2021; Li Y. et al., 2024) and often lack a holistic evaluative framework. To fill this gap, this paper seeks to delineate the relationship between LCCP and HQD. Utilizing panel data from 351 Chinese cities from 2000 to 2021, a difference-in-differences (DID) methodology is applied to explore the relationship and mechanisms through which the LCCP influences HQD. Considering the significant disparities in development levels and resource endowments across different regions of China, this analysis further differentiates the policy impacts between general cities and provincial capitals and between autonomous ethnic regions and Han-majority provinces.

This study makes significant contributions in four key areas: (1) previous studies have typically focused on the one-dimensional impacts of the LCCP without an integrated assessment framework. Our study employs HQD as the dependent variable to address this limitation, facilitating a comprehensive evaluation across social, economic, and environmental dimensions. This approach encompasses the multifaceted impacts and enhances the understanding of the overall benefits associated with the LCCP, providing a more holistic perspective for future research. (2) Previous methods of measuring HQD have been criticized for being overly simplistic and having overlapping indicators among variables. Therefore, we developed a detailed HQD evaluation framework comprising five secondary indicators, namely, industrial structure, inclusive total factor productivity (TFP), technological innovation, ecological environment conditions, and residents' living standards. This system effectively addresses issues related to indicator selection, offering a more accurate and comprehensive measurement standard that aids researchers and policymakers in better understanding and promoting HQD. (3) We furnished new empirical evidence to substantiate the theory by integrating the PH with empirical studies on LCCP. This synthesis aids in validating the applicability of the PH within the Chinese context and introduces a novel theoretical lens to examine the relationship between LCCP and HQD. Additionally, we utilized insights from the PH, endogenous growth theory, new structural economics, neoclassical economics, the biophilia hypothesis, and landscape ecology to deepen our understanding of the LCCP impact mechanisms, focusing on technological innovation, industrial upgrading, infrastructure development, and energy structure optimization. (4) Based on the analysis of LCCP, our study demonstrates that urban low-carbon governance can significantly enhance HQD. By detailing the impact of mechanisms between the two, this study addresses the gaps in the existing literature regarding indirect pathways. In addition, the study enhances the scope of heterogeneity analysis by incorporating urban classification and ethnic diversity, thus providing a more nuanced understanding of the policy impacts. Specifically, our research results can assist policymakers in designing and implementing more effective environmental policies, thereby advancing SDGs on a global scale.

The remainder of this paper is structured as follows: Section 2 discusses the literature review. Section 3 outlines theoretical hypotheses. Section 4 introduces research methods and materials. Section 5 presents empirical analysis, including baseline regression, robustness tests, tests for mechanisms, and heterogeneity analysis. Finally, Section 6 discusses the conclusions, theoretical implications, policy impacts, limitations, and suggestions for future improvements.

2 Literature review

2.1 Progress in LCCP evaluation research

The LCCP is a pivotal initiative adopted by China to advance energy conservation and reduce emissions. The policy is a "testing ground" for evaluating climate policies and a model for the "diffusion effect" from a local pilot to a national rollout. The existing literature on LCCP evaluation mainly discusses whether the policy conforms to the PH (Tian et al., 2021), which is primarily reflected in the impact on enterprise impacts, industrial structure, environmental protection, social benefits, and other aspects. At the enterprise level, Luo S. et al. (2024) provided evidence that the LCCP considerably facilitates low-carbon technological innovation. Li et al. (2024a) further substantiated the efficacy of the PH in enhancing green innovation within firms under the LCCP, highlighting the significant intermediary role of public environmental awareness. Concurrently, Yu et al. (2024) and Wan et al. (2024) corroborated that implementing LCCP positively influences firms' environmental, social, and governance performance within the pilot areas. Furthermore, LCCP has been shown to boost corporate profitability by escalating investment in innovation and augmenting financial subsidies (Han et al., 2023). Adjustments in the industrial structure are essential for economic advancement. Some scholars have observed a favorable impact of the LCCP on the industrial structure supererogation (Zheng et al., 2021). Environmentally, the LCCP significantly reduces carbon emission intensity in pilot cities (Hou et al., 2023; Zeng et al., 2023), enhances carbon emission efficiency (Wen S. et al., 2022), and robustly supports green growth (Cheng et al., 2019; Liu et al., 2022). In addition, Du et al. (2022) developed a novel hybrid trigonometric envelopment analysis for an ideal solutions model to assess the eco-efficiency of cities, highlighting that LCCP contributes positively to eco-efficiency, primarily through the mechanisms of green technology innovation. Regarding social benefits, the LCCP may either deter entrepreneurial activities by increasing production costs or foster them by accumulating human capital and promoting technological innovation (Wang Y. et al., 2023). Fu et al. (2024) identified a marked positive impact of LCCP on urban employment, attributing improvements to enhanced output and creativity levels. Although existing studies have extensively examined the effects of LCCP, they generally focus on evaluating individual aspects of the policy, thereby lacking a holistic and comprehensive assessment framework.

2.2 Literature review on HQD

2.2.1 Development of indicator construction

HQD encompasses a broad and evolving set of concepts reflected in the diverse definitions offered by scholars in the field. Guo et al. (2024) developed a comprehensive indicator system for China's HQD, categorizing it into five critical areas, namely, innovation-driven growth, coordinated development, economic progress, environmental sustainability, and social wellbeing, with 24 sub-indicators. Du (2023) proposed a model focused on three dimensions—environmental sustainability, economic structure optimization, and social welfare enhancement—to assess the structural optimization of economic growth. Similarly, Ma et al. (2019) introduced an evaluation framework comprising 28 indicators across five dimensions, namely, high-quality supply, demand, development efficiency, economic operation, and international openness.

Despite these innovative contributions, the existing frameworks of indicators exhibit certain limitations that warrant further refinement. First, these systems tend to overlap process and result indicators. Since HQD epitomizes the outcomes of socio-economic progress, it is essential that the chosen indicators predominantly reflect results rather than processes. However, several existing indicators pertain more to ongoing processes. Second, the issue of redundancy in indicators persists; for instance, the overlapping measures of capital output efficiency, labor productivity, and TFP in previous systems exhibit strong correlations and similarities, which may impede the precise measurement of HQD. To overcome these challenges, future research should focus on devising more targeted and innovative indicators that differentiate between processes and outcomes and minimize redundancy within the evaluation system.

2.2.2 Study on the factors affecting HQD

A blend of external and internal factors drives HQD. Among the internal factors, upgrading the industrial structure is the core driver of achieving HQD. Yang and Tian (2023) demonstrated that industrial intelligence upgrading exerts a substantial spatial spillover effect on regional economic quality. Furthermore, digital financial inclusion, often called the "catfish effect," mitigates enterprise financing constraints by reducing information asymmetry and addressing the misallocation prevalent in traditional monetary systems. This facilitates substantial capital inflow for expansive development, catalyzing the transition to HQD (Lee et al., 2023; Li Z. et al., 2024). Investment-led growth, mainly through government infrastructure investments, also fosters economic advancement. Yang et al. (2022) identified a significant positive impact of government infrastructure investments on HQD, while Wang and Liu (2023) distinguished the varying effects of different types of infrastructure investments on economic enhancement.

Among the external drivers of HQD, the interplay between foreign direct investment and the host country's growth has garnered significant scholarly interest. The pollution haven hypothesis argues that foreign investment and financial openness can catalyze the development of environmentally low-carbon industries, thereby facilitating HQD (Singhania and Saini, 2021). In addition, environmental regulation is a critical metric of governmental environmental governance and is pivotal in fostering sustainable development (Wu, 2025). Current literature predominantly assesses the impact of environmental regulation on HQD through its effects on TFP (Lian et al., 2024; Tong et al., 2022; Wen S. et al., 2022). The prevalent method for measuring environmental regulation involves quantifying the frequency of environment-related terms in government work reports (Du, 2023). Although this method offers a means to quantify the intensity of environmental regulation, it does not provide a thorough analysis of the effects resulting from the implementation of specific environmental policies. Therefore, it is essential to redirect research efforts toward more detailed environmental policies. This shift will enable a deeper understanding of how environmental regulation influences HQD.

2.3 Literature gaps and improvements

Previous literature has established a solid foundation for our study, yet it contains notable gaps. First, while existing research has thoroughly examined the effects of LCCP, these studies typically focus on evaluating a single aspect and lack a comprehensive evaluation framework. This approach introduces significant limitations in assessing the overall impact and long-term sustainability of the LCCP. Second, regarding research subjects, current methods of determining HQD suffer from significant shortcomings, including an inability to effectively distinguish between process and outcome indicators. Additionally, there is a considerable overlap in assessment indicators, which compromises the precision and efficiency of evaluations. Third, although there is a burgeoning interest in the nexus between environmental regulation and HQD, most studies have approached this relationship from a macro perspective. There remains a scarcity of research concentrating on the implications of specific environmental policies.

