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The impact of new quality productivity on carbon emission intensity: evidence from China

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The new quality productivity, which integrates the concepts of technological innovation, industrial upgrading, and green development, plays a pivotal role in achieving carbon emission reduction targets. Given that current research on the relationship between new quality productivity and carbon emission intensity remains limited, in order to delve into the impact of new quality productivity on carbon emission intensity, its underlying mechanisms, as well as its heterogeneous performance across different regions and city types, we select panel data from 251 Chinese cities spanning from 2010 to 2021 and conduct an empirical analysis using a panel data two-way fixed-effects model. The research findings reveal that new quality productivity can significantly reduce carbon emission intensity. Further analysis demonstrates that new quality productivity can achieve a reduction in carbon emission intensity by enhancing urban innovation levels and the intensity of government environmental regulations. Moreover, the heterogeneity analysis indicates that, compared with other regions, the inhibitory effect of new quality productivity on carbon emission intensity is more pronounced in the western regions and non-resource-based city samples. This study not only enriches the relevant theories on the relationship between new quality productivity and carbon emissions but also provides a crucial basis for governments to formulate targeted carbon emission reduction policies. Based on this, this paper proposes that investment in areas related to new quality productivity should be increased, technological innovation and industrial upgrading should be promoted, and government environmental regulations should be strengthened. Particular attention should be paid to the development of the western regions and non-resource-based cities to give full play to the role of new quality productivity in carbon emission reduction.

KEYWORDS

new quality productivity, carbon emission intensity, carbon emission, carbon reduction, urban innovation

1 Introduction

Amidst the intensifying global warming phenomenon and formidable challenges posed to sustainable development (Zhang et al., 2022), carbon emission intensity (CEI) has emerged as a pivotal metric for evaluating the environmental ramifications of economic endeavors within a nation or region. The relentless surge in greenhouse gas levels in the atmosphere, fueled by the accelerated industrialization and urbanization processes, has further exacerbated the grave scenario of global climate change (Wang and Ma, 2021). Consequently, the reduction of carbon emissions and the facilitation of energy transition and upgrading have become issues of universal concern within the international community. China, as one of the foremost carbon emitters globally, has unequivocally proclaimed the ambitious aim of achieving carbon peaking by 2030 and carbon neutrality by 2060. This commitment not only epitomizes a proactive stance towards global climate change but also constitutes an inherent imperative for propelling high-quality economic and social development domestically. However, in the pursuit of this formidable objective, China confronts dual pressures stemming from the high energy consumption associated with industrialization and urbanization (Shi et al., 2018) and the enduring causal nexus between economic growth and carbon emissions (Kirikkaleli, 2020). Hence, the formidable task of effectively mitigating CEI while fostering high-quality economic development has emerged as a pressing research endeavor. The advent of the concept of new quality productivity (NQP) offers timely insights and pathways to address this pressing challenge. Characterized by efficiency, intelligence, and eco-friendliness, NQP propels the optimization and upgrading of industrial structures through technological innovation, industrial transformation, and shifts in production paradigms, thereby enhancing resource utilization efficiency, diminishing energy consumption and emissions, and ultimately realizing sustainable economic and social development (Hu and Liu, 2024). Therefore, this study endeavors to delve deeply into the ramifications of NQP on CEI, utilizing empirical analysis to unravel the carbon reduction effects of NQP, with the aspiration of contributing Chinese wisdom and prowess to the attainment of global sustainable development goals.

Since its inception by Chinese President Xi Jinping in September 2023, NQP has swiftly garnered substantial attention within the academic domain. Rooted deeply in classical economics, this concept has evolved dynamically with the temporal progression, particularly in the contemporary epoch where innovation and sustainability are highly prioritized (Esfahani et al., 2024). It marks a profound shift from traditional productivity paradigms driven by capital and labor to productivity paradigms fueled by technological innovation and sustainability (Coomes et al., 2019; Lyu et al., 2023). Scholars are vigorously exploring the multifaceted dimensions and perspectives of NQP, emphasizing its core of diversified innovation that catalyzes the rapid progression of emerging industries characterized by technological upgrading, economic efficiency augmentation, and environmental amicability (Wang and Juo, 2021; Yue H. et al., 2024). Furthermore, NQP places paramount importance on sustainable development, striving for a harmonious coexistence between economic growth and environmental stewardship (Guo et al., 2024; Jiang et al., 2024).

