Impact of the Low-Carbon City Pilot Policy on Residents' Health: The Dual Pathways of Pollutant Emissions and Green Behavior

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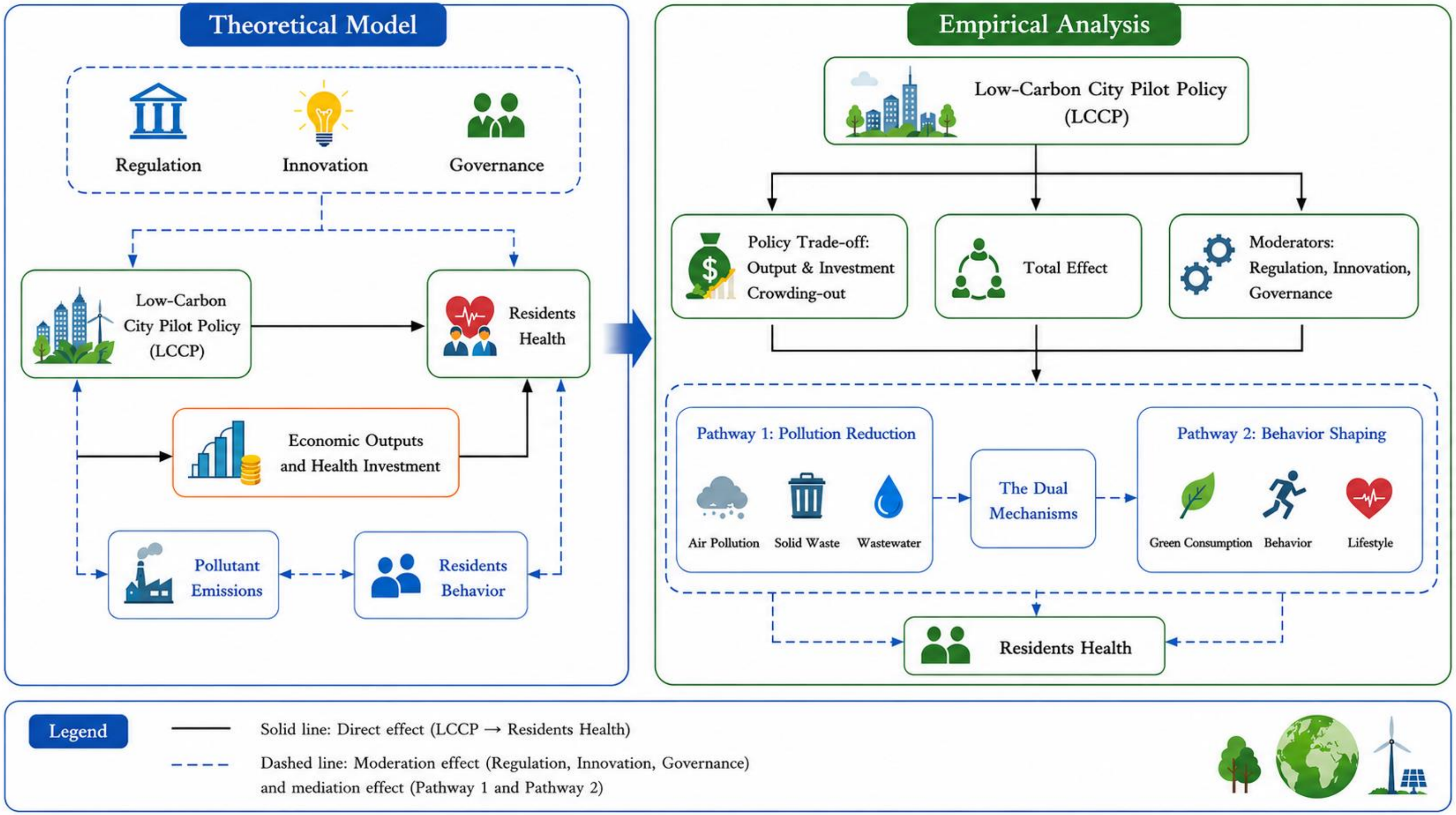
Graphical Abstract



Abstract: The low-carbon city pilot (LCCP) policy plays an important role in promoting green transformation, but evidence on its impact on residents' health remains lacking, especially research identifying its internal and external dual transmission mechanisms. Based on panel data from 285 prefecture-level cities in China from 2003 to 2020, the multiperiod difference-in-difference, mediating and moderating models are used to explore path of LCCP affecting residents' health. The results show that LCCP significantly improves residents' health, with a core coefficient of 0.0375. Output efficiency declines in later pilot cities, and compliance costs in less developed cities may crowd out health investment. Mechanism analysis reveals that LCCP promotes residents' health through the dual paths: reducing pollutant emissions (in air pollution with of -0.18 and solid waste with -0.126) and guiding residents' low-carbon behavior with a coefficient of 0.542. Meanwhile, the moderating effects show that environmental supervision intensity, innovation and pollution control efficiency have positive moderating effects. In addition, heterogeneity analysis indicates that the positive effect of low-carbon economy on residents' health in developing cities in the west is smaller than that in developed cities in the east, and that of non-capital cities is more significant. Therefore, the dual paths and multiple moderating effects discovered in this study provide empirical evidence for evaluating the public health value of LCCP. Future research may adopt micro survey data to expand heterogeneity analysis and carry out interdisciplinary studies combining environmental economics and public health.

Keywords: Multiperiod difference-in-difference model; Pollutant emission; Green behavior; Environmental supervision; Innovation; Pollution control efficiency

1. Introduction

Against the backdrop of rapid urbanization in China, coordinated governance of environmental quality and residents' public health has become a critical policy priority, given the tight causal linkage between urban pollution and population health risks (Meng et al., 2026). The Lancet Planetary Health reported that approximately 9 million premature mortalities in 2019 were attributed to pollution, of which nearly 75% were caused by excessive exposure to air pollutants, degradation of aquatic ecosystems, and the spread of heavy metal pollution (Fuller et al., 2022). This environmental crisis exhibits significant spatiotemporal dynamics in China (Zhang et al., 2025), and urbanization has been identified as one of the important channels for the negative impact of environmental pollution (Hu et al., 2024). As the world's largest developing country, China faces dual challenges in advancing its carbon peaking and carbon neutrality goals. According to the National Bureau of Statistics, urban economic activities account for 70% of national carbon emissions, and their energy-intensive growth exacerbates climate risk externalities. Meanwhile, environmental deterioration leads to physical and mental health losses primarily through respiratory system damage (Zhu & Lu, 2023). Notably, China's low-carbon city pilot (LCCP) policy, which aims to break the lock-in effect of the "Environmental Kuznets Curve" (Lee & Erickson, 2017), has encountered bottlenecks. Imbalanced industrial development, insufficient corporate innovation, and inadequate investment in environmental protection further intensify pollution, exposing residents' health security to heightened risks. Therefore, it is urgent to reconstruct a policy coordination framework for environmental regulation and health promotion from the perspective of mechanism design.

The coordinated development of environmental governance and public health in China's urbanization process has become a theoretical proposition that needs to be deepened. At the level of pollutant emission, there exists a significant nonlinear correlation between environmental regulation intensity and pollution abatement (Shao et al., 2023), which is mainly reflected in the improvement of energy efficiency in industrial production. Cui et al. (2025) find that public health inequality in the Chengdu-Chongqing region of China has intensified across trade-related spatial dimensions. At the level of low-carbon ideology, strategic gaming under information asymmetry restricts the transformation of residents' consumption patterns and hinders the internalization of environmental externalities (Liu & Xu, 2022). Light passenger vehicles and heavy trucks are predominant sources of emissions, which in turn affect public health (Li et al., 2026). Nevertheless, extant studies lack systematic identification of LCCP's multi-path health transmission mechanisms, particularly the synergistic effects between environmental governance and resident green behavior changes.

In the context of developing countries facing intensified environmental constraints, the law of diminishing marginal returns of economic growth and the structural imbalance of public health supply have formed a superimposed effect. Based on the theoretical intersection of environmental economics and public health, this study constructs a dual-path transmission mechanism analysis framework of pollutant emission reduction and green behavior transformation, systematically deconstructs the compound impact mechanism of LCCP on residents' health and welfare, and reveals the asymmetric contradiction between environmental governance policy and health enhancement, and its institutional causes. This provides a policy optimization framework with regional adaptability for developing countries to balance economic growth quality and health equity.

