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EDITED BY
Jill L. Tao,
Incheon National University, Republic of Korea

REVIEWED BY
Min Xu,
Chinese Academy of Fishery Sciences, China
Jinshui Liang,
Chinese Academy of Forestry, China

*CORRESPONDENCE
Yue Liu,
✉ liuyue0901@163.com
Yaodong Cang,
✉ 302826434@qq.com

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How to promote local governments collaboration? evidence from carbon reduction in the Yangtze River Delta

Yue Liu[1]* and Yaodong Cang[2]*

[1]College of Economics and Management, Nanjing Forestry University, Nanjing, China, [2]School of Economics and Management, Dalian University of Technology, Dalian, China

China's central government has proposed a "dual carbon" goal to promote carbon peaking in every province. Collaboration on carbon reduction among local governments is considered an efficient approach to address the carbon emission issues in China. In response, the YRD region implemented the collaborative mechanism and achieved success in carbon reduction. However, there are still some factors that limit the effectiveness of collaboration, such as inconsistencies in priority sectors and goals for carbon reduction. Therefore, comprehensively identifying the factors that influence collaboration would contribute to understanding the reasons for inefficient collaboration, and exploring the relationships among these factors could provide guidance on promoting collaboration. This study presents a structural model and an impact mechanism model for collaboration through grounded theory, cluster analysis and variation coefficient analysis. The results suggest that there are five factors that influence collaboration: Equitable allocation and pressure from monitoring are pressure factors, governance cost and collaborative benefit are state factors, and governance responsibility is the individual factor. The pressure factors could affect collaboration by affecting state factors, while individual factor plays a moderating role between state factors and collaboration. The research findings provide new insights for promoting collaboration on carbon reduction.

KEYWORDS

collaboration on carbon reduction, local governments, grounded theory, K-means cluster, variation coefficient analysis

1 Introduction

Since carbon emissions have contributed greatly to global warming, China's central government has set a "dual carbon" goal. This includes reaching the peak of carbon emissions nationally by approximately 2030, and achieving the peak in every province as well. As a result, local governments, as the responsible body for environmental governance, are under significant pressure to promote carbon reduction (Zhang and Guo, 2023).

To cope with governance pressures, the collaborative governance among local governments is put forward. It proposes that neighboring local governments should negotiate on policy-making and with the goal of reducing overall regional emissions. Chinese central government issued policies and regulations to encourage the collaboration on carbon reduction, and the local government also responded positively. For example, the Yangtze River Delta (YRD) region (including Zhejiang, Anhui, Jiangsu and Shanghai) established a collaborative meeting system to implement joint prevention and control of air pollution in 2013. In order to solve the increasingly serious environmental pollution, the YRD region established the Ecological Environmental Protection Collaboration Group in 2021 and the Implementation Plan for the Coordinated Control of Total Pollutant Quantities in 2023. This plan proposed that the three provinces and one city should share information on environmental monitoring, and jointly issue air quality forecasts for the YRD region.

In recent years, the YRD region has made progress in collaboration on carbon reduction. Due to collaboration on carbon reduction, the growth rate of carbon emissions in the YRD region has decreased to 4.89% in 2019, which is lower than the national average of 5.57%. However, the growth rate of carbon emissions in the YRD region varies among provinces. During the 13th Five Year Plan Stage (2015–2019), Shanghai's carbon emissions decreased by 1.23%, while Zhejiang's carbon emissions increased by 2.08%. However, Anhui and Jiangsu provinces have experienced significant increases in carbon emissions, with growth rates of 11.54% and 9.85% respectively, which are among the highest in the country. As both Anhui and Jiangsu are large carbon-emitting provinces, achieving the dual carbon goals would be a great challenge for them.

As a complex system, the collaboration among local governments could be influenced by various factors (Zheng, 2023; Wang H. et al., 2019), such as inconsistencies in priority sectors and goals for carbon reduction. These factors could limit the effectiveness of the collaboration on carbon reduction. For instance, the chemical fiber industry is identified as a priority sector for carbon reduction in Zhejiang Province, but not in Jiangsu Province. In addition, in their plans to achieve the dual carbon goal, Shanghai aims to increase the proportion of non-fossil energy to 20%, while Anhui only aims to increase it to 15.5%. These inconsistencies could motivate high-emission enterprises to relocate from regions with strict regulations to areas with looser regulations to avoid the treatment cost through cross-regional transfer (Tang et al., 2023). As a result, the overall effect of collaboration on carbon reductions has been weakened. Taking carbon emissions in the petroleum processing and coking industry as an example, it can be seen that from 2015–2019, Zhejiang and Shanghai experienced a decline of 40% and 28.1% respectively, while Anhui Province saw an increase of 21.6%.

However, the factors influencing collaboration remain unclear, which leads to an inadequate understanding of the causes of insufficient collaboration. Thus, comprehensively identifying the factors that influence collaboration would contribute to understanding the reasons for inefficient collaboration, and exploring the relationships among these factors could provide guidance on promoting efficient collaboration.

Based on the above background, the main research questions are put forward as follows: (1) What are the key factors influencing collaboration on carbon reduction? (2) What are the logical relationships among these factors? (3) What measures should be taken to mitigate the adverse impact of these factors? The remaining part of this paper, therefore, is structured as follows: Section 2 presents the relevant literature and existing research gaps; Section 3 outlines the methodology for identifying and screening factors, including the grounded theory, k-means analysis and variation coefficient analysis; Section 4 presents the result analysis, including key influencing factors and the theoretical model; Section 5 is the discussion; and Section 6 proposes the conclusions and implications.

2 Literature review

2.1 Research background

The YRD region established a collaborative meeting system to implement joint prevention and control of air pollution in 2013. The process of air pollution collaborative governance can be divided into three dimensions: decision-making dimension, coordination dimension and implementation dimension, as shown in Figure 1. The decision-making dimension will focus on the Symposium of the main leaders of three provinces and one city to consider and decide on the major issues of the coordinated control of air pollution in the YRD region. The coordination dimension is mainly a joint meeting between the executive vice governors and executive vice mayors of three provinces and one city, which further refined the above matters and negotiated and determined the phased collaborative governance objectives and requirements. The executive dimension is operated by the local governments through holding office meetings and signing agreements to promote the collaborative work of reducing pollution and carbon. These lays the foundation for intergovernmental collaborative carbon reduction. Therefore, the intergovernmental collaborative carbon reduction in the YRD region is an environmental governance system based on provincial government decision-making, deputy provincial government coordination and municipal government implementation.

2.2 Collaboration on environmental governance

Existing research has defined and measured the collaboration on environmental governance. Chang et al. (2022) believed that collaborative governance in China is a policy decision-making process, and the policy coordination was measured by the policy text of environmental regulation. To explore the effect of the Joint Prevention and Control System of Regional Air Pollution (JPCSRAP) in China, Zhou et al. (2022) introduced the degree of collaborative governance (DCG) to evaluate collaborative governance based on the synergy of air pollution emissions per unit of GDP. Considering economic social and environmental factors, Wang et al. (2020) constructed an evaluation index system for collaborative governance including economic development capacity, energy consumption and carbon capacity, carbon transfer capacity, technology and carbon sink capacity and industrial development capacity.

Furthermore, the effectiveness of collaboration on pollution reduction was examined. Ge et al. (2023) used panel data from 285 cities in China during 2003–2019 and a multi-period difference-in-differences (DID) method to assess the influence of regional collaborative governance on air pollution. The results showed that regional collaborative governance significantly reduces air pollution. Chang et al. (2022) investigated the effectiveness of collaborative

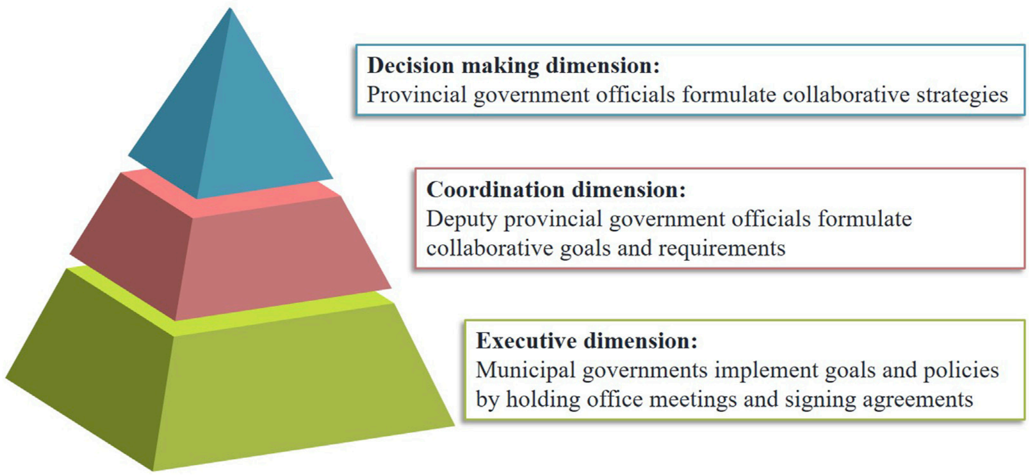

FIGURE 1
The process of air pollution collaborative governance in YRD region in 2013.

governance on haze pollution control by using panel data of 284 Chinese cities during 2008–2018. The results showed that collaborative governance has a positive effect on haze pollution reduction, in which government effort is indispensable. Wang and Zhao (2021) confirmed the causal relationship between collaborative environmental governance and air pollutant reduction by using the regression discontinuity design (RDD).

