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# From Micro-Scale Data to Macro-Scale Governance: A Multi-Dimensional Framework for the Sustainable Community Human Settlement Environment

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### Abstract

Against the backdrop of the interweaving sustainable development goals and rapid urbanization, the governance of community human settlement environment (CHSE) is confronted with the “scale paradox” of the disconnection between macro policies and micro demands. This study addresses the core research question: How to construct a high-quality and sustainable governance framework that links micro-community data with macro-district-level policies so as to resolve the scale paradox? It constructs a four-dimensional governance framework of “institutional supply - multi-party co-construction - cultural cultivation - technological adaptation”, and establishes an innovative data-driven evaluation model linking community data to district-level policies. Drawing on multi-source data from 80 communities in Beijing, the study finds that the governance level exhibits a spatial differentiation characterized by a “high center and low periphery” (average score: 4.30/5.0). The four dimensions exhibit distinct characteristics: The institutional supply dimension is high and balanced, the multi-party co-construction dimension is highly polarized, and the cultural cultivation and technological adaptation dimensions are highly correlated. Spatial heterogeneity provides a new perspective for precise governance. This study achieves three major innovations through a hybrid approach: Proposing a four-dimensional collaborative framework with clear internal logic at the theoretical level, establishing an extensible policy diagnostic tool with detailed AHP implementation at the methodological level, and revealing the policy value of spatial patterns for data-driven decision-making at the practical level. Based on this, a mechanized path is proposed to provide replicable solutions for the modernization of governance in megacities. Research findings confirm that through multi-dimensional collaborative governance, the CHSE can be transformed from “survival-oriented” to “quality-oriented”, providing an important reference for global sustainable urban development.

### Keywords

Community human settlement environment; Sustainable governance; Scale paradox; Policy innovation; Data-driven governance; Beijing case

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## 1. Introduction

Against the backdrop of the deep interweaving of the global urbanization process and the Sustainable Development Goals (SDGs), the governance of CHSE has emerged as a core issue in realizing “people’s aspiration for a better life” and also a micro-practical field for exploring “how to maximize public interests” (West, 2019). However, the current governance practice is confronted with a prominent scale paradox: The top-level design of policies is macroscopic and abstract, while the real perception and demands of residents arise from the microscopic community life scenarios. How to effectively transform the complex information at the micro level into operational and evaluable policy interventions at the meso (district-level) level has become a key innovation point in promoting the modernization of grassroots governance.

China has incorporated the construction of a “high-quality human settlement environment” into the strategic framework of modernizing national governance. The 2025 Central Urban Work Conference proposed to “build innovative, livable, beautiful, resilient, civilized and smart modern cities for the people”, which is highly consistent with the United Nations’ New Urban Agenda and the 2030 Sustainable Development Goals (SDG 11) (Hu *et al.*, 2023; Biggeri *et al.*, 2019). Although extensive research has been conducted on the human settlement environment at the urban and rural scales, studies at the micro-community scale—those that can more accurately depict the quality of human settlement environment and directly align with policy implementation remain inadequate (Lang *et al.*, 2016). Most of the existing research is limited to case descriptions and lacks a systematic evaluation framework to effectively aggregate community data to support the differentiated and precise policy-making of district-level governments (Li *et al.*, 2019).

Therefore, the core research question of this paper is: How to build a high-quality sustainable governance framework for human settlement environment that can connect micro-community data with macro-district-level policies through the collaborative innovation of methodology and governance mechanisms, in order to solve the “scale paradox” in governance practice?

To answer this question, this study takes the megacity Beijing as a case study, based on field research of 80 communities, 1,939 valid questionnaires and multi-source data, aiming to achieve the following breakthroughs:

1. Theoretical innovation: Propose a four-dimensional collaborative governance framework of “institutional supply - multi-party co-construction - cultural cultivation - technological adaptation”, elevating sustainable governance from technical restoration to the level of systematic policy innovation.