This paper advances the existing literature in three significant ways. First, we pivoted from a macro-level analysis of environmental regulations to a targeted examination of the LCCP. Through a holistic evaluation framework based on HQD, we systematically examine the LCCP's multi-dimensional effects across economic, environmental, and social domains, offering a valuable complement to current research. Second, in terms of index selection, we draw on the research of Zhao et al. (2022) and set up a multi-dimensional evaluation system composed of five secondary indicators, namely, industrial structure, inclusive TFP, technological innovation, residents' living standards, and ecological environment, which effectively addressed the dilemma of index selection mentioned above. This is reflected in the fact that the index system eliminates the indicators with duplicate information or low influence and uses comprehensive indicators (such as the inclusive TFP index) to replace multiple single indicators, thus reducing possible duplication in the evaluation process. Finally, guided by the PH, this paper systematically analyzes the LCCP's effects on HQD and investigates the interaction mechanisms between the two. Our findings extend the applicability of the PH within the Chinese context and offer practical insights for policymakers on refining environmental strategies to foster global low-carbon development.

3 Theoretical hypotheses

3.1 Direct effect

Conventional perspectives on environmental regulation often posit that such regulations escalate operational costs for firms, potentially undermining their competitive edge. However, the PH presents a counter-narrative, suggesting that stringent environmental policies can catalyze innovation within firms, thereby bolstering their competitiveness and aiding environmental conservation—a dual-benefit scenario (Feichtinger et al., 2005; Lanoie et al., 2008; Porter and Van der Linde, 1995; Sun et al., 2024). Numerous scholarly investigations have explored the PH, and empirical evidence corroborates it across various fields, including facilities (Lanoie et al., 2011), firms (Chen et al., 2022; Wei Y. et al., 2022), industries (Wang et al., 2022; Wu and Lin, 2022), and regions (Nie et al., 2021). The rationale behind the hypothesis is multifaceted: first, environmental regulations guide technological advancements within companies; second, they mitigate investment uncertainties in environmental values; third, they heighten corporate environmental consciousness; fourth, they alter the traditional competitive landscape; and finally, they exert external pressures that necessitate innovation and progression within firms. This framework suggests that environmental regulatory policies and economic efficiency are not inherently contradictory but can complement and enhance one another. The academic community has gradually shifted the research focus of the PH to the benefits of specific environmental pilot policies, confirming the validity of the PH (Jin et al., 2022; Yu et al., 2023).

Building on this framework, we argue that the LCCP motivates firms to innovate. This innovation helps offset the costs associated with environmental protection and enhances these firms' profitability and market competitiveness, thereby supporting HQD. Moreover, the LCCP steers pilot cities toward adopting state-of-the-art environmental technologies and methods. This adoption markedly reduces pollution levels and diminishes the costs tied to environmental management (Chakraborty and Chatterjee, 2017). In its governance strategies, China has accelerated the development of green and low-carbon industries and consistently championed a green transformation in its development paradigm. This shift not only propels new engines of economic growth but also harmonizes green economic progress with the overarching goals of HQD (Yan et al., 2023). Consequently, the LCCP is instrumental in improving environmental quality and spurring an economic shift toward sustainability. Based on this comprehensive analysis, we formulate the following hypothesis. A diagram of research hypotheses is shown in Figure 2.

Hypothesis 1: The LCCP exerts a significant positive influence on HQD.

3.2 Indirect effects

3.2.1 Mechanism—technological innovation

Innovation-driven development and breakthroughs in core technologies constitute the foundational pillars of HQD. As postulated by the endogenous growth theory, endogenous factors such as technological innovation, characterized by positive externalities, are essential for sustaining long-term economic growth (Romer, 1986). This theory is robustly supported by empirical evidence indicating that green innovations catalyze significant advancements in economic development and environmental protection (Zhou et al., 2023). Regarding policy implementation, on one hand, the LCCP encourages enterprises to pursue independent innovation through proactive policy guidance, fiscal incentives, tax exemptions, and innovation funds. These measures effectively drive the development and adoption of low-carbon technologies, thereby reducing energy consumption and pollution emissions while enhancing the ecological capital. Furthermore, advancements in technological innovation contribute to higher labor productivity, expand the potential scope of economic activities, and enable the high-quality growth of the economy (Jiang et al., 2024). On the other hand, local governments often utilize command-and-control policy tools to enforce strict environmental standards for enterprises' technology and production processes. This approach pressures pollution-intensive industries to increase innovation investments, facilitating green transformation and promoting HQD (Qu et al., 2023). In addition, existing empirical studies consistently demonstrate that technological innovation can reduce reliance on fossil fuels, lower greenhouse gas emissions, and foster sustainable economic growth (Du et al., 2025).

Furthermore, the PH articulates that stringent environmental regulations incrementally elevate production costs for enterprises characterized by high pollution, high energy consumption, and low production efficiency. This regulatory pressure compels firms to enhance resource utilization efficiency through technological innovation (Porter and Van der Linde, 1995). Extensive research confirms that in the context of severe environmental regulations, pilot cities facilitate the integration of digital technologies with energy-efficient and low-carbon solutions, thereby expediting the supply and diffusion of green technological innovations. This process promotes the transformation of traditional industries toward more sustainable and intelligent operational frameworks, thereby enhancing both technical efficiency and labor productivity within the traditional manufacturing sectors (Yu et al., 2023; Zhao et al., 2023). Hence, the role of technological innovation in moderating the effect of LCCP on enhancing HQD is crucial as it can guide economic growth toward a greener, more inclusive, and more sustainable path. Based on this, we advance the following hypothesis:

Hypothesis 2: Technological innovation plays a positive moderating role in the relationship between LCCP and HQD.

3.2.2 Mechanism—industrial upgrading

According to the PH, stringent environmental regulations can mandate a constructive "cleansing" within industrial clusters by instigating a process of natural selection. This can enhance the quality and competitiveness of industries and ultimately facilitate an upgrade in the industrial structure (Porter and Van der Linde, 1995). Empirical studies substantiate that the LCCP effectively stimulates the upgradation of urban industrial structures (Wang and Chu, 2024; Xie and Teo, 2022). Specifically, at the metropolitan level, the

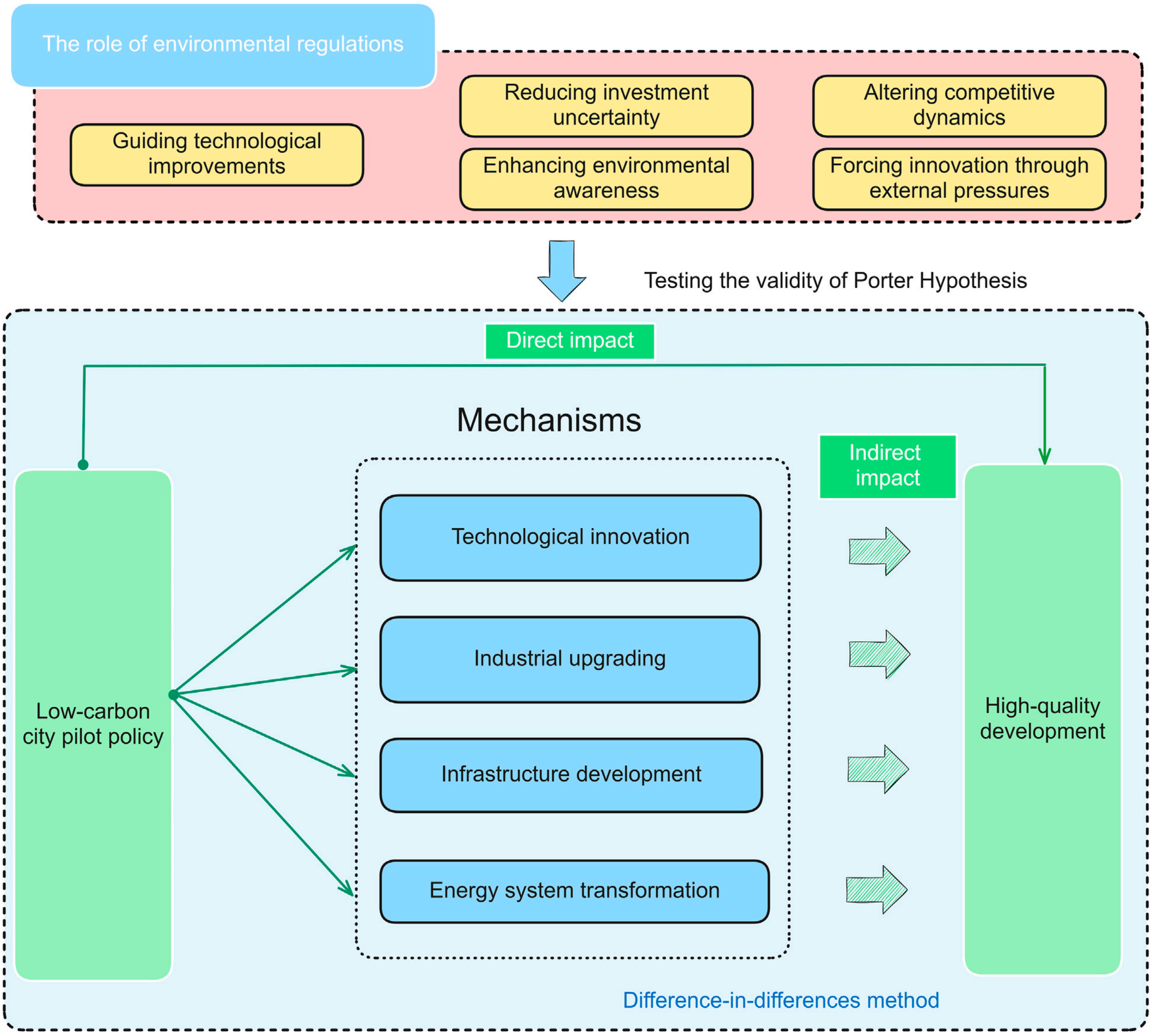

FIGURE 2
Diagram of the research hypotheses.

