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Carbon reduction effects of energy transition strategies: a discussion on multi-stakeholder carbon governance

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Investigating the carbon reduction effects of the New Energy cities Demonstration Policy (NECDP) is crucial for promoting the energy transition strategy and meeting the "dual carbon" targets. This study, grounded in stakeholder theory, examines the mechanisms behind the NECDP's carbon reduction effects from the perspectives of both constraints and incentives. Using panel data from 266 cities at the prefecture level and above in China, A difference-in-differences model and mediation effect model are used to assess the impact and mechanisms of the NECDP on carbon emissions. The study's results indicate that: 1) The NECDP significantly reduced carbon emissions, and this conclusion holds up after robustness checks that control for other policies and variable replacements. From a dynamic perspective, the carbon reduction effect of the NECDP did not become significant until the third year, suggesting a certain time lag. 2) Mechanism tests show that the NECDP, as a weak constraint and weak incentive environmental policy. It generates both constraints and incentives for environmental stakeholders, such as governments, businesses, and the public. The government enhances environmental oversight and increases investment in technology, while the public becomes more environmentally conscious, engages in green and low-carbon consumption, and participates in environmental regulation. Businesses, in turn, innovate in green technologies and adopt clean, low-carbon production methods, which help drive industrial upgrades and reduce carbon emissions. 3) Heterogeneity analysis shows that the carbon reduction effects of the NECDP are stronger in regions with lower urbanization, fewer resource-based industries, greater digitization, and stronger government environmental focus.

KEYWORDS

new energy demonstration cities, stakeholder behavior, carbon emission reduction, incentives and constraints, energy conservation and carbon reduction

1 Introduction

China is a major energy consumer and carbon emitter. According to the "World Energy Statistics Yearbook 2021," China's energy consumption and carbon emissions accounted for about 26.5% and 30% of global totals, respectively. Meanwhile, China's energy consumption per unit GDP was 3.4 tons of standard coal per million USD, and its carbon emissions per unit GDP were 6.7 tons of CO_2 per million USD—1.5 and 1.8 times the global averages, respectively. As cities are the primary sources of energy consumption and carbon emissions (Allan et al., 2023), Advancing the low-carbon transition of urban energy systems is crucial for achieving carbon peak and carbon neutrality goals ("dual carbon" goals). The "China's Energy Transition" white paper, released by the State Council Information Office in August 2024, emphasized the need to strengthen constraints on energy conservation and carbon reduction, foster green energy consumption patterns, and achieve energy-saving and carbon-reduction goals through collaboration among governments, businesses, and the public. Specifically, the government drives the low-carbon transition through regulatory constraints and policy incentives; businesses promote industrial transformation by adopting green technologies and clean energy; and the public contributes by increasing environmental awareness and engaging in green consumption. To support the development of the new energy industry and energy-saving, low-carbon technologies, and to improve urban energy efficiency, the National Energy Administration initiated the construction of NECDP in 2014. the National Energy Administration launched the NECDP. By promoting clean energy and developing green technological innovation, the policy aimed to reduce dependence on traditional fossil fuels, optimize the energy structure, and accelerate the transition to a green, low-carbon industry. These measures collectively support China's objectives of the "dual carbon" goals. In this context of urgent energy transition needs and the goal of achieving "dual carbon" targets, this study uses the NECDP as a case to explore how it can advance energy transition and carbon reduction through the collaborative efforts of government, businesses, and the public.

The structure of this paper is arranged as follows: Section 2 reviews the existing literature and highlights the marginal contributions of this study. Section 3 outlines the theoretical mechanisms and presents the research hypotheses. Section 4 summarizes the main models used in this study and organizes the relevant data. Section 5 presents the empirical results analysis, robustness tests, mechanism analysis, and heterogeneity analysis. Section 6 discusses the research findings. Section 7 covers the study's limitations and future directions, while Section 8 Summarizes conclusions and proposes policy suggestions.

2 Literature review

Achieving urban energy transformation and green, low-carbon development has become a major area of academic focus. The literature related to this research topic can be broadly categorized into two main groups. The first group centers on the factors influencing carbon emissions. Factors influencing carbon emissions can be broadly categorized into two types. The first includes factors that contribute to reducing carbon emissions, such as current environmental regulations (Chen et al., 2021; H; Wang et al., 2024) green technological innovation (Du et al., 2019) government intervention (Kou and Xu, 2022; Xiang et al., 2023) and industrial structure upgrading (Dong et al., 2020; Gu et al., 2022). The second includes factors that contribute to increasing carbon emissions, including industrial structure upgrading (Dong et al., 2020; Gu et al., 2022), urbanization (Dong et al., 2018), industrialization (Dong et al., 2019; Wang et al., 2019) foreign trade openness (Wang & Zhang, 2021; Z. H. Wang et al., 2021), population size (Hong et al., 2022; Kumar and Sen, 2025; Zhu and Peng, 2012) energy consumption (Shan et al., 2021; Wang et al., 2020) financial development (Acheampong et al., 2020; Huang and Guo, 2022) and economic development level (Sarkodie et al., 2020; Zhao et al., 2022) Among these, green technological innovation and industrial structure upgrading are widely recognized as two important mechanisms for reducing carbon emissions. (Wang et al., 2024). The second group of literature focuses on evaluating the effects of new energy demonstration city pilot policies. Some scholars have explored the green innovation effects of the NECDP, noting that it increases government funding support, promotes the concentration of human capital and other innovation factors, and enhances energy efficiency, thereby fostering green innovation (Chen et al., 2023; Feng et al., 2024; Song et al., 2024) Other studies have examined the environmental and economic effects of the NECDP. It has been shown to promote technological innovation and industrial upgrading (Yang et al., 2023), optimize resource allocation (Yang et al., 2021) strengthen environmental regulation (Ding et al., 2024) reduce energy consumption, and improve energy efficiency (Cheng et al., 2023; Liu et al., 2023), thus advancing high-quality economic development (Guo et al., 2023) characterized by pollution reduction, carbon reduction (Gao et al., 2024), and green growth (Yang et al., 2022).

In summary, existing literature primarily focuses on analyzing the factors influencing carbon emissions, as well as the environmental and economic effects of the NECDP. However, there is limited research that explores the mechanisms through which the NECDP affects carbon emissions from the perspective of multiple stakeholders, including government, businesses, and the public. Under the background of China's "dual carbon" goals and strategic constraints, this study leverages the exogenous variations in timing and selection of pilot cities induced by the NECDP. A multi-period Difference-in-Differences (DID) model is employed to effectively identify differences in carbon emissions between pilot and non-pilot cities, thus accurately evaluating the carbon reduction effects of NECDP. The potential contributions of this study are as follows: First, it provides a thorough analysis of the intrinsic mechanisms and pathways through which the NECDP influences carbon emissions. Given that the NECDP is an environmental policy with weak constraints and incentives, it exhibits typical environmental regulation features. By combining stakeholder theory, the study investigates the behavior choices of governments, businesses, and the public from both the constraint and incentive perspectives during the implementation of the NECDP. This approach helps uncover the mechanisms through which the NECDP impacts carbon emissions and establishes a logical framework linking the behavior of government, businesses, and the public with carbon reduction. Second, this study incorporates policy variables such as "low-carbon city pilot," "innovative city pilot," and "smart city pilot" into the empirical model, analyzing the net effects of carbon emissions after excluding the influence of various pilot policies. Additionally, it explores heterogeneity by considering factors such as government environmental awareness, urban clusters *versus* non-urban clusters, digitalization levels, and resource endowments.

3 Theoretical analysis

Carbon emissions inherently involve negative externalities, impacting broader society beyond the emission sources. Their complex and dynamic nature implies that emission mitigation requires coordinated action from multiple stakeholders—including local governments, enterprises, and the public. The NECDP represents a comprehensive environmental governance policy involving these diverse stakeholders (Li et al., 2023), Thus, this study analyzes the carbon emission reduction mechanisms embedded within the NECDP, specifically by examining the behavioral motivations of local governments, enterprises, and the public. The detailed analyses are as follows.