In the realm of NQP research, scholars have not only delved into its definition and contemporary significance but have also ventured deeply into the exploration of quantitative methodologies. Hu and Liu (2024) contend that NQP represents the capability of laborers, facilitated by advancements in science and technology, to engage in larger-scale and more efficient combinations, to comprehend, utilize, and transform nature, thereby creating material and spiritual wealth essential for fulfilling the aspirations of a better life for the populace. Hu (2023) further underscores that the introduction of NQP enriches Marxist productivity theory and provides a fresh perspective for global societal progress. In terms of quantitative research, numerous scholars have constructed evaluation systems for NQP: Wang and Wang (2024) utilize the entropy method to assess the NQP levels across various provinces in China, based on three dimensions: labor, labor objects, and means of labor. Shao et al. (2024) establish a corresponding indicator system centered on innovation, greenness, and productivity. Zhang et al. (2024) propose another evaluation framework emanating from laborers, labor objects, and labor tools. Yue S. et al. (2024) and Song et al. (2024) assess the NQP of listed companies from the perspectives of labor and technology, as well as labor force and production tools, respectively. These studies provide empirical support for a deeper understanding of NQP; however, future endeavors must further refine quantitative research to fully elucidate the intrinsic linkages between NQP, industrial structure, and economic development.

Considerable literature has focused on the determinants of carbon emission intensity, which can be broadly categorized into economic, technological, and structural dimensions. Regarding economic factors, existing research suggests an inverted U-shaped relationship between economic development and carbon emission intensity (Hao and Liu, 2016; Kang et al., 2016). Uncertainty in economic policies significantly increases regional carbon emission intensity (Deng et al., 2023). Financial development can markedly decrease carbon emission intensity (Tao et al., 2023). At the corporate level, financial development lowers financing costs, prompting enterprises to expand production, which may lead to increased energy consumption and elevated carbon emissions (Wang et al., 2023). Technological factors exhibit a generally negative correlation with carbon emission intensity (Ali et al., 2023; Manigandan et al., 2023). Yin et al. (2020) argue that advancements in low-carbon technology ultimately facilitate carbon reduction through the promotion of renewable energy research and development, optimization of energy structures, and reduction of energy consumption intensity. Additionally, low-carbon technological progress exhibits a threshold effect on carbon reduction efficacy. However, in certain industries, technological advancements may trigger rebound effects, thereby increasing carbon emissions (Yang and Li, 2017). Smart infrastructure can mitigate carbon emission intensity through technological innovation and agglomeration effects (Yi et al., 2024). Structural factors primarily encompass industrial structure, energy consumption structure, and population distribution structure. The optimization and upgrading of industrial structures can decrease carbon emission intensity (Cheng et al., 2018). The industrial upgrading of the manufacturing sector notably reduces carbon dioxide emissions (Brännlund et al., 2014). The proportion of coal usage in total energy consumption positively correlates with carbon emission intensity (Xu et al., 2020). Increasing the share of clean energy in energy consumption structures is pivotal for reducing carbon emissions in the manufacturing sector (Soytas and Sari, 2007). The development of renewable energy significantly lowers carbon emission intensity (Alam et al., 2025) and influences the carbon emission intensity of neighboring regions through short- and long-term spatial spillover effects (Wang and Lei, 2024). Population agglomeration aids in reducing regional carbon emission intensity, albeit with a potential gradual weakening of its emission reduction effect over time (Yan and Huang, 2022).

This paper conducts an empirical analysis of the impact, mechanisms, and heterogeneous manifestations of NQP on carbon emission intensity based on panel data from 251 Chinese cities spanning from 2010 to 2021. The aim is to delve deeply into the intrinsic connection between NQP and carbon emission intensity, providing new perspectives and empirical evidence for the realization of Sustainable Development Goals (SDGs). In the global context where countries are actively pursuing the SDGs and striving to strike a balance between economic development and environmental protection, China, as the world's largest developing country, faces significant pressure for carbon emission reduction while promoting economic growth. Meanwhile, countries like India are also actively addressing sustainable development issues. For instance, India has announced environmental agendas to achieve carbon neutrality and substantially reduce its carbon intensity levels (Shabbir Alam et al., 2023). Against this backdrop, studying the impact of NQP on carbon emission intensity holds great practical significance.

The potential innovations of this paper are manifested in the following aspects. Firstly, from the perspective of NQP, this paper investigates its impact on carbon emission intensity, providing empirical evidence for the factors influencing carbon emission intensity and expanding research in related fields. Secondly, previous measurements of NQP levels have mostly focused on the provincial and enterprise levels, and most of them have established indicator systems to measure NQP. In contrast, this paper utilizes text data from government work reports to measure the level of NQP at the city level, enriching empirical research related to NQP. Thirdly, in the empirical analysis, on the basis of effectively addressing endogeneity issues, this paper examines the impact of NQP on carbon emission intensity. It explores the mechanisms of this impact from two aspects: the innovation mechanism and the environmental regulation mechanism, and investigates the heterogeneous manifestations of this impact from the perspectives of regions and resource endowments. Through a comprehensive and in-depth study, this paper expects to clarify the role of NQP in carbon emission reduction, providing a scientific basis for governments to formulate targeted carbon emission reduction policies and assisting China and even the global community in better achieving the SDGs.