The marginal contributions are as follows: First, based on the Environmental Kuznets Curve (EKC) theory, this study constructs a dual-path analysis framework of pollutant emission reduction and green behavior transformation for the first time, and systematically reveals the mediating transmission mechanism of the LCCP affecting residents' health. This enriches the theoretical intersection of low-carbon governance and public health research. Second, this study takes environmental regulation intensity, innovation capability and pollution control efficiency as moderating variables, and introduces them into the dual-path analysis framework of LCCP affecting residents' health, integrating environmental economics and health behavior theory, providing a more comprehensive explanatory framework for the health effects of low-carbon policies. Third, a quasi-natural experimental design combining multiperiod difference-in-difference and instrumental variable estimation is adopted to effectively control policy endogeneity and sample selection bias. On this basis, it further reveals heterogeneous health effects of the policy grouped by city development level and administrative grade, providing refined empirical evidence for differentiated low-carbon governance.

The structure of this study is organized as follows: Section 2 presents the literature review and theoretical framework. The description of the Methodologies and data are presented in Section 3. Section 4 provides the empirical results, detailed discussion and robustness. Section 5 presents the main results and concludes policy implications.

2. Literature review and hypothesis

2.1. The effects of low-carbon city pilot policy

The low-carbon pilot city policy was first proposed in China in 2010; most scholars have evaluated and discussed the policy effect of LCCP. Some scholars focused on the environmental effects of low-carbon pilot cities, including the effect of energy saving and emission reduction and the effect of ecological improvement (Yu & Zhang, 2021) From the macro level, the LCCP could significantly promote green economic growth by using progressive difference-in-difference. At the micro level, the policy effect of LCCP have been verified from the perspective of industrial innovation and productivity (Xu & Cui, 2020), and the social effects of LCCP mainly focus on employment and living standards (Wang & Ge, 2022).

LCCP has also exerted significant impacts on green behavior and residents' health, stimulating corporate green innovation (Yin et al., 2023) and positively influencing natural population growth through economic, political, and technological factors (Zhang et al., 2023). The positive effects on public health are attributed to improved air quality and reduced unemployment rates, particularly benefiting urban areas (Nie et al., 2023). At the micro level, the LCCP enhances corporate energy efficiency through green innovation and agglomeration effects (Xiao et al., 2023). Low-carbon initiatives such as digital investment and green finance can improve corporate environmental performance through technological innovation and alleviation of financing constraints

(Jin et al., 2023; Wang et al., 2025). These studies collectively highlight the interconnections between low-carbon city policies, green behavior, and residents' health, emphasizing the broad benefits of sustainable urban development initiatives.

Furthermore, research on the factors affecting residents' health primarily covers multiple dimensions: family social relationships, household consumption structure, and lifestyle (Deng et al., 2020; Kola et al., 2021), as well as government policies, climate change, environmental pollution, and economic growth (Egger, 2009; Cole, 2019). Extreme weather events can indirectly affect residents' health by disrupting corporate operations and exacerbating resource shortages (Lei & He, 2025; Lei, 2026). Additionally, economic growth may lead to urban congestion, environmental degradation, outflow of health resources, and an increase in traffic accidents, thereby harming residents' health (Gong et al., 2012; Cox et al., 2018).

2.2. The impact of LCCP on the residents' health

China's LCCP policy focuses on addressing global climate change and urban environmental issues, requiring pilot cities to promote low-carbon construction in industrial systems, emission management, target assessment, and residents' lifestyles to comprehensively improve quality of life and health (Peng et al., 2020). Based on the background that China has implemented three batches of low-carbon city pilot policies, low-carbon construction first takes the path of environmentally friendly development to reduce urban air pollution, prevent the emergence of phenomena such as garbage siege, and build a livable city. Therefore, the construction of low-carbon cities affects residents' health mainly from two aspects: environmental emissions and residents' behavior (Li & Xing, 2024).

Low-carbon city construction promotes urban industrial high-quality development and a sustainable environment, thereby improving residents' health. It accelerates industrial layout adjustment and structural upgrading (Liu et al., 2023): high-pollution, high-emission heavy industries are transferred to urban peripheries with supporting pollution treatment facilities, while low-emission service industries are concentrated in urban centers to reduce residents' exposure to pollution. From the perspective of industrial upgrading, low-carbon construction requires green and efficient industrial production methods, and industries with low efficiency and high emissions would be eliminated (Lu et al., 2020). At the same time, the land for agricultural production would be more intensive, and the proportion of green services would be greatly increased, such as clean technology services. Climate change also indirectly affects the level of residents' health security by influencing regional green development performance (Wu et al., 2025; Li & Lei, 2024). With the gradual advancement of the industrial structure, the city's major air pollution emissions, solid waste emissions, and sewage discharges would be effectively controlled, and environmental conditions and residents' health would be improved.

H1: LCCP can significantly promote residents' health.

Low-carbon city construction strengthens emission management, forcing energy-saving and emission-reduction technology innovation and improving energy utilization efficiency. For one thing, the low-carbon economy tends to assess the pollution emissions of enterprises through hard constraints such as regulations and guidelines at the early stage of development, introduces new technologies and equipment to improve energy utilization efficiency, reduce pollution emissions, and strengthen pollution prevention measures. For another, the pilot cities can enjoy dual support from the local government and the central government in terms of funding and institutions (Wang & She, 2020), which is conducive to technological innovation. Market-oriented environmental regulations such as energy rights trading can also promote emission reduction through corporate green investment and technological innovation (Lei et al., 2025). However, the cities approved for the pilot program enjoy "honorary incentives", but also accompanied by the pressure of energy saving and emission reduction targets, which may compress urban output and reduce health investment, inhibiting residents' health enhancement. Some scholars argue that the low-carbon city pilot policy has improved air quality but reduced labor productivity, indicating a trade-off between environmental benefits and economic output, which may affect health investments (Yao & Shen, 2021).

H1a: LCCP can promote sustainable development but may cause a dampening effect in economic outputs and decrease health investment.

2.3. The living environment and green behaviors

The impact of LCCP policies on residents' health is influenced by external environmental factors, especially air quality improvement, unemployment alleviation, and pollution reduction. Based on EKC theory, the LCCP promotes the earlier arrival of the inflection point of the EKC curve through proactive intervention, and the improvement of the living environment serves as a key mediator linking environmental quality and residents' health. By clarifying emission reduction targets and promoting low-carbon industrial transformation, the LCCP breaks the path dependence of economic growth on the environment, such as relocating high-pollution heavy industries and eliminating high-emission industries, thereby reducing pollutant emissions from both spatial and supply sides. Existing studies have confirmed that the LCCP have a positive effect on residents' health by improving air quality and mitigating unemployment issues, with more pronounced effects observed in urban areas. The low-carbon city pilot policy could reduce industrial pollutant emissions, especially wastewater discharge, to improve environmental quality. Subsequently, it benefits residents' health by enhancing urban ecological conditions (Wen et al., 2022). Meanwhile, some studies show that the LCCP has significantly reduced exhaust gas, wastewater pollutants and solid waste, contributing to environmental improvement and residents' health (Fu, 2024). In addition, combined with the health production function, a high-quality living environment is a positive input for health production, while pollutants are negative inputs. The LCCP optimizes environmental quality by advancing the inflection point of the EKC curve, which essentially adjusts the input structure of health production, thereby increasing residents' health output and forming the core of the "LCCP-improvement of living environment-enhancement of residents' health" pathway.

H2: LCCP have positive effect on residents' health by improving the living environment.