3.1 The central government's incentives and constraints imposed on local governments

The NECDP) as an energy transition policy, is characterized by weak incentives and weak constraints. From the perspective of incentives, the central government does not explicitly provide additional financial support to pilot cities but instead reallocates existing fiscal resources. From the perspective of constraints, central government oversight is limited, with performance assessments conducted only at the conclusion of the 2015 planning period, lacking continuous monitoring of subsequent activities. Despite these limitations, local governments remain highly motivated to actively participate in NECDP implementation for two main reasons:

Firstly, active engagement in NECDP facilitates local governments in achieving performance evaluation targets and gaining promotion opportunities. China's environmental governance experience indicates that local governments' environmental efforts are significantly driven by central government performance evaluations, financial incentives, and political promotion opportunities (Chen et al., 2024; Miao and Gu, 2024). As early as the 11th Five-Year Plan (2006), China set explicit binding targets—reducing energy intensity by 20% and major pollutants emissions by 10%—signifying a shift from a GDP-centered assessment towards incorporating environmental performance indicators. Given China's increased emphasis on ecological civilization, environmental evaluation mechanisms strongly encourage pilot governments to fulfill environmental performance goals. NECDP specifically promotes the development of the new energy sector and green technology innovations, aligning closely with central performance assessments by driving local economic growth, environmental quality improvement, industrial upgrading, and employment (Lu and Wang, 2019).

Secondly, the central government's acknowledgment of local governments' political legitimacy facilitates resource allocation and priority policy support, enhancing local governmental authority and regulatory capabilities over enterprises and the public. To enhance political legitimacy and resolve central-local incentive incompatibility issues (Mei and Wang, 2017; Ye et al., 2024), pilot governments actively utilize policy instruments like environmental regulation and fiscal subsidies in implementing NECDP, thereby promoting energy efficiency and reducing carbon emissions. Accordingly, this leads to Hypothesis 1.

H1: Effective implementation of the NECDP significantly reduces urban carbon emissions, thus promoting cities' green and low-carbon transition.

3.2 Local governments' incentives and constraints imposed on enterprises

Enterprise production activities are the primary sources of energy consumption, greenhouse gas emissions, and pollutant emissions; therefore, they represent the main targets of governmental environmental regulation. From the perspective of constraints, NECDP, as a policy primarily focused on pollution prevention at the source, sets binding targets related to renewable energy adoption, energy consumption intensity, and environmental pollution. In response, pilot local governments distribute renewable energy utilization objectives to enterprises, mandating adjustments to meet specific renewable energy consumption ratios. Specifically, pilot governments employ regulatory tools that increase both the sunk and marginal costs for energy-intensive, high-carbon, and heavily polluting firms. These regulations effectively decrease the number of such enterprises, restrict low-end, energy-intensive production methods, and encourage these firms to either exit the market, merge, or transition towards renewable energy production and consumption. Under these regulatory pressures, enterprises are incentivized to eliminate outdated capacity, enhance efficiency, fulfill corporate social responsibility, and shift toward clean energy sectors. Consequently, they increase investment in renewable energy technology R&D, install renewable energy facilities, and enhance renewable energy consumption, ultimately promoting structural upgrading and significantly reducing fossil energy use and carbon emissions.

From the perspective of incentives, considering that green technology R&D requires substantial financial input, has long return cycles, and involves high uncertainties (Peng and Liu, 2012), enterprises often cannot fully internalize the environmental benefits generated. Thus, pilot governments and relevant provincial authorities provide enterprises with various financial incentives, including subsidies and preferential tax policies Enterprise production activities are the primary sources of energy consumption, greenhouse gas emissions, and pollutant emissions; therefore, they represent the main targets of governmental environmental regulation. From the perspective of constraints, NECDP, as a policy primarily focused on pollution prevention at the source, sets binding targets related to renewable energy adoption, energy consumption intensity, and environmental pollution. In response, pilot local governments distribute renewable energy utilization objectives to enterprises, mandating adjustments to meet specific renewable energy consumption ratios. Specifically, pilot governments employ regulatory tools that increase both the sunk and marginal costs for energy-intensive, high-carbon, and heavily polluting firms. These regulations effectively decrease the number of such enterprises, restrict low-end, energy-intensive production methods, and encourage these firms to either exit the market, merge, or transition towards renewable energy production and consumption. Under these regulatory pressures, enterprises are incentivized to eliminate outdated capacity, enhance efficiency, fulfill corporate social responsibility, and shift toward clean energy sectors. Consequently, they increase investment in renewable energy technology R&D, install renewable energy facilities, and enhance renewable energy consumption, ultimately promoting structural upgrading and significantly reducing fossil energy use and carbon emissions.

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H2: Under NECDP constraints and incentives, enterprises actively engage in green technological innovation and cleaner, low-carbon production practices, thereby significantly reducing urban carbon emissions.

3.3 Public participation behaviors

As both supervisors and beneficiaries of the NECDP, public satisfaction with environmental quality has increasingly gained attention from the central government. The enhancement of public environmental awareness indirectly strengthens local governments' regulatory intensity, thereby influencing and constraining enterprise production behaviors (Wu et al., 2022). Firstly, by actively engaging with environmental news and leveraging social media platforms, the public effectively supervises local governments' environmental practices. This helps prevent local authorities from easing environmental regulations in pursuit of economic growth. Public pressure, coupled with central government inspections, ensures the rigorous enforcement of environmental policies. Secondly, public participation through reporting, petitions, and complaints effectively mitigates information asymmetry between local governments and enterprises, reducing the regulatory burden on local authorities (Chu et al., 2022), This increased transparency exposes high-energy-consuming and high-emission enterprises, prompting them to adopt low-carbon technologies and cleaner production processes to avoid penalties and enhance corporate reputation (Liu et al., 2024) ultimately reducing carbon emissions.

To cultivate green consumption behavior, pilot governments actively enhance public education initiatives focused on promoting green, low-carbon lifestyles, encouraging public transportation, walking, and cycling. On one hand, direct financial incentives such as subsidies for new energy vehicles and discounts for energy-efficient appliances are provided to lower the economic threshold for green consumption. For example, Shenzhen promotes new energy vehicle adoption by offering subsidies (up to 20,000 RMB per vehicle) and prioritized road access (e.g., bus lane privileges), which significantly boosted consumer demand for such vehicles. On the other hand, local governments adopt green procurement strategies to share R&D costs associated with low-carbon products, thereby reducing market prices and enhancing consumer willingness to purchase green products. This mechanism not only fosters green consumption but also incentivizes enterprises to adopt cleaner production methods, improving green production efficiency (Li and Zhao, 2024).

Overall, NECDP fosters public environmental awareness and cultivates green consumption behaviors through educational initiatives and financial incentives. This facilitates consumers' preference for eco-friendly products and green commuting, driving enterprises to innovate and upgrade towards greener production models. Such consumer-driven shifts promote industrial transformation towards low-carbon sustainability. Based on this analysis, the following hypothesis is proposed.

H3: NECDP significantly enhances public environmental awareness and facilitates the transition to green lifestyles, thereby promoting enterprise green technology innovation, driving industrial structure upgrading, and ultimately reducing carbon emissions the specific mechanism is illustrated in Figure 1.

