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The impact of public participatory environmental regulation on carbon emission intensity: a policy text analysis

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Carbon emissions have emerged as a critical global environmental challenge, with public participatory environmental regulation becoming an increasingly vital governance tool in promoting carbon reduction. This study employs panel data from 278 prefecture-level cities in China spanning 2011–2020 to construct a public participatory environmental regulation index through policy text analysis, empirically examining its impact mechanism on carbon emission intensity. The findings reveal that: (1) public participatory environmental regulation significantly reduces carbon emission intensity; specifically, baseline regression results indicate that a one-unit increase in public participatory environmental regulation intensity leads to a 0.05 unit decrease in carbon emission intensity, significant at the 1% level; (2) mediation analysis demonstrates that public environmental participation serves as a significant intermediary between environmental regulation and carbon emission reduction; (3) heterogeneity analysis indicates that official characteristics significantly moderate policy effectiveness, with regulations implemented by non-local, shorter-tenured, and less-educated officials showing stronger inhibitory effects on carbon emissions compared to their counterparts. These findings underscore the importance of strengthening public participation mechanisms in environmental governance and considering official characteristics in policy implementation. This study provides both theoretical foundations for optimizing public participatory environmental regulation policies and practical implications for enhancing carbon reduction effectiveness.

KEYWORDS

public participatory environmental regulation, environmental governance, carbon emission intensity, local official characteristics, policy text analysis

1 Introduction

Currently, global climate change has become a major challenge facing humanity, with reducing carbon emissions and achieving low-carbon development emerging as a common aspiration of the international community (Nakhli et al., 2022; Wang et al., 2023). As a key participant in global carbon reduction, China is actively assuming the responsibilities of a major nation, contributing Chinese wisdom and solutions to global climate governance. To this end, China has solemnly committed to the international community to strive to achieve carbon peaking before 2030 and carbon neutrality before 2060. Realizing this ambitious goal requires a deep understanding of the factors influencing carbon emissions and exploring effective governance pathways.

To address the challenge of carbon emissions, academia has conducted extensive and in-depth research on the characteristics and influencing factors of carbon emissions. Research shows that carbon emissions exhibit significant regional differences and industry-specific characteristics (Wang et al., 2023; Wang et al., 2022; Zhang et al., 2023). Regarding the influencing factors of carbon emissions, traditional research has primarily focused on industrial structure (Wang and Wang, 2021; You and Zhang, 2022), energy structure (Wu et al., 2021), and technological progress (Kou et al., 2022; Li et al., 2023). However, optimizing and adjusting these influencing factors requires effective policy guidance and institutional guarantees. Although China has established a carbon reduction system based primarily on command-and-control and market-based environmental regulations, this system still faces numerous problems such as high regulatory costs, severe information asymmetry, and low implementation efficiency, resulting in practical dilemmas of "government failure" and "market failure" (Diebecker and Sommer, 2017; Ge et al., 2020).

Public participatory environmental regulation, as a key component of the modern environmental governance system, breaks through the traditional single governance model of "government-led, passive corporate response." By activating social forces and strengthening public supervision, it forms a diversified governance pattern where government regulation, market incentives, and public participation work in synergy, providing a new governance pathway for carbon reduction (Chang et al., 2022; Chu et al., 2022). Existing research consistently demonstrates that this governance model has played a positive role in promoting technological innovation (Cao and Chen, 2024; Tang and Li, 2022), improving environmental governance effectiveness (Song and Majeed, 2023; Zhao and Cheng, 2024) and promoting carbon reduction (Guo et al., 2024; Tang and Li, 2022; Yang et al., 2024). Despite extensive research on the effectiveness of public participation in environmental management, significant limitations remain in measurement methods. Current research primarily adopts four types of indicators: (1) complaint-based data, such as measurements derived from the 12,369 environmental protection complaint system (Jiao Y et al., 2024; Zhou et al., 2024); (2) media attention metrics, utilizing media coverage frequency as a proxy for regulatory intensity (Wang and Jia, 2021; Zhang Y et al., 2022); (3) environmental NGO evaluations, employing indices such as the Pollution Information Transparency Index (PITI) or environmental reputation indices (Birkey et al., 2016; Cao and Chen, 2024); and (4) public subjective intention measures, constructing indicators through surveys on public environmental participation or environmental awareness (Jiao J et al., 2024; Triguero et al., 2016).

However, existing measurement methodologies exhibit several significant limitations. First, when governments guide public participation in environmental governance, they typically establish comprehensive institutional frameworks through multiple complementary policies, encompassing stakeholder identification, participation channels, procedural standards, and rights protection. Single indicators employed in existing research fail to capture this comprehensive policy framework. For instance, complaint data merely reflects public participation through petition channels, while media coverage only indicates the intensity of social supervision—neither fully represents the complete policy system of public participatory environmental regulation. Second, these indicators overemphasize outcome measurements of government-guided public participation while neglecting the policy essence of public participatory environmental regulation. Environmental petition data, media coverage, and public participation metrics primarily reflect participatory behavioral outcomes within the government-established institutional framework, failing to directly measure governmental policy efforts in institutional design, channel development, and procedural standardization. Third, outcome-oriented measurements (such as complaint quantities) potentially suffer from endogeneity issues. Changes in these indicators might stem from either strengthened governmental regulation or passive responses to deteriorating environmental conditions, making it difficult to establish clear causal relationships between environmental regulatory policies and governance outcomes. Fourth, indicators obtained through questionnaires or environmental organization evaluations are susceptible to sample selection bias and varying evaluation standards, raising concerns about reliability and comparability.

To address these methodological limitations, this study adopts a direct policy-text approach, systematically analyzing environmental policies from 278 prefecture-level cities in China from 2011 to 2020. Through policy text analysis, we measure public participatory environmental regulation intensity by evaluating both policy attribute strength and implementation intensity, empirically examining its carbon reduction effects. Furthermore, considering that public participatory environmental regulation aims to achieve environmental governance objectives by activating social supervision, we incorporate public environmental participation into our analytical framework, investigating how such regulation influences carbon emission intensity through public participation mechanisms. Additionally, as local government officials are primary agents in environmental policy formulation and implementation, their personal characteristics may influence policy tool selection and implementation effectiveness (Shi et al., 2020). Therefore, we examine the heterogeneous effects of official characteristics including age, origin, education level, and tenure to deepen understanding of policy implementation variations.

This study makes several distinctive contributions to the existing literature. First, to construct a comprehensive index for measuring public participatory environmental regulation intensity at the prefecture-level city level in China through policy text analysis. Second, to empirically examine the impact of public participatory environmental regulation on carbon emission intensity using panel data from Chinese cities. Third, to investigate the mediating role of public environmental participation in the relationship between public participatory environmental regulation and carbon emission intensity. Fourth, to analyze the heterogeneous effects of local official characteristics (age, origin, education level, and tenure) on the effectiveness of public participatory environmental regulation in reducing carbon emission intensity. Finally, based on the empirical findings, we aim to provide policy recommendations to optimize public participatory environmental regulation and enhance carbon reduction effectiveness.

2 Theoretical foundation and hypothesis development

2.1 Public participatory environmental regulation and carbon emission intensity

Public participatory environmental regulation, as a bottom-up governance instrument, primarily constrains corporate environmental behavior through environmental information disclosure, public supervision, environmental complaints, and whistleblower incentives, effectively addressing both "government failure" and "market failure" (Chu et al., 2022). This regulatory approach creates sustained social pressure by expanding public discourse rights and supervisory powers in environmental governance.

On the institutional side, governmental design expands public participation space by activating public attention to social issues. A distinctive feature of public participatory environmental regulation is its comprehensive information disclosure system, including mandatory corporate environmental information disclosure and key polluter information publicity mechanisms, which substantially reduce public costs in accessing environmental information (Li et al., 2021; Zhang H et al., 2022). Additionally, diversified supervision channels, such as the "12,369″environmental protection hotline and online reporting platforms, provide convenient institutionalized pathways for public participation in environmental governance (Jiao Y et al., 2024; Zhou et al., 2024). This transparent institutional design enhances both public right to information and the timeliness and effectiveness of environmental supervision.

On the social mobilization side, activated social forces generate effective constraints on enterprises (Almeida et al., 2018; Liao, 2018). Another key feature is the multi-tiered social supervision system. Environmental organizations provide technical support through professional monitoring and data analysis (Cao and Chen, 2024; Li et al., 2018); media outlets amplify environmental issues through public opinion supervision (Zhang Y et al., 2022); and the public exerts direct pressure through complaints and reports (Jiao Y et al., 2024; Zhou et al., 2024). This multi-stakeholder collaborative supervision significantly enhances the professionalism and influence of social oversight.