LCCP has facilitated enhanced resource efficiency and catalyzed the transformation and upgrading of low-carbon industries, leading to reduced carbon emissions and improved environmental quality. At the industry level, the constraints imposed by low-carbon governance have curbed the expansion of pollution-intensive sectors and fostered the growth of clean industries, emerging manufacturing sectors, and services, thereby contributing to the optimization of industrial structures. At the enterprise level, the enforcement of LCCP has increased the cost of emissions, compelling firms to optimize their supply chains and reduce energy consumption to meet carbon reduction targets. In the long term, this has promoted organizational transformation and technological upgrading. Moreover, the policy has eliminated obsolete production capacity in high-energy-consuming and high-emission industries, imposed more stringent entry standards for these sectors, and incentivized the rapid development of the green industry sectors.

Upgrading the industrial structure influences the pollution intensity of production activities and the quality of the environment, thus serving as a dependable indicator for fostering HQD (Feng et al., 2024). Drawing from the theory of new structural economics, it is argued that endowment-driven structural transformations and industrial upgrades amplify an economy's overall productivity and efficacy (Lin, 2021). Consequently, the optimization of industrial structures yields a "structural dividend" that not only enhances resource distribution but also improves the functionality of ecosystems. Additionally, numerous studies have corroborated that industrial upgrades under the impetus of the LCCP typically embody high technological sophistication and low carbon footprints (Wei Q. et al., 2022), thus critically contributing to the optimization of economic structures and the promotion of sustainable development (Wang Z. et al., 2023; Zheng et al., 2021). From the analysis presented, we propose the following hypothesis:

Hypothesis 3: Industrial upgrading plays a positive moderating role in the relationship between LCCP and HQD.

3.2.3 Mechanism—infrastructure development

Green infrastructure represents a concept counterposed to "gray infrastructure" (such as roads, utility networks, and other municipal support systems). This concept underscores the necessity of integrating green spaces and natural areas within urban planning as indispensable resources for sustainable development (Taczanowska et al., 2024). From the landscape ecology perspective, green infrastructure is vital for sustaining biodiversity within urban environments, contributing to ecological balance, and enhancing environmental services (Vilanova et al., 2024). The LCCP advocates for expanding urban green infrastructure, recognizing it as a crucial catalyst for sustainable development. This initiative gives rise to the "green magnet effect," a positive cyclical feedback mechanism in which urban green infrastructure actively contributes to urban development (Jiao et al., 2023).

This effect has been validated across various dimensions, including economic growth, environmental sustainability, and social and mental wellbeing (Hong et al., 2020). Economically, green infrastructure under the LCCP enhances a city's attractiveness, increases real estate values, and attracts tourists and investors, stimulating economic growth. LCCP-driven green spaces also encourage the development of new economic models, such as eco-tourism, green commerce districts, and sustainable urban development initiatives (Shan et al., 2024). Environmentally, the LCCP's focus on expanding green spaces significantly improves urban environmental quality. By mitigating heat island effects, improving air quality, enhancing biodiversity, and regulating the urban water cycle, green spaces help create a healthier, more sustainable urban environment. Socially, these spaces offer recreational opportunities that elevate life quality and communal wellbeing. From a psychological perspective, the biophilia hypothesis posits that green spaces act as a crucial psychological refuge in contemporary urban life's rapid pace. These areas facilitate stress reduction, mood improvement, and enhanced psychological resilience, thus supporting mental health in urban populations (Lin et al., 2019; Yang et al., 2019). Thus, green infrastructure is essential for promoting HQD and providing far-reaching benefits across multiple fronts.

Hypothesis 4: Infrastructure development plays a positive moderating role in the relationship between LCCP and HQD.

3.2.4 Mechanism—transformation of the energy system

Neoclassical economics identifies that energy consumption frequently entails negative externalities, including air pollution and greenhouse gas emissions, which precipitate market failures because the associated costs are not fully integrated into market prices (Spanjer, 2009). Accordingly, the neoclassical economics theory advocates for internalizing these external costs through policy mechanisms such as carbon taxes and emission trading systems. Consumers and producers are incentivized to adopt more energy-efficient practices and technologies by factoring these costs into energy prices, thus enhancing overall energy efficiency (Illge and Schwarze, 2009). Additionally, drawing on the PH, the LCCP is anticipated to generate an "innovation compensation effect." This effect posits that improvements in energy efficiency will enable economic growth at reduced energy consumption levels or potentially allow for continued economic expansion with a decrease in total energy use, thus facilitating sustainable development (Porter and Van der Linde, 1995).

With the promotion and implementation of LCCP, local governments can exert pressure on enterprises by encouraging the decarbonization of energy consumption structures and utilizing mechanisms such as emission trading. These actions help reduce the use of non-renewable, finite energy sources while promoting low-carbon and zero-carbon production models, thereby improving overall energy efficiency (Malinauskaite et al., 2020). Second, local governments support the development of low-carbon and renewable energy industries, such as solar, wind, and hydro energy. This strategy aims to foster the coordinated development of ecological civilization and economic growth, ultimately contributing to green economic development. Furthermore, the policy emphasizes the importance of establishing a robust energy management system, which includes energy audits, real-time monitoring, and efficiency evaluations. These measures are essential for identifying and addressing issues related to energy waste, thus optimizing energy utilization. Promoting greater energy efficiency and reducing environmental impacts contribute to sustainable development and play a pivotal role in fostering high-quality economic growth. Based on these premises, we propose the following hypothesis.

Hypothesis 5: The transformation of the energy system plays a positive moderating role in the relationship between LCCP and HQD.

4 Material and methods

4.1 Model specification

In practical social science research, conducting rigorous randomized controlled trials to assess the impact of policies is often challenging. Therefore, quasi-natural experiments offer a viable alternative. The DID model, a quasi-natural econometric tool, has been extensively used to evaluate policy effects (Walker, 2011). It assesses the impact of policy interventions by comparing the changes in outcomes over time between a treatment group and a control group. Additionally, it effectively addresses issues caused by omitted variables (Shi and Zhang, 2023). This method accurately reflects the actual impact of policies, thus providing a scientific basis for policymaking and adjustment. The LCCP is usually implemented in specific cities, creating a natural comparison group with cities where the policy has not been applied. This setup forms the basis for using the DID method. Building on the research methodologies of Li et al. (2024a) and Wang S. et al. (2024), this study uses the LCCP as a quasi-natural experiment and employs the DID model to investigate the impact of the LCCP on HQD. The specific model is shown in Equation 1 as follows:

$$ln\,HQD_{it} = \propto + \beta LCCP_{it} + X_{it} + Year\ fixed\,effects + Province\ fixed\,effects + \varepsilon_{it}, \tag{1}$$

TABLE 1 Systems of evaluation indicators for the HQD index.