4 Research design

4.1 Model construction

Given that the NECDP during the sample period is implemented in multiple batches, and referring to the research approach of Guo and Zhong, (2022), a multiple-period difference-in-differences (DID) model is constructed based on the temporal differences in policy implementation across cities. The baseline two-time-point fixed effects model is as follows:

$$\ln CO_{2it} = \alpha_0 + \alpha_1 NECP_{it} + \delta_i X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

According to Equation 1, $\ln CO2_{it}$ is the dependent variable, representing the carbon emission level; $NECDP_{it}$ is the key independent variable, If city i implements NECDP in year t, then $NECDP_{it}$ will take a value of one for the current and subsequent years; otherwise, $NECDP_{it}$ will be 0. X_{it} represents the control variables, and μ_i and λ_t denote individual and time fixed effects, respectively. ε_{it} is the random error term.

The theoretical analysis suggests that local governments promote enterprise green technological innovation and industrial upgrading through environmental regulations and technological investments. Concurrently, the public contributes by enhancing environmental awareness and transitioning to greener lifestyles, which collectively support carbon emission reduction. To empirically validate Hypotheses 2, 3, and drawing upon the research framework of Wen and Ye, (2014), the following mechanism model is constructed:

$$\ln Y_{it} = \gamma_0 + \gamma_1 NECDP_{it} + \gamma_2 Med_{it} + \gamma_i X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{2}$$

$$Med_{it} = \beta_0 + \beta_1 NECDP_{it} + \beta_i X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{3}$$

$$\ln Y_{it} = \gamma_0 + \gamma_1 NECDP_{it} + \gamma_2 Med_{it} + \gamma_i X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{4}$$

In Equations 2-4, $\ln Y_{it}$ denotes industrial structure upgrading and green technological innovation, identified as two key pathways

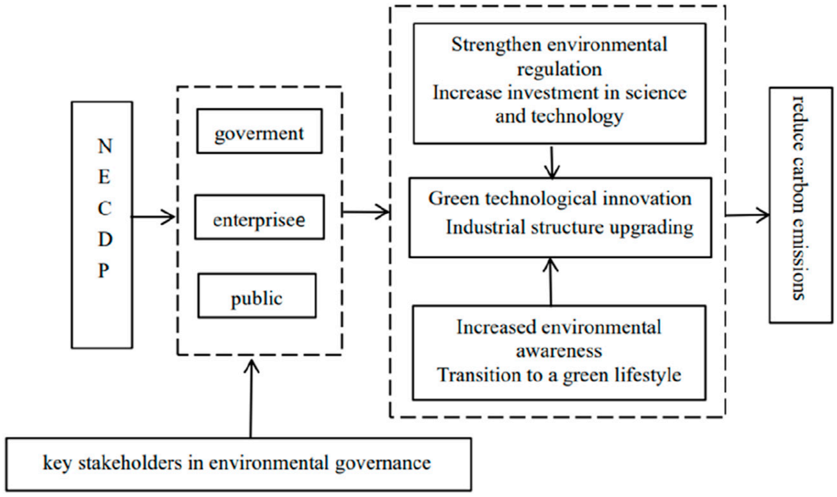

FIGURE 1
The carbon reduction mechanism of NECDP.

for promoting carbon emission reduction. The variable *Medit* represents the mediating mechanisms, including technological investment, environmental regulation, public environmental awareness, and the green transformation of public lifestyles. The coefficient β_1 measures the influence of NECDP on the mediating variables, while γ_1 captures the effect of NECDP on industrial upgrading or green technological innovation after accounting for the mediators. If both β_1 and γ_2 are statistically significant, and the significance or magnitude of γ_1 decreases, it indicates that the mediating variables exert a partial mediating effect in the relationship between NECDP and green technological innovation or industrial structure upgrading.

4.2 Variable definitions

4.2.1 Dependent variable

The dependent variable is urban carbon emissions ($lnCO_2$). Based on the method of continuous dynamic distribution proposed by Wu et al. (2016), the calculation results are obtained and logarithmic transformation is applied.

4.2.2 Independent variable

The NECDP variable (DID_{it}) is treated as a quasi-natural experiment in this study. If city i implements the NECDP in 2014, the group indicator variable is set to 1, otherwise it is set to 0. The time indicator variable for the years in which the city participates in the pilot program and the subsequent years is set to 1, while it is set to 0 for the years prior to the selection as a new energy demonstration city. The interaction term between the group indicator and the time indicator is used as the core independent variable to represent the impact of NECDP on carbon emissions.

4.2.3 Mediating mechanism variable

(1) Environmental regulation (*Eri*). environmental pollution control investment is selected as a variable representing government behavior, capturing the government's regulatory constraints on enterprises. It is important to note that due to the lack of data on environmental pollution control investment at the prefecture-level, we follow the method of Wang (2023), where the weight is determined by the ratio of the city's secondary industry output to the total secondary industry output of its province, and this ratio is then multiplied by the provincial-level environmental pollution control investment to estimate the city-level data.

(2) Technological investment intensity (*Kj*). Following the work of Dong et al. (2022), the ratio of government technological investment to GDP is used to measure governmental incentives provided to enterprises.

(3) Green technology innovation (*Pgpan*). Since patents effectively and intuitively reflect innovation ability (Lindman and Söderholm, 2016), the number of green patents per ten thousand people in each city is used to measure green technology innovation.

(4) Industrial structure upgrading (*Isu*). Following C. Wang et al. (2019), industrial upgrading is defined as the weighted product of the share of each industry and its corresponding labor productivity, with the formula as:

$$Isu = \sum_{j=1}^{3} \left(Y_{ij}/Y_i\right) \times \left(Y_{ij}/L_{ij}\right) \tag{5}$$

According to Equation 5, Y_{ij}/L_{ij} represents the labor productivity of industry j in region i. Since Y_{ij}/Y_i is dimensionless while Y_{ij}/L_{ij} has dimensions, a normalization method is applied to eliminate the dimensional differences.

(5) Public environmental concern (*Pub*). Referring to L. Wu et al. (2022), the Baidu haze search index is used to measure public environmental awareness. The reasons for using this index are twofold: first, Baidu, as the largest Chinese search engine, providing extensive coverage and high data availability,

providing comprehensive environmental search index data. Second, compared to keywords like "environmental pollution," the public has greater awareness of haze, so the level of concern about haze more accurately reflects public attention to environmental issues.

(6) Green transformation of public lifestyles (*Lz*). Building on the work of Peng et al. (2024), we construct a composite *Lz* index encompassing several key dimensions. Specifically, it incorporates green and low-carbon awareness (*per capita* park green space area), green travel (*per capita* number of public buses in operation at year-end), green environmental behavior (household *per capita* gas consumption), and digital life (*per capita* number of mobile phones, *per capita* telecommunications usage, and internet penetration rate). We then apply the entropy-weighted TOPSIS method to evaluate this composite index.

4.2.4 Control variables

To address the bias of endogeneity, a series of variables affecting carbon emissions are controlled for, as discussed in the literature review. These include: ①Economic development level (ln*Y*), measured as the logarithm of *per capita* GDP, with GDP deflated to real values using 2005 as the base year. ②Population size (*lnPop*), represented by the logarithm of the total population. ③Financial development (*Fin*), measured as the ratio of total deposits and loans to regional GDP. ④Urbanization level (*Urb*), represented by the ratio of employment in the secondary and tertiary sectors to total employment. ⑤Openness level (*Open*), measured as the ratio of total import and export trade to GDP. ⑥Transport infrastructure (*Inf*), represented by *per capita* road area. To reduce heteroscedasticity issues, logarithmic transformation is applied to the control variables. ⑦Economic volatility (*Bd*),represented by the coefficient of variation in economic growth rates over a 5-year period. ⑧Government intervention (*Gov*),measured as the ratio of general budget fiscal expenditure to regional *GDP*.