2.3 Identification of factors influencing collaboration on environmental governance

First, the existing studies have identified the factors that influence collaboration through quantitative analysis. McNaught (2024) present a quantitative systematic literature review of the core factors that enhance the collaborative governance for climate and disaster resilient development at the local level, and the results showed that consideration of diverse worldviews, a broad range of engagement approaches, and skilled facilitation by collaborative convenors are among the factors. Drawing on collaborative governance theory and literature on climate change adaptation, Dapilah et al. (2021) used multiple qualitative research methods to identify and explore collaborative adaptation governance (CAG) in Northern Ghana. Results indicated that there exist interwoven governance challenges, including questions of trust, commitment, transparency, accountability and the representation of diverse interests. Based on key informant interviews with policy actors in Eeyou Istchee, Che and Hickey (2021) suggested that challenges to collaborative environmental governance include the absence of essential supporting programs (land-use plans, regional environmental frameworks, lead monitoring agencies, designated funding), and high levels of distrust between proponents and NGOs.

Second, there were also studies examined the impact of factors using quantitative methods. Song et al. (2022) studied the impact of the heterogeneity difference between local governments on the quantum game system. The results showed that the heterogeneity difference does not change the equilibrium of the quantum game, and the combination of punishment mechanism and information disclosure mechanism has a controlling effect on free-riding behavior. Zheng (2023) adopted the differential game method to study the mechanism of collaborative governance of regional haze pollution. The results showed that the effort of local governments in the region to control haze is negatively correlated with their governance cost; the introduction of the supervision, assessment, and punishment (SAP) mechanism could make local governments more enthusiastic about haze control, and improve the synergistic benefits of haze control. Yu et al. (2024) employed time-varying difference-in-differences to estimate the incentive impact of China's cross-border horizontal ecological compensation policy on water pollution governance during 2006–2018. The results showed that in addition to promoting horizontal coordination between upstream and downstream regions, vertical central governmental inspections are crucial for effectively stimulating and guaranteeing horizontal collaborative governance between upstream and downstream local governments.

2.4 Summary

Previous studies have demonstrated the characteristics and effectiveness of collaboration. Based on the existing studies, this study defines the intergovernmental collaborative carbon reduction as the behavior process of carbon reduction governance among municipal governments, including policy formulation to implementation. However, there are still some research gaps that need to be addressed: (1) Although previous research has examined collaboration among various organizations, few have focused on collaboration among horizontal local governments. Given that local governments are key actors in regional carbon reduction, their collaboration would contribute to a more efficient carbon reduction. Therefore, this study aims to explore the collaboration among local governments to provide recommendations for further promoting carbon reduction. (2) Previous studies have analyzed the impact of certain influencing factors on collaboration. However, a comprehensive overview of impact mechanism among all the factors influencing collaboration on carbon reduction is still lacking. As there exist multiple factors influencing collaboration on carbon reduction, a comprehensive identification of their impact mechanism could lead to a more detailed understanding of the reasons for the inefficient collaboration on carbon reduction. Therefore, this study employed grounded theory to explore the impact mechanism among factors influencing collaboration on carbon reduction. (3) Previous research has explored the factors that impact collaboration using qualitative methods. However, there is a lack of quantitative screening of these factors. As a subjective research method, qualitative studies may result in issues of duplication and overlap among factors. To address this, this study employed K-means and cluster analysis to verify the plausibility of the factors identified.

3 Research design and data sources

3.1 Research method

3.1.1 The qualitative identification of influencing factors

Grounded theory is a qualitative research method, which could derive conclusion from research data via a bottom-up process so as to establish a theory (Yin et al., 2022). As the impacts on local government behavior could often be micro and processual, the focus of factor identification is therefore on how to extract factors from the collaboration processes. In this regard, grounded theory could provide comprehensive descriptions to clarify the "how" and "why" questions, illuminate the factors and uncover logical relationships among them. Therefore, grounded theory was used in this study to identify the factors that influencing collaboration on carbon reduction among local governments.

Therefore, this study mainly adopts procedural grounded theory, which constructs the theory of influencing factors of collaboration through three steps: open coding, axial coding and selective coding of text materials. During the process of data analysis, the theory is refined and revised by constantly comparing the summarized categories until theoretical saturation is reached (i.e., newly acquired data no longer contribute to the construction of the theory).

3.1.2 The quantitative screening of influencing factors

As a qualitative research method, grounded theory cannot address highly subjective issues, such as the lack of compartmentalization among factors. Therefore, a screening analysis of factors is necessary. It could not only contribute to identify key influencing factors, but also narrow the scope of the study.

To screen the factors more rationally, a combination of K-means clustering and coefficient of variation was employed. Specifically, K-means cluster analysis categorizes factors by comparing the similarity among factors. It was used to ensure that each factor in the same category represents a different of this category, thus avoiding the duplication of factors and maintaining the comprehensiveness of the factor set. The coefficient of variation measures the degree of dispersion among factors. The coefficient of variation (CV) is used to retain the factors with relatively consistent expert opinions and delete those with divergent opinions, thus avoiding duplication and redundancy of the factors and ensuring the representativeness of the factor set (Wang et al., 2021).

Specifically, the quantitative screening procedure for influencing factors in this study comprises the following steps: (1) Determining the optimal number of clusters for each corresponding category using the silhouette coefficient method; (2) Grouping corresponding categories according to the optimal cluster number, where corresponding categories within the same group are considered intrinsically homogeneous; (3) Screening corresponding categories within each group using the CV, eliminating those with relatively lower CV values. This quantitative screening process could ensure the identified influencing factors exhibit both scientific rigor and model parsimony.

3.1.2.1 Silhouette coefficient

Establishing a scientifically justified cluster count (K) is fundamental to ensuring stable classification outcomes in indicator clustering analysis. As an unsupervised learning technique, determining the optimal number of clusters in cluster analysis cannot rely on subjective judgment. Currently, the silhouette coefficient method represents a widely adopted approach for identifying optimal cluster numbers (Yun et al., 2024). For a given sample point i, it's silhouette coefficient SC_i is calculated as follows:

$$SC_i = \frac{b(i) - a(i)}{\max\{a(i), b(i)\}}$$
$$a(i) = \frac{1}{|W_i - 1|}\sum d(i,j), j \in W_i, i \neq j \quad (1)$$
$$b(i) = \min \frac{1}{|W_t|}\sum d(i,j), j \in W_t, t \neq i$$

where $a(i)$ represents the average distance from sample point i to all other points within its assigned cluster, quantifying the intra-cluster compactness. $b(i)$ indicates the smallest average distance from sample point i to points in any other cluster, measuring the inter-cluster separation. W_i denotes cluster assigned to sample i, $d(i, j)$ represents distance metric between samples i and j,

W_t denotes the arbitrary cluster different from W_i.

The overall silhouette coefficient S_i is computed as the mean SC_i across all samples, given by Equation 2

$$S = \frac{1}{U} SC_i \quad (2)$$

As shown in Equation 3, the S_i is mathematically bounded within [-1, 1]. To optimize clustering performance, the k-value corresponding to the peak silhouette coefficient is routinely designated as optimal number of clusters, serving as a statistically robust heuristic for determining partition efficacy.

$$S_i = \begin{cases} 1 - a(i)/b(i), a(i) < b(i) \\ 0, a(i) = b(i) \\ b(i)/a(i) - 1, a(i) > b(i) \end{cases} \quad (3)$$

3.1.2.2 K-means clustering

K-means clustering algorithm is named after the representation of each cluster using its mean (average). In this paper the K-means cluster analysis is implemented using SPSS software. The basic process is as follows (He et al., 2022):

(1) Select K points as the initial center of K clusters respectively; (2) Assign the remaining points to the initial K clusters based on the principle of the minimal Euclidean distances; (3) Recalculate the means of each cluster to obtain the new centroids that could represent this cluster. (4) Reassign each point to nearest cluster; (5) Repeat steps 3 and 4 until cluster membership stabilizes.

The optimal number K of clusters can be determined by the Silhouette index (SI), and the higher the SI values indicating more robust clustering (Khorshidi et al., 2021).