2. Methodological innovation: Develop an extensible evaluation model that combines the Analytic Hierarchy Process (AHP) with spatial analysis to achieve scientific measurement and spatial visualization from micro-community data to district-level governance levels, providing precise “targets” for policy diagnosis.

3. Policy Innovation: Based on the empirical discovery of spatial heterogeneity patterns, an institutionalized policy solution is constructed to provide a replicable toolkit for the transformation of the CHSE in Beijing and other megacities from “campaign-like improvement” to “institutionalized governance”.

## 2. Theoretical Foundation: Reconstructing the Policy Framework for Human Settlement Environment Governance

The research on the sustainable governance of the CHSE is rooted in the profound tradition of Science of Human Settlements and the theory of sustainable development (Kahachi *et al.*, 2024). However,

the traditional theoretical perspective shows limitations in dealing with the complexity of community governance in megacities, especially in resolving the “scale paradox”. This section aims to critically review the relevant theories and, on this basis, systematically expound the theoretical innovation of this article—a “four-dimensional synergy” governance framework aimed at bridging micro values with macro policies.

### 2.1. *Theoretical evolution and critical review*

#### 2.1.1. *Theoretical basis and limitations of human settlement science*

This study is based on the important heritage of Human Settlement Science. Doxiadis (1970) proposed “Ekistics”, a discipline that conceptualizes the human settlement environment as an integrated system and emphasizes the comprehensive study of human settlements. This idea was further developed by Wu Liangyong (1991), who proposed “Science of Human Settlements”, emphasizing an overall grasp of the reality of the region. Davidson (1985) explored the resource utilization mode of human settlements, laying a preliminary foundation for the discipline. Grand (1999) further emphasized the significance of cultural identity and community practice in shaping the human settlement environment. Cong *et al.* (2021) analyzed the driving forces of sustainable development of urban human settlements in China, supplementing the empirical research support of human settlement science. Qin *et al.* (2024) studied the evolution of human settlement quality from the perspective of “production-living-ecological” spaces, enriching the spatial dimension analysis of the discipline. These studies provide an important basis for systems thinking in the research of human settlement environment, but they overly focus on physical space planning and lack in-depth exploration of the interaction among multiple subjects, power structure and institutional arrangements in the governance process.

#### 2.1.2. *Macro guidance and micro deficiencies of sustainable development theory*

The theory of sustainable development (Martinet and Rotillon, 2007; Bertinelli *et al.*, 2012) emphasizes the coordination of the three pillars of economy, society and environment, providing goal-oriented governance for communities. In particular, the implementation of United Nations Sustainable Development Goals (SDG 11) has promoted the development of urban sustainability assessment tools (Kaur and Garg, 2019; Biggeri *et al.*, 2019). The research on smart sustainable cities by Bibri and Krogstie (2017a; 2017b) and the analysis of sustainable community planning by Roseland and Spiliotopoulou (2024) have both provided important insights for the implementation of sustainable development goals at the local level. Zhang *et al.* (2024) put forward practical indicators and progress assessment methods for integrating SDGs into China’s ecological civilization construction, which provides a direct operational reference for local governments to carry out sustainable governance assessment. Vanhulst *et al.* (2025) further pointed out that the reflexive process in sustainability science is crucial to bridging the gap between theoretical research and practical application, which helps to avoid the separation of sustainable development policies from grassroots needs. However, the macro scale of this theory often struggles to guide specific community practices and lacks a theoretical bridge to transform grand goals into actionable measures at the grassroots level.