Residents' green behaviors refer to actions such as energy saving, green commuting, waste reduction, and sustainable consumption. These behaviors play a crucial role in reducing greenhouse gas emissions and promoting health. The health production function emphasizes that green behaviors, as positive inputs, can not only directly improve health outputs (green commuting reduces pollution) but also optimize the living environment through emission reduction, supplementing and strengthening the environmental improvement effect of the EKC. Some studies have highlighted the importance of low-carbon policies such as information, economic incentives, and administrative regulations in influencing residents' consumption and travel behaviors (Lin et al., 2025). Factors affecting low-carbon travel behaviors include personal attributes, satisfaction with the travel process, environmental attitudes, public transportation development, and family characteristics (Zhao et al., 2023). Moreover, residents' participation and satisfaction with low-carbon policies positively influence their intentions for low-carbon behavior, underscoring the significance of policy awareness in shaping behavior. From an extended perspective of the EKC theory, green behaviors extend the main body of environmental governance from enterprises to residents, supplement the insufficiency of industrial emission reduction through emission reduction in daily life, and consolidate the environmental improvement effect of the LCCP (Briganti et al., 2023), and provide stable positive environmental input for healthy production. The improvement of healthy output will in turn incentivize green behavior, forming a virtuous cycle. Low-carbon city construction promotes health quality improvement by advocating for residents to form a green and low-carbon lifestyle, including green travel, household consumption, and waste disposal, reducing pollution in the living environment (Wang et al., 2022).

H3: LCCP have positive effect on residents' health by promoting the low-carbon behavior.

2.4. The moderating effect of regulation, innovation and governance

Environmental regulation plays a significant moderating role in the impact of low-carbon city pilot policies on residents' health. Studies have shown that environmental regulations improve residents' respiratory system and cardiovascular health by improving air quality and reducing pollutant emissions (Jia & Fan, 2023). Environmental regulations also further enhance the health benefits of low-carbon city pilot policies by promoting the construction of green infrastructure and raising public awareness of environmental protection (Li & Zhang, 2021). In addition, some studies have shown that cities with higher investment in innovation could more effectively implement low-carbon technologies and environmental protection measures, improve air quality and reduce pollutant emissions (Qian et al., 2024). The improvement of pollution governance efficiency has enhanced the promotion effect of low-carbon city pilot policies on residents' health by optimizing resource allocation and improving policy execution (Wang & Chen, 2022).

H4: Regulation, innovation and governance can positively moderate the impact of LCCP on residents' health.

However, relevant studies lack unified core conclusions. Most focus on national or provincial levels, ignoring urban heterogeneity, and discuss environmental emissions or residents' behavior in isolation, failing to integrate environmental, economic, and behavioral perspectives in LCCP effect research. Accordingly, based on the theory of sustainable development, this study links the important social factor of residents' health with low-carbon city pilot policies, and analyzes the mechanism from the perspective of the emissions reduction and behavior, which has positive implications for achieving high-quality development in China and other developing countries in response to climate change risks.

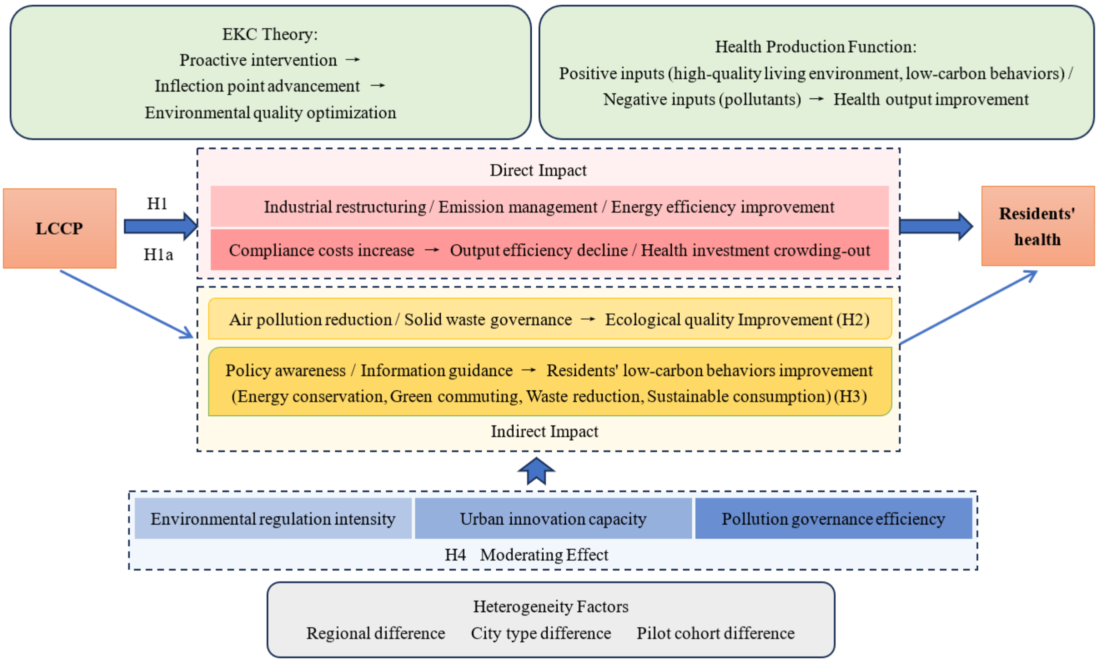


Figure 1. Analytical framework

3. Methodologies and data

3.1. Methodologies

3.1.1. Multiperiod difference-in-difference model

To measure accurately whether low-carbon urban development can improve residents' health, a quasi-natural experiment is conducted based on China's low-carbon city pilot policy and the policy effects are evaluated through a difference-in-difference model (DID) in this study. China began implementing the first batch of low-carbon city pilot policies in 2010 and then announced the second and third batches of pilot cities in 2012 and 2017. While the Ordinary difference-in-difference models cannot simultaneously account for multi-temporal policy effects, the policy effect time is considered, and the cities approved as policy pilots are taken as the experimental group and the remaining cities are taken as the control group to estimate using a multiperiod difference-in-difference model.

$$lndead_{it} = \alpha_0 + \beta_0 treat_i \times D_{it} + \gamma_0 Control_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (1)$$

Where i represents the prefecture-level city, t represents the year, and $lndead_{it}$ is the logarithm of the population mortality rate, representing residents' health. The $treat_i$ indicates whether the city is a pilot city for low-carbon policies, where the $treat_i$ variable is taken as 1 for cities that become low-carbon pilots and 0 for the rest of the cities. D_{it} is used as a variable to identify when a city becomes a low-carbon pilot city. When city i in year t is affected by the low-carbon pilot policy, D_{it} takes a value of 1, and the other cities take a value of 0. Specifically, cities selected in 2010 take the value of 1 from 2010 onward, cities selected in 2012 take the value of 1 from 2012 onward, and cities selected in 2017 take the value of 1 from 2017 onward. Cities that are never selected as pilots remain 0 throughout the sample period. This setting allows different cities to enter the treatment group in different years according to their actual pilot approval time. Therefore, using the interactive items of $treat_i$ and D_{it} to consider whether and when it is affected by the LCCP. The coefficient β_0 can reflect whether the policy effect of a multiperiod low carbon pilot has a significant impact on residents' health. To simplify the expression later, it is expressed by td. γ_0 is the coefficient of the effect of control variables. $Control_{it}$ is the set of control variables containing economic growth, government expenditure, education, health service, residents' consumption ability, population density, and industrialization degree. α_0 is the constant term. μ_i represents city fixed effects and σ_t is year fixed effects. ε_{it} is the random error term.

In this multiperiod DID framework, the control group varies over time. In each year, the control observations consist of cities that have not yet implemented the policy, including both never-treated cities and not-yet-treated cities. Therefore, the policy effect is identified by comparing changes in residents' health between cities already exposed to the LCCP and cities not yet exposed, after controlling for city fixed effects, year fixed effects, and time-varying city-level characteristics. The identification of the multiperiod DID model relies on the parallel trend assumption; that is, in the absence of the LCCP, the residents' health of pilot and non-pilot cities would have evolved similarly. This assumption is examined through the parallel trend test in the subsequent empirical analysis. Since the LCCP was implemented in different batches, the estimated coefficient should be interpreted as the average policy effect across different pilot cohorts and years, rather than as the effect of any single pilot batch.

3.1.2. Mediation effect model

Based on theoretical hypothesis, in order to study further the relationship between LCCP and residents' health and analyze its mechanism of effect, the hierarchical regression method is used to construct a mediating effect model as follows:

$$M_{it} = \alpha_1 + \beta_1 treat_{\ i} \times D_{it} + \gamma_1 Control_{\ it} + \mu_i + \sigma_t + \xi_{it} \quad (2)$$

The model (1) is considered the base regression model representing the total effect, and model (2) is the regression of core solution variables on the mediating variables and the total regression model with the addition of mediating variables, respectively, to verify whether the mediating mechanism is significant. M_{it} denotes the set of mediating variables, including air pollution, solid waste pollution, and wastewater pollution. β_1 and γ_1 are the regression coefficients of the LCCP and control variables in model (2). $\alpha_1$is the constant term. ξ_{it} represents the error terms of the models.