4.3 Sample selection and data sources

The sample space selected in this study is panel data from 266 prefecture-level cities between 2005 and 2020, with 56 cities designated as the experimental group for the new energy demonstration program, and 210 cities not selected as the control group. Since the sample data includes cities at the prefecture level and above, certain cities that use industrial parks (e.g., Tianjin Eco-city, Dalian Sanlibao Industrial Park) or specific districts (e.g., Beijing's Changping District, Qingdao's Laoshan District) as pilot sites are excluded to ensure effective policy evaluation. The list of new energy demonstration cities is obtained from the "National Energy Administration website," patent data comes from the National Intellectual Property Administration, and the green patent classification codes are from the WIPO Green Patent List. Other data is sourced from the "China City Statistical Yearbook," the EPS database, and the WIND database.

Descriptive statistics for each variable are presented in Table 1. As shown, the minimum, mean, and maximum values of carbon emissions are 1.775, 6.082, and 9.432, respectively, highlighting significant regional differences in carbon emissions. There are also substantial variations among prefecture-level cities in terms of green technology innovation (*Pgpan*), industrial structure upgrading (*Isu*), environmental regulation (*Eri*), technological investment (*Kj*), energy consumption intensity (*Egyx*), environmental awareness (*Pub*), economic development (ln*Y*), population size (ln*Pop*), urbanization level (*Urb*), openness (*Open*), infrastructure (*Inf*), financial development (*Fin*), Green Transition of Lifestyle (*Lz*), and Economic volatility (*Bd*), Government intervention (*Gov*).

5 Empirical analysis

5.1 Parallel trend test

Before applying the multi-period DID model to evaluate the impact of NECDP on carbon emissions, it is necessary to perform a parallel trends test on the carbon emissions levels of the experimental and control groups. This study follows the event study approach proposed by Beck et al. (2010) to analyze the dynamic trends of the policy effects over time, and establishes a regression model that captures the policy shock effects at different time periods.

$$\ln CO2_{it} = \alpha_0 + \sum_{j=M}^{N} \delta_j Ploc_{i,t-j} + \delta_i X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (6)$$

According to Equation 6, *Ploc_(i,t-j)* is a dummy variable. If city *i* was selected as a new energy demonstration city at time *t-j*, this variable takes the value of 1; otherwise, it is 0 (M and N represent the number of periods before and after the policy, respectively). If the coefficients from δ_(-M) to δ_(-1) are not significant, it suggests that there were no significant differences in carbon emissions between the experimental and control groups prior to the policy implementation, thus supporting the parallel trends assumption. δ_(0) to δ_(N) represent the current period and lagged effects (m = 1, … , M) for city i after being selected as a new energy demonstration city. These terms are used to capture the dynamic effects of the policy. If these coefficients are significant, it indicates that NECDP has a significant impact on carbon emissions.

The parallel trend test results shown in Figure 2 indicate that in the 5 years before the policy implementation, the regression coefficients for the impact of NECDP on carbon emissions did not pass the significance test within the 95% confidence interval. This suggests that, prior to being selected as a new energy demonstration city, there was no significant difference in carbon emissions between selected and non-selected cities, which supports the parallel trend assumption. After the city was selected as a new energy demonstration city, the carbon reduction effect was not immediately observed, but became statistically significant in the third year. This indicates that the carbon reduction effect of the NECDP has a time lag. The delayed policy effects observed in this study can primarily be attributed to the following factors: 1) Institutional and Implementation Lag: Despite clear guidelines from central policies, their effectiveness at the local level may be limited by insufficient resource allocation, misinterpretations of

TABLE 1 Statistical description of variables.

Variable name	Min	Mean	Max	S.D	Sample size
Carbon Dioxide Emissions (*lnCO2*)	1.775	6.082	9.432	1.171	4,256
Policy Variable (*NECDP*)	0	0.092	1	0.289	4,256
Industrial Structure Upgrading (*Isu*)	0.115	1.391	9.246	0.991	4,256
Green Technology Innovation (*Pgpan*)	0.002	0.769	19.53	1.542	4,256
Environmental Regulation (*Eri*)	0.0840	22.82	1,049	37.04	4,256
Technology Investment (*Kj*)	0.002	0.216	6.310	0.245	4,256
Energy Consumption Intensity (*Egyx*)	0.004	0.088	4.189	0.138	4,256
Environmental Awareness (*Pub*)	0.000	24.783	439.344	41.978	4,256
Green Transition of Lifestyle (*Lz*)	1.010	1.140	1.744	0.083	4,256
Economic Development Level (*lnY*)	7.782	10.36	13.06	0.752	4,256
Population Size (*lnPop*)	2.846	5.861	8.140	0.693	4,256
Urbanization Level (*Urb*)	0.202	0.629	1	0.146	4,256
Openness (*Open*)	0	0.181	3.488	0.338	4,256
Infrastructure (*Inf*)	0.139	4.335	73.04	5.878	4,256
Financial Development (*Fin*)	0.556	2.305	19.57	1.292	4,256
Economic volatility (*Bd*)	−21.604	0.305	30.166	0.972	4,256
Government intervention (*Gov*)	0.011	0.187	3.760	0.157	4,256

policy details, and difficulties in inter-departmental coordination. These institutional challenges lead to a delay in policy impacts becoming evident. Moreover, variations among local governments in comprehending and executing policy goals further extend the time required for effective policy implementation. 2) Long Construction Cycles for New Energy Projects: New energy projects typically involve extended timelines, including initial planning, land approvals, securing funding, equipment procurement, construction, trial operation, and formal commissioning phases. Specifically, infrastructure projects such as power grid enhancements and renewable energy installations (photovoltaic and wind power projects) have an average construction period of 2–3 years, influenced by factors like policy approval processes, funding availability, and technical support. 3) Enterprise Technological Transformation Period: While policies encourage enterprises to adopt low-carbon technologies, the actual technological upgrading process—including research, development, experimentation, and production-line transformation—can take several years. Additionally, the diffusion and market acceptance of new green technologies typically involve a gradual learning curve. Consequently, the effects of policy implementation on enterprise behavior are often more apparent in the medium to long term.

5.2 Baseline regression analysis

Table 2 presents the results of the baseline regression. The robustness of the results is assessed by sequentially adding control variables. From columns (1) to (7), it is evident that the *NECDP* coefficient of the core explanatory variable is significantly positive at the 1% level, indicating that NECDP can significantly reduce carbon emissions and foster a green, low-carbon urban transformation. The reasons for this are: first, the development of new energy cities compels high-consumption, low-productivity industries to transition towards greener, low-carbon alternatives, promoting a resource-efficient and environmentally friendly industrial structure that helps achieve carbon reduction and pollution control targets. Second, by setting targets such as "new energy utilization," "energy consumption restrictions," "energy consumption per unit of GDP," and "industrial wastewater and exhaust treatment rates," new energy cities encourage a shift from an energy-intensive, high-emission growth model to a more sustainable, low-carbon economic model, which in turn reduces carbon emissions. Hypothesis H1 is supported.