Target layer	Sub-target layer	Criteria layer	Calculating method
HQD	Industrial structure	Advanced (+)	The ratio of the output value of the tertiary industry to the secondary industry
		Rationalized (−)	The Theil index is measured by the ratio of employment numbers and output values among the three sectors
		Share of productive services (+)	The proportion of productive service industry employees among urban unit employees
	Inclusive TFP (Hicks–Moorsteen method) (+)	Capital input	The initial urban capital stock (determined by multiplying the proportion of fixed asset investment of that year by the total provincial investment by the capital stock of each province (Huang et al., 2019)
		Labor input	Total societal employment (employees in formal sectors, private enterprises, and individual businesses)
		Desirable output	Actual gross domestic product (GDP)
		Undesirable output	Rural–urban income gap (ratio of disposable income of urban residents to net income (or disposable income) of rural residents)
	Technological innovation	Innovation index (+)	Report on city and industrial innovation in China (Kou and Liu, 2017)
	Ecological environment	Sulfur dioxide removal rate (+)	Before 2011: sulfur dioxide removal/(sulfur dioxide production + sulfur dioxide removal)
			2011: Treatment of 3-year averages including before and after periods
			After 2011: (Sulfur dioxide production − sulfur dioxide emission)/sulfur dioxide production
		Comprehensive utilization rate of industrial solid waste (+)	Amount of industrial solid waste utilized/total amount of industrial solid waste generated
		$PM_{2.5}$ concentration (−)	Data from Washington University in St. Louis
	Residents' living standards	GDP *per capita* (+)	Data from China Statistical Bureau
		Expenditure on education (yuan per person) (+)	Expenditure on education/urban resident population, data from China Statistical Bureau
		Hospital beds (ten thousand people) (+)	Number of hospital beds/urban resident population, data from China Statistical Bureau

Notes: the symbol "(+)" indicates that the indicator exhibits a positive value; the symbol "(−)" signifies that the indicator exhibits a negative value.

where $ln\,HQD_{it}$ represents the logarithmized level of HQD for city i in year t. $LCCP_{it}$ is an interaction term combining $Treat_i$ and $Period_t$. They are dummy variables representing whether a city is a designated pilot under the LCCP and whether the policy has been activated. $Treat_i$ is assigned a value of 1 for cities selected as pilot locations by the LCCP (treatment group) and 0 for all others (control group). Given that the LCCP was rolled out in three phases, $Period_t$ is set to 0 before implementation and switches to 1 post-implementation. X_{it} denotes the control variables at the city level. ε_{it} is the randomized disturbance term. β is the core regression parameter of this paper, reflecting the marginal effect of the LCCP on HQD. When β is considerably higher than 0, it suggests that implementing low-carbon governance in urban areas notably impacts promoting HQD.

4.2 Variable measurement and description

4.2.1 Explained variable: HQD

The pursuit of HQD is a necessary consequence of adhering to the inherent laws of economic progression and is essential for societal advancement toward modernization (Bei, 2018). The 19th National Congress report of the Communist Party of China notes the transition of the Chinese economy into a new era, moving from a period of high-speed growth to a stage characterized by growth focused on HQD (Wang, 2020). HQD aims to achieve efficient, sustainable, inclusive, and balanced economic growth (Luo Y. et al., 2024; Zhao et al., 2019). Therefore, based on the relevant literature (Chao and Ren, 2011; Yi et al., 2019; Zhao et al., 2022) and the inherent principles of HQD, we establish a multidimensional evaluation system comprising five secondary indicators, namely, industrial structure, inclusive TFP, technological innovation, ecological environment, and residents' living standards (see Table 1).

First, the current industrial structure is a key indicator for assessing whether an economy has achieved HQD. In this dynamic process, it is crucial to evaluate the proportional relationship among the three sectors of the economy and the degree of coordination in their development. This includes not only the upgradation of the industrial structure but also its rationalization. Furthermore, the production-oriented service sector, as a central field in the ongoing technological revolution and industrial transformation, should be incorporated into the evaluation of the HQD of the industrial structure. Thus, the advancement and rationalization of the industrial structure, alongside the share of productive services, form a three-tiered measure of high-quality industrial development. Second, the extent to which HQD embodies the inclusive characteristics of both efficiency and fairness constitutes another fundamental dimension for evaluating the quality of economic growth. The inclusive TFP index serves as a robust tool for assessing this dimension as it holistically measures the degree to which the benefits of economic growth are equitably distributed, thereby providing an indicator of the extent to which HQD has been realized. Third, technological innovation plays a pivotal and direct role in enhancing the quality of economic development. It improves productivity and optimizes industrial structures, simultaneously stimulating the emergence of new industries and facilitating the transformation of traditional sectors. Consequently, incorporating technological innovation as a fundamental dimension in the assessment of HQD aligns with current economic trends and offers a precise gauge of both the quality and future potential of economic growth. Fourth, HQD emphasizes the coordinated integration of economic, social, and environmental objectives. Specifically, ecological environmental protection, efficient resource utilization, and the concept of green development have progressively become core drivers of economic growth. This paper employs secondary indicators of the ecological environment index, such as the sulfur dioxide removal rate, industrial solid waste recycling rate, and $PM_{2.5}$ concentration, to assess the city's primary investments and outcomes in environmental governance. Fifth, the wellbeing of the populace is the ultimate goal of economic development. Therefore, the evaluation of HQD must place people at its core. Beyond economic output, the quantity and quality of social public goods, such as education and healthcare, directly influence residents' quality of life and happiness. In this regard, *per capita* GDP, *per capita* education expenditure, and *per capita* hospital bed availability are incorporated as tertiary indicators under the dimension of living standards in the framework for evaluating HQD.

Drawing on the calculation methods of Zhao et al. (2022), we employed the entropy weight method to measure the HQD of 351 prefecture-level cities in China from 2000 to 2021. The specific measurement steps for HQD are as follows.

In the first step, the raw indicators were standardized, as shown in Equation 2, 3:

(1) Positive variables (property: +):

$$X_{ijt} = \frac{x_{ijt} - min\left(x_{jt}\right)}{max\left(x_{jt}\right) - min\left(x_{jt}\right)}. \tag{2}$$

(2) Negative variables (property: −):

$$X_{ijt} = \frac{max\left(x_{jt}\right) - x_{ijt}}{max\left(x_{jt}\right) - min\left(x_{jt}\right)}. \tag{3}$$

Here, x_{ijt} is the value of the jth indicator (j = 1, 2, . . . , n; n is the number of indicators) after standardization for city i in year t (i = 1, 2, . . . , m; m is the number of cities), x_{jt} is the original indicator, $max\,(x_{jt})$ is the maximum value of the jth indicator for all years, and $min\,(x_{jt})$ is the minimum value.

In the second step, the proportional value P_{ijt} for the jth indicator of city i in year t is calculated, as shown in Equation 4:

$$P_{ijt} = \frac{X_{ijt}}{\sum_{i=1}^{m} X_{ijt}}. \tag{4}$$

In the third step, the entropy value E_{jt} is calculated for the jth indicator in year t, as illustrated in Equation 5:

$$E_{jt} = -\frac{1}{\ln m}\sum_{i=1}^{m} P_{ijt}\ln P_{ijt}. \tag{5}$$

In the fourth step, the weight W_{jt} of the jth indicator in year t is calculated, as outlined in Equation 6:

$$W_{jt} = \frac{Y_{jt}}{\sum_{j=1}^{n} Y_{jt}}, Y_{jt} = 1 - E_{jt}. \tag{6}$$

In the fifth step, the HQD index is calculated, as presented in Equation 7:

$$HQD_{it} = \sum_{j=1}^{n} W_{jt} \times X_{ijt}. \tag{7}$$

4.2.2 Explanatory variable

This paper assesses urban low-carbon governance by incorporating the LCCP as a DID variable. A city designated as a low-carbon pilot city is assigned a value of 1 from the time of its establishment and 0 otherwise. China introduced the LCCP in three distinct waves—2010, 2012, and 2017—choosing cities based on their foundational achievements in environmental management and the characteristics of their resource endowments (Dong et al., 2023).

4.2.3 Control variables

To rigorously assess the broader impacts of the LCCP, it is crucial to incorporate control variables that might influence the results. Drawing from the research of Wang and Liu (2023) and Weng et al. (2022), we select the following control variables: foreign investment (FI), measured as the logarithm of annual utilized foreign capital (USD in ten thousand); education development (ED) level, quantified by the logarithm of *per capita* educational spending (yuan); information infrastructure development (IID), represented by the logarithm of internet broadband user numbers (thousands of households); regional total population (RTP), indicated by the logarithm of the area's total population (ten thousand people); regional development (RD) level, calculated as the logarithm of the regional GDP (billions of yuan); and *per capita* development (PCD) level, gauged by the logarithm of GDP *per capita* (yuan).

4.3 Data sources and descriptive statistics

Considering the disruptive impact of the COVID-19 pandemic on the trajectory of HQD, this analysis examines data spanning

TABLE 2 Descriptive statistics.

Variable name	Definition	N	Mean	Standard deviation
lnHQD	High-quality development	7,754	−1.480	0.570
LCCP	$LCCP_{it} = Treat_i \times Period_t$	7,754	0.020	0.090
lnRD	Regional development level	6,211	6.380	1.410
lnPCD	Per capita development level	7,754	9.870	0.570
lnED	Education development level	7,754	8.640	0.580
lnRTP	Regional total population	6,225	5.700	0.860
lnIID	Information infrastructure development	5,335	5.550	1.390
lnFI	Foreign investment	5,364	9.420	2.040

from 2000 to 2018 across 351 prefecture-level and higher cities in China, culminating in a panel dataset encompassing 7,754 city-year observations. Table 2 delineates the descriptive statistics of the primary variables. The research employs data from a variety of sources, including the China Rural Statistics Yearbook, China Population and Employment Statistics Yearbook, China Urban and Rural Construction Statistics Yearbook, China Education Statistics Yearbook, China Urban and Rural Statistics Yearbook, China Social Statistics Yearbook, China Civil Affairs Statistics Yearbook, China Tertiary Industry Statistics Yearbook, and China Agro-product Processing Industry Yearbook. Additionally, data from the Wind database and Washington University in St. Louis were used in this analysis.