3.1.3. Moderating effect model

Some potential factors may moderate the impact of LCCP on residents' health, a moderating effects model is constructed for estimation:

$$lndead_{it} = \alpha_2 + \beta_2 treat_i \times D_{it} \times R_{it} + \beta_3 R_{it} + \beta_4 treat_i \times D_{it} + \gamma_2 Control_{it} + \mu_i + \sigma_t + \delta_{it} \quad (3)$$

Where, R_{it} is the set of moderating variables, with adding the interaction item coefficients of the moderating variables. α_2 is the constant term. δ_{it} represents the error terms of the models.

3.2. Variable measurement

3.2.1. Independent variable and dependent variable

The Independent variable of this study is the LCCP. China established three batches of low-carbon pilot units in 2010, 2012, and 2017, which need to be represented by a dummy variable (td), whether city i becomes a low-carbon pilot city in year t. If it does, take 1; otherwise, take 0.

The dependent variable is residents' health. This study adopts the logarithmic population mortality rate ($lndead$) as the inverse proxy for residents' health. The selection rationales are as follows: On the one hand, according to Grossman's health production function (Grossman, 1972), health is regarded as a continuously depreciating stock of human capital. The environmental pollution and poor living conditions will accelerate the depletion of health stock, and mortality is an observable terminal outcome after severe exhaustion of health capital. A large number of studies have proven that a decline in mortality could directly reflect the improvement of residents' overall health status (Fuller et al., 2022; Moutet et al., 2025; Zhou et al., 2026). On the other hand, official mortality data follow unified statistical standards, which avoids statistical bias caused by micro health indicators.

3.2.2. Mediating variables and moderating variables

Based on the analysis of the theoretical framework of this study and relevant studies (Yu et al., 2020), the proposed mediating variable of living environment includes air pollution ($lnair$), solid waste emissions ($lndust$), and wastewater pollution ($lnwater$), which are expressed by sulfur dioxide emissions, dust emissions, and wastewater emissions. The mediating variable of low-carbon behavior (Act) is measured based on the consumption perspective, which is expressed as the inverse of carbon emissions per unit of consumption (Du et al., 2015). The three important moderating factors include urban environmental regulation intensity ($rule$), urban innovation capacity ($innovate$), and urban pollution governance efficiency ($dispose$). The environmental regulation intensity is expressed by the frequency of occurrence of environmental protection-related terms in the government work reports of each prefecture-level city crawled by big data. The innovation capacity is replaced by the China Regional Innovation and Entrepreneurship Index published by the Enterprise Big Data Research Center of Peking University, and the pollution governance efficiency is represented by the harmless domestic waste treatment rate.

3.2.3. Control variables

The effect of the LCCP on residents' health may be disturbed by other factors. Based on the health production function proposed by Grossman (1972), residents' health is mainly affected by economic development, public service quality, medical level, personal income and consumption, and social welfare. The economic growth, government expenditure, education, medical services, residents' consumption ability, population density, and industrialization are selected as control variables to estimate the effect of low-carbon pilot city construction on residents' health accurately in this study. First, economic growth ($lnpgdp$) is chosen to represent the GDP per capita. The government expenditure ($lngovt$) is chosen to reflect the government's financial support, expressed by the total public finance expenditure of the city in that year. The level of education ($lnedu$) is measured by the sum of the number of students enrolled in general secondary and elementary schools. The medical services ($lndoctor$) is chosen to represent the number of medical personnel at the prefecture level. The consumption ability of residents ($lnconsume$) is approximated by the total retail sales of social consumer goods (Collins, 2004). The urban population density ($lnpeo$) reflects the density of the urban population and is calculated as the ratio of the total urban population to the urban area at the end of the year. The degree of industrialization ($lnindus$) is expressed by the output of industrial enterprises above the scale in the city.

Table 1 shows the descriptive statistics of the selected variables. The data are logarithmized to eliminate the heteroskedasticity distress in the empirical estimation process. The obvious outliers are not observed, and the mean and standard deviation of the indicators are within the acceptable range. Thus, the next step of empirical analysis can be conducted.

Table 1. Results of descriptive statistical analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
dead	5130	6.424	4.313	0.02	20.1
lnpgdp	5130	10.265	0.846	7.545	15.675
lngovt	5130	14.149	1.124	10.101	18.241
lnedu	5130	3.915	0.52	1.723	5.771
lndoctor	5130	8.769	0.775	5.932	11.683
lnconsume	5130	15.036	1.229	11.236	18.886
lnindus	5130	16.233	1.463	10.356	19.653

Note: *dead* refers to the mortality rate as a percentage. *lnpgdp* represents the GDP per capita. *lngovt* represents the government expenditure. *lnedu* represents the level of education. *lndoctor* represents the medical services. *lnconsume* represents the consumption ability of residents. *lnpeo* represents the urban population density. *lnindus* represents the degree of industrialization.

3.3. Data sources

The data used in this study are mainly from the China Statistical Yearbook, the China Urban Statistical Yearbook, provincial statistical yearbooks, and statistical bulletins. The annual panel data of 285 major prefectural cities are selected in China from 2003 to 2020, with 5130 observations. Some missing data are filled in by the mean and linear interpolation methods. The base period of the study is set at 2003. Furthermore, the first batch of LCCP is mainly planned at the provincial level, and the last two batches of pilot policies have increased in number and are mainly planned at the prefectural level. Therefore, conducting the main study at the prefectural level is reasonable. The provincial areas and individual counties and districts covered by LCCP are not considered, and some cities with missing data are excluded from the sample. A total of 70 prefectures is included in the experimental group, and 215 prefectures are included in the control group.

4. Empirical results and discussion

The smoothness of the data is a prerequisite to ensure the truthfulness of the empirical model estimation. Table 2 reports the panel unit root test results using the LLC and IPS methods. All variables, after logarithmic transformation, significantly reject the null hypothesis of a unit root at the 1% or 10% levels, confirming the stationarity of the panel data for subsequent regression analysis.

Table 2. Unit root test results

Variable	LLC unit-root test		IPS unit-root test	
	Adjusted t	p value	Z-t-tilde-bar	p value
lndead	-3.7194	0.0001	-14.7628	0.0000
lnpgdp	-3.9385	0.0000	-1.2963	0.0974
lngovt	-15.3129	0.0000	-22.2535	0.0000
lnedu	-16.9715	0.0000	-35.3699	0.0000
lndoctor	-17.2130	0.0000	-19.6243	0.0000
lnconsume	-9.1151	0.0000	-12.1982	0.0000
lnindus	-10.0257	0.0000	-4.1521	0.0000
lnwater	-4.3048	0.0000	-6.0837	0.0000
lnair	-3.4883	0.0002	-8.1638	0.0000
lndust	-2.7298	0.0032	-1.2942	0.0978
rule	-14.9287	0.0000	-21.4009	0.0000
innovate	-17.5315	0.0000	-14.9411	0.0000

4.1. Regression analysis results

Table 3 presents the stepwise regression results for Model (1). The core explanatory variable, LCCP, consistently shows a statistically significant negative coefficient across all specifications. Specifically, in the model with controls, the coefficient is -0.0375 ($p < 0.05$), indicating that the LCCP significantly raises urban residents' overall health level by approximately 0.0375 units. This finding provides strong empirical evidence that low-carbon city construction effectively improves public health, thereby supporting H1.

Regarding the control variables, economic growth, medical services, and population density significantly boost residents' health status ($p < 0.05$). Interestingly, government spending hinders residents' overall health. A plausible explanation is that excessive investment in urban infrastructure and sprawl may crowd out public health resources or degrade environmental quality. Other controls, including education, consumption, and industrialization, exhibit signs consistent with theoretical expectations.