5.3 Placebo test

To further verify that the reduction in urban carbon emissions is caused by NECDP and not by random influences from other unobservable factors, a placebo test was conducted, following existing studies (Zhang et al., 2021). First, 56 cities were randomly selected from the full sample to form the experimental group. A virtual variable representing the policy implementation time was then generated for each city. This resulted in the core explanatory variable $NECDP_{it}$, which includes both the experimental group and the policy implementation time. The random sampling process was repeated 500 times, and the baseline model was estimated repeatedly. As a result, 500 estimates of the $NECDP_{it}$ variable coefficients and their corresponding p-values were obtained. This randomization

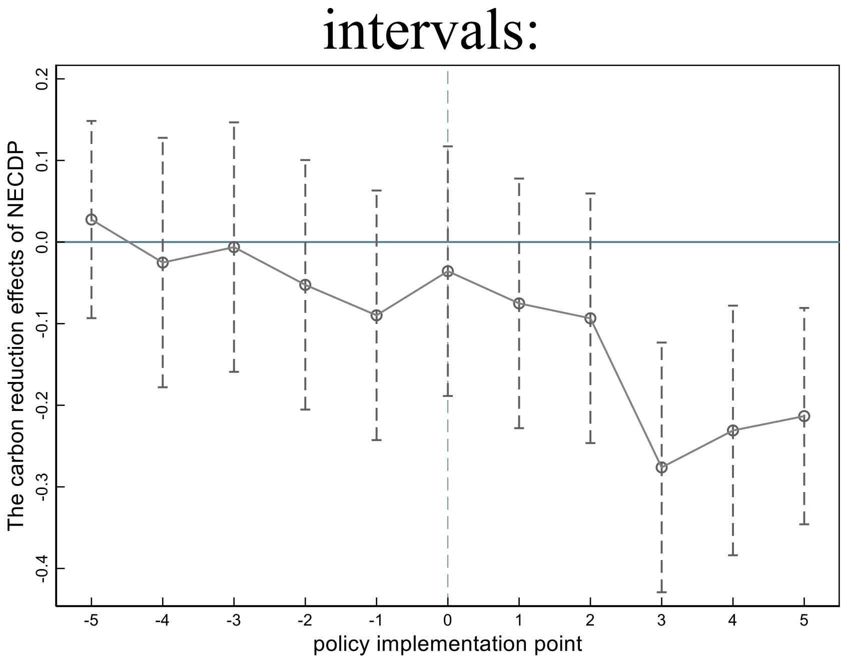

FIGURE 2
Parallel trend test results.

procedure helped eliminate the interference of other factors on the $NECDP_{it}$ variable within the NECDP framework. After this procedure, the regression coefficient for $NECDP_{it}$ was −0.049, with a p-value of 0.149, which did not pass the significance test. Figure 3 displays the kernel density distribution and the p-value scatter plot after randomization. It is evident that the actual estimated coefficient value is −0.155, significantly different from the coefficient values in the placebo test, and the p-values are concentrated around zero. This suggests that the policy effect of NECDP in reducing urban carbon emissions is real and not driven by random, unobservable factors.

5.4 Robustness analysis

5.4.1 Excluding other pilot policies

Previous studies have shown that pilot policies for low-carbon cities (LCT), smart cities (SC), and innovative cities (IC) can effectively reduce carbon emissions (Chiappinelli et al., 2024; Wang et al., 2015). Therefore, corresponding policy dummy variables are constructed and included in the empirical model to verify the net effect of NECDP on carbon emissions. If the coefficient of DID in the regression results is no longer significant, it would indicate that the negative impact of the new energy demonstration cities on carbon emissions is caused by other pilot policies in cities, and the baseline regression results would lack credibility. The regression model is specified as follows:

$$\ln CO2_{it} = \eta_0 + \eta_1 NECDP_{it} + \eta_j policj_{it} + \eta_i X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (7)$$

According to Equation 7, $policy_{1it}$ represents the impact of SC on carbon emissions, $policy_{2it}$ reflects the effect of LCT on carbon emissions, and $policy_{3it}$ represents the influence of IC on carbon emissions. The dummy variables are constructed as follows: (1) The first batch of SC was launched in 2012, with the latest batch in 2014. For the group dummy variable, cities that have both "smart city" and new energy demonstration city status are assigned a value of 1, while other cities are assigned a value of 0. For the time dummy variable, the years 2012–2020 are set to 1, and other years are set to 0. The interaction term between the group and time dummy variables is represented as $policy1_{it}$, which indicates the impact of the SC on carbon emissions. (2) The National Development and Reform Commission established the first batch of low-carbon pilot cities in 2010, with the most recent batch in 2017. Cities that simultaneously implement LCT and NECDP are coded as 1, while others are set to 0, forming the group dummy variable. The years 2010–2020 are set to 1, while other years are set to 0 for the time dummy variable. The interaction term between the group and time dummy variables, $policy_{2it}$, captures the impact of the "low-carbon city" policy on carbon emissions. (3) In 2008, China launched its first innovative city pilot program in Shenzhen, and by 2018, six batches of cities were included. For the group dummy variable, cities that have both the "new energy demonstration city" and "innovative city" titles are assigned a value of 1, while others are assigned a value of 0. The years 2008–2010 are set to 1, while other years are set to 0 for the time dummy variable. The interaction term between the group dummy variable and the time dummy variable, $policy_{3it}$, measures the impact of the "innovative city" policy on carbon emissions.

From the regression results in Table 3 (Columns 1–4), it is evident that NECDP did increase urban carbon emissions, but it is not the sole policy factor responsible for carbon emission reductions. Specifically, as shown in Columns (1) and (2), the *NECDP* coefficient is negative and significant at the 5% level, while the coefficients for

TABLE 2 Empirical results of baseline regression.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
NECDP	−0.130***	−0.149***	−0.156***	−0.157***	−0.154***	−0.156***	−0.155***	−0.155***	−0.155***
	(0.029)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
lnY		0.519***	0.521***	0.489***	0.472***	0.465***	0.480***	0.483***	0.485***
		(0.035)	(0.035)	(0.036)	(0.035)	(0.035)	(0.036)	(0.036)	(0.036)
lnPops			0.410***	0.372***	0.474***	0.426***	0.444***	0.447***	0.450***
			(0.102)	(0.102)	(0.102)	(0.104)	(0.104)	(0.104)	(0.104)
Urb				0.680***	0.520***	0.508***	0.473***	0.472***	0.474***
				(0.160)	(0.160)	(0.160)	(0.161)	(0.161)	(0.161)
Open					0.388***	0.380***	0.387***	0.386***	0.386***
					(0.048)	(0.048)	(0.048)	(0.048)	(0.048)
Inf						−0.007**	−0.006**	−0.006**	−0.006**
						(0.003)	(0.003)	(0.003)	(0.003)
Fin							0.021***	0.021***	0.021***
							(0.007)	(0.007)	(0.007)
Gov								0.038	0.038
								(0.047)	(0.047)
Bd									0.005
									(0.006)
_Cons	5.396***	0.528	−1.877***	−1.727**	−2.150***	−1.785**	−2.057***	−2.108***	−2.138***
	(0.023)	(0.328)	(0.681)	(0.680)	(0.677)	(0.696)	(0.702)	(0.705)	(0.706)
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.651	0.669	0.671	0.672	0.677	0.678	0.678	0.678	0.679
N	4 256	4 256	4 256	4 256	4 256	4 256	4 256	4 256	4 256

Note: t-values in parentheses, *, **, and *** indicate significance at the 10%, 5%, and 1% levels. We controlled the city-fixed effect and year-fixed effect.

$policy_1$ and $policy_2$ are also negative and significant at the 1% level. Compared to Column (7) in Table 1, the absolute value of the *NECDP* coefficient has decreased, suggesting that both the LCT, which focuses on reducing carbon emissions and developing new clean energy, and the smart city policy, aimed at enhancing innovation capacity and digital transformation, also significantly reduce carbon emissions. In Column (4), after including the SC, LCT, and IC, the $NECDP_{it}$ coefficient decreases to −0.083, which remains significant at the 5% level. This indicates that, after controlling for other city pilot policies, the carbon reduction effect of NECDP remains significant.

5.4.2 PSM-DID regression

To mitigate the bias introduced by the non-random selection of NECDP, and to control for carbon emission differences arising from other unobservable factors, this study employs the propensity score matching difference-in-differences (PSM-DID) method for robustness checks of the regression results. Based on the approach outlined by Y. Chen et al. (2024), control variables are treated as covariates, and kernel matching is applied using the logit model to identify the regions most similar to the selected cities as the control group. This approach further verifies the effect of NECDP on urban carbon emissions. As shown in Column (5) of Table 4, the coefficient for the impact of NECDP on carbon emissions is significantly positive at the 1% level, confirming that the baseline regression results are robust and reliable.