3.1.2.3 Coefficient of variation analysis

The basic process of coefficient of variation analysis is as follows, given by Equation 4:

$$cv_i = \frac{s_i}{\bar{x}_i} \tag{4}$$

where $\bar{x}_i$ is the overall average value, and s_i is standard deviation. The coefficient of variation (CV) quantifies the dispersion of expert assessments. Specifically, a higher CV value indicates greater volatility in importance ratings and more pronounced divergence among experts. Consequently, for indicators within the same peer cluster derived from clustering analysis, this study systematically eliminated corresponding categories exhibiting higher CV values.

3.2 Material

Based on the principle of triangular validation, the materials for qualitative identification were obtained from three sources: web news text, literature analysis and semi-structured interview. Relevant news was searched for on major Chinese news websites using the keywords "co-operation", "collaboration", and "carbon reduction". This study retrieved online news articles from comprehensive databases including the China Important Newspapers Database and Wisenews. The news were from 1 January 2012, to 31 December 2023, aligning with the inaugural policy milestone—the introduction of the Joint Prevention and Control Mechanism for Air Pollution in the Key Regions Air Pollution Prevention and Control Plan (12th Five-Year). Duplicate news was deleted after comparing the content, resulting in 628 web news being retained. With same key words, 60 literature in Chinese and 28 literature in English were retained. CNKI (China National Knowledge Infrastructure) Journal Database and ScienceDirect were chosen as the databases for literature searching.

Based on existing literature and web news, a semi-structured interview framework was developed. The statement of informed consent is attached to the interview. The experts can adjust the interview framework according to their own wishes. The formal interview framework mainly included "What are the current shortcomings of collaborative carbon reduction in the YRD region?" "What are the conflicts of interest among local governments in collaboration on carbon reduction?" "What characteristics and systems of local government do you think are conducive to promoting intergovernmental cooperation on carbon reduction?", etc. To guarantee the venerability, we selected local civil servants in the YRD region as the interviewees, and interviewed a total of 12 civil servants who work in environmental protection. The 12 experts selected in this study are civil servants from different departments, including the Bureau of ecological environment, the Bureau of planning and natural resources, the national development and Reform Commission, and Bureau of industry and information technology. All experts have worked for more than 12 years and have participated in intergovernmental collaborative carbon reduction. The specific information of each expert interviewed is shown in Table 1. The contents were converted into text after the interview. The interview corpus comprises approximately 30 thousand words of verbatim transcripts, constituting a methodologically adequate sample size for robust qualitative analysis (Di and Hu, 2020).

The materials for quantitative screening were obtained through expert scoring. Based on the prior studies (Fengrui et al., 2023), the panel of scoring experts was determined to comprise twenty-five individuals to align with established methodological benchmarks for reliability and validity. To ensure the significance of the expert scoring results, we invited five professors from different universities and 20 civil servants working in the field of environmental protection to score the following factors. A 7-point Likert scale questionnaire was used, and all 25 questionnaires were completed and returned. In the Likert 7 scale, 1 score is "strongly disagree" and 7 score is "strongly agree". Based on the influencing factors identified by online news texts, literature analysis and semi-structured interviews, we designed a questionnaire and invited experts to score the importance of each factor. The questionnaire is distributed through the online platform of "questionnaire star" and is answered anonymously. The statement of informed consent is attached to the questionnaire. Before the participants answer the questionnaire questions, we inform them that the results are only used for academic integrity analysis, do not involve personal privacy information and so on. The participants should answer the questionnaire after agreeing with the above statement.

4 Data analysis

4.1 The qualitative identification of influencing factors

4.1.1 Open coding

Open coding is the process of abstractly labeling original statements in the collected data, and assigning preliminary codes to these words and phrases. During this process, the codes are continuously compared until the content of the codes and the original concepts can be overlapped. 18 categories were discovered after multiple rounds of data comparisons and analysis. The examples of formation processes of these categories are as shown in Table 2.

4.1.2 Axial coding

Based on the open coding, axial coding aims to re-analyze the extracted corresponding categories, and attempts to reveal the internal logical relationships among these categories. The analysis shows that the 18 corresponding categories formed in open coding could be divided into five main categories, as shown in Table 3.

4.1.3 Integration of literature

To improve the accuracy and comprehensiveness of the factor identification, we organize and summarize the influencing factors

TABLE 1 Interview expert information.

NO.	Region	Department	Gender	Working years
1	Shanghai	Ecological environment bureau	Male	17
2	Shanghai	Planning and natural resources bureau	Female	13
3	Jiangsu	Development and reform commission	Male	15
4	Jiangsu	Bureau of industry and information technology	Male	18
5	Jiangsu	Planning and natural resources bureau	Male	19
6	Jiangsu	Ecological environment bureau	Female	17
7	Zhejiang	Ecological environment bureau	Female	12
8	Zhejiang	Development and reform commission	Male	15
9	Zhejiang	Planning and natural resources bureau	Female	14
10	Anhui	Bureau of industry and information technology	Female	16
11	Anhui	Development and reform commission	Male	13
12	Anhui	Rural revitalisation bureau	Female	17

TABLE 2 Examples of open coding analysis.

NO.	Categories	Original statements (initial concept)
1	Negotiation	Co-establishment of the Yangtze River Delta Regional Co-operation Office (co-operative organization)
		Focus on consultation and communication to improve the coordination function of the joint meeting (joint meeting)
2	Planning consistency	Jointly set industry emission standards (standards consistency)
		Strengthening the seamless integration of environmental protection planning in the YRD region (Convergence of planning)
3	Conflict resolution	Building consensus on green development (Building consensus)
		It is difficult to reconcile interregional interests and claims (Reconciliation of interests)
4	Resource sharing	Ensure smooth information sharing between regions (information sharing)
		Strengthening the exchange of pollution prevention and control technology and sharing the results of environmental protection scientific research (technological resources sharing)

proposed in the selected literature. It is found that, as shown in Table 4, the factors identified through open coding largely cover the factors proposed in the literature, with the addition of two new influencing factors: “trust and commitment” and “executive support”.

Equitable distribution, collaborative benefit, pressure from supervision, governance cost and governance responsibility constitute the set of influencing factors. Equitable distribution involves negotiation, planning consistency and conflict resolution. Collaborative benefit consists of resource sharing, compatibility, complementary advantage and imitation effect. Pressure from supervision includes superior government accountability, trust and commitment, regulation by superior government and social opinion supervision. Governance cost includes support from superior government, support from public, support from enterprises, incentive from superior government and carbon reduction capacity.

4.2 Quantitative selection of influencing factors

Based on the three data sources of network news text, literature analysis and semi-structured interview, this study combined with grounded theory to identify the influencing factors of intergovernmental collaborative carbon reduction. In order to further simplify these influencing factors and ensure the scientificity and conciseness of the research results, we further conduct quantitative screening on the factors through expert scoring to obtain the key influencing factors. The large amount of indicators could increase the complexity and cost of analysing the influencing factors, and qualitative identification methods could not address the correlation and overlap among indicators. Therefore, this study combines the K-means cluster and variation coefficient to screen the identified factors (Wang et al., 2021).

TABLE 3 Axial coding analysis.

Main categories	Corresponding categories	Connotation of categories
Equitable distribution	Negotiation	Decision-making and communication costs to reduce divergent interests
	Planning consistency	
	Conflict resolution	
Collaborative benefit	Resource sharing	Efficiency gains and cost reductions through collaboration
	Compatibility	
	Complementary	
	Imitation Effects	
Pressure from supervision	Superior government accountability	Oversight and constraints in the collaborative process
	Regulation by superior government	
	Contractual restraint	
	Social opinion supervision	
Governance cost	Support from superior government	Governance costs in the collaborative process
	Incentive from superior government	
	Carbon reduction capacity	
	Support from public	
	Support from enterprises	
Governance responsibility	Public satisfaction	Emphasis on Carbon Emission Reduction by Local Governments
	Environmental awareness	
	Carbon reduction effort	

4.2.1 Comprehensive factor screening based on K-Means cluster analysis

Factors in the same main category are clustered by cluster analysis and the optimal number of clusters is determined by the silhouette coefficient method. Taking the main category of “Equitable distribution” (A) as an example, since there are 4 corresponding categories, the number of groups K should meet $1 < k < 4$. We calculate the contour coefficients respectively when the number of groups is 2 and 3. The larger the contour coefficient, the more obvious the difference between groups, that is, the better the grouping effect. Since when $k = 3$ the silhouette coefficient is greater than that when $k = 2$, we divide the four subcategories (A_1-A_4) under Category A into three groups, as shown in Table 5, these factors are clustered into three categories, with “trust and commitment” (A_3) and “conflict resolution” (A_4) are clustered into the same category. In additional, a K-W (Kruskal–Wallis) test is conducted on the clustering results. If the sig value is greater than 0.05, it indicates that the clustering is reasonable.