5 Empirical results

5.1 Baseline regression

The DID model, a primary tool for assessing policy impact, is extensively used in quasi-natural experimental settings due to its operational simplicity. The model efficiently manages systematic variations between treatment and control groups, enabling research on changes within the treatment group both before and after policy implementation (Imbens and Wooldridge, 2009). This study employs the DID methodology, progressively integrating control variables into the baseline regression to evaluate the impact of the LCCP on HQD, with the regression results detailed in Table 3. Column (1) reveals that the basic model, which controls for year and province fixed effects without additional control variables, yields a regression coefficient of 0.036, significant at a 5% level. Subsequently, control variables such as FI, ED, and IID are introduced. As shown in column 2, the regression results adjust the coefficient to 0.006, which is significant at the 1% level. This finding demonstrates that the LCCP has significantly enhanced the HQD of the pilot cities, aligning with the anticipated effects of urban low-carbon governance policies. This is consistent with the research findings of Fan and Guo (2023), substantiating our research Hypothesis 1.

The LCCP is recognized as a strategic implementation of environmental regulatory measures. Our findings indicate that cities adopting the LCCP have significantly improved HQD. This finding challenges the compliance cost theory, which posits that environmental regulations increase environmental costs and inhibit productivity growth (Levinson and Taylor, 2008; Palmer et al., 1995), and the uncertainty hypothesis, which asserts that the relationship between environmental regulations and economic factors is indeterminate (Qiu et al., 2021; Wang et al., 2019). Instead, our research substantiates the PH, suggesting that ecological regulations stimulate innovation and enhance economic development. This also confirms the effectiveness of the PH in the Chinese context. By expanding the relevance of the PH to various economic and cultural settings, especially in developing countries and economies in transition, our study offers vital practical insights for the development of future environmental policies.

However, the analysis has certain limitations. Ideally, treatment groups should be established through random rather than purposive selection. In this case, the selection of low-carbon pilot cities was not random. Still, it was guided by specific criteria and policy orientations, which could affect our findings' interpretation and require further analytical refinement. Therefore, we introduce the propensity score matching (PSM)-DID test in the robustness tests to solve this problem.

5.2 Robustness tests

5.2.1 Parallel trend test

This paper identifies the LCCP's promotive effect on HQD in China in the baseline analysis. One crucial assumption of the DID model is that the treatment and control groups should exhibit parallel trends before implementing the LCCP. Given that meeting the parallel trends assumption is a fundamental prerequisite for utilizing DID, this study employs the event study approach (Jacobson et al., 1992; Wu et al., 2023) to structure the econometric model accordingly as follows:

$$\begin{aligned} lnHQD_{it} = \propto &+ \beta_1 treat_{it}^{-5} + \beta_2 treat_{it}^{-4} + \beta_3 treat_{it}^{-3} + \ldots \\ &+ \beta_{15} treat_{it}^{9} + X_{it} + \text{Year fixed effects} \\ &+ \text{Province fixed effects} + \varepsilon_{it}, \end{aligned} \tag{8}$$

where the dummy variable $treat_{it}^{q}$ denotes the LCCP events; q represents periods before and after the LCCP; X_{it} signifies the

TABLE 3 Baseline regression results.

Model	(1)	(2)
Variable	lnHQD	lnHQD
LCCP	0.036**	0.006***
	(2.013)	(2.852)
lnRD		0.001
		(0.892)
lnPCD		0.844***
		(69.547)
lnED		0.063***
		(18.148)
lnRTP		−0.001
		(−1.035)
lnIID		0.002**
		(2.209)
lnFI		−0.000
		(−0.254)
Year fixed effects	Yes	Yes
Province fixed effects	Yes	Yes
N	7,754	4,774
Adj. R^2	0.953	0.995

Notes: *, **, and *** denote 10%, 5%, and 1% significance levels. The brackets are t-values; lnRD, regional development level; lnPCD, *per capita* development level; lnED, education development level; lnRTP, regional total population; lnIID, information infrastructure development; lnFI, foreign investment.

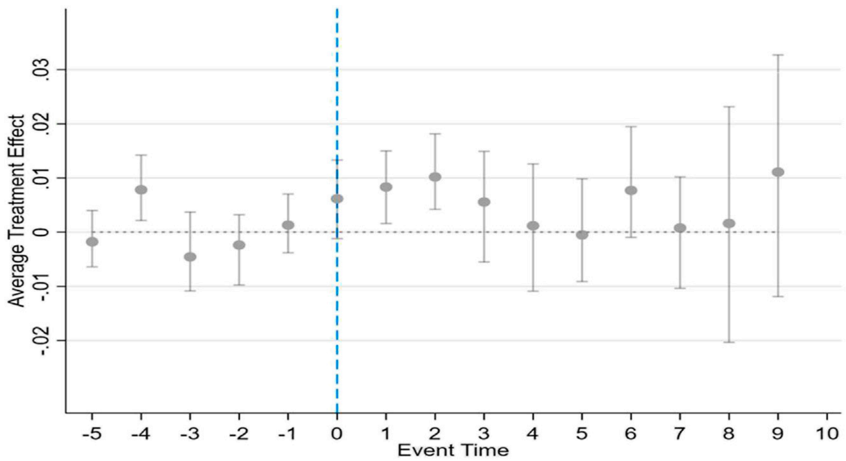

FIGURE 3
Event study of the LCCP on HQD.

control variables; Year FE refers to year fixed effects; Province FE refers to province fixed effects; and ε_{it} represents the random disturbance term.

Figure 3 presents the results of the event study based on Equation 8. Before the policy's implementation, the parameter β_k fails to reject the null hypothesis, which indicates no significant

TABLE 4 Balance test results of PSM matching.

Variable	Matched	Treated	Control	% bias	|bias|	t	p>|t|
lnRD	U	8.2198	6.6272	142.8	89.3	24.73	0.000
	M	8.1655	7.995	15.3		1.98	0.048
lnPCD	U	10.218	9.9697	55.9	89.0	9.87	0.000
	M	10.198	10.171	6.1		0.77	0.441
lnED	U	8.9992	8.7394	56.0	90.6	9.98	0.000
	M	8.9785	8.954	5.3		0.66	0.512
lnRTP	U	6.2463	5.8728	52.6	68.1	9.72	0.000
	M	6.2426	6.1235	16.8		2.01	0.045
lnIID	U	7.2298	5.4068	160.9	94.2	24.33	0.000
	M	7.1804	7.075	9.3		1.44	0.151
lnFI	U	11.429	9.3391	107.9	91.0	18.25	0.000
	M	11.365	11.176	9.8		1.27	0.205

Notes: M stands for matched; U stands for unmatched; lnRD, regional development level; lnPCD, *per capita* development level; lnED, education development level; lnRTP, regional total population; lnIID, information infrastructure development; lnFI, foreign investment.

TABLE 5 PSM-DID results.

Variable	Dependent variable: lnHQD	
Model	(1)	(2)
	Kernel matching	Nearest-neighbor matching
LCCP	0.005***	0.005**
	(2.652)	(2.476)
lnRD	0.001	0.000
	(0.463)	(0.294)
lnPCD	0.859***	0.859***
	(66.195)	(65.844)
lnED	0.063***	0.063***
	(13.337)	(13.362)
lnRTP	−0.003	−0.002
	(−1.321)	(−1.268)
lnIID	0.003*	0.003*
	(1.756)	(1.739)
lnFI	−0.001	−0.001
	(−1.219)	(−1.039)
Year fixed effects	Yes	Yes
Province fixed effects	Yes	Yes
N	2,855	2,844
Adj. R^2	0.994	0.994

Notes: *, **, and *** denote 10%, 5%, and 1% significance levels. The brackets are t-values; lnRD, regional development level; lnPCD, *per capita* development level; lnED, education development level; lnRTP, regional total population; lnIID, information infrastructure development; lnFI, foreign investment.

TABLE 6 Results of the expanded sample analysis (2000–2021).