#### 2.1.3. *The evolution of governance theory and the shift towards polycentric governance*

To make up for the above deficiencies, governance theory provides important inspirations. The

“polycentric collaboration” framework proposed by the New Public Governance Theory (Bache and Flinders, 2004) and Faludi’s (2005) research on polycentric territorial cohesion policies both advocate breaking the single government dominance model and promoting the joint participation of multiple subjects in governance. Finka and Kluvánková (2015) further proposed a multi-center approach to managing the complexity of urban systems. Bailey (2012) discussed the role of community enterprises in urban renewal, supporting the viewpoint of community subject participation under the polycentric governance theory. These studies provide a theoretical basis for understanding the interaction of multiple subjects at the community level, especially the critical analysis of social capital in environmental governance at the community level by Ishihara and Pascual (2009), and the cross-community domain research on the collaborative management of shared environmental resources by Ssekajja (2025). All of them provide important perspectives for understanding the complexity of community governance.

In terms of specific governance mechanisms, Janssen *et al.* (2023) studied the use of games for social learning to promote self-governance, while Paliokait and Sadauskait (2023) analyzed the institutionalization process of participatory and collaborative governance in Lithuania and Finland. Füller *et al.* (2017) studied the role of professionalism in innovation contest communities, supporting the value analysis of social subjects participating in co-construction. These studies have all emphasized the importance of multi-participation, but a systematic operational framework has not yet been formed on how to achieve effective “value co-creation” through specific institutional design, technical means and cultural cultivation (Sarmah *et al.*, 2015).

## 2.2. *Theoretical innovation of this paper: four-dimensional collaborative governance framework*

Integrating and transcending existing theories, this paper constructs a four-dimensional collaborative governance framework aimed at achieving “scale transformation”, which is composed of four interrelated and dynamic dimensions: institutional supply - multi-party co-construction - cultural cultivation - technological adaptation. The four dimensions form an organic whole of “guarantee - engine - soul - enabler”, with the core goal of solving the scale paradox in governance innovation.

### 2.2.1. *Institutional supply: the cornerstone of sustainable governance*

This dimension focuses on establishing a long-term and sustainable policy guarantee system. North (1990) pointed out that institutions are the cornerstone of economic performance, which provides a core theoretical basis for this dimension. It goes beyond short-term project-based policy tools and focuses on providing stable expectations and rules for governance behaviors through the construction of the rule of law, innovation in fiscal and financial mechanisms, and a collaborative mechanism with clear rights and responsibilities. This echoes the research of Chen and Xie (2024) on the mediating role of governance among natural resources, technological progress, efficient energy and sustainability, and is also significantly related to the research of Wu and Wang (2023) on the planning environmental impact assessment method in China.

### 2.2.2. *Multi-party co-creation: the engine of sustainable governance*

This dimension is the concretization of the “multi-center collaboration” theory, aiming to establish a sustainable governance mechanism of “government coordination - market operation - resident self-governance - social participation”. Li *et al.* (2024) compared the government-led and market-led

governance models, providing theoretical support for the design of this dimension. This is closely related to the research by Jiang *et al.* (2025) on the influence of institutional factors on the opportunities for social organizations to participate in community governance, as well as the one by Li *et al.* (2025) on modeling residents' participation behaviors in green renewal projects in Chinese communities through social networks and multi-agent simulation. The research on smart city governance and quality of life by De Guimarães *et al.* (2020) also provides support for this dimension. Zollet and Qu (2024) proposed that community-oriented policies for the settlement of urban newcomers through counter-urbanization can effectively revitalize rural areas, which expands the application scenario of multi-party co-construction governance from urban to rural communities.

### 2.2.3. *Cultural cultivation: the soul of sustainable governance*

The core of this dimension lies in activating residents' sense of "ownership" and fostering a participatory governance culture led by residents. This echoes the research by Liu *et al.* (2024) on interpreting residents' trust in grassroots governments to promote dynamic resident participation in neighborhood regeneration, as well as the research by Anderson-Coto *et al.* (2024) on achieving culturally sustainable design through participatory design. The research by Das (2014) on women's participation in water governance at the urban community level in India also provides important insights for this dimension. Deng and Li (2025) proposed that social interaction can incentivize residents' energy-saving behaviors, which provides a reference for the design of residents' participation incentive mechanisms in this dimension.