4.2.2 Representative indicator screening based on variation coefficient analysis

The variation coefficient for each indicator is calculated by inputting the collected data into Equation 1. The variation coefficient reflects the degree of data dispersion, with a larger coefficient of variation indicating a greater the degree of dispersion. As the data source for this paper is the scores of the expert group, and the coefficient of variation reflects the difference in the level of importance of the indicators as perceived by the expert group, controversial indicators with large coefficients of variation should be removed, while indicators with smaller coefficients of variation and more uniform views among the expert group should be retained.

Taking the main category A as an example, its factors are clustered into three categories, A_3 and A_4 are both classified in category III. As the variation coefficient of A_3 is 0.315, larger than that of A_4, therefore A_3 is deleted.

The structural model for influencing factors of collaboration on carbon reduction is as shown in Figure 2.

4.3 Selective coding

In selective coding, the internal connections between the various main categories are explored, and based on this, the categories are connected within a storyline, then a systematic theoretical framework. As elaborated above, five main categories are collectively related to the collaboration on carbon reduction. In order to analyze internal linkages in a rational way, this study combines Pressure-State-Response (PSR) model for storyline grooming.

TABLE 4 Influencing factors from literature.

Main categories	Corresponding categories	Literature source (partial)
Equitable distribution	Negotiation (co-operative organization)	Moore (2021), Zhou and Hu (2023), Li and Jay (2023), Tian and Chen (2020), Luo et al. (2021), Liu et al. (2022)
	Conflict resolution (cost-benefit ratio)	
	Planning consistency (Target consistency) (joint decision-making)	
Collaborative benefit	Resource sharing (information disclosure and sharing)	Song et al. (2022), Yang and Wei (2023), Lv and Liu (2021), Xu et al. (2021), Yi et al. (2021)
	Compatibility	
	Complementary advantage	
	Imitation Effects	
Pressure from supervision	Superior government accountability	Zhang et al. (2023), Collins et al. (2020), Li et al. (2022), Yi et al. (2021), Armstrong (2023), Dapilah et al. (2021), Flye et al. (2023)
	Trust and commitment	
	Regulation by superior government	
	Social *opinion supervision* (Public environmental complaint)	
Governance cost	Support from superior government	Zheng (2023), Gou and Liu (2022), Cao et al. (2023), Ji et al. (2023), Rao and Zhao (2022)
	Support from public (Public participation and transparency)	
	Support from enterprises (Green technological innovation) (Social capital participation)	
	Incentive from superior government	
	Carbon reduction capacity (Fiscal cost)	
	Support from Superior government	
Governance responsibility	Environmental awareness	Chao and Xiaoya (2023), Liu et al. (2021), Li T. et al. (2023)
	Public satisfaction	
	Carbon reduction effort (form a policy combination)	
	Executive Support	

The PSR model was constructed by OECD, and it categories the internal mechanisms of subject's behavior into three parts: external pressures, state changes and behavioral actions taken (Chen et al., 2022). The framework has been extensively used in various research fields, including ecological safety assessment and disaster damage assessment, due to its ability to reveal the interactions of multiple factors. The PSR model categorizes external factors that cause damage or disruption to the system as pressure factors, while state factors characterize the resulting changes to the system. Response factors reflect the system's reaction to these changes. In this study, Equitable distribution (A) and pressure from supervision (B) are classified as pressure factors, collaborative benefit (C) and governance cost (D) as state factors, and the collaboration as response factors. In addition, governance responsibility (E) is categorized as individual factor. Table 6 illustrates the typical relationship among these factors in this study.

Through the continuous allocation of the categories, the storyline of "Theoretical Model of factors influencing collaboration on carbon reduction" can be summarized as follows: There are five factors have a significant impact on collaboration on carbon reduction. Pressure factors affect collaboration through the state factors, and the moderating factor (E) moderates the impacts of state factors (C, D) on collaboration. Based on this, this study constructs an impact framework as shown in Figure 3.

A saturation test was carried out on the withheld interview data and policy text. The categories were summarized into the model, and no new significant categories were formed[1].

1 The results indicated that the existing categories are already summarized comprehensively, with no significant categories missing. Two months after the initial coding, this study conducted a second coding of the above textual materials. The consistency between the two coding results was found to be 92%, which ensured the credibility of the coding results. In addition, five respondents were randomly selected for follow-up feedback, and no new critical views were raised. Thus, the categories and theoretical framework passed the saturation test and were deemed valid.

TABLE 5 Influencing factors from literature.

Main categories	Corresponding categories	Questionnaire source	Clustering result	Sig	Variation coefficient	Screening result
Equitable distribution (A)	Negotiation (A_1)	Shen and Fan (2015)	I	0.477	0.273	Retain
	Planning consistency (A_2)	Liu et al. (2023)	II		0.308	Retain
	Trust and commitment (A_3)	Yi et al. (2021)	III		0.315	Delete
	Conflict resolution (A_4)	Shakeri and Radfar (2017)	III		0.302	Retain
Pressure from supervision (B)	Accountability from superior government (B_1)	Pan and Wang (2020)	I	0.728	0.260	Retain
	Regulation by superior government (B_2)	Wang P. et al. (2019)	II		0.279	Retain
	Contractual restraint (B_3)	Fang et al. (2019)	II		0.301	Delete
	Public *opinion Supervision* (B_4)	Dai and Lu (2020)	III		0.299	Retain
Collaborative benefit (C)	Resource sharing (C_1)	Gao (2018)	II	0.599	0.273	Retain
	Compatibility (C_2)	Wu (2014)	I		0.258	Retain
	Complementary (C_3)	Li (2019)	III		0.255	Retain
	Imitation Effects (C_4)	Liu (2020)	III		0.282	Delete
Governance cost (D)	Support from superior government (D_1)	Yi et al. (2021)	IV	0.377	0.238	Retain
	Incentive from superior government (D_2)	Sun et al. (2014)	II		0.311	Retain
	Carbon reduction capacity (D_3)	Yi et al. (2021)	III		0.279	Retain
	Support from public (D_4)	Ge and Lin (2021)	I		0.335	Retain
	Support from enterprises (D_5)	Yi et al. (2021)	IV		0.315	Delete
Governance responsibility (E)	Public satisfaction (E_1)	Li Z. et al. (2023)	I	0.615	0.342	Retain
	Environmental awareness (E_2)	Peng and Wei (2015)	II		0.270	Retain
	Executive Support (E_3)	Ge and Lin (2021)	II		0.272	Delete

5 Explanation of theoretical impact model for collaboration on carbon reduction

The results of this study suggest that five factors are crucial for efficient collaboration on carbon reduction among local governments including equitable distribution, collaborative benefit, pressure from supervision, governance cost and governance responsibility. However, the impact mechanism of each factor on the collaboration is not consistent. The following section provides a detailed analysis.

5.1 Pressure factors

In this study, equitable distribution includes negotiation, planning consistency and conflict resolution. Collaboration on carbon reduction would face challenges related to conflicting decision-making. Open and transparent information sharing, as well as timely and barrier-free negotiation could improve the efficiency of collaboration among local governments. Therefore, negotiation could stimulate their enthusiasm for collaborative governance and promote the orderly promotion of collaborative carbon reduction (Luo et al., 2021; Flye et al., 2023). Planning consistency could build trust and then address transboundary conflicts (Li and Jay, 2023). Conflicts may arise among local governments. Some local governments have prioritized economic growth over environmental protection, leading to increased pollution. Strengthening planning consistency among local governments can help reduce such conflicts (Yao and Zheng, 2023). Regarding cross-border carbon reduction issues, local governments have different considerations and perceptions when choosing between overall and individual interests, and when balancing economic and environmental concerns. These differences could lead to conflicts of interest, resulting in delays in the governance of cross-border carbon reduction problems. If local governments in a transboundary ecosystem can establish a trustworthy social relationship, they can fulfil their commitments in ecological and environmental governance without prioritizing their own interests over those of others and the public environment. This would improve the efficiency of governance (Tian and Chen, 2020).