2 Theoretical analysis and research hypothesis

NQP, as an advanced form of productivity that integrates technological innovation, industrial transformation, and changes in production patterns, plays a significant role in reducing CEI. Firstly, NQP emphasizes technological innovation (Lyu et al., 2023). By developing and applying new technologies, such as clean energy technologies, carbon capture and storage technologies, significant reductions in carbon emissions during industrial production processes can be achieved. These new technologies not only enhance energy utilization efficiency and reduce energy consumption but also fundamentally decrease CEI by replacing traditional high-carbon energy sources (Lin and Ma, 2022). Secondly, NQP drives industrial transformation, promoting a shift towards a greener and more low-carbon industrial structure (Shao et al., 2024). In this process, traditional high-energy-consuming and high-emission industries undergo upgrading, while low-carbon and environmentally friendly emerging industries thrive. This optimization and adjustment of the industrial structure contribute to reducing carbon emissions from the source, achieving a win-win situation for both the economy and the environment. Furthermore, NQP advocates for changes in production patterns, pushing the economy towards circular and green economic directions. By improving resource utilization efficiency and reducing waste emissions, NQP maximizes resource utilization and reduces CEI. Simultaneously, the circular economy model facilitates the recycling of waste and creates new economic growth points.

NQP can reduce CEI by enhancing urban innovation levels. As a new round of productivity transformation characterized by high technology, high efficiency, and high quality, NQP not only drives the optimization and upgrading of the industrial structure but also promotes a comprehensive improvement of the urban innovation system (Yue H. et al., 2024). This enhancement in innovation levels manifests in various aspects, including strengthened technological innovation capabilities, optimized allocation of innovation resources, and continuous improvement of the innovation environment (Yue S. et al., 2024). With the continuous improvement of urban innovation levels, a series of low-carbon technologies, clean energy, and environmental products emerge and are widely applied. These innovative achievements not only improve energy utilization efficiency and reduce energy consumption but also fundamentally decrease CEI (Ali et al., 2023). The development and application of clean energy technologies optimize the urban energy structure, gradually replacing traditional high-carbon energy sources with low-carbon and non-carbon energy sources (Soytas and Sari, 2007). Meanwhile, the enhancement of urban innovation levels promotes the transformation and upgrading of the industrial structure (Zhao and Toh, 2023). Traditional high-energy-consuming and high-emission industries are gradually replaced by low-carbon and environmentally friendly emerging industries. This optimization and adjustment of the industrial structure contribute to reducing carbon emissions from the source.

NQP can reduce CEI by increasing the intensity of government environmental regulations. As an advanced form of modern productivity development, NQP integrates technological innovation, industrial upgrading, and green development concepts. Its innovation of traditional production methods not only promotes efficiency improvements but also enhances environmental protection awareness. In this process, governments, as policymakers and regulators, play a crucial role in bridging the gap between NQP and reduced CEI by increasing the intensity of environmental regulations. The development of NQP drives the demand for and innovation in environmental technologies. These innovative achievements often require stricter environmental regulations to ensure their effective implementation and widespread application. Consequently, governments face pressure and motivation to enhance the intensity of environmental regulations by formulating stricter environmental regulations, raising emission standards, and other means to guide enterprises towards adopting low-carbon and environmentally friendly production methods. As the intensity of government environmental regulations increases, enterprises must increase their environmental investments, optimize production processes, and adopt clean energy and environmental technologies to reduce CEI. This process not only contributes to achieving environmental protection goals but also promotes technological innovation and transformation among enterprises, achieving a win-win situation for economic development and environmental protection.

Based on the above analysis, the following research hypotheses are proposed.

Hypothesis 1: NQP can reduce CEI.

Hypothesis 2: NQP reduces CEI by enhancing urban innovation levels.

Hypothesis 3: NQP reduces CEI by increasing the intensity of government environmental regulations.

3 Methodology

3.1 Measurement

3.1.1 Dependent variable

The dependent variable in this paper is carbon emission intensity (CEI), which represents the volume of carbon emissions generated per unit of economic output in a city. In specific terms, CEI is derived by calculating the ratio of a city's carbon emissions to its Gross Domestic Product (GDP). This metric serves to gauge the carbon efficiency and environmental impact of urban economic activities. CEI offers a direct and clear depiction of the carbon emissions associated with each unit of economic output in a city. By utilizing this data, one can conduct precise comparisons of carbon efficiency among different cities or across various time periods within the same city. Such comparisons provide crucial empirical support for research on low - carbon development. A lower CEI signifies that a city is achieving more efficient utilization of energy and resources in the process of economic development, thereby realizing lower carbon emissions.