Furthermore, multi-stakeholder collaborative participation facilitates the development of effective environmental governance mechanisms (Chu et al., 2022). Public participatory environmental regulation effectively integrates government supervision with social oversight (Hensengerth and Lu, 2019). The government enhances participatory effectiveness by promptly responding to public complaints and strictly investigating environmental violations. Enterprises, under social supervision pressure, increase their environmental governance investments, while continued public attention drives stronger regulatory oversight. This virtuous interaction mechanism among government guidance, enterprise response, and public participation creates sustained pressure for emission reduction.

As public participation mechanisms continue to mature, the political opportunity structure in environmental governance continuously optimizes. Governments persistently improve information disclosure systems, broaden participation channels, and strengthen reporting incentives, providing enhanced institutional guarantees for public participation. The growing professional capabilities of environmental organizations and expanding media supervision coverage increase the effectiveness of public participation. Enterprises increasingly recognize the importance of proactively addressing public environmental demands, incorporating emission reduction targets into their development strategies.

Based on political opportunity structure theory, public participatory environmental regulation exerts significant inhibitory effects on corporate carbon emissions through comprehensive information disclosure systems, multi-tiered social supervision mechanisms, and collaborative governance between government and society. Therefore, we propose the following hypothesis:

H1. Public participatory environmental regulation is negatively associated with carbon emission intensity.

2.2 Public participatory environmental regulation and public environmental participation

As a bottom-up governance mechanism, public participatory environmental regulation not only provides institutional safeguards for public participation but also enhances public participation capacity and motivation through multiple channels.

Primarily, public participatory environmental regulation establishes diversified participation channels, reducing institutional barriers to public engagement (Zhou et al., 2024). Through the establishment of environmental information disclosure platforms, environmental protection hotlines, and online complaint systems, convenient participation pathways are provided for diverse social groups. The implementation of mandatory environmental information disclosure systems significantly enhances information accessibility, enabling timely public access to corporate environmental behavior information. The establishment of rapid response mechanisms for environmental complaints and whistleblower reward systems further enhances participation convenience and incentivization (Leng et al., 2022). This institutionalized participation mechanism not only reduces participation costs but also strengthens public confidence in engagement.

Furthermore, public participatory environmental regulation promotes environmental awareness and participation capacity among the public. Governments enhance public environmental cognition through environmental education initiatives, dissemination of environmental knowledge, and organization of environmental protection activities. Environmental organizations strengthen public monitoring capabilities through professional training and technical support (Wang et al., 2020; Zhao et al., 2022), while media outlets enhance public environmental risk awareness through environmental news coverage and case studies (Zhang Y et al., 2022). This sustained capacity building not only expands the scope of participating groups but also elevates the professionalism of participation.

Additionally, public participatory environmental regulation establishes effective feedback mechanisms, enhancing public

participation satisfaction. Governments demonstrate tangible participation outcomes through prompt handling of environmental complaints, public disclosure of investigation results, and reporting of rectification measures (Li et al., 2022). Enterprises strengthen public participation confidence through responding to public demands, improving environmental behavior, and proactive information disclosure (Zhang G et al., 2019). Environmental organizations and media reinforce the social impact of public participation by tracking and reporting environmental problem resolution processes (Zhang J et al., 2019). This virtuous feedback mechanism helps the public recognize the value of their participation, stimulating sustained engagement motivation.

In summary, public participatory environmental regulation significantly promotes public environmental participation through institutional innovation, capacity building, and feedback mechanism optimization. The combination of diversified participation channels, continuous capacity enhancement, and effective feedback mechanisms jointly drives public environmental participation toward higher levels of development. This deepening participation further strengthens the governance effectiveness of public participatory environmental regulation. Therefore, we propose the following hypothesis:

H2. Public participatory environmental regulation is positively associated with public environmental participation.

2.3 Public environmental participation and carbon emission intensity

Public environmental participation inhibits corporate carbon emissions through multiple mechanisms. As a crucial social supervision force, it not only directly constrains corporate environmental behavior but also indirectly promotes emission reduction by activating institutional effectiveness. This bottom-up environmental governance model generates sustained social pressure for emission reduction.

On the direct supervision front, public environmental participation constrains high-carbon emission behaviors through environmental complaints, media exposure, and online monitoring, promptly detecting and exposing corporate environmental violations (Jiao Y et al., 2024; Wang and Jia, 2021; Zhang Y et al., 2022; Zhou et al., 2024). This social supervision pressure directly impacts corporate reputation, exposing enterprises to risks of brand image damage and market share decline. Previous research indicates that enterprises must address stakeholder demands to maintain their social image and market position (Barić, 2017; Vos, 2003). Consequently, under public supervision pressure, enterprises proactively adopt emission reduction measures. Additionally, professional monitoring and data analysis conducted by environmental organizations (Cao and Chen, 2024) enhance both public supervision accuracy of corporate environmental behavior and provide decision-making references for government environmental governance improvement.

On the institutional activation front, public environmental participation indirectly promotes corporate emission reduction. Sustained public attention and complaint reporting compel governments to strengthen environmental law enforcement, improving regulatory implementation efficiency (Zhou et al., 2024). Media's continuous coverage intensifies social attention to environmental issues, driving stronger governmental governance measures (Wang and Jia, 2021; Zhang Y et al., 2022). This bottom-up supervision pressure enhances both the targeting and deterrence of environmental governance.

Furthermore, public environmental participation influences corporate behavior through green consumption and social evaluation. Research indicates that enhanced environmental awareness drives consumers toward green product choices (Hidalgo-Crespo et al., 2022; Testa et al., 2021), compelling corporate transformation through market mechanisms. Public attention to corporate environmental reputation affects financing costs and market access, motivating enterprises to prioritize environmental governance investments (Hussainey and Salama, 2010). Environmental organizations' corporate performance evaluations directly impact corporate reputation, promoting proactive environmental responsibility (Birkey et al., 2016). This combined effect of market constraints and social evaluation creates sustained pressure for emission reduction.

In conclusion, public environmental participation significantly inhibits corporate carbon emissions through direct supervision constraints, institutional effectiveness activation, and market reputation influence mechanisms. This multi-dimensional social supervision pressure drives enterprises to continuously improve environmental behavior and achieve emission reduction targets. Therefore, we propose the following hypothesis:

H3. Public environmental participation is negatively associated with carbon emission intensity.

2.4 The mediating role of public environmental participation

Based on political opportunity structure theory, public participatory environmental regulation inhibits corporate carbon emissions by stimulating public environmental participation. This mediating effect demonstrates how environmental regulation achieves emission reduction targets through activating social supervision forces, with public environmental participation serving as a crucial bridge connecting institutional supply with emission reduction outcomes.

First, public participatory environmental regulation provides the institutional foundation for public environmental participation. As a bottom-up governance tool, it reduces institutional barriers to public participation through establishing diversified participation channels, including environmental information disclosure platforms, environmental protection hotlines, and online complaint systems. The implementation of mandatory environmental information disclosure systems enhances information accessibility, while rapid response mechanisms for environmental complaints and whistleblower reward systems strengthen participation incentives. This institutionalized

participation mechanism not only provides convenient participation pathways but also enhances public participation capacity through professional training and technical support. The government's timely handling of environmental complaints and feedback further strengthens public participation confidence and sense of achievement.

Second, public environmental participation inhibits corporate carbon emissions through multiple mechanisms:1. Direct Supervision Mechanism: The public promptly identifies and constrains high-carbon emission behaviors through environmental complaints, media exposure, and online monitoring. Environmental organizations enhance supervision precision through professional monitoring and data analysis.2. Institutional Activation Mechanism: Sustained public attention and complaint reporting compel governments to strengthen environmental law enforcement, improving regulatory implementation efficiency. Policy recommendations from environmental organizations and continuous media coverage drive governmental improvements in environmental governance.3. Market Constraint Mechanism: The public generates market pressure for corporate emission reduction through green consumption choices and social reputation evaluation.

In summary, public environmental participation plays a crucial mediating role between public participatory environmental regulation and corporate carbon emissions. Public participatory environmental regulation stimulates public participation through institutional innovation, while public participation drives corporate emission reduction through multiple mechanisms, ultimately achieving environmental regulatory governance objectives. Therefore, we propose the following hypothesis:

H4. Public environmental participation mediates the relationship between public participatory environmental regulation and carbon emission intensity.