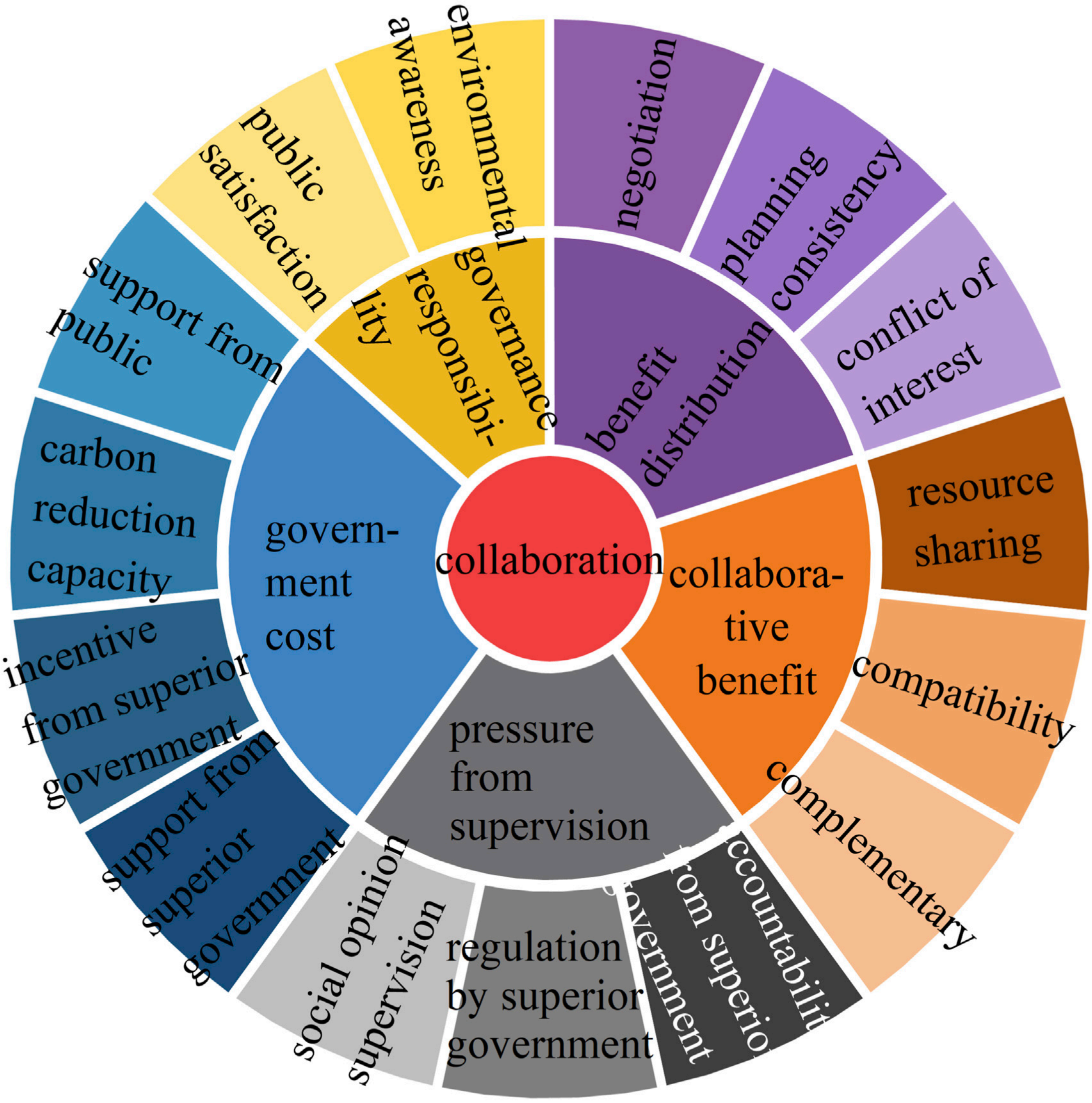

FIGURE 2
The structural model for the influencing factors of collaboration on carbon reduction.

TABLE 6 The typical relational structure of the main category.

Typical relationship structure	Connotation
Equitable distribution (A) → Collaboration	Equitable distribution is an important guarantee for the sustainability of the collaboration, which directly affects the collaboration on carbon reduction
Pressure from supervision (B) → Collaboration	Pressure from supervision is a constraint on collaboration, which directly affects the collaboration on carbon reduction
Collaborative benefit (C) → Collaboration	Collaborative benefit is an important motivation for the formation of collaboration, which directly affects the collaboration on carbon reduction
Governance cost (D) → Collaboration	Governance cost is an obstacle to the implementation of collaboration, which directly affects the collaboration on carbon reduction
Pressure (A-B) → State (C-D) → Collaboration	The pressure factors affect the collaboration through affecting state factors
Governance responsibility (E) ↓ State (C-D) → Collaboration	Governance responsibility moderates the impacts of state factors on collaboration on carbon reduction

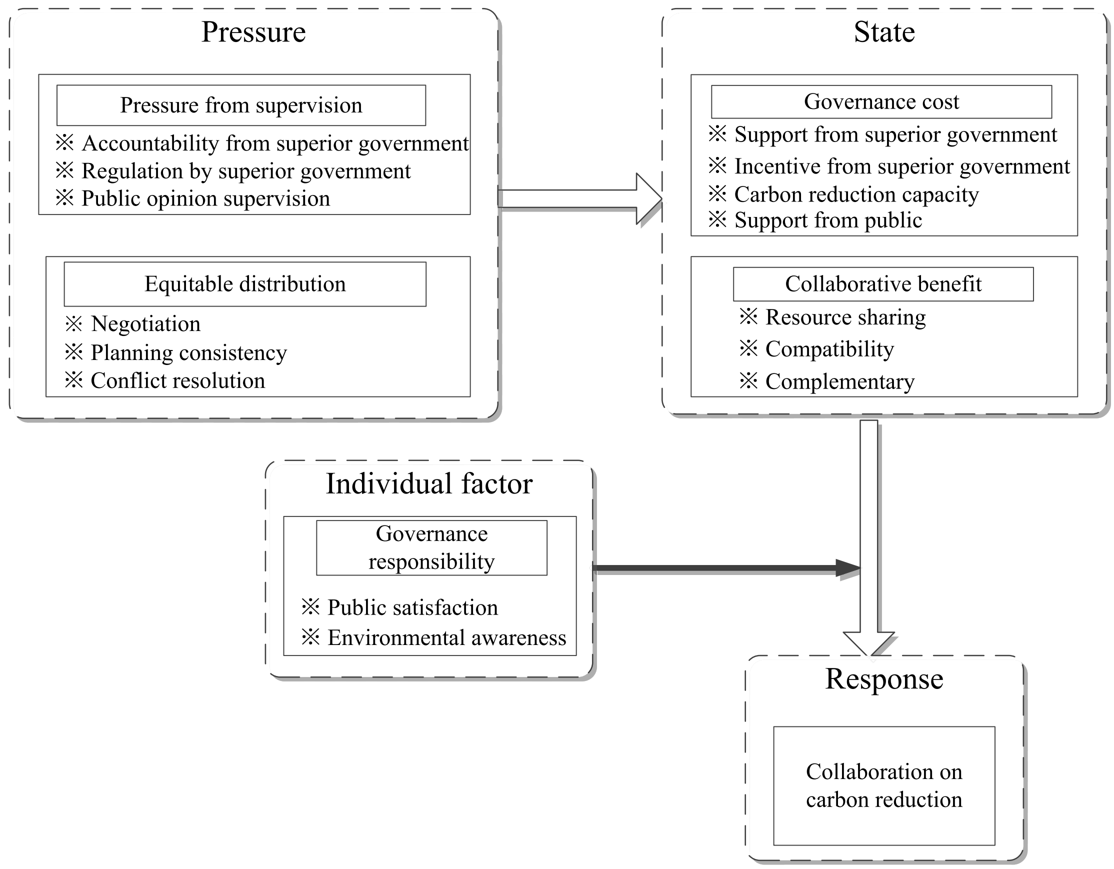

FIGURE 3
Impact model for collaboration on carbon reduction.

In this study, pressure from supervision includes accountability from superior government, regulation by superior government and public opinion supervision. Accountability from superior government, such as administrative penalties and performance evaluation, could directly influence local governments' decisions on carbon reduction (Zhang et al., 2023). At the same time, the central inspection could ensure the continuity of carbon reduction among local governments (Li T. et al., 2023). Regulation by superior government could set clear rules for collaboration, constrain the "free-riding" behavior and thus ensure the effectiveness of collaboration (Zhou and Hu, 2023). And the superior government should clarify the legal basis for intergovernmental collaboration and regulate the behavior of intergovernmental collaboration to reduce the transaction costs of collaboration (Wang and Wang, 2023). Although contractual restraint could constrain free-riding behavior, the dominant member could make the decisions taken more favorable to itself. As the promotion of superior government could play a complementary role (Rao and Zhao, 2022), especially when local governments lack the awareness and motivation to collaborate, regulation by superior government could facilitate the collaboration and thus cover the pressure from contractual restraint. As environmental challenges intensify, the public is increasingly inclined to take action to reduce carbon emissions, such as purchasing green products, advocating for the strict enforcement of environmental laws and regulations, and supervision on government. This aligns with (Wang et al., 2024), who found that active public participation significantly increased government commitment and capacity to formulate and implement environmental policies.