Table 3. Basic regression results

Variables	lndead		
	(1)	(2)	(3)
td	-0.0366*	-0.0432**	-0.0375**
	(0.0191)	(0.0189)	(0.0188)
Llndead	0.632***	0.619***	0.615***
	(0.0394)	(0.0392)	(0.0395)
lnpgdp		-0.0252***	-0.0472***
		(0.00654)	(0.0133)
lngovt		0.0311***	0.0559***
		(0.00619)	(0.0102)
lnedu			-0.0109
			(0.0133)
lndoctor			-0.0364**
			(0.0149)
lnconsume			-0.00153
			(0.0148)
lnpeo			-0.0130**
			(0.00605)
lnindus			0.0125
			(0.00764)
Constant	0.698***	0.502***	0.639***
	(0.0683)	(0.0811)	(0.101)
Observations	4,845	4,845	4,845
R-sq	0.441	0.409	0.411
Number	285	285	285

Note: ***, **, * denote significance at the 1%, 5% and 10% levels.

Under low-carbon development constraints, pilot cities may achieve energy savings and emission reductions by sacrificing overall output (Huang et al., 2023). Such trade-offs can undermine sustainable development and crowd out residents' income and health-capital investment. Accordingly, this study posits a competing H1a alongside H1. Empirically, the LCCP improves residents' health on average, consistent with H1. However, it also reduces the efficiency of social output (Table 4), which may suppress income growth (Li et al., 2022) and weaken health investment. This tension is amplified across pilot batches: the first batch (tr10), self-nominated and state-evaluated, faced relatively modest abatement pressure, whereas later batches operated under stricter low-carbon targets. The intensified pressure likely induced distortions in capital and labor markets, further resulting in resource misallocation among firms and policy failure (Shen et al., 2025), leading to the negative effects of tr12 and tr17 on output.

To quantify the trade-off and its distributional impacts, this study conducts a heterogeneity analysis by economic development level (per capita GDP). As shown in Columns (3) and (4), a clear asymmetry emerges: the policy coefficient is strongly positive in developed cities (5.659) but turns negative in less developed cities (-0.090). For developed cities, the "innovation compensation" effect dominates (Li et al., 2023), allowing them to achieve health co-benefits. Conversely, less developed cities face a "compliance cost" dilemma. Due to limited resource endowments, mandatory low-carbon targets may force local governments and firms to divert funds from public health services and welfare improvement to meet emission standards, thereby causing a "crowding-out effect". This suggests that a "one-size-fits-all" policy may exacerbate regional inequalities (Wang & Wang, 2022). To mitigate these unintended negative effects, central governments should implement targeted fiscal instruments. Specifically, vertical fiscal transfers or special eco-compensation funds should be directed toward less developed regions. These financial aids can offset the compliance costs and ensure that the transition to a low-carbon economy does not come at the expense of social welfare in poorer areas.

Overall, the LCCP can improve the residents' health, but the relationship between the two is still subject to potential shocks. The robustness should be tested to strengthen the validity of empirical results. At the same time, it is necessary to open the "black box" of the impact of low-carbon city construction on residents' health, analyze its specific mechanisms, and interpret the external mechanisms through which low-carbon city construction affects residents' health. What are the internal mechanisms to guide residents' health behavior? A new perspective would be provided for the study of the social benefits of low-carbon city construction.

Table 4. Competitive hypothesis analysis

Variables	(1) outputs	(2) outputs	(3) high	(4) low
td	3.709***	2.666***	5.659***	-0.090
	(0.955)	(0.594)	(1.462)	(0.521)
tr10		12.39***		
		(0.680)		
tr12		-1.252***		
		(0.348)		
tr17		-2.121***		
		(0.374)		
lnpgdp	15.64***	15.60***	16.58***	5.299***
	(1.218)	(1.241)	(1.384)	(1.268)
lngovt	2.860***	1.898**	4.076**	-1.034***
	(0.716)	(0.659)	(1.818)	(0.342)
lnedu	1.348***	0.994**	3.079***	0.155
	(0.456)	(0.453)	(0.932)	(0.259)
lndoctor	-1.068	-1.031	-1.596	-0.300
	(0.906)	(0.887)	(1.773)	(0.450)
lnconsume	0.906	1.445**	-1.813	2.632***
	(0.624)	(0.607)	(1.302)	(0.322)
lnpeo	0.0525	-0.166	-0.587	-0.256
	(0.257)	(0.246)	(0.756)	(0.247)
lnindus	0.0845	0.0177	2.251***	-0.0114
	(0.481)	(0.506)	(0.625)	(0.492)
Constant	-195.1***	-185.6***	-194.2***	-57.68***

	(9.105)	(9.208)	(12.43)	(9.840)
Observations	4,661	4,661	2,466	2,195
R-sq	0.416	0.434	0.307	0.351
Id	285	285	285	285

Note: ***, **, * denote significance at the 1%, 5% and 10% levels.

4.2. Parallel trend tests

The validity of the difference-in-difference model estimates relies on the fact that the trends in the core variables of the experimental group remain parallel to the core variables of the control group until the policy occurs. Beck et al.'s (2010) approach is referred to construct a parallel trend test model.

$$lndead_{it} = \omega_0 + \sum_{j\neq 0, j\geq -7}^{7} \theta_j d_{it}^{j} + \mu_i + \sigma\_t + \delta_{it} \tag{4}$$

where d denotes the policy effect dummy variable. When $j > 0$, if city i is a low-carbon pilot city and is in the j years after the pilot, d takes 1, otherwise, it takes 0. When $j < 0$, if city i is a low-carbon pilot city and is in the j years before the pilot, d takes 1, otherwise, it takes 0. The policy pilot time is 2010, 2012, and 2017, mainly considering comparing the four years before and after the start of the policy. The regression coefficient θ_j indicates the LCCP implementation after j years (or before j years) and whether a significant difference is observed in residents' health in the experimental and control groups.

Fig. 2 reflects the results of the parallel trend test for residents' health before and after the time determined by the city where the low-carbon pilot was built. The point when the policy started as the first period that has been affected by the policy, is designated as current. The base period (d_1) is removed to avoid the problem of multicollinearity under two-way fixed effects. Fig. 2 presents the estimated coefficients θ and their confidence intervals before and after the implementation of the LCCP.

Before the implementation of the policy, the estimated coefficients of the pre-treatment leads are -0.06, -0.10, -0.058 and-0.09 from $d_{-5}$to d_{-2}, respectively. Most of these pre-treatment coefficients are statistically insignificant, and their confidence intervals generally include zero. Although some pre-treatment estimates are slightly negative, they do not show a systematic upward or downward trend before policy implementation. Therefore, the results provide supportive evidence that there is no strong differential pre-trend between pilot and non-pilot cities before the LCCP, and the parallel trend assumption is not rejected. After the implementation of the LCCP, the estimated coefficients become significantly different from zero in most post-treatment periods, indicating that the health outcomes of pilot cities begin to differ from those of non-pilot cities after the LCCP takes effect, indicating that the experimental and control groups differed significantly at this stage and the policy effect is significantly present.

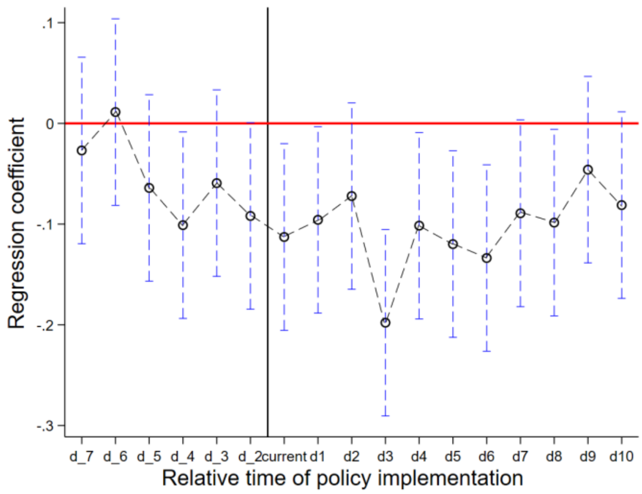


Figure 2. Parallel trend test

4.3. Endogeneity treatment

The endogeneity problems are addressed through the instrumental variables approach. The lagged term of the policy variable and a constructed historical instrument are selected for the instrumental variable regression. The endogenous variable is highly correlated with its lagged term, and the lagged term is a "predetermined variable" that has already occurred, satisfying the exogeneity assumption. To strictly satisfy the exclusion restriction, this paper discards the conventional green area variable and construct a historical instrument: the interaction term between the city's historical industrial base (the number of industrial enterprises in 1984) and a time trend. The choice of this historical instrument is based on two crucial aspects. First, regarding relevance, cities with a heavy historical industrial base suffer from path-dependent carbon emissions and face tremendous pressure for green transformation; thus, they are significantly more likely to be selected as LCCP pilot cities by the central government. Second, regarding the exclusion restriction, the industrial enterprises from nearly 40 years ago cannot directly affect the mortality rate of residents during our sample period. The historical industrial base only influences current health outcomes indirectly through its institutional path-dependent effect on the LCCP, which rigorously satisfies the exogeneity condition of the instrumental variable.