5.4.3 Replace the dependent variable

Considering the strong link between economic development and carbon emissions, and following Lei et al. (2023) and Yang et al. (2022), this study adopts carbon emissions per unit of output as a measure of carbon intensity. Based on this approach, an empirical analysis is conducted. The results, presented in Columns (6) of Table 3, show that t The coefficient of *NECDP* is −0.083, which remains statistically significant at the 1% significance level, suggesting that NECDP can reduce carbon intensity, thereby driving low-carbon development in cities.

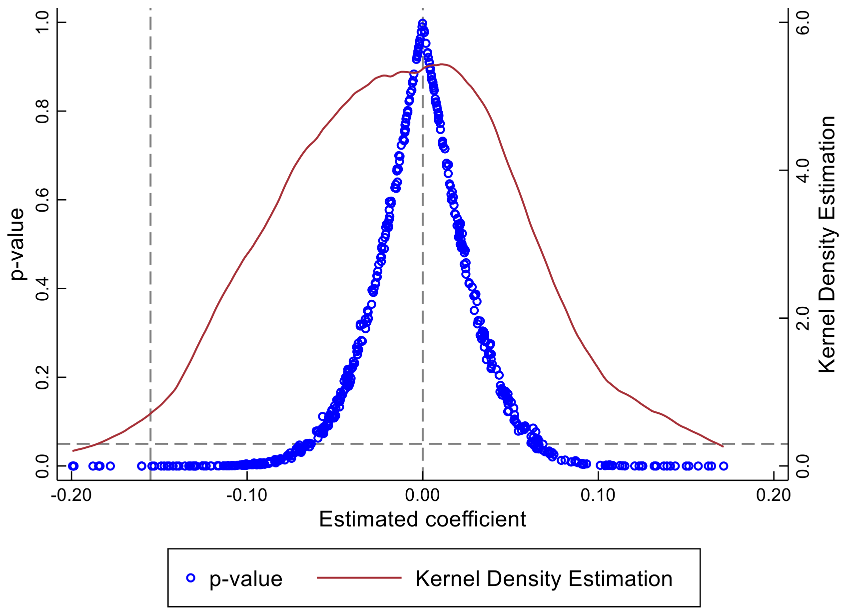

FIGURE 3
Placebo test.

TABLE 3 Robustness test of the Impact of NECDP on carbon emissions.

Variables	SC (1)	LCT (2)	IC (3)	Net effect (4)	PSM-DID (5)	Replace the dependent variable (6)	SDM (7)
NECDP	−0.116*** (0.033)	−0.118*** (0.030)	−0.145*** (0.030)	−0.083** (0.035)	−0.103*** (0.030)	−0.083*** (0.027)	−0.154*** (0.027)
W NECDP*							1.089** (0.447)
ρ							0.494*** (0.100)
$Policy_1$	−0.103** (0.047)			−0.107** (0.050)			
$Policy_2$		−0.161***		−0.162***			
		(0.048)		(0.049)			
$Policy_3$			−0.046 (0.051)	0.025 (0.055)			
Controls	Yes	Yes	Yes	Yes	Yes	Yes	
City FE	Yes	Yes	Yes	Yes	Yes	Yes	
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	
R^2	0.908	0.909	0.908	0.909	0.898	0.711	0.524
LogL							−1,608.241
N	4 256	4 256	4 256	4 256	3 365	4 256	4 256

Note: same as Table 2.

5.4.4 Alternative estimation method

Cities are the primary sources of carbon emissions, which show significant spatial correlations. The NECDP may affect carbon emissions in neighboring regions. Therefore, a Spatial Durbin Model (SDM) is constructed to identify the spatial spillover effects of NECDP. The model formula is as follows:

TABLE 4 Testing the emission reduction mechanism through government behavior.

Variables	Government actions					
	Effect of technology expenditure			Effect of environmental regulation		
	Pgpan (1)	*Kj* (2)	*Pgpan* (3)	*Isu* (4)	*Eri* (5)	*Isu* (6)
NECDP	0.283***(0.061)	0.025**(0.012)	0.252*** (0.059)	0.090*** (0.026)	3.673*(1.971)	0.083***
Kj			1.216***(0.076)			
Eri						0.002***(0.000)
_Cons	−24.317*** (1.540)	−4.157***(0.314)	−19.248***(1.531)	−14.533***(0.646)	−351.967*** (49.842)	−13.573***(0.643)
mediating effect value	−0.031** (Z = −2.001)			0.007** (Z = 2.250)		
95% confidence interval	[0.0057, 0.076]			[0.0027, 0.2959]		
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.529	0.304	0.558	0.701	0.153	0.707
N	4 256	4 256	4 256	4 256	4 256	4 256

Note: same as Table 2.

$$\ln CO_{2it} = \rho W \ln CO_{2it} + \alpha_1 NECDP_{it} + \alpha_2 WNECP_{it} + \delta_i X_{it} + \theta_i W X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (8)$$

According to Equation 8, W represents the geographic distance weight matrix, ρ is the spatial autoregressive coefficient, and α_2 and θ_i are vectors of spatial lag coefficients for explanatory and control variables, respectively. After conducting tests for spatial correlation, spatial effects, Wald, and LR tests (detailed results are omitted but available upon request), the SDM model with two-way fixed effects was selected for estimation. The results are shown in Column (7) of Table 3. Under the geographic distance weight matrix, the coefficient ρ passed the 1% significance level test, suggesting that urban carbon emissions are influenced by both local and neighboring regional factors. The coefficients of *NECDP* and *W* NECDP* are negative and positive at the 1% and 5% significance levels, respectively, indicating that NECDP reduced carbon emissions in pilot cities but increased them in adjacent non-pilot cities.

Three potential explanations are as follows: 1) Resource and Policy Siphon Effect: During policy implementation, pilot cities attracted substantial investments, technologies, and talents, causing a "siphon effect" that deprived neighboring non-pilot cities of resources. The resource shortage hindered these cities' green transformation, forcing them to rely more on traditional high-carbon industries, thereby increasing carbon emissions. 2) Policy Imitation Leading to Pollution Effect: Non-pilot cities may imitate the strategies of pilot cities. However, due to the lack of policy support, technological capacity, and management experience, such imitation is often superficial. Gaps in policy implementation and technology introduction may prevent effective industrial transformation, resulting in a "policy imitation pollution effect" where high-carbon industries continue to dominate. 3) Industrial Transfer Effect: Under demonstration policies, pilot cities are encouraged to develop green, low-carbon industries while restricting high-pollution enterprises. As a result, some high-carbon enterprises may relocate to neighboring non-pilot cities, contributing to a "pollution transfer effect" and raising emissions in these areas.

5.5 Mechanism test of the effect of NECDP on carbon emissions

The theoretical analysis suggests that local governments facilitate enterprise green technological innovation and industrial structure upgrading by implementing environmental regulatory constraints and providing technological investment incentives, ultimately contributing to carbon emission reduction. To test this transmission mechanism, technological output and environmental regulation are used as mediating variables. Table 4 shows the effects of NECDP on industrial structure upgrading and green technology innovation. From columns (2) and (5), the coefficients for NECDP's impact on technological spending and environmental regulation are significant at the 5% and 10% levels, respectively. This suggests that NECDP significantly encourages the government to strengthen environmental regulation and technological investment. From columns (3) and (6), the coefficients for the effects of technological spending and environmental regulation on green technology innovation and industrial structure upgrading are significantly positive at the 1% level. Additionally, the promoting effect of NECDP on green technology innovation and industrial structure upgrading is weaker compared to columns (1) and (4), implying that technological spending and environmental regulation

TABLE 5 Mechanism test of emission reduction under public behavior.