3 Research design

3.1 Sample and data sources

This study selects 2011–2020 as the research period. The year 2011 marks the first year of China's "12th Five-Year Plan" implementation, during which carbon emission intensity reduction was formally incorporated as a binding target, signaling the systematic advancement of market-based environmental regulation policies. Choosing 2011 as the starting year allows for a comprehensive observation of the entire process of market-based policy instruments from their inception to gradual refinement. Additionally, 2020 holds special significance for environmental regulation research. In this year, China made its "dual carbon" commitment to the international community, marking a new development stage for market-based environmental regulations. Simultaneously, 2020 concluded the "13th Five-Year Plan," by which time the effects of various policies had become evident and the data relatively complete.

This study examines prefecture-level cities in mainland China, using the 293 prefecture-level cities officially designated in the 2020 National Administrative Division of Cities as the baseline sample. To ensure sample consistency, we exclude cities that were elevated to prefecture-level status after 2011. Additionally, we eliminate samples with severe data deficiencies, such as Lhasa and Sansha, resulting in a final analysis sample of 278 prefecture-level cities. Data on public participatory environmental regulations are primarily sourced from official government documents and reports. Data on official characteristics are collected from authoritative online sources including Xinhua News Agency, People's Daily Online, and Baidu Encyclopedia, with mayoral appointment dates primarily verified through contemporary political news when specific dates are not explicitly stated. Additional data are obtained from the China City Statistical Yearbook, municipal statistical yearbooks, and municipal economic and social development statistical bulletins.

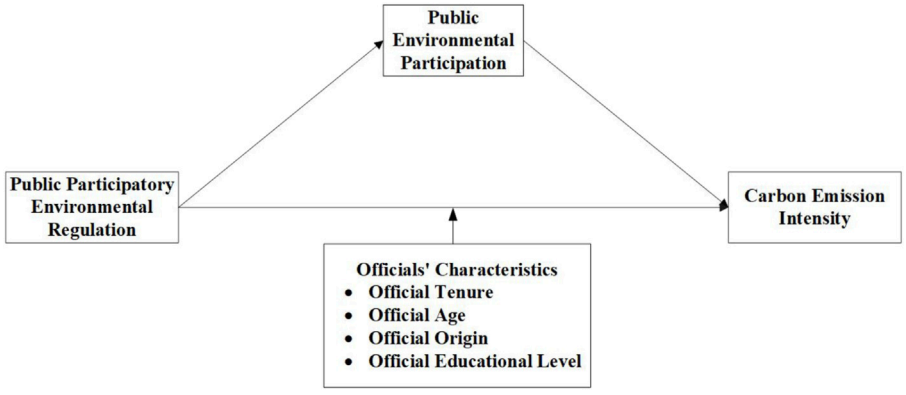

FIGURE 1
Research framework mechanism diagram.

3.2 Variable selection and measurement

(1) Carbon Emission Intensity (CI)

Following established literature that utilizes carbon emission intensity as a key indicator for assessing carbon reduction performance (Cheng et al., 2018; Li et al., 2024; Wang et al., 2016)), we measure carbon emission intensity as the ratio of carbon emissions to GDP. This metric effectively reflects the carbon emissions generated per unit of economic output, providing a standardized and comparable measure across regions and over time. To calculate total carbon emissions, based on the Intergovernmental Panel on Climate Change (IPCC, 2006) guidelines and considering data availability in China, we consider eight primary energy sources known to be significant contributors to carbon emissions: coal, fuel oil, crude oil, coke, kerosene, gasoline, diesel, and natural gas. These energy sources represent the major fossil fuels consumed in China and are comprehensively covered in official energy statistics, ensuring data reliability and accuracy for carbon emission calculations. The calculation formula is Equation 1:

$$CO_2 = \sum_{i=1}^{n} CO_{2,i} = \sum_{i=1}^{n} E_i \times NCV_i \times CEF_i \times COF_i \times \frac{44}{12} \quad (1)$$

(2) Public Participatory Environmental Regulation (public)

This study employs policy text analysis to measure public participatory environmental regulation intensity. We adopt this approach because policy text analysis allows us to directly capture the essence of government-led public participation initiatives by focusing on the policy design itself, rather than relying solely on outcome-based measures which may be influenced by various confounding factors and suffer from endogeneity issues. By analyzing policy documents, we can systematically quantify the government's efforts in establishing institutional frameworks, participation channels, and procedural standards for public involvement in environmental governance. The specific measurement steps are as follows, ensuring a robust and valid methodology for quantifying this complex policy construct:

Step 1: Policy Text Collection. We selected 2011–2020 as the study period, which represents a critical phase in China's advancement of ecological civilization and establishment of modern environmental governance systems, accumulating rich practical experience in carbon emission control policies. Based on high-frequency word statistics and expert opinions, we identified 26 key carbon reduction terms, including "low-carbon," "carbon peak," "carbon neutrality," "carbon reduction," "decarbonization," "carbon dioxide," "carbon source," and "carbon sink." Finally, we retrieved 4,465 policy documents of various types including "opinions," "notices," "decisions," and "plans."

Step 2: Public Participatory Environmental Policy Screening. Public participatory environmental regulation refers to a regulatory approach where governments, through institutional design and policy arrangements, establish standardized participation channels and procedures to guide and safeguard public participation in environmental decision-making and supervision through various forms such as environmental petitions, information disclosure, public hearings, and environmental assessment notifications, thereby achieving environmental governance objectives (Zhou et al., 2024; Chu et al., 2022). Based on these core elements and through in-depth discussions with environmental policy experts, we systematically screened and identified policy texts exhibiting characteristics of public participatory environmental regulation.

Step 3: Content Analysis Unit Determination. Considering both research objectives and operational feasibility, we defined the analysis units as specific regulatory provisions within policy texts. Through systematic review of 4,465 policy documents, we constructed a three-tier coding system ("document number-chapter-specific provision") based on regulatory tool frequency and relevance.

Step 4: Policy Attribute Strength Assessment. Based on the legal effectiveness of policy texts, combined with administrative levels and document types, we established a five-level scoring system: local regulations (ordinances, provisions) - 5 points; government rules (regulations, measures, detailed rules) - 4 points; government administrative documents (schemes, plans, methods) - 3 points; government guidance documents (opinions, notices) - 2 points; departmental rules (opinions, notices) - 1 point.

Step 5: Policy Implementation Strength Assessment. We constructed quantitative criteria encompassing dimensions such as action plan support, indicator constraints, and responsibility assessment specificity to evaluate carbon reduction policy implementation strength.

Step 6: Data Processing. The data processing was conducted in three steps. First, we calculated the policy formulation intensity for each environmental policy text based on policy attribute strength; second, we computed the implementation supervision intensity for all prefecture-level cities annually according to environmental target responsibility and assessment evaluation systems; third, after obtaining these two sets of data, we used Equation 2 to calculate annual values of public participatory environmental regulation intensity for 278 prefecture-level cities during 2011–2020, generating panel data of public participatory environmental regulation intensity for each prefecture-level city over the years.

$$TEP_{ij} = \sum PEA_{ij}{}^{*}P_{ij}\, i \in [2011, 2020] \quad (2)$$

Where i represents the year, N denotes the number of policies issued in year i, and j indicates the *j*th policy issued in year i. P_{ij} represents the policy attribute strength of provision j. PEA_{ij} represents the policy strength of environmental target responsibility system and assessment evaluation system in year i. Thus, TEP_{ij} can represent the public participatory environmental policy intensity in year i. In practice, an environmental policy continues to influence carbon dioxide emissions as long as it has not been abolished by the government. Therefore, the effectiveness of environmental policies in reality is not merely exerted by policies

introduced in the current year but is cumulative of all effective environmental policies up to a certain point. Hence, when measuring, we must also consider the stock of environmental policies, making appropriate adjustments based on policy validity periods, modifications, and abolitions.

(3) Public Environmental Participation (index): This variable reflects public attention to and participation in environmental issues, measured by the "average daily search frequency of 'carbon emissions' in Baidu Index."
(4) Control Variables.

Economic Growth (growth): Represented by "regional GDP growth rate" to control for the scale effect of economic activity on carbon emissions. Higher economic growth typically implies increased industrial production and consumption activities, which, without effective environmental regulations, can lead to higher carbon emissions. Therefore, controlling for economic growth allows us to isolate the specific impact of public participatory environmental regulation beyond the general effect of economic expansion.

Population Density (lnpop): Expressed as the" logarithm of total population per unit area," considering the potential impact of population concentration on environmental quality and carbon emissions. Densely populated areas often experience higher resource consumption, waste generation, and environmental pressure, potentially leading to increased carbon emission intensity. Controlling for population density helps to account for the variations in carbon emissions attributable to population distribution.