5.2 State factors

In this study, collaborative benefits include resource sharing, compatibility and complementary. Resource sharing, such as environmental information and technology, could help local governments adopt effective measures for carbon reduction (Song et al., 2022). Resource sharing could also provide local governments with more information about each other and reduce the risk of free-riding behavior, thereby increasing the cost of non-collaborative governance. Therefore, resource sharing could encourage local governments to collaborate. The similarity of environments among regions enables compatibility in governance, which in turn promotes collaboration. Compatibility enhances resources sharing among local governments, thereby increasing the likelihood of collaboration (Zhao and Xu, 2022). As responsibilities, powers, and resources differ among local governments, the transfer of funds, the location of enterprises, and technological transformations can lead to the joint development of urban agglomerations and promote collaboration

(Lv and Liu, 2021). Furthermore, if a local government chooses to improve environmental standards and technologies, neighboring local governments are likely to imitate, thus creating an imitation effect (Cao et al., 2024).

This study defines governance cost as the support from superior government, incentive from superior government, carbon reduction capacity and support from public. To incentivize local governments, superior government could use policy tools such as special funds and commendations (Chai et al., 2023). To address the mismatch between local policies and resource endowments, the central government, as the supervisor and coordinator, should employ policy instruments such as special funds and special projects to guide local governments. Therefore, the incentive and support from superior government could address not only the weak willingness of local governments to reduce emissions, but also their lack of carbon reduction capacity. Local governments frequently face financial constraints, one-size-fits-all emission reduction policies, and inefficiencies in carbon reduction (Yang and Wei, 2023). However, regional carbon reduction requires significant investment and effort from local governments. Therefore, it is crucial to alleviate the financial burden on the government and implement reasonable policies (Gou and Liu, 2022). Collaboration could be affected by carbon reduction capacity. When implementing carbon reduction policies, it is important to have active participation from local residents. Therefore, public support is crucial for successful collaboration (Liu et al., 2021). Furthermore, the public's desire for a high quality of life could influence the social reputation of companies by creating public pressure to adopt low-carbon production methods (Xu et al., 2023). As a result, support from public is crucial for successful collaboration.

State factors could be affected by pressure factors as mediating factors. Local governments may adjust their governance behaviors in response to different pressures from monitoring and benefit allocation scenes (Jiang et al., 2023; Qu and Cang, 2022), which could in turn affect their collaborative benefit and governance cost.

5.3 Individual factor

In this study, governance responsibility comprises support from public satisfaction and environmental awareness. The governments are committed to improving the quality of environment for the public. Therefore, public satisfaction with carbon reduction could influence the goals and decisions of governments (Zhang et al., 2019). The environmental awareness of local governments reflects the importance they place on low carbon governance (Ji et al., 2023), and local governments with high environmental awareness will actively formulate carbon reduction strategies and thus actively participate in collaboration to reduce carbon emissions. The environmental awareness of local governments is a reflection of the decisions made by government executives (Liu and Peng, 2019).

As individual factors, governance responsibility could exert a moderating impact. The impact of external factors on collaboration could be better realized by increasing the sense of responsibility of local government for environmental protection. For instance, "*Some local governments may not have developed an urgent need to reduce carbon emissions, resulting in the non-implementation of carbon emissions policies.*"

6 Conclusions and policy recommendations

6.1 Main conclusions

This study present an exploratory theoretical analysis of the factors influencing collaboration on carbon reduction. Interviews, policies and news text were analyzed based on grounded theory. Combined with the existing literature, the factors were identified. The identified factors were then screened using a combination of K-means analysis and coefficient of variation methods. The main findings are as follows.

(1) The factors influencing collaboration on carbon reduction could be divided into equitable distribution, collaborative benefit, pressure from supervision, governance cost and governance responsibility. Among them, governance responsibility factor is the moderating factor, while the pressure from supervision and equitable distribution are pressure factors, and governance cost, collaborative benefit are state factors.

(2) The screening of key influencing factors revealed that equitable distribution includes negotiation, planning consistency and conflict resolution, while trust and commitment could be covered by the remaining factors. Collaborative benefit includes resource sharing, compatibility and complementary, while imitation effect could be represented by these factors. Pressure from supervision includes accountability from superior government, regulation by superior government, contractual restraint and public opinion supervision. And the impact of contractual restraint could be represented by other factors. Among governance cost, support from enterprises could be covered by the remaining factors including support from superior government, incentive from superior government, carbon reduction capacity and support from public. Governance responsibility comprises support from public satisfaction and environmental awareness, which could represent executive support.

(3) The pressure factors could influence the collaboration through state factors, and the individual factor, governance responsibility, moderates the impacts of external factors on collaboration on carbon reduction.

6.2 Policy recommendations

6.2.1 Pressure factors

To enhance collaboration, local governments should improve their communication and consultation mechanisms and share benefits fairly. Since inadequate communication and consultation would lead to inefficient collaboration, local governments could take turns in organizing joint conference to strengthen the influence of less developed regions. Once a consensus is reached, an intergovernmental agreement should be signed and at the same time announced to the public and subjected to public scrutiny. At the same time, the regular consultation process should be further improved to promote comprehensive cooperation among local governments in specific areas such as standards, policies and funding.

6.2.2 State factors

To enhance the benefits of collaboration in governance, it is recommended to develop a diversified assessment and development system. As local governments have varying governance capacities and conditions, this system would guide them to generate comparative advantages and avoid homogeneous competition. On the other hand, establishing a cooperation platform would promote a comprehensive sharing of technology, information and systems, and enhancing the efficiency of mutual learning among local governments. This would also assist local governments in selecting suitable partners and improving the effectiveness of collaboration.

Increase monitoring of local governments to encourage their participation. Since there lack clear guidance and supervision for local governments to implementing collaboration, superior government should improve the institutional framework and top design for regional environmental collaboration, and formulate clear planning frameworks, cooperation visions, common goals and action programmes for intergovernmental cooperation, and clarify the rights, responsibilities and obligations of local governments. Furthermore, the superior government should employ a flexible combination of policy instruments to achieve optimal guidance for the characteristics of each local government. This could result in a coordinated effort to continuously improve the performance of local governments in reducing carbon emissions. Moreover, enhancing public participation in monitoring mechanisms is imperative. To enhance ecological environmental protection and pollution control policies, it is recommended to encourage the growth of environmental non-governmental organizations (NGOs) as third-party monitoring agencies, which can act as a bridge between the government and the public, and monitor local government decision-making in consultation procedures.

6.2.3 Individual factor

Reduce the cost of carbon reduction for local governments. Since local governments frequently face fiscal pressure to carbon reduction, establish a regional green development fund could not only provide a stable and sustainable financial guarantee for regional environmental governance, but also coordinate the interests of local governments in the region and effectively mitigate conflicts between economic development and environmental protection in economically backward areas. And the superior government should enhance the enforcement of environmental policies, while ensuring coordination among regulations, environmental taxes, special subsidies and other policies.

The lack of environmental awareness results in the pursuit of GDP performance by local governments, and it is therefore necessary to rebuild local governments' awareness of ecological responsibility. Thus, the education and training on environmental awareness for local governments should be enhanced. Furthermore, the environmental awareness throughout society should be increased. An environmental monitoring system, involving enterprises, the public, the media, and non-governmental organizations could be established to regulate local governments on carbon reduction.

6.3 Limitations and outlooks

Collaboration on carbon reduction among local governments is a complex policy issue. This research establishes a theoretical foundation for promoting collaboration. However, it still has limitations related to the limitations of the research scope. This study only constructed a theoretical impact model for collaboration, it has not been empirically tested, which still needs to be further explored. Similarly, due to the limited availability of data, this study failed to explore the influencing factors of intergovernmental collaborative carbon reduction in other countries. It is expected that future studies will comprehensively consider the characteristics of intergovernmental collaborative carbon reduction in different countries and summarize a more universal framework of influencing factors. In addition, while the grounded theory approach and cluster-dispersion coefficient method employed in this study provide valuable qualitative insights, their inherent subjectivity imposes limitations on analyzing the dynamic evolution of influencing factors and underlying mechanisms in intergovernmental carbon reduction collaboration. Future research would benefit from incorporating objective analytical frameworks to systematically track temporal variations in these critical determinants and their operational pathways. At last, due to the short implementation time of intergovernmental collaborative carbon reduction, the number of experts we can find is limited. It is expected that future research can increase the sample size and select more research objects to enrich the research data.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://www.webofscience.com/.

Ethics statement

The participants provided written informed consent to participate in this study.

Author contributions

YL: Writing – review and editing, Formal Analysis, Funding acquisition. YC: Writing – original draft, Data curation, Methodology.