3.1.2 Independent variable

The independent variable in this paper is New Quality Productivity (NQP). NQP refers to the productivity generated through innovation, technological advancement, and efficient resource utilization. This form of productivity not only focuses on economic growth but also emphasizes environmental protection and sustainable development. NQP encompasses aspects such as the application of green technologies, the utilization of clean energy, and efficient production methods, all aimed at promoting the low-carbon transformation and sustainable development of cities and enhancing the coordination between the economy and the environment. We employed the Python software to conduct word segmentation on government work reports and calculated the word frequencies of 46 keywords related to NQP within these reports. The specific details of each keyword are presented in Figure 1. Based on this, this paper represents NQP using the ratio of the sum of the word frequencies of these 46 keywords to the total word frequency of the government work report text. The relevant data were sourced from the Macrodatas website (https://www.macrodatas.cn). The 46 keywords selected in this paper are closely related to the connotation of NQP and cover its key aspects. By calculating word frequencies and the ratio, we can quantify the degree to which these keywords are reflected in the government work reports, thus reflecting the level of attention and actual development of NQP in the reports.

3.1.3 Control variables

To accurately analyze the impact of NQP on CEI, avoid omitted variable bias, and ensure robust empirical results, the following control variables were introduced into the regression model. The first variable is urban economic development. Cities with higher levels of economic development typically possess more comprehensive infrastructure and stronger capital accumulation capabilities, providing economic support for urban low-carbon transformations. In this study, the logarithm of GDP is used to measure economic development (LGDP). The second variable is industrial structure. A higher proportion of the tertiary industry often implies lower energy consumption and pollution emissions, facilitating cities' low-carbon transitions. This study employs the ratio of tertiary industry GDP to secondary industry GDP to measure industrial structure (IS). The third variable is fixed asset investment. Higher fixed asset investment can drive infrastructure construction and technological upgrades in cities, contributing to the realization of low-carbon transformations. This study utilizes the ratio of total fixed asset investment to GDP to measure fixed asset investment (FAI). The fourth variable is human capital. Enhanced human capital can lead to greater technological innovation capabilities and more efficient resource utilization, thereby promoting low-carbon transformations. In this study, the logarithm of the number of students enrolled in ordinary institutions of higher learning is used to represent human capital (HC). The fifth variable is net fixed asset value. A higher net fixed asset value generally signifies more advanced production equipment and technologies, which can improve resource utilization efficiency and reduce carbon emissions. This study employs the ratio of the annual average balance of fixed assets to GDP to represent net fixed asset value (NFAV). The sixth variable is population density. Higher population density typically generates more transportation and housing demands but may also promote the prevalence of public transportation and energy-efficient buildings, thereby exerting a complex influence on low-carbon transformations. In this study, population density is measured by the ratio of total urban population to urban area (PD).

3.2 Statistical model

To conduct an empirical examination of the impact of NQP on CEI, we utilize the panel data two-way fixed-effects model (Nie et al., 2025b). This model serves as a statistical approach for analyzing panel data, characterized by its ability to simultaneously account for both individual fixed effects and time fixed effects. Specifically, by incorporating individual dummy variables and time dummy variables, it can effectively control for unobservable heterogeneous factors, thereby enabling a more precise estimation of the influence of the independent variable on the dependent variable (Shen et al., 2025; Nie et al., 2025a). The specific form of the benchmark model is presented in Equation 1:

$$CEI_{it} = \alpha_0 + \alpha_1 NQP_{it} + \beta Control + \mu_i + v_t + \varepsilon_{it} \quad (1)$$

In this model, i represents cities, and t represents years. The independent variable, NQP, signifies new quality productivity, while CEI denotes urban carbon emission intensity. Control represents

New Quality Productivity, Artificial Intelligence, Scientific and Technological Innovation, Technological Revolution, Scientific Development, Innovation Momentum, Disruptive Technology, Breakthrough Technology, Revolutionary Innovation, Emerging Technology, Cutting-edge Technology, High-tech, Advanced Technology, New Energy, New Economy, Digital Economy, Innovation-driven Economy, Future Economy, New Business Format, Digital Transformation, Industrial Upgrading, New Model, Strategic Emerging Industries, Future Industries, High-tech Industries, New Kinetic Energy Industries, Innovation-driven Development, Technology-driven Development, Innovation Leadership, Major Breakthrough, Productivity Enhancement, Qualitative Transformation, Productivity Improvement, High Efficiency, High Performance, High Productivity, High Output, High-quality Development, Quality Priority, Efficiency Improvement, High-standard Development, Dominant Technology, Innovation Leadership, Science and Technology Guidance, Key Breakthrough, Core Technology Breakthrough

FIGURE 1
Summary of NQP related vocabulary.