Foreign Direct Investment (lnfdi): Quantified by the "logarithm of actual utilized foreign direct investment," as FDI may influence environmental conditions through technology transfer and other mechanisms. The impact of FDI on carbon emissions is complex and debated, with possibilities of both "pollution haven" effects (relocating polluting industries to regions with lax regulations) and "pollution halo" effects (introducing cleaner technologies and management practices). Including FDI as a control variable allows us to account for these potential influences on carbon emission intensity.

Human Capital (hum): Measured by the "ratio of higher education students to total regional population," as human capital levels may affect environmental policy implementation and green technology innovation. Regions with higher human capital are likely to have a more skilled workforce capable of adopting and innovating cleaner technologies, as well as a more environmentally conscious public that can effectively participate in environmental governance. Controlling for human capital helps to isolate the impact of public participatory regulation from the influence of human capital advantages.

Industrial Structure (str): Represented by the "ratio of secondary industry value-added to GDP," as different industrial structures contribute differently to energy consumption and environmental pollution. Secondary industries, particularly heavy industries, are generally more energy-intensive and contribute more significantly to carbon emissions compared to tertiary industries. Controlling for industrial structure accounts for the heterogeneity in carbon emission intensity arising from varying economic structures across regions.

During indicator calculation, GDP, foreign direct investment, and other indicators were adjusted using 2000 as the base year, with foreign direct investment converted to RMB using current exchange rates to ensure comparability across different years and control for inflation and exchange rate fluctuations. Table 1 is the variable measurement scale of this paper.

3.3 Model construction

Following existing research (Baron and Kenny, 1986), we develop a three-step approach to examine the impact of public participatory environmental regulation on carbon emission intensity and the mediating role of public participation:

Step 1: Estimate the impact of public participatory environmental regulation on carbon emission intensity using Equation (3). Here, $CI_{i,t}$ is the dependent variable representing carbon emission intensity; $public_{i,t}$ is the core explanatory variable representing public participatory environmental regulation; *Control* represents a series of control variables. The model controls for both city-specific fixed effects and time fixed effects.

$$CI_{i,t} = \alpha_0 + \alpha_1 public_{i,t} + \sum Control + \sum PROVINCE + \sum YEAR + \varepsilon_{i,t} \quad (3)$$

TABLE 1 Variable measurement.

Variable	Acronym	Variable measurement
Carbon Emission Intensity	CI	Total Carbon Emissions/GDP
Public Participatory Environmental Regulation	public	Text-based measurement from policy documents
Public Environmental Participation	index	Average Daily Search Frequency of "Carbon Emissions" in Baidu Index
Regional Economic Growth	growth	Regional GDP growth rate
Foreign Direct Investment	lnfdi	Logarithm of actual utilized foreign direct investment amount
Population Density	lnpop	Logarithm of total population per unit area
Human Capital	hum	Ratio of higher education students to total regional population
Industrial Structure	str	Ratio of secondary industry value-added to GDP

Step 2: Estimate the impact of public participatory environmental regulation on public environmental participation using Equation 4. Here, $index_{i,t}$ is the dependent variable representing public environmental participation; $public_{i,t}$ is the core explanatory variable representing public participatory environmental regulation. Control variables remain consistent with Equation 3, and the model controls for both city-specific fixed effects and time fixed effects.

$$index_{i,t} = \alpha_0 + \alpha_1 public_{i,t} + \sum Control + \sum PROVINCE + \sum YEAR + \varepsilon_{i,t} \quad (4)$$

Step 3: Estimate the mediating effect of public environmental participation using Equation 5. Here, $CI_{i,t}$ is the dependent variable representing carbon emission intensity; $public_{i,t}$ and its quadratic term are core explanatory variables; $index_{i,t}$ represents the mediating variable for public environmental participation. Control variables remain consistent with Equation 3, and the model controls for both city-specific fixed effects and time fixed effects.

$$CI_{i,t} = \alpha_0 + \alpha_1 public_{i,t} + \alpha_2 index_{i,t} + \sum Control + \sum PROVINCE + \sum YEAR + \varepsilon_{i,t} \quad (5)$$

4 Empirical analysis

4.1 Descriptive statistics

The above figure displays the spatial distribution of carbon emission intensity at the prefecture-city level in China, generated using ArcGIS software. Based on Figure 2, we observe significant temporal and spatial heterogeneity in carbon emission intensity patterns. From a temporal perspective, high-intensity regions are primarily concentrated in central China, with their scope gradually diminishing, reflecting carbon reduction achievements in heavy industrial areas. Low-intensity regions maintain relative stability in western and eastern coastal areas, indicating either inherently cleaner industrial structures or successful industrial transformation in these regions. Medium-intensity regions show slight expansion in eastern areas, revealing potential impacts of industrial transfer.

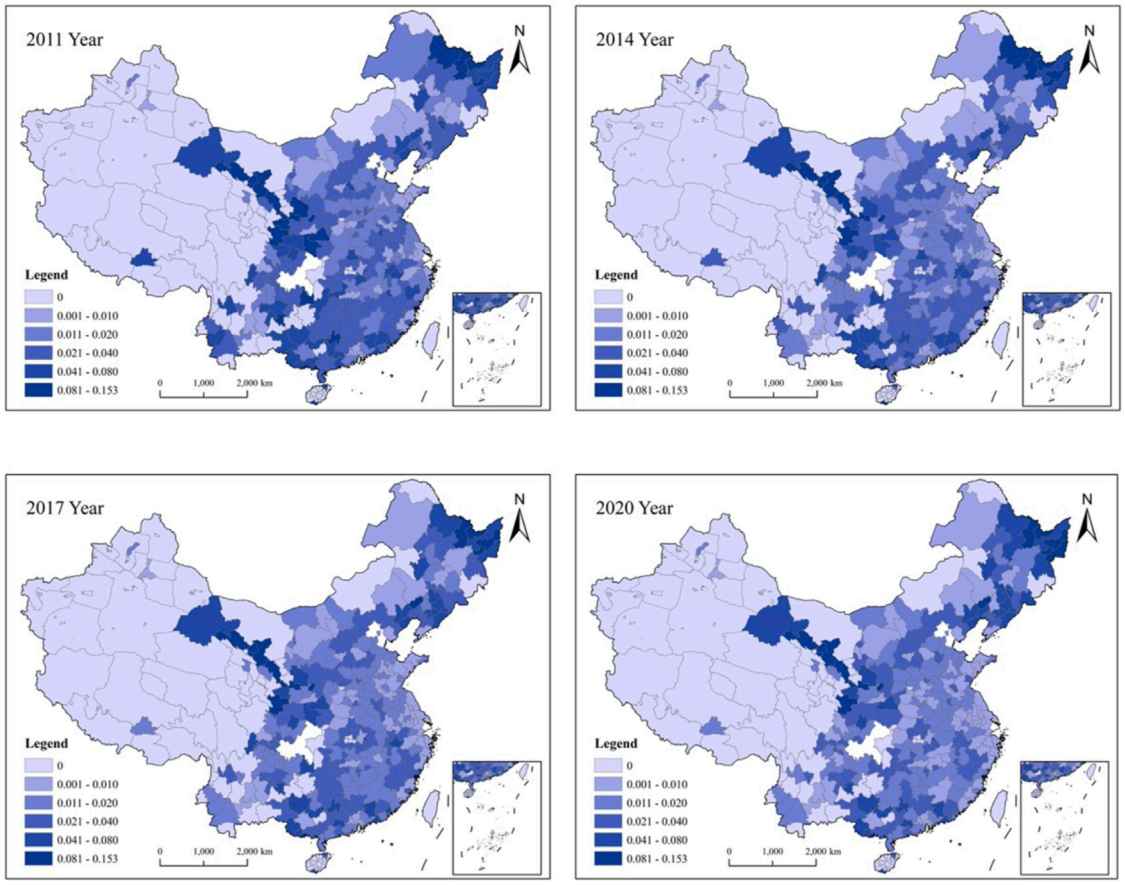

FIGURE 2
Spatial distribution of carbon emission intensity in China's prefecture-level cities.

From a spatial distribution perspective, a distinct "three-zone" pattern emerges: The eastern coastal zone predominantly features low carbon emission intensity, benefiting from advanced industrial structures and technological levels; the central transition zone shows concentrated high-intensity areas, primarily due to heavy industry concentration and coal-dominated energy structures; the vast western zone generally maintains low intensity, closely related to its relatively lower industrialization level. The evolution trend from 2011 to 2020 indicates gradually narrowing regional disparities in carbon emission intensity, with high-intensity areas becoming more spatially concentrated and low-intensity areas expanding. This transformation trend aligns with China's strategic goals of carbon peak and carbon neutrality.