The results are shown in Table 5. The two columns on the left are the lagged terms of the dependent variables as instrumental variables. The LCCP variable is highly correlated with its lagged term. The LM statistic used for the identification test is 587.070 at the 1% significance level by the two-stage least squares regression. The coefficient of the td is highly significant, and the direction of the effect is the same as the basic regression, which indicates the robustness of the basic regression results. The two columns on the right are the two-stage least squares regressions utilizing a historical instrument: the interaction between a city's historical industrial base (the number of industrial enterprises in 1984) and a time trend. ($iv\_history$) as the instrumental variable. In the first-stage regression, this historical industrial base exhibits a strong correlation with current LCCP assignment, with the LM statistic for the identification test being 66.380 at the 1% significance level, indicating no underidentification problem. In the second-stage regression, the coefficient of the LCCP variable remains significantly negative. In conclusion, after addressing endogeneity utilizing these robust instrumental variables, the LCCP consistently demonstrates a significant promotion effect on the improvement of residents' health.

Table 5. Regression results of instrumental variables

Variables	**First-stage**	**2SLS**	**First-stage**	**2SLS**
	td	**lndead**	**td**	**lndead**
Iv(L.td&iv_history)	0.969***		0.004***	
	(0.005)		(0.001)	
td		-0.076***		-0.724***
		(0.022)		(0.024)
Constant	-0.266***	0.573***	-1.541***	-0.629
	(0.042)	(0.103)	(0.116)	(0.722)
Control	Yes	Yes	Yes	Yes
Observations	4,845	4,845	4,845	4,845
Kleibergen-Paap rk LM		587.070***		66.380***
R-sq	0.840	0.411	0.244	0.138
Number	285	285	285	285

Note: ***, **, * denote significance at the 1%, 5% and 10% levels.

4.4. Robustness test

4.4.1. Generalized method of moments

The two-stage GMM method is used to estimate model (1) again as shown in the first column of Table 6. The coefficient of the impact of the LCCP is -0.076 at the 1% confidence level, implying that the implementation of LCCP can improve residents' health under GMM estimation and the regression results of the basic model are robust.

Table 6. Robustness test results I

Variables	lndead	UMC	UMC	UMC
	2-Step GMM	**OLS**	**Clustered OLS**	**IV**
td	-0.0764***	-0.155***	-0.146***	-0.229***
	(0.0193)	(0.0346)	(0.0301)	(0.0417)
Constant	0.572***	4.848***	6.522***	4.814***
	(0.0861)	(0.212)	(0.467)	(0.181)
Control	Yes	Yes	Yes	Yes
Observations	4,845	5,098	5,098	4,814
R-sq	0.411	0.485	0.543	0.481
Number	285	285	285	285

Note: ***, **, * denote significance at the 1%, 5% and 10% levels.

4.4.2. Substitution of variables

To assess robustness, this study re-estimates the models by substituting the explained variable with urban mortality count (UMC), with relevant results reported in Table 6. Column (2) presents OLS results, Column (3) reports OLS with standard errors clustered by year, and Column (4) shows two-stage IV estimates using the two instruments. Across specifications, LCCP significantly reduces urban mortality count, with the coefficients of -0.155, -0.146, and -0.229 ($p < 0.01$). These findings remain robust when this study redefines the health outcome and vary the estimator, reinforcing the main conclusions.

4.4.3. PSM-DID model

To mitigate selection bias and strengthen comparability between treated and control cities, this study implements propensity score matching (PSM) to construct a matched control group with similar pre-treatment covariates. This paper then estimates difference-in-differences (DID) models on the matched samples using kernel, radius, nearest-neighbor, and martingale matching, with heteroskedasticity-robust standard errors (Figure 3). Across specifications, the LCCP coefficient retains the same sign as in the baseline, and although statistical significance is somewhat attenuated, LCCP still significantly improves health outcomes. Overall, the PSM-DID evidence corroborates the robustness of our main estimates.

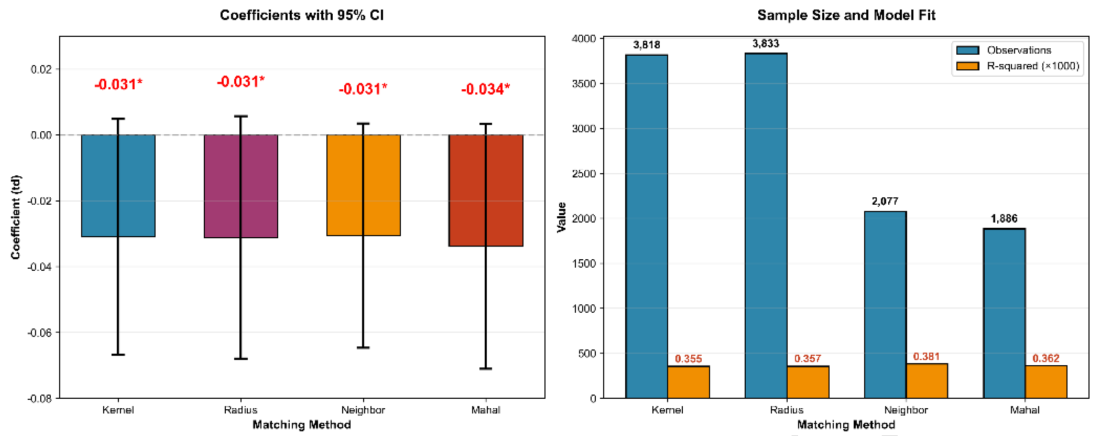


Figure 3. Robustness test results II

4.4.4. Placebo test

This paper assesses potential bias from unobserved factors using a placebo test that randomizes treatment assignment. Specifically, this study conducts 500 pseudo-treated groups by randomly assigning the LCCP to cities and re-estimate the baseline DID model each time. In 492 of the 500 replications, the absolute value of the placebo coefficient is smaller than that of the baseline LCCP coefficient; only 8 replications exceed it, indicating a low probability of obtaining effects as large as the baseline under random assignment. These results suggest that unobserved confounders are unlikely to drive our main findings. Figure 4 shows the kernel density of the placebo coefficients, which are approximately normally distributed and centered around zero, consistent with the expectations of the test.

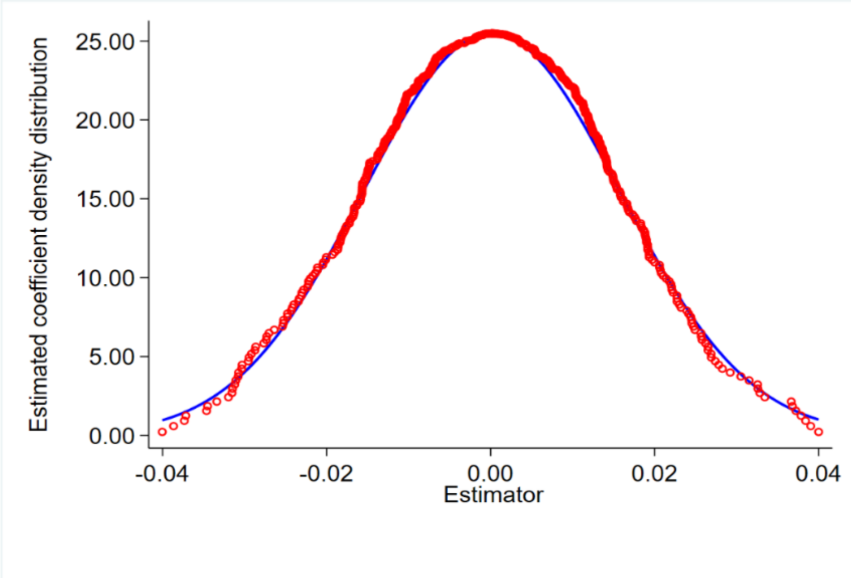


Figure 4. Placebo test results

4.4.5. Counterfactual prediction

The true policy timing is changed, and counterfactual predictions are conducted to test the reliability of the estimated results of the basic DID model. If the model results after changing the policy time are still significant, then the real policy effect may be in doubt. If not, it can prove the existence of the real policy effect. Given that the interval between the first two batches of LCCP is only two years, the start of all three batches of LCCP is estimated three years earlier to avoid duplication, as shown in the first column of Table 7. The estimated coefficient of the counterfactual predicted policy variable $ftsd$ is -0.0198, which does not pass the significance test, indicating that the real effect of the LCCP is significant and robust.