TABLE 1 Descriptive statistics and correlations.

Variables	Observations	Mean	Sd	Min	Max
CEI	3,012	0.0221	0.0220	−0.0008	0.1279
NQP	3,012	0.0041	0.0017	0.0007	0.0088
LGDP	3,012	16.6880	0.9131	14.7710	19.1626
IS	3,012	1.0180	0.5301	0.3263	3.4146
FAI	3,012	0.9092	0.4618	0.1130	2.7222
HC	3,012	10.6808	1.3334	7.1974	13.7122
NFAV	3,012	0.5631	0.7837	0.0565	5.5000
PD	3,012	0.0454	0.0321	0.0025	0.1778

a series of city-level control variables. α and β are the regression coefficients corresponding to each variable. μ_i captures city-fixed effects, υ_t represents year-fixed effects, and ε_{it} is the random disturbance term.

3.3 Data sources and descriptive statistics

The present study focuses on 251 prefecture-level and above cities in China spanning from 2010 to 2021. Data on urban carbon emissions were sourced from the CEADs database (https://www.ceads.net.cn), while all other data were obtained from the National Bureau of Statistics of China (http://www.stats.gov.cn). Descriptive statistics for the primary variables are presented in Table 1.

4 Empirical analysis

4.1 Baseline regression

To explore the impact of NQP on CEI, this paper employs the model specified in Equation 1 for testing. The regression results are reported in Table 2. Specifically, Column (1) presents the regression between NQP and CEI; Column (2) includes control variables in the regression; Column (3) clusters standard errors at the city level; Column (4) clusters standard errors at the city-year level; and Column (5) adopts robust standard errors with two-way clustering by city and year. The results consistently show significant negative coefficients for NQP, indicating that NQP has a significant effect in reducing CEI. Hypothesis 1 is thus supported.

4.2 Instrumental variable regression

Addressing the potential endogeneity issues arising from omitted variables, reverse causality, and measurement errors, we employ the instrumental variable (IV) approach using the two-stage least squares (2SLS) method for endogeneity testing. Regarding this analysis, other possible methods include conducting direct regression using ordinary least squares (OLS) or employing fixed-effects models or random-effects models to control for unobservable heterogeneity. However, when dealing with data that suffers from endogeneity issues, OLS will lead to biased and inconsistent estimation results. Although fixed-effects models

TABLE 2 Baseline regression results.

Variables	(1)	(2)	(3)	(4)	(5)
	CEI	CEI	CEI	CEI	CEI
NQP	−0.5236***	−0.6274***	−0.6274**	−0.6274***	−0.6274***
	(0.1864)	(0.1779)	(0.2575)	(0.2211)	(0.2159)
LGDP		−0.0237***	−0.0237***	−0.0237***	−0.0237***
		(0.0017)	(0.0054)	(0.0023)	(0.0053)
IS		−0.0057***	−0.0057***	−0.0057***	−0.0057***
		(0.0011)	(0.0021)	(0.0010)	(0.0021)
FAI		−0.0036***	−0.0036**	−0.0036***	−0.0036**
		(0.0007)	(0.0017)	(0.0009)	(0.0016)
HC		−0.0061***	−0.0061	−0.0061***	−0.0061
		(0.0008)	(0.0044)	(0.0018)	(0.0041)
NFAV		0.0001**	0.0001***	0.0001***	0.0001***
		(0.0001)	(0.0001)	(0.0001)	(0.0001)
PD		0.0237	0.0237	0.0237	0.0237
		(0.0697)	(0.0541)	(0.0280)	(0.0503)
Constant	0.0249***	0.4936***	0.4936***	0.4936***	0.4936***
	(0.0008)	(0.0297)	(0.1235)	(0.0501)	(0.1209)
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	3,012	3,012	3,012	3,012	3,012
R^2	0.803	0.822	0.822	0.822	0.822

Note: Standard errors in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01.

and random-effects models can, to some extent, control for unobservable heterogeneity, their ability to address endogeneity problems caused by omitted variables, reverse causality, and measurement errors is limited. Consequently, these methods were not adopted. The advantage of the 2SLS estimator lies in its capability to effectively resolve endogeneity problems arising from omitted variables, reverse causality, and measurement errors. By introducing instrumental variables, it decomposes the endogenous explanatory variable into a component that is uncorrelated with the error term, thereby obtaining a consistent estimator. This technique was employed in this study because the NQP may potentially have endogeneity issues. The 2SLS method can leverage the characteristics of instrumental variables to more accurately estimate the impact of NQP on CEI while controlling for other factors.