Model	(1)	(2)
Variable	lnHQD	lnHQD
LCCP	0.032**	0.005***
	(2.344)	(2.778)
lnRD		0.001
		(1.050)
lnPCD		0.844***
		(71.471)
lnED		0.064***
		(19.717)
lnRTP		−0.001
		(−1.029)
lnIID		0.001
		(1.509)
lnFI		0.000
		(0.629)
Year fixed effects	Yes	Yes
Province fixed effects	Yes	Yes
N	8,813	5,418
Adj. R^2	0.954	0.995

Notes: *, **, and *** denote 10%, 5%, and 1% significance levels. The brackets are t-values; lnRD, regional development level; lnPCD, *per capita* development level; lnED, education development level; lnRTP, regional total population; lnIID, information infrastructure development; lnFI, foreign investment.

differences in HQD between pilot and non-pilot cities, thus affirming the parallel trends assumption. After the policy's enactment, the regression coefficient exhibits fluctuations, consistent with the cyclical nature of the policy. The phased implementation of the policy in 2010, 2012, and 2017 shows significant effects in the first to third years, the sixth year, and the ninth year, demonstrating that the LCCP significantly influences HQD during the early and mid-phases of the policy cycle. This cyclical manifestation is likely influenced by variations in resource allocation, implementation intensity, and external environmental factors during policy execution (Heimberger, 2023). Notably, the event study confirms the absence of pre-trends, validating the identification strategy.

5.2.2 PSM-DID estimation

The selection of pilot cities in the LCCP is not entirely random, and the heterogeneity among these cities introduces additional complexities that may impact the validity of conclusions drawn from DID analyses. PSM provides a viable solution for addressing sample selection bias and city-specific heterogeneity within the DID model (Luo et al., 2023). Based on counterfactual reasoning, PSM effectively minimizes estimation errors caused by selection bias by matching treated and control units with similar propensity scores (Yu et al., 2022). The matching variables included RD, PCD, ED, RTP, IID, and FI. The balance test results of PSM matching (kernel matching) are reported in Table 4. After balance testing, the bias in all matched covariates between the two groups was reduced by at least 60%, and all t-tests confirmed the null hypothesis, indicating no systematic differences between the treatment and control groups. The p-values for the matched samples suggest a consistent distribution of covariates between the groups. This consistency validates the choice of covariates and the effectiveness of the matching process. Thus, we can confidently state that the matched sample fulfills the requirements for further regression analysis.

Increasingly, studies are integrating PSM with DID models to assess the effectiveness of policy implementations (Feng et al., 2021; Heckman et al., 1997; Hu and Wang, 2023; Xu et al., 2024). The PSM-DID analysis addresses individual heterogeneity and potential selection biases to some extent by matching treated and control groups (Hu and Ahmad, 2024). Accordingly, this paper employs the PSM-DID methodology to evaluate the effects of LCCP on HQD. To ascertain whether different matching methods yield varying results, kernel matching and nearest-neighbor matching were applied to validate the conclusions, with results presented in Table 5. Regardless of the matching method used, the impact of LCCP on HQD is consistently positive. This finding corroborates the previously discussed baseline tests and enhances the causal inference's robustness.

TABLE 7 Result of substituting the explained variable.

Model	(1)	(2)
Variable	lnHQD	lnHQD
LCCP	0.008*	0.006***
	(1.659)	(2.653)
lnRD		0.001
		(0.686)
lnPCD		0.840***
		(56.781)
lnED		0.067***
		(6.197)
lnRTP		−0.001
		(−0.767)
lnIID		0.001
		(1.377)
lnFI		0.000
		(0.110)
Year fixed effects	Yes	Yes
Province fixed effects	Yes	Yes
N	5,037	4,774
Adj. R^2	0.977	0.995

Notes: *, **, and *** denote 10%, 5%, and 1% significance levels. The brackets are t-values; lnRD, regional development level; lnPCD, *per capita* development level; lnED, education development level; lnRTP, regional total population; lnIID, information infrastructure development; lnFI, foreign investment.

5.2.3 Extending the temporal scope of analysis

The initial dataset for this investigation spanned from 2000 to 2018. This selection was based on the premise that the advent of the COVID-19 pandemic in 2019 could introduce statistical anomalies that could compromise the validity of our findings. However, to rigorously assess the persistent effects of the LCCP on HQD and validate our insights' broad applicability, we extended the study period to include data up to the latest available statistics in 2021. Appendix Table A1 demonstrates descriptive statistical analysis. The regression results from 2000 to 2021 are depicted in Table 6. The regression analysis reveals a coefficient of 0.32 in column (1), achieving statistical significance at 5%. Upon integrating control variables, as displayed in column (2), the significance of the results strengthens, maintaining the 1% level. These consistent findings robustly support the hypothesis that the LCCP positively influences HQD.

5.2.4 Substituting the explained variable

To further enhance the robustness and reliability of the research findings, we revisited the explained variable and incorporated additional indicators that more comprehensively reflect the wellbeing of residents. Specifically, we introduced several key variables, including *per capita* consumption expenditure (yuan/person), average years of education (years/person), the number of practicing (assistant) physicians per 10,000 people (persons), and the proportion of social security expenditure to GDP (%). These indicators enable a more holistic evaluation of residents' welfare across economic, educational, healthcare, and social security dimensions, thus providing precise and multidimensional data support for research on HQD. After substituting the explained variable, we re-estimated the model. The results show that the conclusions remain robust, without any significant deviations, as shown in Table 7.

5.3 Impact mechanism tests

The baseline regression results show that the LCCP helps improve HQD. However, what are the mechanisms through which this policy effect is achieved? The hypothesis development in the previous section suggests that the LCCP may affect HQD through technological innovation, industrial upgrading, infrastructure development, and energy system transformation. These factors will be tested in this section. Following the research methods of Yu et al. (2024), we construct Equation 9 as follows:

TABLE 8 Impact mechanism tests.

Variable	Dependent variable: lnHQD			
	(1)	(2)	(3)	(4)
TI × LCCP	0.068***			
	(4.157)			
IU × LCCP		0.011***		
		(2.733)		
ID × LCCP			0.001*	
			(1.713)	
TES × LCCP				−0.001**
				(−2.493)
Control variable	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes
N	4,774	4,774	4,503	4,774
Adj. R^2	0.995	0.995	0.995	0.995

Notes: *, **, and *** denote 10%, 5%, and 1% significance levels. The brackets are t-values. Control variables include the regional development level, *per capita* development level, education development level, regional total population, information infrastructure development, and foreign investment.

$$\begin{aligned} ln\,HQD_{it} = \propto + \gamma LCCP_{it} \times Mechanism_{it} + LCCP_{it} \\ + Mechanism_{it} + X_{it} + \text{Year fixed effects} \\ + \text{Province fixed effects} + \varepsilon_{it}, \end{aligned} \tag{9}$$

where $ln\,HQD_{it}$ denotes the level of HQD of the city i in year t; $LCCP_{it}$ represents the pilot city i in year t, which is denoted as 1 if city i is a low-carbon pilot city in year t, and 0 otherwise; $Mechanism_{it}$ is set to technological innovation (TI), industrial upgrading (IU), infrastructure development (ID), and the transformation of energy structure (TES); X_{it} denotes the control variables; Year FE refers to year fixed effects; Province FE refers to province fixed effects; ε_{it} represents the random disturbance term; and γ is the core regression parameter of this study, reflecting the marginal effect of the $LCCP_{it}{*}Mechanism_{it}$ on HQD.

5.3.1 Technological innovation

In this study, we adopt the innovation index defined by Kou and Liu (2017) as a measure of technological innovation. This index is calculated by estimating the mean value of patents of varying ages and weighting them according to the urban dimension. The results in Table 8 show a significant positive regression coefficient of 0.068 at the 1% significance level in column 1. This indicates that technological innovation is a critical mechanism through which the LCCP enhances HQD, thereby corroborating the PH. Although previous studies (Wang and Chu, 2024; Yu et al., 2023) primarily consider technological innovation as a dependent variable in exploring the relationship between LCCP and technological innovation, our analysis positions it as an influence mechanism, thus broadening the scope of existing research. We recognize that innovation is vital in shifting the development paradigm from resource-driven to efficiency-driven models (Tian et al., 2024). In practical terms, low-carbon urban governance has effectively reduced pollution emissions by fostering technological innovation and expediting the research, development, and widespread adoption of cleaner production technologies. Furthermore, low-carbon technological innovations stimulate a green transformation of consumption across various sectors, thereby driving sustainable economic growth. In essence, the LCCP fosters HQD by enhancing technological innovation. Consequently, Hypothesis 2 is substantiated.

5.3.2 Industrial upgrading

In our analysis, we derive an index of industrial sophistication using the ratio of tertiary to secondary industry output values, a method described by Gan et al. (2011), to assess the degree of industrial upgrading. According to the results presented in Table 8, the regression coefficient for IU × LCCP in column 2 is 0.011, significantly positive at the 1% level, which supports that the level of IU positively moderates the relationship between LCCP and HQD. In other words, as the level of IU increases, the positive impact of LCCP on HQD strengthens, thus supporting the moderating effect proposed in Hypothesis 3. Previous research indicates that intensified LCCP efforts drive a more rational allocation of the industrial structure, attracting higher-value-added production elements through improved environmental quality, thus accelerating industrial modernization (LOISEL, 2010; Pan et al., 2023). Our findings extend this narrative, illustrating that LCCP-induced industrial upgrading contributes notably to HQD. Under low-carbon governance, the digital economy catalyzes changes in the industrial structure, which is crucial for advancing the development of a modern, eco-friendly industrial system (Zhong et al., 2022). Furthermore, this industrial upgrading fosters positive interplay

TABLE 9 Heterogeneity analysis.