Table 7. Robustness test III

Variables	**Indead**		
	Counterfactual	**Policy intensity**	**Time specific**
fstd	-0.0198 (0.0133)		
sttd		-0.0345** (0.0175)	
sttimetd			-0.0417* (0.0232)
Constant	0.950***	0.920***	0.664***

	(0.133)	(0.130)	(0.0825)
Control	Yes	Yes	Yes
Observations	4,845	4,845	4,845
R-sq	0.443	0.444	0.411
Number	285	285	285

Note: ***, **, * denote significance at the 1%, 5% and 10% levels.

4.4.6. Policy intensity DID

The first batch of the LCCP list in 2010 included five provinces, and the second batch in 2012 included one province. Cities that are both present in the included provincial domains and the subsequent low-carbon city pilot list may be subject to stronger policy effects. Thus, the treat value of 2 is taken for such recurring individuals in the experimental group to represent the intensity effect of considering repeated policy implementation. The policy intensity DID estimation results are shown in the second column of Table 7, and the estimated coefficient of the intensity policy variable $sttd$ is -0.0345 at the 5% confidence level. Therefore, after considering the policy intensity, the effect of LCCP on the residents' health is still significant and enhanced.

4.4.7. Detailed representation of policy time

In terms of the implementation time of the LCCP, the three groups of pilots are in July 2010, November 2012, and February 2017. The basic DID estimation roughly assumes the existence of policy effects in all policy implementation years, therefore, this study further disaggregates the policy implementation time into months to verify robustness. The policy effect variable of the first batch of LCCP starting from July of the policy year should be changed to 5/12. Similarly, the policy effect variable of the second batch is changed to 1/12, and the policy effect variable of the third batch is changed to 5/6. The estimated results of the policy effect of the city pilot taking month into account are shown in the third column of Table 7. After refining the time, the interaction term ($sttimetd$) is significant with an estimated coefficient of -0.0417. Therefore, after making the policy time accurate, the LCCP still significantly promotes residents' health, proving the reliability of the baseline regression.

4.5. Mechanism analysis

This study further identifies the external and internal mechanisms by which the LCCP affects residents' health utilizing a mediation effects model, as shown in Table 8. The external mechanism is improving the living environment and the internal mechanism is shaping individual low-carbon behavior. In terms of the external mechanism, the regression coefficients of LCCP on air pollution (Lnair) and solid waste emissions (Lndust) are -0.18 and -0.126, both significant at the 1% level. LCCP effectively curbs atmospheric and solid pollutant emissions and further improves residents' health, which partially verifies H2. The coefficient corresponding to wastewater discharge (Lnwater) is -0.0889 without statistical significance. It may be that LCCP mainly focuses on energy efficiency and emission reduction technology, whose effects are more readily reflected in air and solid-waste pollution than in wastewater discharges. The "Air Pollution Prevention and Control Action Plan" together with strengthened inspection and accountability mechanisms have placed greater weight on air-quality indicators such as SO2 and PM2.5, incentivizing local governments to prioritize resources toward air pollution control and solid-waste management. By contrast, water pollution control relies heavily on long-cycle, capital-intensive infrastructure and is subject to lagged effects and cross-jurisdictional externalities.

In terms of the internal mechanism, the coefficient of LCCP on residents' low-carbon behavior (Act) reaches 0.542 at the 1% significant level. LCCP stimulates residents' green consumption and lifestyle transformation to promote population health, which fully validates H3. This study further applies Sobel and Goodman series tests to verify the statistical significance of each indirect mediating effect. The Sobel Z values for the air pollution, solid waste emissions and low-carbon behavior channels are -1.805, -2.251 and -3.114 respectively, all statistically significant. The wastewater discharge channel fails the significance test. The outcomes of Goodman tests are highly consistent with Sobel test results, which confirms the reliability of mediation statistics in this study.

Therefore, the external environmental mechanism takes the public ecological environment as the carrier. The LCCP advances regional pollution control and environmental improvement (Wang et al., 2024) and generates inclusive and public health benefits. The internal mechanism relies on residents' voluntary behavioral changes. The LCCP guides low-carbon consumption and lifestyles to produce individualized and initiative health gains (Li, 2024). The dual mechanism framework, which distinguishes the public effect of environmental governance and the individual effect of residents' green behaviors, reveals the composite health effects of the LCCP and provides targeted references for policy optimization.

Table 8. Regression results of mediating effects

Variables	Lnair	Lndust	Lnwater	Act
td	-0.180***	-0.126**	-0.0889	0.542***
	(0.0594)	(0.0582)	(0.0751)	(0.0647)
Constant	10.58***	8.220***	7.982***	16.29***
	(0.283)	(0.290)	(0.450)	(0.580)
Control	Yes	Yes	Yes	Yes
Observations	5,130	5,130	5,130	5130
R-sq	0.277	0.190	0.232	0.481

Number	285	285	285	285
Robustness Test:				
Sobel z	-1.805*	-2.251**	-1.221	-3.114***
Goodman-1 z	-1.758*	-2.200**	-1.136	-3.095***
Goodman-2 z	-1.856*	-2.305**	-1.328	-3.134***

Note: ***, **, * denote significance at the 1%, 5% and 10% levels.

4.6. Moderating effect analysis

In order to systematically consider the "black box" of the impact of LCCP on residents' health, the moderating factors of this impact are further considered. The interaction term between the moderating and independent variables are introduced and the coefficient of the interaction term is estimated as shown in Table 10. The regression coefficient of the interaction term $Rule \times td$ is -0.0498 ($p < 0.05$), indicating that environmental regulation can strengthen the effect of low-carbon city construction on residents' health. Environmental regulation is conducive to implementing LCCP, which can help urban low-carbon construction and improve residents' health. The coefficient of the interaction term $Innovate \times td$ is -0.0645 ($p < 0.01$), indicating that the city's innovation ability has a positive moderating effect. The stronger the city's innovation ability, the faster the industrial energy-saving and emission reduction technology innovation, the easier it is to achieve low-carbon construction, and improve residents' health. The coefficient of the interaction term $Dispose \times td$ is -0.0434 ($p < 0.05$), and the pollution governance efficiency of the city can also have a positive regulating effect. Building a low-carbon city limits industrial emissions and focuses on guiding residents to form a low-carbon lifestyle and strengthening the emission reduction of residents' lives. Improving the efficiency of domestic waste pollution treatment in cities can improve residents' living environment, enhance their environmental protection awareness, and encourage a low-carbon lifestyle, which benefits residents' health.

Table 9. Regression results of moderating effects

Variables	Regression with interaction terms		
	lndead	lndead	lndead
Rule×td	-0.0498**		
	(0.0244)		
rule	-0.0174		
	(0.0217)		
Innovate×td		-0.0645***	
		(0.0230)	
innovate		-0.0184	
		(0.0263)	
Dispose×td			-0.0434**
			(0.0192)
dispose			-0.0300
			(0.0219)
Constant	0.640***	0.569***	0.665***
	(0.103)	(0.0977)	(0.0870)
Control	Yes	Yes	Yes
Observations	4,845	4,845	4,845
R-sq	0.4115	0.4119	0.4118
Number	285	285	285

Note: ***, **, * denote significance at the 1%, 5% and 10% levels.