Table 2 presents descriptive statistics for all variables, including means, standard deviations, minimum and maximum values. The carbon emission intensity (CI) shows a mean value of 0.028, indicating relatively low carbon emissions per unit of economic output. Its standard deviation of 0.027 suggests modest variation across cities and years, while the range from 0.002 to 0.153 highlights significant regional and temporal differences in emission intensity. Public participatory environmental regulation (public) exhibits a mean value of 2.055 which is relatively low compared to its maximum value of 4.344. The standard deviation of 0.840 indicates moderate variation in public participation levels across regions, with values ranging from 0 (no participation) to 4.344 (high participation). Public environmental participation (index) demonstrates a mean value of 0.914, suggesting relatively low average public attention to and engagement in environmental issues. The standard deviation of 0.864 reveals considerable variation in public participation behavior, ranging from 0 (no participation) to 3.840 (high participation).

TABLE 2 Descriptive statistical analysis of main variables.

	Count	Mean	sd	min	max
CI	2780	0.028	0.027	0.002	0.153
public	2780	2.055	0.840	0.000	4.344
index	2780	0.914	0.864	0.000	3.840
pop	2780	5.721	0.911	2.864	7.200
growth	2780	10.720	0.553	9.455	12.052
fdi	2780	0.016	0.016	0.000	0.070
str	2780	0.878	0.076	0.618	0.995
hum	2780	0.019	0.025	0.001	0.120

4.2 Baseline regression

Table 3 presents detailed results of public participatory environmental regulation's impact on carbon emission intensity, providing a foundation for in-depth analysis. A careful interpretation of the data yields the following findings:

Column (1) demonstrates that public participatory environmental regulation exerts a significant linear inhibitory effect on carbon emission intensity. The regression coefficient of −0.004 is significant at the 1% level, indicating that increased public participation significantly reduces carbon emission intensity. This result validates Hypothesis 1, confirming that public participatory environmental regulation serves as an effective carbon reduction tool by enhancing public environmental awareness and participation to promote low-carbon development.

TABLE 3 Impact of public participatory environmental regulation on carbon emission intensity.

	(1)	(2)	(3)
	CI	index	CI
public	−0.004***	1.242***	−0.025***
	(0.001)	(0.105)	(0.005)
index			−0.007***
			(0.001)
pop	−0.001	0.269***	−0.008***
	(0.001)	(0.011)	(0.001)
growth	−0.022***	0.478***	−0.007***
	(0.001)	(0.028)	(0.001)
fdi	−0.009	−0.680	−0.079***
	(0.011)	(0.649)	(0.028)
str	−0.025***	−0.248	−0.044***
	(0.006)	(0.192)	(0.008)
hum	0.025	16.433***	0.127***
	(0.018)	(0.436)	(0.023)
_cons	0.288***	−5.959***	0.199***
	(0.008)	(0.232)	(0.011)
N	2780	2780	2780
Adj-R^2	0.973	0.678	0.393

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

Column (2) reveals the impact of public participatory environmental regulation on public environmental participation. The regression coefficient of 1.242 is significant at the 1% level, clearly demonstrating that public participatory environmental regulation significantly promotes public environmental participation. This finding confirms Hypothesis 2, which posits a significant positive relationship between public participatory environmental regulation and public environmental participation.

Column (3) presents regression results incorporating public participatory environmental regulation, public environmental participation, and carbon emission intensity. Public environmental participation shows a regression coefficient of −0.007 on carbon emission intensity, significant at the 1% level. Simultaneously, public participatory environmental regulation maintains a coefficient of −0.025 on carbon emission intensity, also significant at the 1% level. These results further demonstrate that public environmental participation plays a crucial mediating role in how public participatory environmental

regulation influences carbon emission intensity. In other words, public participatory environmental regulation affects carbon emission intensity both directly and indirectly through promoting public environmental participation. This finding validates Hypothesis 4, confirming the mediating effect of public environmental participation.

4.3 Robustness tests

4.3.1 Excluding 2020 data to control for pandemic impact

Table 4 presents detailed robustness test results of the mediating effect of public environmental participation after excluding specific years' data. The results demonstrate that public environmental participation maintains its significant positive mediating role in the relationship between public participatory environmental regulation and carbon emission intensity, even after excluding data from special periods.

4.3.2 Excluding sub-provincial cities

To ensure model robustness, we conducted a data screening by excluding sub-provincial cities. Considering that sub-provincial cities possess certain advantages over other cities in terms of administrative level, economic development, innovation factor concentration, and innovation capacity, these differences might introduce bias when analyzing the overall data, potentially affecting the accuracy and universal applicability of our conclusions. Therefore, we excluded these cities' data to more accurately capture and assess development patterns in other Chinese cities and regions. After excluding sub-provincial cities, regression analysis results shown in Table 5 remain largely consistent with our previous findings. This confirms our model's robustness even after excluding these special cities, and demonstrates that our conclusions and hypotheses are generally applicable across different city types.

4.3.3 Alternative dependent variable

To further ensure result robustness and reliability, we employed *per capita* carbon emission intensity as an alternative measure for carbon emission intensity. This substitution of the dependent variable represents a common robustness testing approach, aimed at examining the stability of research conclusions under different measurement criteria. The results presented in Table 6 remain fundamentally consistent with our previous analysis.

TABLE 4 Results excluding 2020 data.

	(1)	(2)	(3)
	CI	index	CI
public	−0.004***	1.291***	−0.023***
	(0.001)	(0.110)	(0.005)
index			−0.008***
			(0.001)
pop	−0.002	0.268***	−0.008***
	(0.001)	(0.012)	(0.001)
growth	−0.022***	0.483***	−0.007***
	(0.001)	(0.029)	(0.001)
fdi	−0.004	−0.657	−0.079***
	(0.013)	(0.691)	(0.030)
str	−0.020***	−0.422**	−0.044***
	(0.006)	(0.202)	(0.009)
hum	0.029	16.294***	0.131***
	(0.020)	(0.457)	(0.025)
_cons	0.298***	−5.865***	0.200***
	(0.010)	(0.239)	(0.012)
N	2502	2502	2502
Adj-R^2	0.974	0.677	0.386

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

TABLE 5 Results excluding sub-provincial cities.

	(1)	(2)	(3)
	CI	index	CI
public	−0.004***	1.241***	−0.023***
	(0.001)	(0.103)	(0.005)
index			−0.008***
			(0.001)
pop	−0.001	0.253***	−0.009***
	(0.001)	(0.011)	(0.001)
growth	−0.022***	0.425***	−0.008***
	(0.001)	(0.028)	(0.001)
fdi	−0.009	−0.234	−0.066**
	(0.012)	(0.644)	(0.029)
str	−0.023***	−0.094	−0.042***
	(0.006)	(0.189)	(0.008)
hum	0.025	16.620***	0.137***
	(0.019)	(0.440)	(0.024)
_cons	0.290***	−5.449***	0.207***
	(0.008)	(0.231)	(0.011)
N	2660	2660	2660
Adj-R^2	0.973	0.666	0.392

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

TABLE 6 Results with alternative dependent variable.

	(1)	(2)	(3)
	CI	index	CI
public	−0.001**	1.242***	−0.006***
	(0.000)	(0.105)	(0.001)
index			−0.001***
			(0.000)
pop	−0.002***	0.269***	−0.003***
	(0.000)	(0.011)	(0.000)
growth	−0.004***	0.478***	−0.001***
	(0.000)	(0.028)	(0.000)
fdi	−0.000	−0.680	−0.015**
	(0.003)	(0.649)	(0.007)
str	−0.005***	−0.248	−0.013***
	(0.001)	(0.192)	(0.002)
hum	0.004	16.433***	0.022***
	(0.004)	(0.436)	(0.005)
_cons	0.070***	−5.959***	0.046***
	(0.002)	(0.232)	(0.003)
N	2780	2780	2780
Adj-R^2	0.975	0.678	0.422

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

4.4 Endogeneity analysis

When exploring the relationship between environmental regulation and carbon emission intensity, it is essential to address potential bidirectional causality. While environmental regulation theoretically aims to reduce carbon emission intensity through pollution control, changes in carbon emission intensity may conversely influence government environmental regulation strategies.