Variable	Dependent variable: lnHQD			
	(1)	(2)	(3)	(4)
Provincial capital cities	0.005			
	(1.074)			
General cities		0.006**		
		(2.299)		
Ethnic autonomous regions			−0.003	
			(−1.152)	
Han Chinese provinces				0.007***
				(3.051)
Control variable	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
N	4774	4774	4774	4774
Adj. R^2	0.995	0.995	0.995	0.995

Notes: *, **, and *** denote 10%, 5%, and 1% significance levels. The brackets are robust t-values. Control variables include the regional development level, *per capita* development level, education development level, regional total population, information infrastructure development, and foreign investment.

among the primary, secondary, and tertiary sectors, steering the economic framework toward a service-driven economy and facilitating a leapfrog approach to sustainable economic growth (Hu et al., 2023). Overall, our study demonstrates how urban low-carbon governance promotes the green upgrading of industrial structures, effectively driving HQD.

5.3.3 Infrastructure development

To assess the impact of urban green space infrastructure on HQD, we constructed a measure of infrastructure development based on the green space area of parks *per capita* using data from the China Bureau of Statistics. In column 3 of Table 8, the regression coefficient of ID × LCCP is 0.001, significantly positive at the 10% level. This finding suggests that enhancements in infrastructure development substantially contribute to HQD. Our results corroborate the "green magnet effect," where the construction of urban green spaces positively influences the economic development of cities (Hong et al., 2020), aligning with the conclusions drawn by He et al. (2024). The efficient use of urban land for green purposes is pivotal for optimizing economic value while minimizing resource consumption and environmental impact (Song et al., 2022). Given the scarcity of urban land resources, the strategic utilization of limited green space in community parks for maximal ecological benefits represents a critical challenge for current infrastructure research in China (Ma and Wang, 2023). Consequently, urban low-carbon governance in China emphasizes landscape gardening and urban greening initiatives to enhance urban livability and ecological networks, thereby fostering a green, low-carbon transformation and sustainable urban development. In conclusion, the LCCP is instrumental in driving HQD by enhancing infrastructure development, and Hypothesis 4 is verified.

5.3.4 Transformation of the energy system

In this paper, we measure energy system transition using the energy consumption elasticity coefficient, which is calculated as the ratio of the energy consumption growth rate to the economic growth rate. This coefficient effectively illustrates shifts in energy dependency throughout economic development. A coefficient greater than 1 suggests that energy consumption growth outpaces economic growth, potentially indicating inefficiencies in energy use. Conversely, a coefficient less than 1 implies that enhancements in energy efficiency largely fuel economic expansion. With technological advancements and improved efficiency, a higher economic output is expected to be achieved with reduced energy consumption, which is typically reflected by a lower elasticity coefficient (Ghadaksaz and Saboohi, 2024).

Regression analysis presented in Table 8, column 4, reveals that the coefficient TES × LCCP is −0.001, which is statistically significant at the 5% level. This indicates an inverse relationship between the energy consumption elasticity coefficient and HQD. The decline in energy consumption elasticity coefficient signals an enhancement in energy utilization and signifies a successful transformation within the energy sector. This supports the effectiveness of energy system transformations in fostering HQD. The LCCP has been instrumental in continuously optimizing the energy structure, enhancing energy conservation, and advancing renewable energy and the servitization of manufacturing. These efforts contribute to the robust development of the circular economy (Cheng et al., 2023). Collectively, these strategies confirm that the low-carbon energy transition positively moderates the enhancing effect of the LCCP on HQD. Therefore, Hypothesis 5 is valid.

5.4 Heterogeneity analysis

To further analyze the impact of the LCCP on HQD across different types of cities, we categorize the sample based on distinctions in city classification (provincial capital cities and general cities) and the nature of ethnic provinces (autonomous regions and Han Chinese provinces). We construct Equation 10 as follows:

$$ln\,HQD_{it} = \propto + \delta LCCP_{it}{}^{*}Heteroganeity_{it} + X_{it} + \text{Year fixed effects} + \text{Province fixed effects} + \varepsilon_{it}, \quad (10)$$

where $ln\,HQD_{it}$ denotes the level of HQD of city i in year t; $Heteroganeity_{it}$ are defined for provincial capital cities and general cities, autonomous regions, and Han Chinese provinces[1]; control variables are represented by X_{it}; year fixed effects are indicated by year FE; province fixed effects are represented by province FE; ε_{it} represents the randomized disturbance term; and δ is the core regression parameter of this analysis. Table 9 demonstrates the results of the heterogeneity analysis.

5.4.1 City hierarchy

The empirical results indicate that the regression coefficients for general cities in column (2) of Table 9 pass the significance test, suggesting that the LCCP significantly impacts the HQD of general cities more than provincial capitals. This disparity can be attributed to several factors. First, the stages of urbanization across different cities are highly heterogeneous. Some urban areas are in the acceleration stage, while others are in the late urbanization stage (Qiao et al., 2024). Provincial capital cities are generally in the middle to late stages of industrial transformation and upgrading. New green industries are developing rapidly, and environmental governance has already achieved a certain success. As a result, the impact of the LCCP is less significant in these areas. In contrast, many general cities are in the early stages of urbanization, where the effect of building scale on carbon emissions is relatively moderate, and economic development levels are lower. The LCCP allows these cities to implement sustainable building practices that can yield long-term benefits in reducing carbon footprints, making them more sensitive and responsive to the LCCP. Furthermore, some provincial capital cities rely heavily on resource-based industries such as coal and oil, resulting in an imbalanced industrial structure where economic growth is predominantly driven by resource extraction and related energy sectors. These cities face significant challenges, including high energy and water consumption, low industrial waste recycling rates, and persistently high carbon emissions. To overcome these obstacles and effectively leverage the LCCP to promote HQD, additional time is needed to address the "carbon curse" issue (Lee et al., 2024). Therefore, this paper argues that the LCCP is more conducive to promoting HQD in general cities, thereby contributing to the achievement of commonwealth among cities.

5.4.2 Ethnic diversity

China, a nation with diverse ethnic groups, exhibits significant developmental disparities among its various ethnic provinces (YangLiu and Li, 2020). Our analysis, specifically the results shown in column (4) of Table 9, indicates that the impact of the LCCP is more pronounced in Han Chinese provinces than in ethnic autonomous regions, with a regression coefficient of 0.007, significant at the 1% level. The possible reasons are as follows: ethnic minority regions often depend heavily on traditional industries and agriculture, sectors that are typically less adaptable to rapid transformation into low-carbon or green industries. Furthermore, historical and geographical factors have contributed to the persistent economic underdevelopment of ethnic autonomous regions compared to the national average (Shi et al., 2022). These regions generally possess a weaker industrial base and lack the necessary technological and capital support to effectively implement the LCCP. Additionally, issues such as the limited awareness of low-carbon governance and lagging technological innovation in ethnic autonomous regions undermine the efficacy of the LCCP. The geographical remoteness of these regions often complicates policy implementation and oversight. Local governments in these regions may struggle with inadequate implementation power and resource allocation, which are crucial for meeting the sophisticated demands of the LCCP. Given these challenges, this paper argues that the LCCP should emphasize the unique conditions in ethnic autonomous regions.

6 Conclusion and discussion

6.1 Conclusion

As the challenge of climate change intensifies, many countries prioritize harmonizing economic growth with climate change mitigation and carbon emission reductions. In this context, China's LCCP is a pivotal initiative to foster a green and low-carbon transition (Zeng et al., 2023). Utilizing a quasi-natural experimental design, this study analyzed panel data from 351 Chinese cities from 2000 to 2021 and employed the DID methodology. The results indicate that (1) the LCCP can enhance HQD by 0.006 units, indicating that urban low-carbon governance has a significant positive effect on HQD, thus proving to be a rewarding gift. This positive impact is robust, as evidenced by additional tests, including the parallel trend test, PSM-DID, and an expanded sample analysis. The study also explores the temporal dynamics of policy impact, noting that the economic benefits of the LCCP are more pronounced in the early and middle stages of implementation. (2) The analysis of impact mechanisms reveals that the LCCP achieves HQD through technological innovation, industrial upgrading, infrastructure development, and the transformation of energy systems. (3) The paper also assesses heterogeneity in policy impact, finding that LCCP's influence on HQD is more pronounced in general cities than in provincial

1 Autonomous regions: Xinjiang Uygur autonomous region, Tibet autonomous region, Guangxi Zhuang autonomous region, Ningxia Hui autonomous region, and Inner Mongolia autonomous region.

capitals and is significantly stronger in provinces predominantly populated by Han Chinese, as opposed to ethnic autonomous regions. This comprehensive examination highlights the effectiveness of the LCCP in promoting sustainable economic growth amidst the challenges of climate change.