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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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References

Armstrong, J. H. (2023). Formal local government coordination to mitigate climate change. *Urban Clim.* 51, 101636. doi:10.1016/j.uclim.2023.101636

Cao, T., Sun, F., and Sun, T. (2023). Spatial test of collaborative treatment efficiency measurement and driving factors of air pollution in China's yangtze river Delta urban agglomeration. *Urban Clim.* 49, 101454. doi:10.1016/j.uclim.2023.101454

Cao, Y., Ren, W., and Yue, L. (2024). Environmental regulation and carbon emissions: new mechanisms in game theory. *Cities* 149, 104945. doi:10.1016/j.cities.2024.104945

Chai, S., Liu, Q., and Yang, J. (2023). Renewable power generation policies in China: policy instrument choices and influencing factors from the central and local government perspectives. *Renew. Sustain. Energy Rev.* 174, 113126. doi:10.1016/j.rser.2022.113126

Chang, Y., Hu, P., Huang, Y., and Duan, Z. (2022). Effectiveness and heterogeneity evaluation of regional collaborative governance on haze pollution control: evidence from 284 prefecture-level cities in China. *Sustain Cities Soc.* 86, 104120. doi:10.1016/j.scs.2022.104120

Chao, Li., and Xiaoya, H. (2023). Research on integrated measurement and collaborative governance of yangtze river Delta integration (in Chinese). *East China Econ. Manag.* 37, 35–46. doi:10.19629/j.cnki.34-1014/f.221027004

Che, T. Q., and Hickey, G. M. (2021). Assessing the potential for collaborative governance to support cumulative effects assessment in the Indigenous Cree territory of eeyou istchee, Canada. *J. Environ. Manage* 298, 113444. doi:10.1016/j.jenvman.2021.113444

Chen, D., Hu, W., Lu, X., and Li, Y. (2022). Exploring the influencing mechanism of newly-added urban construction land expansion: a configuration analysis based on PSR Framework(In Chinese). *China Land Sci.* 36, 85–93. doi:10.11994/zgtdkx.20220707.110211

Collins, R., Johnson, D., Crilly, D., Rickard, A., Neal, L., Morse, A., et al. (2020). Collaborative water management across England – an overview of the catchment based approach. *Environ. Sci. Policy* 112, 117–125. doi:10.1016/j.envsci.2020.06.001

Dai, W., and Lu, W. (2020). The lmpact of environmental public opinion pressure on manufacturing firms' GreenInnovation capability:the chain mediating role of leader environmental awareness and organizational green learning (in Chinese). *Sci. and Technol. Prog. Policy* 37, 131–137. doi:10.6049/kjjbydc.Q201908680

Dapilah, F., Nielsen, J. Ø., Lebek, K., and D'Haen, S. A. L. (2021). He who pays the piper calls the tune: understanding collaborative governance and climate change adaptation in northern Ghana. *Clim. Risk Manag.* 32, 100306. doi:10.1016/j.crm.2021.100306

Di, F., and Hu, Z. (2020). Construction and applicationof China's agriculturalmodernizarion evaluationindex System(In Chinese). *Chin. J. Agric. Resour. Regional Plan.* 41, 46–56. doi:10.7621/cjarrp.1005-9121.20200606

Fang, W., Xiao, L., Yang, B., and Wang, L. (2019). An empirical study of influencing factors on civil-involved military knowledge transfer: a perspective of civil-military integration collaborative innovation(In Chinese). *Stud. Sci. Sci.* 37, 664–678. doi:10.16192/j.cnki.1003-2053.2019.04.011

Fengrui, S., Weiwei, M., Xuanming, Z., and Zhifeng, Q. (2023). Improved method for partitioning clustering k-values and center Initialization(In Chinese). *Comput. Eng.* 49, 85–93. doi:10.19678/j.issn.1000-3428.0065422

Flye, M. E., Sponarski, C. C., McGreavy, B., and Zydlewski, J. D. (2023). Leading the charge: a qualitative case-study of leadership conditions in collaborative environmental governance structures. *J. Environ. Manage* 348, 119203. doi:10.1016/j.jenvman.2023.119203

Gao, M. (2018). Does interaction behavior certainly help to collaboration in collaborative innovation?(In Chinese). *Stud. Sci. Sci.* 36, 1524–1536. doi:10.3969/j.issn.1003-2053.2018.08.020

Ge, J., and Lin, B. (2021). Impact of public support and government's policy on climate change in China. *J. Environ. Manage* 294, 112983. doi:10.1016/j.jenvman.2021.112983

Ge, T., Chen, X., Geng, Y., and Yang, K. (2023). Does regional collaborative governance reduce air pollution? quasi-Experimental evidence from China. *J. Clean. Prod.* 419, 138283. doi:10.1016/j.jclepro.2023.138283

Gou, K., and Liu, Y. (2022). Study on the policy of air pollution control in chengdu–chongqing economic circle, China. *Energy Rep.* 8, 68–76. doi:10.1016/j.egyr.2022.10.116

He, Y., Xing, Y., Zeng, X., Ji, Y., Hou, H., Zhang, Y., et al. (2022). Factors influencing carbon emissions from China's electricity industry: analysis using the combination of LMDI and K-means clustering. *Environ. Impact Asses* 93, 106724. doi:10.1016/j.eiar.2021.106724

Ji, Z., Zhang, Z., and Wang, M. (2023). Lmpact of low-carbon governance attention on collaborative carbon emission reduction performance (in Chinese). *Enterp. Econ.* 42, 24–35.

Jiang, Y., Xiao, Y., Zhang, Z., and Zhao, S. (2023). How does central-local interaction affect local environmental governance? Insights from the transformation of central environmental protection inspection in China. *Environ. Res.* 243, 117668. doi:10.1016/j.envres.2023.117668

Khorshidi, N., Parsa, M., Lentz, D. R., and Sobhanverdi, J. (2021). Identification of heavy metal pollution sources and its associated risk assessment in an industrial town using the K-means clustering technique. *Appl. Geochem* 135, 105113. doi:10.1016/j.apgeochem.2021.105113

Li, L. (2019). Advantage complementarity and risk aversion in alliance evolution. *Sci. Sci. Manag. S.&.T.(Monthly)* 40, 75–87.

Li, S., and Jay, S. (2023). Addressing transboundary challenges: exploring the interactive relations between collaborative governance and transboundary marine spatial planning in Europe. *Mar. Policy* 158, 105880. doi:10.1016/j.marpol.2023.105880

Li, Y., Zhang, Q., and Shi, Y. (2022). *The nature of Dilemmas,Political authority,and cross-domain collaborative EnvironmentaGovernance: based on comparative analysis of cases in the Beiiing-Tianjin-Hebei region*. Journal of Central University of Finance and Economics, 119–128.

Li, T., Qiao, C., Li, Y., and Cao, S. (2023). Construction of air quality public satisfaction model and evaluation index system based on questionnaire. *Res. Environ. Sci.* 36, 2314–2321. doi:10.13198/j.issn.1001-6929.2023.10.13

Li, Z., Zhao, Y., and Xia, Z. (2023). Environmental protection supervision and the improvement of regional efficiency incoordinated governance for smog reduction and carbon reduction: quasi-Natural experimental estimation based on environmental protection interviews. *China Soft Sci.*, 198–207. doi:10.3969/j.issn.1002-9753.2023.12.019

Liu, J. (2020). Study on the transformation and upgrading of manufacturing enterprises in guangdong-hong kong-macao greater Bay area. *Technoeconomics and Manag. Res.* 293, 45–52. doi:10.3969/j.issn.1004-292X.2020.12.008

Liu, H., and Peng, Y. (2019). "Race to the bottom" test of collaborative management in haze pollution area. *Resour. Sci.* 41, 185–195. doi:10.18402/resci.2019.01.17

Liu, G., Fu, X., Han, Q., Huang, R., and Zhuang, T. (2021). Research on the collaborative governance of urban regeneration based on a Bayesian network: the case of chongqing. *Land Use Policy* 109, 105640. doi:10.1016/j.landusepol.2021.105640

Liu, X., Wang, W., Wu, W., Zhang, L., and Wang, L. (2022). Using cooperative game model of air pollution governance to study the cost sharing in yangtze river Delta region. *J. Environ. Manage* 301, 113896. doi:10.1016/j.jenvman.2021.113896

Liu, Y., Peng, L., and Peng, J. (2023). Research on the factors affecting the stability of enterprise strategic alliance based on the dynamic Perspective(In Chinese). *Sci. Technol. Manag. Res.* 43, 224–231. doi:10.3969/j.issn.1000-7695.2023.12.025

Luo, A., Zuberi, M., Liu, J., Perrone, M., Schnepf, S., and Leipold, S. (2021). Why common interests and collective action are not enough for environmental cooperation – lessons from the China-EU cooperation discourse on circular economy. *Glob. Environ. Change* 71, 102389. doi:10.1016/j.gloenvcha.2021.102389

Lv, Z., and Liu, Y. (2021). A study on inter-governmental coordination in provincial basin governance from the perspective of policy tools:an analysis of policy texts of the jiulong river basin from 1999 to 2021(In Chinese). *J. Beijing Adm. Inst.*, 40–48. doi:10.3969/j.issn.1008-7621.2021.06.005