To address this endogeneity concern, we introduce instrumental variables (IVs) to avoid direct endogenous associations between environmental regulation and carbon emission intensity. Our IV selection is based on correlation with explanatory variables while maintaining independence from error terms. Specifically, we employ the average public participatory environmental regulation levels of other cities as instruments. Public participatory environmental regulation depends on public environmental awareness, participation willingness, and action capability. Other cities' participation levels influence the studied city's public attitudes and behaviors through information dissemination and social networks, thereby indirectly affecting its regulatory intensity. This social influence and demonstration effect establishes the correlation basis between instrumental and explanatory variables. Unlike direct environmental regulation, other cities' public participatory environmental regulation levels have no direct causal relationship with the studied city's carbon emission intensity, operating instead through socio-cultural and psychological mechanisms, thus satisfying exogeneity requirements.

To ensure IV validity, we employ the Anderson canonical correlation LM statistic for endogeneity testing. This test examines whether instruments correlate with explanatory variables while remaining independent of error terms. Significant LM statistics indicate effective instruments capable of addressing endogeneity concerns. Additionally, we conduct weak instrument tests using the Cragg-Donald Wald F statistic to verify instrument strength, specifically examining whether instruments sufficiently correlate with explanatory variables. Significant F statistics at the 5% level confirm instrument strength, ensuring IV estimation consistency and efficiency.

Through these methodological strategies, we successfully address the endogeneity between environmental regulation and carbon emission intensity, obtaining more accurate and reliable model estimates. The results maintain statistical significance and directional consistency with previous analyses, further validating our research hypotheses and conclusions.

In summary, the empirical analysis presented in this section robustly demonstrates the significant negative impact of public participatory environmental regulation on urban carbon emission intensity. This finding provides strong empirical support for Hypothesis H1 and underscores the effectiveness of public participatory environmental regulation as a tool for carbon reduction. Importantly, this section contributes theoretically by developing and validating a novel text-based index for measuring public participatory environmental regulation intensity. This index offers a more nuanced and direct measure of policy effort compared to outcome-based indicators, addressing a critical gap in existing literature and providing a valuable methodological contribution for future research in this domain. Table 7 is the result of the endogeneity test of this article.

5 Official characteristic heterogeneity

Under China's decentralized system, environmental regulation policy implementation largely depends on the balance between economic and environmental considerations, and local government officials' governance philosophy—specifically, how they interpret and implement the concept that "lucid waters and lush mountains are invaluable assets." Within the decentralized administrative system, local officials often control substantial fiscal and economic resources, wielding significant administrative power to intervene in market resource allocation and make relatively independent economic decision (Shi et al., 2020). Variations in officials' educational background, professional experience, and economic development philosophy may lead to differences in environmental regulation policy formulation and implementation, thereby affecting carbon emissions (Shi et al., 2020). Therefore, to examine whether individual characteristics of different officials influence the relationship between various types of environmental regulation (command-and-control, market-incentive, and public participatory) and carbon emissions, this study analyzes four official characteristics: tenure, education level, age, and origin.

TABLE 7 Endogeneity test results.

	CI
public	−0.028***
	(0.006)
pop	−0.010***
	(0.000)
growth	−0.011***
	(0.001)
fdi	−0.077***
	(0.028)
str	−0.042***
	(0.008)
hum	0.003
	(0.019)
_cons	0.248***
	(0.010)
idstat	1485.976
widstat	3174.005
N	2780

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

TABLE 8 Heterogeneity test based on official age.

	(1)	(2)
	age = 1	age = 0
public	−0.002	−0.003
	(0.002)	(0.003)
pop	−0.000	0.001
	(0.001)	(0.003)
growth	−0.024***	−0.018***
	(0.001)	(0.002)
fdi	−0.003	−0.026
	(0.014)	(0.022)
str	−0.025***	−0.033**
	(0.007)	(0.015)
hum	0.056**	−0.054
	(0.022)	(0.035)
_cons	0.305***	0.246***
	(0.009)	(0.026)
N	2160	620
Adj-R^2	0.346	0.970

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

5.1 Official age

Previous research indicates that prefecture-level city party secretaries and mayors experience significantly decreased promotion probability and increased likelihood of secondary positions once they exceed 54 years of age (Ji et al., 2014). To examine the influence of different age groups, we categorize officials based on whether their age is greater than or equal to 54 years. The dummy variable 'age' is assigned a value of 1 for officials younger than 54 years and 0 otherwise, examining the impact of environmental regulation on carbon emissions.

Based on empirical results shown in columns (1) and (2) of Table 8, public participatory environmental regulation shows no significant impact on carbon emissions regardless of official age. This may be attributed to several factors: First, the effectiveness of public participatory environmental regulation largely depends on public environmental awareness and participation capacity. Under China's current policy environment, public participation depth and breadth may not have reached the critical threshold necessary to significantly impact carbon emissions. This condition persists regardless of official characteristics like age, as public participation effectiveness depends more on overall social environment and institutional design. Second, the contradiction between information asymmetry and policy complexity is a crucial factor. Carbon emission control involves complex technical and economic issues, and the public may lack sufficient expertise for effective decision-making participation. This information asymmetry may limit actual public participation effectiveness, preventing significant impact on carbon emissions. Regardless of official age, this gap between professional knowledge and public cognition likely persists, affecting policy effectiveness. Additionally, the integration level between public participation mechanisms and traditional governance models warrants attention. China's environmental governance has traditionally followed a top-down model, and introducing public participatory policies may face institutional inertia. These institutional transformation challenges may not significantly vary with official age as they involve systemic adjustments rather than individual decision-making differences. Policy implementation time lag is also an important consideration. Public participatory policies may require extended periods to cultivate public awareness and participation capacity before substantively affecting carbon emissions. Finally, the synergistic effects between public participation and other types of environmental regulation policies might explain this phenomenon. Public participatory policies might primarily function in raising environmental awareness and promoting information transparency rather than directly affecting carbon emissions. This indirect effect may require combination with other environmental regulation types (market-incentive or command-and-control) to significantly impact carbon emissions. The complexity of such synergistic effects may make it difficult to observe significant impacts when

examining public participatory policies alone, and this situation would not change with differences in official age.

5.2 Official origin

Since the 1990s, the central government has established a series of cadre exchange systems, significantly impacting talent team building and urban development. Local officials from different origins exhibit varied personal experiences that may influence the relationship between environmental regulation and carbon emissions. The central government's official exchange system has had a prominent influence on talent development and urban growth. To further verify the influence of official origin, we conduct group tests based on whether officials are local, with the dummy variable 'source' assigned a value of 1 for local officials and 0 otherwise.

According to columns (1) and (2) in Table 9, when officials are locally promoted, public participatory environmental regulation shows no significant impact on carbon emissions. However, when officials are from other regions, such regulation significantly reduces the city's carbon emission intensity. This may be attributed to several factors: locally promoted officials might have deeper connections with existing interest groups, potentially facing greater resistance or tending to maintain the *status quo* when promoting public participation. In contrast, non-local officials may be more inclined to break through existing interest patterns and more actively promote public participation mechanisms. Non-local officials might bring new governance concepts and experiences, helping break local inherent decision-making patterns and more effectively promoting public participatory environmental policy implementation. Furthermore, non-local officials may focus more on establishing achievements, thus being more willing to try innovative governance approaches, including deepening public participation. The effectiveness of public participatory policies largely depends on information transparency and diversification. Non-local officials might be more inclined to break information barriers and promote multi-stakeholder participation, thereby improving policy targeting and effectiveness. Meanwhile, non-local officials may face greater political pressure and performance evaluation, potentially motivating them to more actively seek public support and participation to achieve better environmental governance outcomes. While locally promoted officials might better understand local conditions, this familiarity could lead to reduced sensitivity to existing problems. In contrast, non-local officials might bring new perspectives, more easily identifying and addressing long-overlooked environmental issues. The effectiveness of public participation mechanisms also depends on public enthusiasm and capability. The arrival of non-local officials might inspire greater public participation enthusiasm as they may be viewed as reform promoters. Additionally, different regions' public participation experiences and models might be cross-regionally transmitted through non-local official transfers, promoting best practices dissemination. However, this finding also raises further research questions, such as how to maintain policy continuity while fully leveraging the advantages of officials from different origins, and how to design more effective public participation mechanisms that can function positively under officials with different backgrounds.

TABLE 9 Heterogeneity test based on official origin.