### 2.2.4. *Technological adaptation: the enabler of sustainable governance*

This dimension emphasizes that technological empowerment must serve governance goals and avoid the trap of the "technology omnipotence theory". Sharifi *et al.* (2024) studied the synergy between smart cities and SDGs, providing a policy goal connection basis for this dimension. The core lies in using digital tools to achieve precise identification and intelligent decision-making of human settlement environment issues. This is closely related to the research on digital twin technology by Bibri *et al.* (2024) and the research on cognition, communication, coordination and control in crisis management by Comfort (2007). Papadopoulou's (2021) research on technology and sustainable development goals in the context of smart cities also provides support for this dimension. Leal Filho *et al.* (2024) analyzed the role of artificial intelligence in the implementation of SDG 11, supplementing the technical application support of this dimension. Regona *et al.* (2024) studied the application of artificial intelligence in the construction industry, providing industry practice reference for technological adaptation.

### 2.2.5. *Overall logic of the framework*

The four dimensions are not isolated: Institutional supply provides a ruling boundary for multi-party co-construction and technological adaptation; multi-party co-construction provides a practical carrier for cultural cultivation; cultural cultivation provides a social foundation for institutional implementation and technological application; technological adaptation provides a tool support for institutional optimization and efficiency improvement of co-construction. The four dimensions collaborate to achieve the scale connection of "micro demands - macro policies", providing theoretical support for governance innovation.

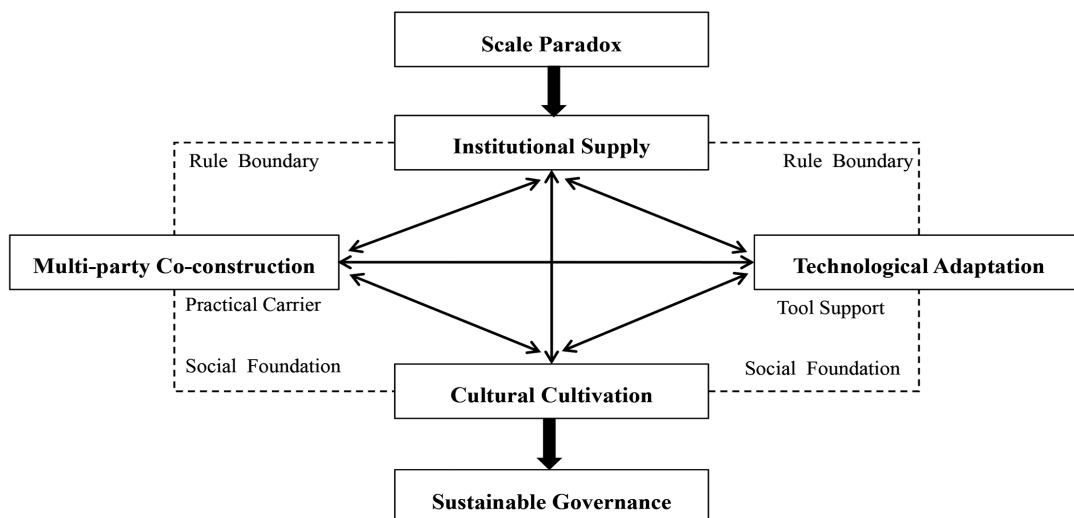


Fig. 1. Four-dimensional collaborative innovation policy framework.

### 2.3. Theoretical rationality of scale transformation: the district level serves as a key policy intervention unit

The innovation of this framework lies in its integration of the above four dimensions into an organic whole and its clear application scenarios are directed towards district-level administrative units. Under the dual background of rapid urbanization and social transformation, district-level governments play a crucial role in connecting the upper and lower levels in China's governance system. This scale transformation makes this theoretical framework not only an analytical tool but also a policy diagnosis and innovation system, which can precisely locate the spatial distribution of governance shortcomings, thereby providing direct theoretical basis and empirical support for formulating differentiated district-level policies.