4.7. Heterogeneity analysis

The effect of LCCP on cities with different levels of development or different administrative levels may be different. A total of 285 prefectural cities in China is analyzed for heterogeneity, and the results are shown in Figure 5. First, the effect of the LCCP on residents' health in developing cities is slightly smaller than that in developed cities. This is due to the fact that the development pattern of developing cities needs to be optimized, the proportion of heavy industry is still in a high state, and their industrial emissions are larger than those of eastern developed cities. Thus, the effect of LCCP is more intuitive and obvious, and the difference between the effect of LCCP and that of the eastern region is relatively small.

Second, comparing the provincial capital cities with other city subsamples, the

LCCP has a significant effect on improving residents' health in the non-capital city sample, while the effect on the provincial capital city sample is not significant. The LCCP mainly promotes the improvement of residents' health by reducing emissions, alleviating urban environmental pressure, and creating a livable environment for residents. The provincial capital cities have a strong technical foundation for emission reduction and residents have a relatively strong awareness of low carbon, leading to a weak marginal effect of LCCP. The LCCP can effectively promote the transformation and upgrading of the development model of non-capital cities, improve the urban environment, and promote the improvement of residents' health.

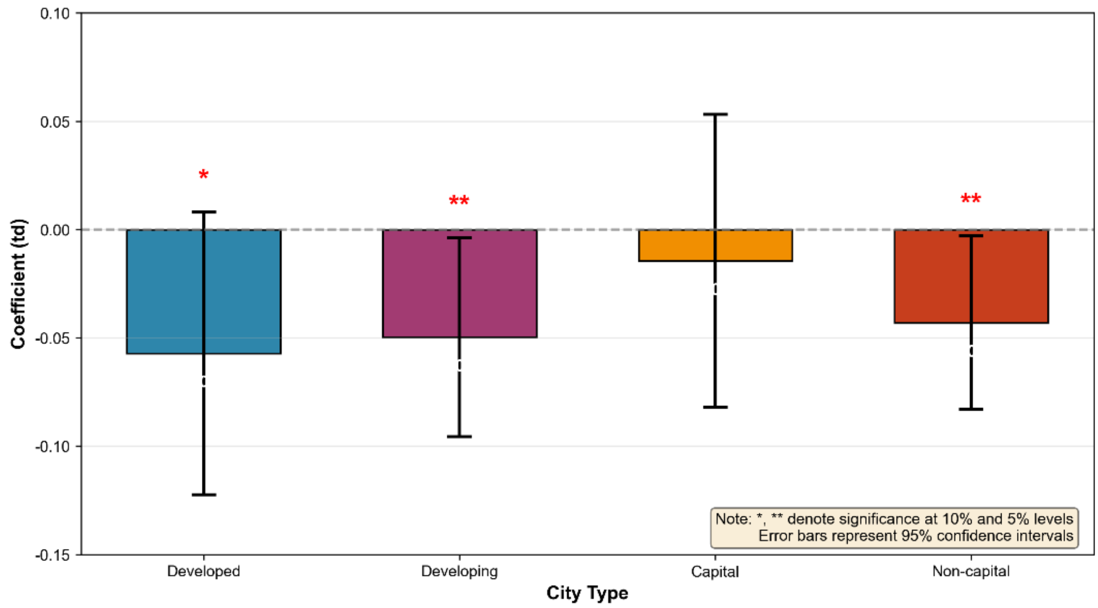


Figure 5. Heterogeneity analysis results

4.8. Discussions

Previous studies have mostly focused on the pollution reduction and economic growth effects of the LCCP (Yu & Zhang, 2021), while rarely unpacking its internal and external transmission mechanisms affecting residents' health. Furthermore, existing carbon-related research is mostly confined to single perspectives such as blue carbon accounting frameworks and farmland soil ecological cycles (Yaseen et al., 2026; Solangi et al., 2024). Different from previous research, this study identifies the dual paths linking the policy to public health: external optimization of living environments and internal shifts in residents' low-carbon awareness and behaviors. Different from the existing heterogeneity analysis conducted around regions (Liu et al., 2023), this study reveals the differences between capital cities and non-capital cities, and identifies the short-term output efficiency trade-off effect of later pilot cities. Although some studies have mentioned the roles of environmental regulation and innovation capacity (Jia & Fan, 2023; Qian et al., 2024), they fail to empirically test their moderating mechanisms for the health dividends of low-carbon city policies. This study fills this research gap accordingly.

Accordingly, the core empirical contributions in this study are as follows: it identifies dual paths of LCCP (external environmental improvement and internal low-carbon behavioral transformation), extends heterogeneity analysis to city development level and administrative grade, and verifies that environmental supervision, innovation ability and pollution control efficiency positively moderate LCCP's health dividends.

5. Conclusions and policy implications

5.1. Conclusions

Based on the panel data of 285 cities in China from 2003 to 2020, this study adopts the multiperiod DID, mediating and moderating effect models to explore the dual functional paths through which the LCCP policy affects residents' health. The results indicate that: (1) The LCCP significantly improves public health, with a core coefficient of 0.0375. However, the LCCP exhibits pronounced temporal and developmental heterogeneity with inherent policy trade-offs: later pilot cities suffer lower output efficiency, while less developed cities face compliance costs that crowd out public health investment. (2) The LCCP affects residents' health through the dual paths: externally by improving the living environment (reductions in air pollution with a coefficient of -0.18 and solid waste with a coefficient of -0.126) and internally by fostering residents' low-carbon behaviors with a coefficient of 0.542, while the path of wastewater emission reduction is not yet significant. (3) Stronger environmental regulation (0.0498), greater urban innovation capacity (0.0645), and higher pollution governance efficiency (0.0434) amplify the health benefits of the LCCP. (4) Health gains are larger in eastern, more developed cities than in western, developing cities; they are significant in non-capital cities but attenuated and generally insignificant in provincial capitals. This study reveals that the LCCP promotes residents' health through a dual mechanism of pollution control and green behavior, enriching the mechanistic framework of the health effects of low-carbon policies and providing differentiated policy implications for coordinating carbon emission reduction and public health in China.

5.2. Policy implications

Based on the research conclusions, the following policy implications are proposed: First, strengthen differentiated fiscal guarantees to avoid exacerbating regional inequalities. Governments should provide targeted support to less developed regions through vertical fiscal transfers or special ecological compensation funds to offset their compliance costs of low-carbon transition. Meanwhile, in response to the decline in output efficiency of later pilot cities, implement a flexible phased emission reduction target strategy to reserve a buffer period for industrial transformation. Second, focus on the dual paths and make up for governance shortcomings. Prioritize strengthening the coordinated control of air pollution and solid waste to quickly realize the environmental and health dividends. In view of the insufficient effect of the wastewater treatment pathway, implement a pollution reduction standard plan, increase subsidies for technological R&D and the construction of demonstration bases, and cultivate residents' low-carbon behaviors through green consumption subsidies and knowledge popularization. Third, strengthen the support of moderating factors and improve the environmental supervision and assessment system. Link emission reduction effects with health indicators, increase investment in low-carbon technology R&D, and build an intelligent pollution governance system to improve management and control efficiency. Fourth, implement differentiated strategies for different regions and city types. Underdeveloped western cities should be given a longer transition buffer period. Short-term emission reduction and energy conservation assessments should be appropriately relaxed. This avoids excessive low-carbon constraints that squeeze local fiscal and livelihood investment. Meanwhile, a health-oriented ecological compensation fund should be established for underdeveloped regions. It can cover extra environmental governance costs and health security gaps during low-carbon transition. This effectively eases the negative impact of compliance costs on residents' health. On this basis, developed eastern cities should take quality improvement as the core and play a leading and radiating role. They should help western regions improve environmental infrastructure and capacity to undertake green industries, and promote orderly green industrial transfer. Non-provincial-capital cities should be granted greater governance autonomy, while provincial capitals should gradually shift energy-intensive industries in an orderly manner. Meanwhile, the allocation of medical and health resources should be optimized to achieve balanced coordination between regional health benefits and low-carbon development.

5.3. Limitations and Prospects

This study explores the impacts and mechanisms of LCCP on residents' health, yet there are still areas for further research. Future studies may select resident health samples from specific regions and conduct in-depth analyses combining microdata and field surveys. Meanwhile, the heterogeneity of low-carbon policies can be further examined from multiple dimensions such as local policy attention and implementation intensity. In addition, future research can be carried out from an interdisciplinary perspective integrating environmental economics, public health and other disciplines.

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