	(1)	(2)
	source = 1	source = 0
public	−0.001	−0.005***
	(0.002)	(0.002)
pop	−0.001	−0.002*
	(0.001)	(0.001)
growth	−0.019***	−0.021***
	(0.001)	(0.001)
fdi	0.070***	−0.024*
	(0.024)	(0.014)
str	0.001	−0.043***
	(0.008)	(0.008)
hum	0.048*	0.026
	(0.026)	(0.028)
_cons	0.231***	0.301***
	(0.015)	(0.011)
N	1177	1603
Adj-R^2	0.970	0.970

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

5.3 Official education level

Education level typically reflects an individual's formal education attainment, indicating psychological quality at work and knowledge accumulation in problem-solving (Hambrick and Mason, 1984). Although officials at all levels have shown significant improvement in educational attainment since China's reform and opening up, considerable differences in education levels still exist among officials. To further analyze the impact of officials' education level on the relationship between environmental regulation and carbon emissions, we conduct group tests using master's degree as the threshold. The dummy variable 'education' is assigned a value of 1 for officials with master's degrees or above, and 0 otherwise.

According to columns (1) and (2) in Table 10, when officials have higher education levels, public participatory environmental regulation shows no significant impact on carbon emission intensity. However, when officials have lower education levels, such regulation actually reduces carbon emission intensity. Several factors may explain this phenomenon: First, from a policy cognition and implementation capability perspective, highly educated officials might tend to adopt more theoretical, technology-oriented policy implementation methods while relatively neglecting the substantive implications of public participation and local specificities. This "elitist" decision-making model may create a disconnect between policy implementation and public needs, weakening the actual

TABLE 10 Heterogeneity test based on official education level.

	(1)	(2)
	education = 1	education = 0
public	−0.002	−0.006**
	(0.001)	(0.003)
pop	−0.001	−0.004
	(0.001)	(0.004)
growth	−0.020***	−0.019***
	(0.001)	(0.002)
fdi	−0.004	−0.065**
	(0.013)	(0.032)
str	−0.034***	−0.037**
	(0.006)	(0.017)
hum	0.032	−0.004
	(0.020)	(0.056)
_cons	0.276***	0.280***
	(0.009)	(0.029)
N	2351	429
Adj-R^2	0.970	0.970

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

effectiveness of public participation. In contrast, officials with lower education levels might tend to adopt more practical and flexible implementation strategies, placing greater emphasis on absorbing and responding to public opinion, thereby more effectively mobilizing public participation in environmental governance. Second, from an institutional incentive and innovation motivation perspective, public participatory environmental regulation, as a new governance model, demands higher requirements for officials' communication, coordination abilities, and innovative thinking. Officials with lower education levels might more actively explore innovative policy implementation methods, including more effective integration of public opinion and local resource mobilization, due to greater promotion pressure and performance evaluation pressure, thereby achieving more significant carbon reduction results. In contrast, highly educated officials might overly rely on existing knowledge systems and experience patterns, finding it difficult to fully utilize the advantages and innovative potential of public participation when facing complex environmental governance issues. Furthermore, officials' risk attitudes and sense of responsibility may be key factors affecting policy implementation effectiveness. Officials with lower education levels might maintain more cautious and responsible attitudes toward new policy tools, paying more attention to details and practical effects during implementation, thereby promoting the effective operation of public participation mechanisms and achievement of carbon reduction goals. This prudent attitude may lead them to place greater emphasis on grassroots feedback and public demands, better balancing environmental protection and economic development relationships during policy implementation.

5.4 Official tenure

Tenure generally refers to the time period during which officials exercise formal power (Jiang and Li, 2021). In the context of "competition for growth," some scholars argue that newly appointed officials tend to adopt strategies that stimulate rapid economic growth in the short term, potentially adversely affecting the environment (Deng et al., 2019). However, other studies find that longer-tenured local officials are more likely to establish political connections with local enterprises and protect their polluting behaviors to maintain economic growth and stable tax sources (Li and Lu, 2021), thus hampering environmental governance efficiency. A third perspective suggests an inverted U-shaped relationship between official tenure and environmental governance, with officials' attention to environmental governance showing a trend of first decreasing, then increasing, and finally decreasing again during their tenure. Cao et al. found a U-shaped relationship between party secretary tenure and PM2.5 concentration (Cao et al., 2019); Zhang and Gao's research revealed a weak inverted U-shaped relationship between time constraints and economic growth, as provincial governors are more likely to adopt drastic measures to meet performance assessments when their terms are ending (Yu et al., 2019), sometimes at the expense of environmental protection.

According to columns (1) and (2) in Table 11, when officials' tenure is greater than or equal to 5 years, public participatory environmental regulation shows no significant impact on carbon emissions. However, when officials' tenure is less than 5 years, such regulation significantly reduces carbon emission intensity. This may be attributed to several factors: First, officials with shorter tenures face greater achievement pressure and innovation motivation, potentially leading them to adopt more open and active policy implementation methods, emphasizing public participation and rapidly mobilizing societal engagement in environmental governance. This approach may encourage enterprises to adopt clean production technologies more quickly while stimulating public awareness in monitoring high-emission behaviors, effectively reducing carbon emission intensity. In contrast, longer-tenured officials may develop relatively rigid governance patterns, with declining emphasis on public participation over time, potentially leading to gradual decrease in environmental protection enthusiasm among enterprises and the public. Second, from institutional incentive and policy innovation perspectives, shorter-tenured officials are more likely to experiment with new governance approaches, including broadly introducing public participation mechanisms, to achieve significant results within their limited terms. This innovation orientation may promote more effective enterprise-government-public collaboration models, accelerating low-carbon technology promotion and application. Longer-tenured officials might overly rely on existing management models and interest networks, lacking sufficient innovation motivation, potentially allowing high-emission enterprises' inertial behaviors to persist uncorrected.

TABLE 11 Heterogeneity test based on official tenure.

	(1)	(2)
	tenure = 1	tenure = 0
public	−0.005	−0.004***
	(0.005)	(0.001)
pop	0.012	−0.001
	(0.008)	(0.001)
growth	−0.014***	−0.021***
	(0.004)	(0.001)
fdi	0.092	−0.010
	(0.101)	(0.012)
str	0.032*	−0.031***
	(0.018)	(0.007)
hum	0.095	0.031
	(0.061)	(0.021)
_cons	0.083	0.289***
	(0.065)	(0.009)
N	299	2481
Adj-R^2	0.970	0.970

Standard errors in brackets.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

Furthermore, the evolution of relationships between officials and local interest groups is a key factor affecting carbon emissions. Shorter-tenured officials may not yet have formed close ties with local interest groups, making it easier to maintain neutral positions, objectively handle public feedback, and effectively promote carbon reduction. This relative independence may facilitate more equitable environmental policy implementation, avoiding inappropriate protection of high-emission enterprises. Conversely, longer-tenured officials may have established deep local relationship networks, potentially favoring vested interests in policy implementation, leading to excessive tolerance of high-emission enterprises. Notably, shorter-tenured officials focus more on short-term visible policy outcomes, aligning with public participatory environmental regulation characteristics, capable of improving policy transparency and public satisfaction in the short term. This short-term orientation may motivate officials to adopt more active measures, such as increasing penalties for high-emission enterprises and enhancing environmental protection incentive policies' attractiveness, achieving significant carbon reduction effects in a relatively short period.

The analysis of official characteristic heterogeneity reveals nuanced findings regarding the effectiveness of public participatory environmental regulation. Specifically, regulations implemented in regions governed by non-local, shorter-tenured, and less-educated officials exhibit a stronger inhibitory effect on carbon emissions. These results not only support Hypothesis H4, highlighting the complex interplay between official characteristics and policy effectiveness, but also contribute several key theoretical insights. First, this section provides empirical evidence supporting the mediating role of public environmental participation in the environmental regulation-carbon emission intensity nexus, further elucidating the policy transmission mechanisms at play. Second, the identification of heterogeneous effects based on official characteristics adds valuable nuance to the literature on policy implementation and local governance, suggesting that local leadership attributes significantly shape the effectiveness of environmental regulations. Finally, these findings contribute to the political opportunity structure theory by demonstrating its applicability in explaining the varying effectiveness of public participatory environmental regulation in China, where official characteristics can be viewed as shaping the political opportunity structure for policy implementation and public engagement.

6 Research conclusions and policy recommendations

6.1 Research conclusions

This paper examines the impact of public participation-based environmental regulation on carbon emission intensity and its underlying mechanisms, using panel data from 278 prefecture-level cities in China during 2011–2020 and constructing a public participation-based environmental regulation index through policy text analysis. The research yields the following major conclusions:

First, public participation-based environmental regulation significantly reduced carbon emission intensity. Through institutional arrangements such as environmental information disclosure platforms, environmental complaint systems, and public supervision channels, public participation-based regulation effectively constrained corporate environmental behavior, prompting companies to proactively control carbon emissions. This result validates the political opportunity structure theory, indicating that government-led public participation mechanisms can effectively complement "government failure" and "market failure," becoming an important governance tool for promoting carbon reduction.