Specifically, we utilize the Post Stations (PS) of the Ming Dynasty and Urban Slope (US) as instrumental variables. These IVs are valid for the following reasons: (1) From the perspective of correlation, the post-stations in the Ming Dynasty, as a crucial component of the ancient postal and transportation system, are closely associated with modern communication infrastructure. Regions that had post-stations in history often correspond to higher levels of information infrastructure, well-developed logistics services, and favorable trade development conditions in contemporary times. Such regions or cities tend to have more vibrant social and economic activities, and the NQP of cities in these areas may also be relatively high. Urban slope, on the other hand, exerts an influence on the geographical morphology and traffic convenience of a city. Areas with relatively flat terrain are more conducive to large-scale urban construction and infrastructure development, thereby promoting economic activities and population agglomeration. Consequently, there is a certain correlation between urban slope and the level of urban development. Generally, flat areas usually exhibit more active economic activities and more complete infrastructure. Based on the above analysis, using the post-stations in the Ming Dynasty and urban slope as

TABLE 3 Endogeneity test results.

Variables	The first stage	The second stage
NQP		−8.0673***
		(2.3781
PS	0.0037***	
	(0.0012)	
US	0.0060***	
	(0.0018)	
Control	Yes	Yes
Kleibergen-Paap LM	27.619	
Kleibergen-Paap Wald F	13.374	
N	3,012	3,012

Note: Standard errors in parentheses, ***p < 0.01.

TABLE 4 Robustness test results.

Variables	(1)	(2)	(3)	(4)	(5)
NQP	−0.6284***	−0.6336***		−0.5436**	−0.4781***
	(0.2219)	(0.2238)		(0.2372)	(0.1340)
L.NQP			−0.4688**		
			(0.2069)		
Constant	0.5027***	0.5001***	0.5226***	0.5498***	0.3705***
	(0.0499)	(0.0510)	(0.0549)	(0.0580)	(0.0224)
Control	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	3,012	2,964	2,761	2,761	3,012
R^2	0.823	0.821	0.831	0.831	0.864

Note: Standard errors in parentheses, **p < 0.05, ***p < 0.01.

IV for NQP satisfies the correlation condition. (2) Exogeneity: As historical data, the Post Stations of the Ming Dynasty are unlikely to influence current CEI. Similarly, urban slope, being a natural geographical characteristic, is independent of modern economic policies and urban planning decisions and cannot directly affect CEI. Hence, both variables meet the exogeneity condition. Given that both variables are cross-sectional data and cannot be directly used as IVs in the model, we construct interaction terms between these variables and time dummy variables to serve as the IVs. Table 3 presents the 2SLS estimation results of the impact of NQP on CEI. Column (1) shows the estimation results of the first-stage regression of the instrumental variable. We treat the endogenous explanatory variable as the dependent variable and conduct regression analysis with the instrumental variables and other exogenous control variables to obtain the predicted values of the endogenous explanatory variable. The results indicate that the two instrumental variables, PS and United States, are highly correlated with NQP. Meanwhile, the Kleibergen-Paap LM and Kleibergen-Paap Wald F tests also demonstrate that the instrumental variables selected in this paper do not suffer from under-identification or weak-identification problems, which confirms the validity of the instrumental variables. Column (2) presents the results of the second-stage regression of the instrumental variable. We replace the endogenous variables with these predicted values in the main regression equation to obtain consistent estimates. The results show that the coefficient of NQP is negative and significant at the 1% level. The above instrumental variable estimation results suggest that the conclusions drawn from the baseline regression in this paper still hold after overcoming potential endogeneity issues.

4.3 Robustness test

To ensure the reliability of the research findings, this paper conducts robustness checks, meticulously controlling and validating through the following five dimensions: Firstly, we control for city administrative levels and time trend terms by incorporating interaction terms between dummy variables for city administrative levels and time trend terms in the baseline regression model. These dummy variables, coded as 1 or 0, signify whether a city is a provincial capital or a sub-provincial city, thereby mitigating the influence of administrative level disparities on the research outcomes. Secondly, to exclude the impact of urban economic development in super-tier cities (such as Beijing, Shanghai, Guangzhou, and Shenzhen) on the research findings, we exclude samples from these cities and re-perform the regression analysis. Thirdly, considering the potential lagged effect of NQP on CEI, we lag NQP by one period to examine its influence on CEI in the subsequent period. Fourthly, to alleviate potential endogeneity issues associated with other control variables, we lag all other control variables by one period and re-conduct the regression analysis. Fifthly, to address potential measurement outliers, we truncate the selected variable data at the 1st and 99th percentiles and re-perform the regression analysis. Through these robustness checks, we obtain the regression results presented in columns (1) to (5) of Table 4. These results demonstrate that the coefficients of NQP and its lagged version (L.NQP) are significantly negative, further validating the reliability and authenticity of the previously reported baseline regression findings.