This framework fundamentally responds to the "scale paradox" proposed in the introduction, aiming to promote the governance of CHSE from "concept advocacy" to "system implementation", and from "campaign-style rectification" to "sustainable governance" through the four-dimensional synergy of systems, subjects, culture and technology. It aims to provide new theoretical perspectives and practical paths for constructing a more complete scientific human settlement environment system (Cong *et al.*, 2021).

## 3. Methodology and Data: A Scalable Assessment Model for Policy Diagnostics

This section elaborates on the scalable evaluation model constructed in this study to achieve the transition from micro-community data to district-level policy diagnosis. The core innovation of this methodology lies in the integration of multi-source data, analytic hierarchy process (AHP), and geospatial analysis, aiming to create a systematic diagnostic tool that not only scientifically measures governance levels but also accurately identifies policy intervention targets.

### 3.1. Research area and multi-source data fusion

This study takes Beijing, a megacity that assumes the functions of a national capital and exhibits typical symptoms of "big city diseases", as a case study. Tian *et al.* (2010) analyzed the spatial pattern

of urban functions in the Beijing metropolitan area, providing a background basis for the selection of the research area. The selection of cases is highly based on policies and representative. To ensure the comprehensiveness and triangulation of the data, this study integrated three types of data:

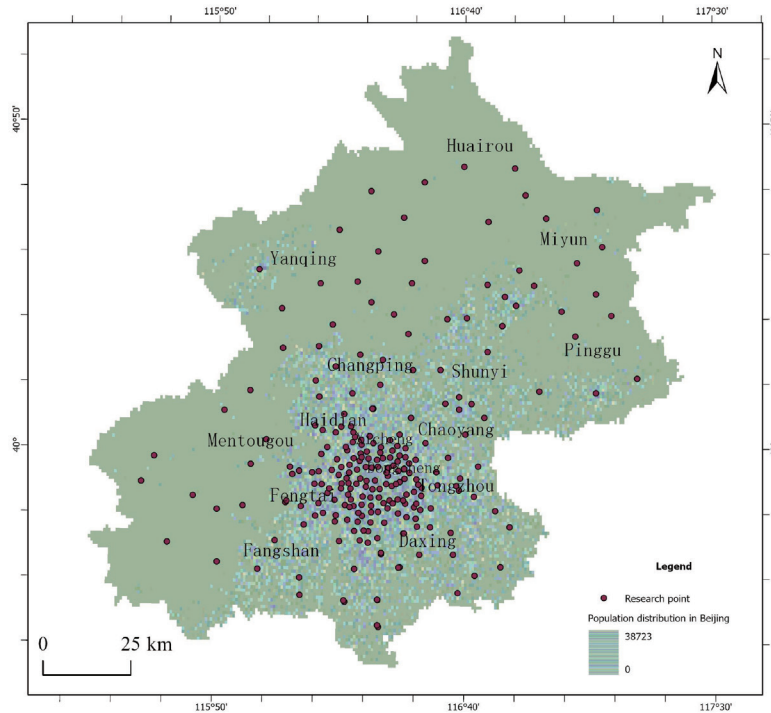


Fig. 2. Schematic diagram of the distribution of the research questionnaire.

**Research data:** Through a four-month collection of electronic and paper questionnaires covering 80 communities in major urban districts of Beijing, a total of 1,939 valid questionnaires were collected, supplemented by over 150,000 words of in-depth interview records, aiming to capture residents' subjective perceptions and genuine demands regarding the quality of the community living environment (Fig. 1). Boutilier *et al.* (2025) studied the factors affecting the participation of community-dwelling elderly in research, providing a reference for the design of questionnaire content related to elderly groups.

**Community materials:** During on-site visits, over 50 internal documents such as community archives, work reports, and statistical statements were collected, providing a qualitative basis for understanding the institutional background and actual operation of community governance.

**Public data:** Integrate the Beijing Statistical Yearbook, government data resources, the seventh national census, land use data, POI (Point of Interest) data and Landsat remote sensing images to provide a macroscopic spatiotemporal background and objective evidence for the analysis. Guan *et al.* (2024) conducted provincial-level evaluation of environmental sustainability, providing a reference for the selection of public data indicators.