6.2 Theoretical implications

In response to global climate change challenges and to support SDGs, China initiated the LCCP in three phases starting in 2010. This research seeks to determine whether the LCCP represents a beneficial gift or a risky gamble for HQD. Our findings indicate that the LCCP significantly enhances HQD, thus acting as a beneficial gift. This conclusion is consistent with the findings of other scholars (Chen et al., 2023; Fu and Zhang, 2024; Huang et al., 2023; Wang J. et al., 2024). Traditionally, studies have assessed policy effects using indicators such as TFP, economic resilience, and green development. However, this paper on HQD measurement integrates social, economic, and environmental dimensions, addressing the limitations of indicator duplication and redundancy found in previous frameworks. As a result, our approach significantly enriches and broadens the empirical analysis of the impacts of the LCCP. Moreover, our study reveals that the effects of the LCCP on HQD are more pronounced during the initial and middle stages of policy implementation. This contrasts with the findings of Wei and Gu (2021), who reported a lagged effect of green economic growth under the LCCP. Additionally, our results support the PH, demonstrating that environmental regulations can yield substantial economic returns. This finding extends the PH within the Chinese context. It provides valuable evidence of the economic and social benefits of the LCCP, thereby contributing significantly to discussions on environmental policy and sustainable development strategies.

Our research integrates insights from the PH, endogenous growth theory, new structural economics, neoclassical economic theories, the biophilia hypothesis, and landscape ecology to deepen the understanding of how the LCCP influences HQD. This interdisciplinary examination reveals that technological innovation, industrial upgrading, infrastructure development, and energy system transformation form a robust mechanism promoting HQD. Unlike previous studies that employed mediation effect methods (Fu et al., 2024; Han et al., 2023), our approach uses interaction terms between LCCP and these mechanisms to enhance the explanatory power of our models, helping uncover complex causal relationships and dependencies. The substantiation of the technological innovation mechanism further corroborates the PH, illustrating that environmental regulation can compel technological innovation, thereby fostering development. This observation aligns with the findings presented by Yang et al. (2023) and Wang S. et al. (2024). Furthermore, our analysis confirms the positive impacts of industrial dividends, the green magnet effect, and energy transition. These results highlight the importance of the LCCP for sustainable development and provide scientific evidence and practical directions for future policy formulation.

Our study introduces innovative approaches to heterogeneity analysis by categorizing the sample into general cities and provincial capitals, as well as ethnic autonomous regions and Han-majority provinces. Our results demonstrate that the LCCP significantly boosts HQD in general cities. This finding contrasts with the assertions made by Wang and She (2020), who argue that the benefits of green growth from the LCCP are more pronounced in cities with higher administrative levels and larger scales, primarily due to enhanced administrative influence and resource availability. From an industrialization perspective, however, we propose that provincial capitals are typically at the middle or late stages of industrial transformation, where the green industry has advanced sufficiently to reduce the noticeable effects of the LCCP. There remains a pressing need for further research to explore the varied impacts of the LCCP across different urban classifications. Our analysis not only underscores the efficacy of the LCCP in promoting HQD in cities broadly but also illuminates the policy's potential to foster shared prosperity on a national scale. Additionally, considering the heightened developmental challenges and environmental pressures in ethnic autonomous regions, government policies should concentrate more rigorously on the implementation and outcomes of the LCCP in these areas, ensuring that sustainable development benefits are equitably distributed across all regions.

6.3 Policy implications

Based on the empirical findings, this study outlines the following policy implications. The research indicates that the LCCP significantly enhances urban HQD, especially during the early and middle stages of policy implementation. In light of this, it is recommended that the government first ensure the continuity of low-carbon governance policies while enhancing monitoring and evaluation mechanisms. This will allow for flexible adjustments to meet evolving development needs at various stages, ensuring that policy objectives are achieved and advanced throughout the process. Second, the government should introduce targeted incentives to motivate more cities to engage in low-carbon initiatives. These measures could involve financial support, tax benefits, and other mechanisms to help cities mitigate the costs of transitioning (Sun and Zhong, 2023). Finally, pilot cities should be leveraged as hubs for testing innovative policies and technologies and constantly exploring and refining locally suitable low-carbon governance approaches (Wang J. et al., 2024). These cities' successful experiences can offer valuable insights contributing to the global shift toward low-carbon economies.

Drawing on insights from the mechanism analysis, the government should intensify support for green technology applications, thus encouraging businesses and research institutions to innovate within the low-carbon sector. Second, industrial upgrading is needed. The government should expedite the green modernization of traditional industries, guiding high-emission sectors such as resource- and energy-intensive industries toward low-carbon, eco-friendly, and high-efficiency practices while fostering the growth of emerging green industries. Third, the government should boost investment in green infrastructure to enhance urban environmental capacity and resource efficiency. Promoting green building standards and transportation systems will reduce energy consumption and improve urban sustainability

(Hong et al., 2020). Finally, the government should facilitate the shift from traditional fossil fuels to renewable energy sources such as solar, wind, and geothermal energy through policy incentives. This includes strengthening the infrastructure for clean energy production, storage, and distribution to increase the share of renewable energy (Xu et al., 2023).

Considering the findings from the heterogeneity analysis, the government should develop tailored LCCP that accounts for the unique conditions of different cities and regions. In general cities and Han ethnic regions, it is crucial to continue harnessing the potential of the LCCP. This requires not only maintaining the current policy framework but also optimizing and strengthening the implementation of the LCCP to better align with the evolving urban development needs and environmental goals. Key priorities should include integrating low-carbon economic principles more thoroughly, advancing the shift toward a circular economy, and enhancing the adoption of low-carbon technologies (Zeng et al., 2024). For provincial capital cities and autonomous ethnic regions, it is essential to strengthen policy enforcement and adopt more targeted approaches. The government should establish flexible policy adjustment mechanisms for continuous optimization based on real-time performance data and feedback, thereby ensuring that policies remain effective across diverse urban environments. Additionally, attention should be given to local characteristics and needs, providing customized support and guidance for the nationwide promotion of HQD. By regularly reviewing and adjusting policies, cities can better achieve their specific objectives and contribute to global climate governance, offering a “Chinese solution” to help more countries bridge the “green divide.”

6.4 Limitations

This study, while comprehensive, has several limitations that warrant further investigation. First, the analysis primarily focuses on data from 2000 to 2021, which may not fully capture the long-term impacts of the LCCP. Future research should consider extending the time frame to include more recent data to assess these policies’ sustainability and evolving effects. Second, the heterogeneity analysis was limited to urban hierarchies and ethnic diversity, leaving out other demographic and geographic variations that might influence the effectiveness of the LCCP. Future studies should explore these variations to better understand how different regions and populations are impacted. Third, although this research identifies fundamental mechanisms such as technological innovation and industrial upgrading, further qualitative studies could investigate these mechanisms to understand the specific processes and interactions that drive HQD. Finally, a key limitation of this study lies in its consideration of the macroeconomic context. Given that the research sample primarily focuses on a specific economic system, the potential for synergies between environmental protection measures and economic development exists; however, the findings may not fully apply to other economic structures in more constrained contexts. Therefore, future research could expand to a broader economic context to more accurately assess the generalizability and feasibility of these policies. Addressing these limitations will enhance the robustness of the findings and contribute to more effective and tailored low-carbon governance strategies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SY: Conceptualization, Data curation, Funding acquisition, Methodology, Software, Writing – original draft and Writing – review and editing. YZ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – review and editing, and Writing – original draft. QM: Funding acquisition, Resources, Supervision, and Writing – review and editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This research was supported by the Innovation Project of Guangxi Graduate Education (Nos. YCSW2024077, YCSW2025079) and the Key Research Base of Humanities and Social Sciences of Universities in Guangxi Zhuang Autonomous Region: China-ASEAN Collaborative Innovation Center for Regional Development.

Conflict of interest

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

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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Appendix

TABLE A1 Descriptive statistical analysis (2000–2021).

Variable name	Definition	N	Mean	Standard deviation
lnHQD	High-quality development	8,813	−1.450	0.570
LCCP	$LCCP_{it} = Treat_i \times Period_t$	8,813	0.130	0.340
lnRD	Regional development level	7,192	6.530	1.420
lnPCD	Per capita development level	8,813	9.900	0.570
lnED	Education development level	8,813	8.670	0.580
lnRTP	Regional total population	7,083	5.720	0.850
lnIID	Information infrastructure development	6,174	5.630	1.430
lnFI	Foreign investment	6,023	9.500	2.060