4.4 Mechanism analysis

4.4.1 Innovation mechanism

This section examines whether NQP can reduce CEI by enhancing urban innovation levels (UIL). In this paper, we utilize the logarithm of the number of urban patent grants as a proxy for UIL. Based on theoretical analysis, we first test whether NQP can elevate UIL and then explore the impact of UIL on CEI. The regression

TABLE 5 Mechanism test results.

Variables	(1)	(2)	(3)	(4)
	UIL	CEI	GERI	CEI
NQP	18.0691**		0.1633***	
	(7.6787)		(0.0359)	
UIL		−0.0011**		
		(0.0005)		
GERI				−0.1388*
				(0.0837)
Constant	5.5451***	0.3722***	0.0127**	0.3713***
	(1.7115)	(0.0322)	(0.0058)	(0.0330)
Control	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	3,012	3,012	2,930	2,930
R^2	0.929	0.864	0.499	0.866

Note: Standard errors in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

results are presented in columns (1) and (2) of Table 5. The findings indicate that NQP significantly boosts UIL, and an increase in UIL substantially decreases CEI, suggesting that NQP can reduce CEI by enhancing UIL. Thus, Hypothesis 2 is validated.

4.4.2 Environmental regulation mechanism

The subsequent section investigates whether NQP can reduce CEI by intensifying government environmental regulation intensity (GERI). Drawing on the approach of Chen et al. (2018), this paper measures the GERI by calculating the ratio of the frequency of environment-related words in government work reports to the total word frequency in these reports. The specific details of the environment-related words are presented in Figure 2. Based on theoretical analysis, we first test whether NQP can elevate GERI and then explore the impact of GERI on CEI. The regression results are displayed in columns (3) and (4) of Table 5. The results demonstrate that NQP significantly enhances GERI, and an increase in GERI substantially decreases CEI, indicating that NQP can reduce CEI by intensifying GERI. Therefore, Hypothesis 3 is confirmed.

4.5 Heterogeneity analysis

We conduct a heterogeneity analysis of the impact of NQP on CEI from the perspectives of regional disparities and resource endowment differences.

4.5.1 Regional heterogeneity

Compared to other regions in China, the western region lags behind in economic development, has relatively inadequate infrastructure, but boasts high resource abundance and tremendous potential for economic growth. To investigate whether the impact of NQP on CEI exhibits differences between western cities and other cities, this paper, with reference to the "Notice of the State Council of the People's Republic of China on Implementing Several Policies and Measures for the Large-Scale Development of the Western Region," divides the research sample into the western region and other regions and conducts sub-sample regressions. The regression results are presented in columns (1) and (2) of Table 6. The findings reveal that in the sample of western cities, the coefficient of NQP is significantly negative and lower than that of non-western cities, indicating that an increase in NQP is more conducive to facilitating the low-carbon transformation of western cities.

4.5.2 Resource endowment heterogeneity

Resource-based cities often rely heavily on their abundant natural resources for economic development over the long term. However, the resource extraction process is accompanied by significant energy consumption and pollution emissions, severely impacting the local environment. Consequently, compared to non-resource-based cities, resource-based cities may exhibit severe high-carbon path dependencies in their economic development, which could affect the role of NQP in reducing CEI. Considering this, we classify the research samples into resource-based and non-resource-based cities based on the National Sustainable Development Plan for Resource-Based Cities (2013–2020) and conduct sub-sample regressions. The regression results are displayed in columns (3) and (4) of Table 6. The results show that the effect of NQP on reducing CEI is not significant in resource-based cities but is significantly negative in non-resource-based cities, suggesting that an increase in NQP is more favorable for promoting the low-carbon transformation of non-resource-based cities.

5 Conclusion

Against the backdrop of global climate change and sustainable development, reducing CEI has emerged as a crucial objective for urban development across nations. NQP, as an emerging driver of economic growth, has attracted significant attention regarding its impact on CEI. Based on panel data from 251 Chinese cities spanning from 2010 to 2021, this paper evaluates the level of NQP in each city. Employing a panel data two-way fixed-effects model, it empirically analyzes the influence and mechanisms of NQP on CEI and delves into how this impact manifests in different city samples. The aim is to thoroughly explore the influence and mechanisms of NQP on CEI and provide theoretical foundations and policy suggestions for cities to achieve green and low-carbon development.

The main conclusions are as follows: Firstly, NQP can significantly reduce CEI. Secondly, NQP can lower CEI by enhancing urban innovation levels and strengthening government environmental regulation intensity. Finally, compared with samples from eastern and central regions and resource-based cities, NQP has a stronger inhibitory effect on CEI in western regions and non-resource-based cities.