This multi-source data fusion strategy ensures that the assessment not only incorporate the “bottom-up” resident experience but also have the objective factual support of the “top-down” approach, laying a solid foundation for the subsequent scale transformation.

### 3.2. Construction of an extensible evaluation index system

Chen *et al.* (2024) constructed a multi-indicator assessment system for urban human settlement sustainability based on SDG 11, providing an international reference for the construction of this index system. Based on the principles of integrity, representativeness, scientificity, operability and people-oriented approach, and referring to international standards and national policies, this study has constructed an evaluation index system for the sustainable governance level of CHSE through two rounds of index screening and expert consultation (Table 1). Xiang *et al.* (2025) proposed a coupling evaluation method for human settlement-environment-energy systems, providing a reference for the coupling design of the index system. Maldet *et al.* (2023) applied the SDG indicator system at the community level, supporting the rationality of the index screening process. This system adopts a hierarchical structure, including the target layer, criterion layer and indicator layer:

Target layer: The sustainable governance level of the CHSE.

Criterion layer: Institutional supply, multi-party co-construction, cultural cultivation, technological adaptation. This fully corresponds to the four-dimensional theoretical framework proposed in Section Two of this article, ensuring the consistency of theory and method.

Indicator layer: It includes specific measurable indicators such as policy continuity, market participation rate, residents' sense of belonging, and digital tool adaptability.

The construction process of this indicator system fully drew on the opinions of multiple evaluation subjects and ensured the professionalism and credibility of the indicators by forming an assessment expert group.

**Table 1**

Evaluation index system for the innovation level of community human settlement environment governance.

First-level indicators	Second-level indicators	Third-level indicators
Institutional supply (A1)	Policy guarantee (B1)	Community governance policy continuity Environmental governance law enforcement intensity
	Fiscal and power mechanism (B2)	Special governance fund stability Multi-department power and responsibility clarity
	Multi-subject participation (B3)	Government coordination efficiency Market participation rate, Resident self-governance rate
Multi-party co-construction (A2)	Co-construction mechanism (B4)	Social organization participation depth Interest-sharing mechanism improvement Conflict coordination effectiveness
	The harmony of community human settlement (B5)	Resident sense of belonging, Willingness to participate in governance
Cultural cultivation (A3)	Cultural activities (B6)	Co-construction and sharing cultural activity frequency Activity participation rate
	Digital tool application (B7)	Community digital governance platform coverage rate
Technological adaptation (A4)	Technological practicality (B8)	Data sharing degree
		Digital tool operation convenience Elderly group adaptability

3.3. AHP (Analytic Hierarchy Process) and calculation of index weights

To transform qualitative judgments into quantitative weights, this study adopts the AHP (Analytic Hierarchy Process), a mature multi-criteria decision-making tool. The specific steps are as follows:

3.3.1. Expert selection and scoring process

Expert selection: Fifteen experts were invited to participate in the scoring process, representing fields such as public administration (5 experts, whose research focuses on urban governance innovation), urban planning (4 experts, specializing in the CHSE), policy-making practice departments (3 professionals, with experience in formulating district-level governance policies), and community governance practice (3 practitioners, community secretaries or directors). Measures were taken to make sure that experts possess both theoretical depth and practical policy experience.

Scoring preparation: Inform the experts with detailed research background, the connotation of the four-dimensional framework, indicator explanations, existing research achievements, and clearly defined scoring rules (19 scale method). Require the experts to allocate weights based on the “effectiveness of governance innovation implementation”.

Scoring process: A two-round scoring system is adopted. After the first round of independent scoring, indicators with significant differences among experts (such as “compatibility for the elderly group” under the “technical compatibility” dimension) are fed back. Then, experts are organized to conduct an online discussion and the second round of scoring is carried out. Ultimately, an effective judgment matrix is formed.