McNaught, R. (2024). The application of collaborative governance in local level climate and disaster resilient development – a global review. *Environ. Sci. Policy* 151, 103627. doi:10.1016/j.envsci.2023.103627

Moore, S. (2021). Toward effective river basin management (RBM): the politics of cooperation, sustainability, and collaboration in the delaware river basin. *J. Environ. Manage* 298, 113421. doi:10.1016/j.jenvman.2021.113421

Pan, F., and Wang, L. (2020). Research on implementation strategy of the local environmental regulation department under the perspective of evolutionary game(In Chinese). *J. Industrial Eng. Eng. Manag.* 34, 65–73. doi:10.13587/j.cnki.jieem.2020.03.007

Peng, X., and Wei, J. (2015). Stakeholders'environmental orientation and eco -innovation: the moderating role of top managers environmental awareness (in Chinese). *Stud. Sci. Sci.* 33, 1109–1120. doi:10.3969/j.issn.1003-2053.2015.07.018

Qu, Y., and Cang, Y. (2022). Cost-benefit allocation of collaborative carbon emissions reduction considering fairness concerns—A case study of the yangtze river Delta, China. *J. Environ. Manage* 321, 115853. doi:10.1016/j.jenvman.2022.115853

Rao, C., and Zhao, S. (2022). The influencing factors and action approaches for the effect of intergovernmental collaboration in governance of cross-domain environmental Pollution-A qualitative comparative analysis based on twelve Cases(In Chinese). *J. Central China Normal Univ. Soc. Sci.* 61, 51–61.

Shakeri, R., and Radfar, R. (2017). Antecedents of strategic alliances performance in biopharmaceutical industry: a comprehensive model. *Technol. Forecast Soc.* 122, 289–302. doi:10.1016/j.techfore.2016.01.003

Shen, X., and Fan, B. (2015). Information Sharing,Collaborative response and relief supplies in emergency Preparation(In Chinese). *Sci. Technol. Manag. Res.* 35, 216–221. doi:10.3969/j.issn.1000-7695.2015.15.041

Song, M., Lai, Y., Zhang, Y., Li, L., and Wang, E. (2022). From neighbors to partners: a quantum game model for analyzing collaborative environmental governance in China. *Expert Syst. Appl.* 210, 118248. doi:10.1016/j.eswa.2022.118248

Sun, X., Li, J., and Liu, B. (2014). A study on the relationship of knowledge alliance incentive synergy and alliance performance. *Manag. Rev.* 26, 182–189.

Tang, Z., Yu, H., and Zou, J. (2023). Neighbor impacts of environmental regulation: the case of low-carbon pilot program in China. *Energy* 276, 127509. doi:10.1016/j.energy.2023.127509

Tian, Y., and Chen, G. (2020). Collaborative governance in cross-domain ecological environment: why it is possible and what it can do? *J. Shanghai Adm. Inst.* 21, 95–102. doi:10.3969/j.issn.1009-3176.2020.02.010

Wang, J., and Wang, P. (2023). The justification of inter-government ecological collaborative governance in the river basin better than territorial governance and its realization path: based on the dynamic evolutionary game model. *J. Nat. Resour.* 38, 1334–1348. doi:10.31497/zrzyxb.20230514

Wang, Y., and Zhao, Y. (2021). Is collaborative governance effective for air pollution prevention? A case study on the yangtze river Delta region of China. *J. Environ. Manage* 292, 112709. doi:10.1016/j.jenvman.2021.112709

Wang, Y., Li, X., Sun, Y., Zhang, L., Qiao, Z., Zhang, Z., et al. (2020). Linkage analysis of economic consumption, pollutant emissions and concentrations based on a city-level multi-regional input–output (MRIO) model and atmospheric transport. *J. Environ. Manage* 270, 110819. doi:10.1016/j.jenvman.2020.110819

Wang, X., Kuang, H., and Wang, Q. (2021). A research on the robustness measurement model of incumbent's digital business model. *Sci. Res. Manag.* 42, 189–199.

Wang, Y., Zhao, Z., Shi, M., Liu, J., and Tan, Z. (2024). Public environmental concern, government environmental regulation and urban carbon emission reduction—Analyzing the regulating role of green finance and industrial agglomeration. *Sci. Total Environ.* 924, 171549. doi:10.1016/j.scitotenv.2024.171549

Wang, H., Xie, Y., and Sun, J. (2019). Study on the 'action' game and synergy factors of air pollution control in Beijing-Tianjin.Hebei under different situations. *China Population,Resources Environ.* 29, 20–30. doi:10.12062/cpre.20190624

Wang, P., Ding, Y., and Wei, B. (2019). *Influencing factors of government information resource sharing under the perspective of whole government - an empirical study based on structural equations*. E-Government, 96–105.

Wu, Q. (2014). Analysis of influencing factors on the selection of strategic alliance partners for school-enterprise Co-operation from the perspective of enterprises. *Enterp. Econ.*, 33–37.

Xu, X., Hou, Y., Zhao, C., Shi, L., and Gong, Y. (2021). Research on cooperation mechanism of marine plastic waste management based on complex network evolutionary game. *Mar. Policy* 134, 104774. doi:10.1016/j.marpol.2021.104774

Xu, L., Wang, H. X., and Shao, S. (2023). The asymmetric effect of collaborative environmental governance of the yangtze river Delta region: based on the dual perspectives of multi-agent and multi-region. *J. Xi'an Jiaot. Univ. Soc. Sci.* 43, 128–142. doi:10.15896/j.xjtuskxb.202302013

Yang, X., and Wei, S. (2023). *On the triple traits of"engaging four practices by going Down to the grassroots"and its inspiration of the new era*. Southeast Academic Research, 176–188.

Yao, R., and Zheng, S. (2023). How do local governments lmprove the capability of environmental collaborative governance? Based on the case study of environmental governance in H City(In Chinese). *Adm. Trib.* 30, 77–86. doi:10.3969/j.issn.1005-460X.2023.01.011

Yi, J., Peng-Qi, D., and Liu, C. (2021). Evolutionary game on trust among local governments in collaborative governance of regional air Pollution(In Chinese). *Operations Res. Manag. Sci.* 30, 110–115. doi:10.12005/orms.2021.0152

Yin, Y., Li, Y., and Zhang, Y. (2022). Influencing factor analysis of household electric vehicle purchase intention of HaiNan free trade port under the background of low-carbon lifestyle. *Energy Rep.* 8, 569–579. doi:10.1016/j.egyr.2022.05.125

Yu, J., Xian, Q., Cheng, S., and Chen, J. (2024). Horizontal ecological compensation policy and water pollution governance: evidence from cross-border cooperation in China. *Environ. Impact Asses* 105, 107367. doi:10.1016/j.eiar.2023.107367

Yun, M., Yang, S., Shen, F., Li, F., and Zhao, X. (2024). Differences in expressway TrafficCharacteristics and optimal ServiceFlow rate on sunny and rainy Days(In Chinese). *J. Tongji Univ. Sci.* 52, 1567–1578. doi:10.11908/j.issn.0253-374x.23195

Zhang, P., and Guo, Q. (2023). Carbon emission reduction effects of China's green local government special bonds under 'dual carbon goals. *Financ. Res. Lett.* 58, 104348. doi:10.1016/j.frl.2023.104348

Zhang, J., Cheng, M., Wei, X., Gong, X., and Zhang, S. (2019). Internet use and the satisfaction with governmental environmental protection: evidence from China. *J. Clean. Prod.* 212, 1025–1035. doi:10.1016/j.jclepro.2018.12.100

Zhang, L., Song, Y., Zhang, M., and Wu, W. (2023). Evolutionary game analysis of strategic interaction of environmental regulation among local governments. *Environ. Dev.* 45, 100793. doi:10.1016/j.envdev.2022.100793

Zhao, H., and Xu, S. (2022). Harm-avoiding intergovernmental cooperation in cross-domain environmental governance: research framework and generative Logic-A case study of Guang-Fo water pollution control(In Chinese). *Theor. Investig.*, 87–95. doi:10.3969/j.issn.1000-8594.2022.03.012

Zheng, L. (2023). Collaborative governance of haze pollution between local governments. *ALEX Eng. J.* 65, 119–129. doi:10.1016/j.aej.2022.09.038

Zhou, F., and Hu, C. (2023). How to realize "Hand-in-hand" cross-regional environmental governance? Based on the fuzzy-set qualitative comparative analysis of multiple-cases. *J. Northeast. Univ. Sci.* 25, 67–76.

Zhou, D., Zhong, Z., Chen, L., Gao, W., and Wang, M. (2022). Can the joint regional air pollution control policy achieve a win-win outcome for the environment and economy? Evidence from China. *Econ. Anal. Policy* 74, 13–33. doi:10.1016/j.eap.2022.01.011