Second, public environmental participation played a significant mediating role between public participation-based environmental regulation and carbon emission intensity. Public participation-based environmental regulation enhanced public environmental participation by lowering institutional barriers to participation, raising public environmental awareness and participation capabilities, and establishing effective feedback mechanisms. In turn, public environmental participation inhibited corporate carbon emissions through multiple mechanisms including direct supervision and constraints, institutional effectiveness activation, and market reputation impacts. This finding deepens the understanding of how public participation-based environmental regulation functions, revealing the important role of social forces in environmental governance.

Third, official characteristics significantly influenced the implementation effectiveness of public participation-based environmental regulation policies. The research found that officials who were appointed from other regions, had shorter

terms in office, or lower education levels showed more significant inhibitory effects on carbon emissions through public participation-based environmental regulation policies. This result reflects that within China's distinctive cadre management system, officials' individual characteristics may affect environmental regulation policy implementation through various pathways, including policy cognition, implementation capability, innovation motivation, and risk attitude.

6.2 Research contributions

First, this study innovatively constructs measurement indicators for public participation-based environmental regulation, expanding the theoretical boundaries of environmental regulation research. Working directly with environmental policy texts, this research systematically reviewed environmental policies issued by 278 prefecture-level cities in China from 2011 to 2020, innovatively constructing a public participation-based environmental regulation index that incorporates both policy attribute intensity and implementation strength. This method overcomes the limitations of existing research that relies on single indicators such as environmental complaint data, media reporting frequency, environmental organization evaluations, or subjective public intentions. It not only comprehensively reflects the policy system of public participation-based environmental regulation but also avoids potential endogeneity problems associated with results-oriented indicators. Based on this measurement indicator, the research systematically examines the impact of public participation-based environmental regulation on carbon emission intensity for the first time, expanding the research boundaries of environmental regulation theory, enriching theoretical understanding of environmental regulation classification and mechanisms, and providing empirical support for constructing a diversified co-governance environmental management system.

Second, this study reveals the mediating role of public environmental participation, establishing a transmission mechanism for how environmental regulation affects carbon emissions. The research clarifies the mediating mechanism of public environmental participation between public participation-based environmental regulation and carbon emission intensity, constructing a theoretical logic chain of "institutional supply-social response-environmental performance." Through empirical testing, the research finds that public participation-based environmental regulation promotes increased levels of public environmental participation by stimulating social supervision forces, lowering institutional participation barriers, and enhancing public environmental awareness and capabilities. In turn, public environmental participation significantly inhibits corporate carbon emissions through multiple mechanisms including direct supervision and constraints, institutional effectiveness activation, and market reputation impacts. This finding not only deepens understanding of the transmission mechanisms of public participation-based environmental regulation but also provides empirical support for multi-agent co-governance theory, revealing the important role of social forces in environmental governance. The research results show that public participation-based environmental regulation significantly reduces carbon emission intensity, and this effect is realized through the mediating role of public environmental participation, providing new empirical evidence for understanding the driving factors of carbon reduction in China.

Finally, this study introduces heterogeneity analysis of official characteristics, enriching theoretical explanations for differences in environmental policy implementation effectiveness. The research incorporates official characteristics into the environmental governance research framework, systematically examining how officials' age, origin, tenure, and educational background moderate the implementation effects of public participation-based environmental regulation policies. The research finds that officials who are appointed from other regions, have shorter terms in office, or lower education levels show more significant inhibitory effects on carbon emissions through public participation-based environmental regulation policies. This result challenges traditional expectations regarding highly educated officials with longer tenures, revealing that official characteristics affect environmental regulation policy implementation through various pathways, including policy cognition, implementation capability, innovation motivation, and risk attitude. This finding provides a new theoretical perspective for understanding the heterogeneity of environmental policy implementation, as well as new empirical evidence for official selection and environmental governance assessment, offering important implications for improving China's distinctive cadre management system and enhancing environmental regulation policy implementation effectiveness.

6.3 Policy recommendation

The empirical findings of this study offer significant practical implications for optimizing environmental governance and achieving carbon reduction targets, particularly within the context of China's ambitious "dual carbon" goals and global climate governance efforts. Based on our analysis, we propose the following policy recommendations:

(1) Optimize the Design and Implementation of Public Participatory Environmental Regulation Policies. Our research confirms the effectiveness of public participatory environmental regulation in reducing carbon emission intensity. Therefore, policymakers should prioritize the continued optimization and robust implementation of such policies. This entails enhancing policy system comprehensiveness by adopting comprehensive policy frameworks that encompass diverse participation channels, clear procedural standards, and robust rights protection mechanisms for public participants. Strengthening policy implementation and supervision requires ensuring effective execution through concrete action plans, measurable indicator constraints, and well-defined responsibility assessment systems at all levels of government. Additionally, policy design and implementation should be tailored to local contexts, considering regional variations in economic development, social conditions, and environmental challenges.
(2) Develop Strategies to Enhance Public Environmental Participation. The mediating role of public environmental participation underscores its importance in translating

environmental regulation into tangible carbon reduction outcomes. Policymakers should improve environmental information transparency by increasing the accessibility of environmental data, pollution sources, and policy details. Expanding public participation channels beyond traditional petition systems through online platforms, social media engagement, and community-based environmental initiatives will facilitate broader public involvement. Investing in public environmental education and awareness campaigns will enhance citizens' understanding of environmental issues, carbon reduction strategies, and their roles in environmental governance.

(3) Consider Official Characteristics in Cadre Management and Policy Implementation. Our findings on the heterogeneous effects of official characteristics suggest that local leadership attributes play a significant role in policy effectiveness. In regions where strong regulatory enforcement is needed, consider assigning officials with characteristics associated with higher regulatory effectiveness, such as non-local officials who may be less constrained by local vested interests. Providing targeted training programs for officials at all levels is particularly relevant for those with lower education levels. While shorter tenures may sometimes be associated with stronger regulatory effects, excessive turnover can disrupt policy continuity, making it crucial to balance fresh perspectives with policy stability.

(4) Contributing to China's "Dual Carbon" Goals and Global Climate Governance. By effectively implementing public participatory environmental regulation and adopting these policy recommendations, China can significantly accelerate its progress towards achieving its ambitious goals of peaking carbon emissions before 2030 and achieving carbon neutrality by 2060. China's experience in leveraging public participation for environmental governance can provide valuable insights for other countries seeking to enhance their climate action. Promoting public participation as a key element of environmental regulation globally can foster more inclusive, effective, and sustainable pathways towards a low-carbon future. By implementing these recommendations, governments can harness the power of public participation to strengthen environmental regulation, accelerate carbon reduction, and contribute to a more sustainable future.

7 Limitations and future research directions

While this study contributes valuable insights into the impact of public participatory environmental regulation on carbon emission intensity, it is important to acknowledge certain limitations that warrant consideration in future research.

First, the geographic scope of this study is limited to prefecture-level cities in mainland China. While focusing on China, a major carbon emitter, provides significant insights within this context, the generalizability of our findings to other regions or countries may be constrained due to differences in political systems, socio-economic contexts, and environmental governance structures. Second, our measurement of public environmental participation relies on the average daily search frequency of "carbon emissions" in Baidu Index as a proxy. While Baidu Index provides a readily available and dynamic measure of public attention, it may not fully capture the depth and breadth of actual public participation behaviors, such as offline activism or engagement through other platforms. Finally, the analysis period of this study concludes in 2020. While this period represents a crucial phase in China's environmental governance development, extending the analysis timeframe to include more recent years, as data becomes available, could provide further insights into the evolving dynamics of public participatory environmental regulation and its long-term impacts on carbon reduction.

To address these limitations and further advance research in this area, several directions for future research are suggested. Comparative studies across different countries or regions could investigate the generalizability of our findings and explore the contextual factors that shape the effectiveness of public participatory environmental regulation in diverse settings. Future research could also explore alternative measures of public environmental participation, such as integrating survey data, social media data, or data from environmental NGOs to provide a more comprehensive assessment of public engagement. Extending the analysis timeframe to investigate the longer-term impacts of public participatory environmental regulation and examining the dynamic effects over time would provide a more nuanced understanding of policy effectiveness. Finally, future studies could explore the synergistic effects of public participatory environmental regulation with other types of environmental regulation policies, such as command-and-control regulations or market-based instruments, to identify optimal policy mixes for maximizing carbon reduction and environmental governance outcomes.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

JW: Writing – review and editing. ZY: Writing – review and editing, Writing – original draft. RW: 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.

Generative AI statement

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2025.1534066/full#supplementary-material

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