Variables	Public behavior					
	Effect of environmental awareness			Green transition of lifestyle (*Lz*)		
	Pgpan (1)	*Pub* (2)	*Pgpan* (3)	*Isu* (4)	*Lz* (5)	*Isu* (6)
NECDP	0.282***(0.061)	13.212***(1.823)	0.137** (0.018)	0.090*** (0.026)	0.003***(0.001)	0.084***(0.025)
Pub			0.011***(0.001)			
Lz						2.015***(0.270)
_Cons	−24.317*** (1.547)	−292.949***(46.095)	−21.331***(1.462)	−14.248***(0.644)		−16.227*** (0.694)
mediating effect value	0.145***(Z = 5.153)			0.006***(Z = 3.29)		
95% confidence interval	[0.0960, 0.2137]			[0.0028, 0.0105]		
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.529	0.578	0.580	0.700		0.705
N	4 256	4 256	4 256	4 256	4 256	4 256

Note: same as Table 2.

are critical channels through which NECDP influences these outcomes.

Furthermore, The mediation effect test, conducted using the Bootstrap method with 1,000 random samples, reveals that the mediation effect values for both technological investment and environmental regulation channels fall outside the 95% confidence interval that includes zero. This indicates the significant presence of mediation effects. The results suggest that NECDP facilitates green technological innovation and industrial structure upgrading by enhancing technological investment and environmental regulation, thereby promoting carbon emission reduction. The conclusion is robust and reliable, confirming the validity of Hypothesis H2.

The theoretical analysis suggests that NECDP enhances public environmental awareness and facilitates the transition to greener lifestyles. This, in turn, promotes green technological innovation and industrial structure upgrading, ultimately contributing to carbon emission reduction. Considering public environmental awareness and lifestyle green transition as mediating variables, Table 5 presents the estimated results of NECDP's influence on green technological innovation and industrial structure upgrading through public behavior, thus supporting carbon reduction efforts. Columns (2) and (4) demonstrate that NECDP's influence on public environmental awareness and lifestyle green transition is significantly positive at the 1% level, indicating that NECDP effectively enhances public environmental engagement and promotes greener lifestyles. Columns (3) and (5) show that both public environmental awareness and lifestyle green transition have significant positive effects on green technological innovation and industrial structure upgrading, also at the 1% significance level. However, NECDP's direct promotion effect on green technological innovation and industrial structure upgrading slightly decreases compared to the effects observed in columns (1) and (4).

Furthermore, the mediation effect test, conducted using the Bootstrap method with 1,000 random samples, reveals that the mediation effect values for public environmental awareness and green lifestyle transition fall outside the 95% confidence interval that includes zero. This confirms the significant presence of mediation effects. The findings suggest that NECDP reduces carbon emissions by enhancing public environmental awareness and fostering low-carbon lifestyles. The conclusion is robust and reliable, confirming the validity of Hypothesis H3.

5.6 Heterogeneity analysis

5.6.1 Government environmental awareness

The government plays a central role in environmental governance. In cities where the government places higher priority on environmental issues, stricter environmental regulations are enforced, and investments in pollution control are increased. Given the differences in economic development, infrastructure, openness, and policy enforcement across regions in China, the impact of the NECDP on carbon emissions may vary regionally. The sample cities were categorized into high and low environmental concern groups for regression analysis. As shown in Columns (1) and (2) of Table 6, the regression coefficients for the effect of NECDP on carbon emissions in cities with high and low environmental concern are −0.188 and −0.096, respectively, both statistically significant at the 1% level. This suggests that the carbon reduction effect of NECDP is stronger in cities with higher levels of government environmental concern. The likely explanation is that

TABLE 6 Results of policy synergy effect test.

Variable	High Attention (1)	Low Attention (2)	High Digitalization (3)	Low Digitalization (4)	Urban Clusters (5)	Non-urban Clusters (6)	Resource-Based (7)	Non-resource-Based (8)
NECDP	−0.188*** (0.044)	−0.096*** (0.034)	−0.160***(0.033)	−0.091**(0.046)	−0.114***(0.037)	−0.213***(0.042)	−0.123**(0.049)	−0.157***(0.033)
_Cons	−4.414*** (1.125)	0.806 (0.912)	−2.945***(0.861)	−1.591 (1.134)	−0.863 (0.932)	−4.611***(1.158)	−7.348***(1.124)	2.303**(0.919)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.629	0.747	0.667	0.708	0.672	0.702	0.635	0.702
N	2 128	2 128	2 128	2 128	2 272	1 984	1 584	2 672

Note: same as Table 2.

when local governments are more focused on environmental issues, they implement stricter environmental regulations and offer more subsidies. This drives businesses to adopt cleaner, low-carbon production practices and encourages green technological innovation, facilitating the transition of industries toward greener, low-carbon alternatives and reducing reliance on fossil fuels, thereby cutting carbon emissions. Additionally, these governments guide the public towards low-carbon lifestyles by promoting the use of public transportation and shared bicycles and offering green consumption subsidies to encourage the purchase of environmentally friendly products.

5.6.2 Degree of digitalization

With the rise of the digital economy, the role of digital government development, enterprise digital transformation, and the upgrading of residents' digital consumption has become increasingly important in enabling cities to transition to green, low-carbon development. To investigate the varying impact of NECDP on carbon emissions across cities with different levels of digitalization, this study follows the methodology of Wang (2023), evaluating urban digitalization based on three dimensions: digital infrastructure, industrial digitalization, and digital industrialization. The cities in the sample are categorized into high and low digitalization groups, and the differences in the impact of NECDP on carbon emissions in these cities are assessed. As shown in Columns (3) and (4) of Table 6, the *NECDP* coefficients for high and low digitalization cities are −0.160 and −0.091, respectively, with statistical significance at the 1% and 5% levels. This suggests that the policy effect of NECDP is stronger in high-digitalization cities. The likely explanation is that in cities with higher levels of digitalization, the digital economy enables participation from the government, enterprises, and the public in the NECDP. This boosts government digital governance capabilities, increases public environmental engagement, and enhances the motivation for businesses to adopt green transformations, all of which help to establish a green, low-carbon lifestyle and production model. Therefore, the carbon reduction effect of NECDP is more pronounced in high-digitalization cities compared to low-digitalization ones.

5.6.3 Urban agglomerations and non-urban agglomerations

With the ongoing process of urbanization, city clusters and metropolitan areas have become the new drivers of economic growth in China. City clusters offer numerous advantages, such as industrial agglomeration, resource sharing, talent mobility, regional integration, and openness. These factors may lead to stronger carbon reduction effects of energy policies in cities within such clusters. To test this hypothesis, following the study of Zhang et al. (2023) the sample cities are divided into two categories: cities in city clusters, including the Beijing-Tianjin-Hebei, Central Yangtze River, Harbin-Changchun, Chengdu-Chongqing, Yangtze River Delta, Central Plains, Beibu Gulf, Guanzhong Plain, Hohhot-Baotou-Ordos-Yulin, Lanci, and Guangdong-Hong Kong-Macau Greater Bay Area city clusters, and cities outside these clusters. A grouped regression is then performed. As shown in Columns (5) and (6) of Table 6, the *NECDP* coefficients for cities within city clusters and non-city-cluster cities are −0.114 and −0.213, respectively, both significant at the 1% level. This indicates that the carbon reduction effect of NECDP is significantly smaller in cities within city clusters than in non-city-cluster cities. The possible explanation is that, although cities in clusters benefit from industrial agglomeration, resource sharing, talent concentration, and policy coordination, which help to enhance inter-city collaborative innovation and industrial upgrading, these city clusters, as major economic hubs, are also the largest energy consumers and the regions with the most severe greenhouse gas emissions in China. Currently, the degree of economic agglomeration has not yet reached the point where energy-saving and carbon reduction effects occur. Therefore, the carbon reduction effect of NECDP is stronger in non-city-cluster cities.