Environmental Protection, Environmental Conservation, Pollution, Energy Consumption, Emission Reduction, Pollutant Discharge, Ecology, Green, Low - Carbon, Air, Chemical Oxygen Demand, Sulfur Dioxide, Carbon Dioxide, PM10, PM2.5

FIGURE 2
Summary of environment-related vocabulary.

TABLE 6 The heterogeneity test results.

Variables	(1)	(2)	(3)	(4)
NQP	-0.7403^{*}	-0.4426^{**}	-0.2724	-0.6447^{***}
	(0.3897)	(0.1790)	(0.2972)	(0.1821)
Constant	0.5256^{***}	0.3163^{***}	0.5816^{***}	0.1676^{***}
	(0.0656)	(0.0374)	(0.0500)	(0.0307)
Control	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	756	2,256	1,080	1932
R^2	0.899	0.829	0.851	0.868

Note: Standard errors in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

These findings are consistent with the conclusions of many scholars. They argue that technological innovation is usually significantly negatively correlated with CEI (Ali et al., 2023; Manigandan et al., 2023), and industrial structure upgrading can also reduce CEI (Cheng et al., 2018). NQP integrates the concepts of technological innovation, industrial upgrading, and green development. Essentially, it aligns with these key factors in reducing CEI. By stimulating the vitality of technological innovation, promoting industrial upgrading, and guiding the development path towards green transformation through enhancing government environmental regulation intensity, it achieves effective suppression of CEI through synergistic effects at different levels. This further validates the rationality and reliability of the research results in this paper.

The research results of this paper have important policy implications in multiple aspects, especially for the policy practices of developing countries in promoting the coordinated development of economic growth and environmental protection. The research also reveals some potential challenges. Although NQP plays a positive role in reducing CEI, it may face problems such as insufficient technological innovation and inadequate policy implementation during the actual promotion and application process. Meanwhile, different regions and cities vary in resource endowments and industrial structures. How to give full play to the role of NQP according to local conditions is a problem that needs to be further addressed. Therefore, this paper puts forward the following policy suggestions:

First, the discovery that NQP can significantly reduce CEI indicates that it is not only an important driving force for urban economic growth but also a crucial pathway to achieve environmental sustainability. In the context of increasingly fierce global competition, Chinese cities should fully recognize the importance of NQP and increase investment and cultivation efforts. The government should introduce relevant policies to encourage enterprises to strengthen technological innovation, enhance industrial added value, and guide NQP towards the green and low-carbon sector, so as to achieve a win-win situation of economic and environmental benefits. For developing countries, in the process of pursuing economic growth, they can learn from China's experience, attach importance to the development of NQP, and regard it as a key strategy to achieve sustainable development goals. Second, the mechanism by which NQP reduces CEI by enhancing urban innovation levels and government environmental regulation intensity suggests that while promoting the development of NQP, we should focus on improving urban innovation capabilities and strengthening government environmental regulation. On the one hand, the government should increase investment in technological innovation, encourage enterprises, universities, and research institutions to carry out industry-university-research cooperation, and promote the continuous emergence of NQP. On the other hand, the government should improve environmental regulations, strengthen environmental supervision, and raise the cost of illegal activities, thereby forcing enterprises to transform and upgrade and reduce carbon emissions. At the same time, the government should also use NQP to improve environmental governance efficiency, such as employing big data, artificial intelligence, and other technological means to monitor environmental conditions and achieve precise pollution control. China's current environmental regulations are in the process of continuous improvement, but there are still some challenges in implementation and supervision. In the future, the refinement and operability of regulations can be further strengthened, and the efficiency and transparency of supervision can be improved. Third, the results of the heterogeneity analysis show that the inhibitory effect of NQP on CEI is stronger in western regions and non-resource-based cities. This requires the government to fully consider regional differences and city-type differences when formulating policies and implement differentiated policies. For western regions and non-resource-based cities, the government should provide more policy support and financial tilts, encourage them to take advantage of NQP, accelerate industrial structure adjustment and transformation and upgrading, and achieve green and low-carbon development. At the same time, the government should also strengthen inter-regional cooperation, promote the wider diffusion and application of NQP, and facilitate green and low-carbon development across the country.

In future research, we can make improvements from the following two aspects. On the one hand, we can further refine the classification of NQP, such as technological innovation, institutional innovation, and management innovation, and separately explore their influence mechanisms and differences on CEI. This will help to gain a deeper understanding of the relationship between NQP and CEI and provide more precise bases for policy formulation. On the other hand, we can expand the research sample to other countries or regions to verify the universality and particularity of the impact of NQP on CEI. Through cross-country or cross-regional comparisons, we can better understand the role of NQP under different institutional backgrounds and economic development levels and provide more universally applicable policy suggestions for global sustainable development.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.ceads.net.cn; http://www.stats.gov.cn.

Author contributions

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

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Conflict of interest

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

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