5.6.4 Resource endowment

According to the "National Sustainable Development Plan for Resource-Based Cities (2013–2020)" issued by the State Council, the sample cities during the study period are classified into two categories: resource-based cities and non-resource-based cities. The impact of NECDP on carbon emissions is then assessed based on the cities' resource endowments. As shown in Columns (7) and (8) of Table 6, the *NECDP* coefficients for resource-based and non-resource-based cities are −0.123 and −0.157, respectively, both significant at the 1% level. This suggests that NECDP can reduce carbon emissions in both types of cities, with a stronger reduction effect in non-resource-based cities. The likely explanation is that NECDP effectively utilizes both command-and-control environmental regulations and market-driven competitive mechanisms, which stimulate green technological innovation in enterprises, forcing them to phase out outdated production capacities, enhance energy efficiency, and reduce carbon emissions. In resource-based cities, however, the long-standing path dependence and low-end lock-in development model result in a reduced carbon reduction effect of NECDP.

6 Discussion

This paper examines the carbon reduction effects of the NECDP in the context of energy transition strategies and urban low-carbon development. As the world's largest energy consumer and carbon emitter, China's efforts in energy conservation and emission reduction are crucial for achieving global carbon neutrality targets. Energy transition policies, as an environmental strategy centered on source prevention, create both incentives and constraints for local governments, businesses, and the public. Carbon emissions, with their negative externalities, broad impacts, dynamics, and complexity, cannot be addressed by government, market, or social mechanisms alone. Solving this issue involves the interests of the nation, government, businesses, and the public. Therefore, studying the energy-saving and carbon-reduction effects of this policy offers valuable insights for constructing a diversified environmental governance system.

This paper builds on existing research by explaining the carbon reduction mechanisms of NECDP from the perspectives of government, businesses, and the public. Empirical findings show that NECDP significantly reduces carbon emissions, although with a time lag effect, emphasizing the need for patience and continuity in policy formulation and implementation. The mechanism analysis reveals that NECDP promotes green technological innovation, clean low-carbon production, and industrial upgrading by influencing the actions of governments, businesses, and the public, thus supporting urban carbon reduction. Consequently, the central government should continue refining local environmental performance assessment systems and long-term supervision mechanisms. It should also expand subsidies for businesses' development of new energy technologies and related tax incentives, encouraging energy-saving and clean technologies as well as new energy product research and development. This will drive more resources into the new energy sector and help shift industrial structures from high-energy, low-efficiency models to green, low-carbon, and intensive forms. Additionally, local governments should guide the public toward green consumption and sustainable travel, promoting joint efforts from governments, businesses, and the public to drive urban energy consumption and low-carbon transformation.

Finally, the heterogeneity analysis highlights that the carbon reduction effect of NECDP is more significant in cities with high levels of government environmental attention, high digitalization, resource-based cities, and non-urban clusters. Thus, during policy implementation, greater emphasis should be placed on the flexibility and adaptability of the policy. Leveraging resource endowments and urbanization models, the coordinated development of digitalization and new urbanization should be accelerated. Digital economy tools can address the energy dependence and low-end lock-in effects in resource-based cities, promote free flow of factors and policy coordination across urban clusters, and accelerate the point at which economic agglomeration in urban clusters leads to energy-saving and emission-reduction effects.

7 Limitations and future research

This study provides an important assessment of the emission reduction effects of NECDP. However, several limitations remain, suggesting directions for future research improvement. 1) This study utilizes panel data from 266 cities in China spanning from 2005 to 2020. While this dataset is highly representative, both the policy environment and urban development dynamics may change over time. Future research could incorporate more recent data to capture the latest effects of policies on carbon reduction and to track the evolving trends of urban low-carbon transformations. Furthermore, in examining the mediating role of green technological innovation, future studies may benefit from using micro-level enterprise data for a more precise evaluation of its impact mechanisms. 2) In examining the carbon reduction mechanism related to public behavior, this study employs the public environmental awareness index to measure the public's level of environmental concern. Increased public environmental participation encourages more green consumption and sustainable travel. However, due to limitations in data availability, city-level data on public green consumption and travel could not be obtained, which broadens the scope of this mechanism analysis. 3) This study uses parallel trend tests, PSM-DID, and robustness checks—such as excluding other policies and substituting dependent variables—to evaluate the effect of NECDP on urban carbon emissions. While these methods provide solid evidence, future research could incorporate more formal statistical approaches, such as pre-trend testing, to further strengthen the robustness of the methodology. 4) This study primarily focuses on China's NECDP and does not fully integrate an international perspective. For example, the EU's Clean Energy Framework emphasizes regulatory uniformity, cross-border coordination, and policy coherence, whereas NECDP is distinguished by stronger local autonomy, a gradual implementation approach, and region-specific pilot programs. Future research could undertake cross-national comparative analyses to assess how energy transition policies in different countries influence urban carbon emissions. Such comparative insights would be instrumental in informing the development of effective global low-carbon energy transition strategies.

8 Conclusion and policy implications

8.1 Conclusion

Using panel data from 266 prefecture-level cities between 2005 and 2020, this study examines the policy effects and mechanisms of NECDP on urban carbon emissions, treating it as an exogenous policy shock.

(1) The findings indicate that NECDP significantly reduces urban carbon emissions and promotes the green, low-carbon transformation of cities. This conclusion holds even after a series of robustness and placebo tests.
(2) The mechanism analysis shows that NECDP encourages governments to enhance environmental regulation and technological investment, raise public environmental awareness, and push businesses to innovate green technologies and adopt clean, low-carbon production practices. These efforts drive industrial restructuring, which in turn reduces urban carbon emissions.
(3) Heterogeneity analysis reveals that the carbon reduction effects of NECDP vary significantly based on government environmental attention, digitalization levels, resource endowment, and city size. Furthermore, while NECDP plays a significant role in reducing carbon emissions, it is not the sole factor; other policies, such as "low-carbon cities" and "smart cities," also facilitate the green and low-carbon transformation of urban areas.

8.2 Policy implications

Firstly, Continuously advance the development of New Energy Cities Demonstration Policy (NECDP). The NECDP effectively promotes collaborative participation from local governments, enterprises, and the public, facilitated by strengthened environmental regulation and subsidy incentives. It is crucial to further enhance environmental governance frameworks, provide clearer financial incentives, and broaden public engagement channels. By empowering the public with a stronger voice in environmental matters, stakeholders—government, enterprises, and the public—can better coordinate efforts toward sustainable, low-carbon production and consumption, ultimately facilitating successful urban low-carbon transition.

Secondly, it is essential to ensure balance in policy implementation. Flexible subsidy strategies should be designed to accommodate different enterprise types, reducing compliance costs for small and medium-sized enterprises to enhance policy fairness and effectiveness. Additionally, enterprise costs, employment impacts, and environmental performance should be monitored regularly. A phased, adjustable environmental regulatory mechanism should be adopted to maintain flexibility and minimize sudden disruptions to business operations. Moreover, the government should concurrently introduce retraining and employment transition programs for workers in traditional industries, alleviating employment pressures associated with the urban energy transition.

Thirdly, Leverage resource endowments and urbanization models to accelerate the coordinated development of digitalization and new urbanization. Specifically, accelerate the development of new infrastructure, enhance the role of the digital economy in driving industrial transformation, and address the energy dependence and low-end lock-in effects in resource-based cities. Facilitate the free movement of factors and policy coordination between cities in urban clusters, promoting the point at which economic agglomeration in urban clusters generates energy-saving and emission-reducing effects. This will help drive the development of greener, low-carbon cities and the digital transformation process during the construction of NECDP.

Data availability statement

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

Author contributions

SW: Conceptualization, Data curation, Methodology, Software, Validation, Writing – original draft, Writing – review and editing.

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Conflict of interest

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

Generative AI statement

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

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