3.3.2. Weight calculation and consistency check

Construct the judgment matrix: Based on the results of the second round of expert scoring, form the judgment matrix of the first-level indicators (four-dimensional framework) and the second-level indicators.

**Table 2**  
The description of the relative importance of each factor.

Scale	Definition
1	Factor <i>i</i> is as important as factor <i>j</i>
3	Factor <i>i</i> and factor <i>j</i> are slightly important
5	Factor <i>i</i> and factor <i>j</i> are relatively important
7	Factor <i>i</i> and factor <i>j</i> are very important
9	Factor <i>i</i> and factor <i>j</i> are absolutely important
2, 4, 6, 8	Scale value corresponding to the intermediate state among the above judgments
Countdown	If factor <i>i</i> is compared with factor <i>j</i> , the resulting judgment value is $a_{ji}=1/a_{ij}$ , $a_{ii}=1$

**Table 3**  
First-level indicator judgment matrix.

First-level indicator	Institutional supply (A1)	Multi-party co-construction (A2)	Cultural cultivation (A3)	Technological adaptation (A4)
Institutional supply (A1)	1	4	3	5
Multi-party co-construction (A2)	0.25	1	0.33	2
Cultural cultivation (A3)	0.33	3	1	3
Technological adaptation (A4)	0.2	0.5	0.33	1

Hierarchical single ranking and consistency check: Calculate the eigenvectors of each judgment matrix to determine the index weights and conduct consistency checks to ensure the logical consistency of expert judgments. The consistency ratio (CR) of all matrices in this study was less than 0.1 (for example,  $\lambda_{\max}$  of the first-level index judgment matrix =4.108, CI=0.036, RI=0.882, CR=0.042), which passed the test and proved that the weight distribution was scientifically reliable. The weight results of the first-level indicators are as follows: Institutional supply weights 0.35, multi-party co-construction 0.25, cultural cultivation 0.20, and technological adaptation 0.20.

**Table 4**  
RI Value comparison table.

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

**Table 5**  
Consistency test.

Judgment matrix	$\lambda_{\max}$	CI	RI	CR	Inspection results
Overall objective layer	4.108	0.036	0.882	0.042	pass
Institutional supply (A1)	2	0	0	0	pass
Multi-party co-construction (A2)	2	0	0	0	pass
Cultural cultivation (A3)	4.207	0.069	0.882	0.078	pass
Technological adaptation (A4)	3	0	0.525	0	pass

Comprehensive score calculation: After obtaining the weights of each level of indicators, starting from the scores of the lowest-level indicators, the scores are weighted and synthesized layer by layer, and finally the comprehensive governance scores of each community are calculated and then aggregated to each district. This method enables the scattered micro-perception data to be systematically aggregated into comparable district-level quantitative scores.

**Table 6**  
The evaluation scores of the governance level of the CHSE of districts in Beijing.

Beijing District	Institutional supply (A1)	Multi-party co-construction (A2)	Cultural cultivation (A3)	Technological adaptation (A4)	Comprehensive level
Changping	4.1582	3.6698	3.8301	3.7986	3.9843
Chaoyang	4.7833	3.8846	3.8900	4.5945	4.4280
Daxing	4.2651	4.2521	4.1919	4.2470	4.2432
Dongcheng	4.8833	4.0245	4.6065	4.7008	4.6913
Fangshan	4.2646	3.5175	3.4609	3.5844	3.9107
Fengtai	4.5833	3.9269	4.3572	4.5445	4.4411
Haidian	4.7750	3.8319	4.3855	4.5864	4.5432
Huairou	4.4137	3.8819	4.0435	4.0177	4.2207
Mentougou	4.4978	4.1120	3.9686	4.0820	4.2805

Table 6. (continued)

Beijing District	Institutional supply (A1)	Multi-party co-construction (A2)	Cultural cultivation (A3)	Technological adaptation (A4)	Comprehensive level
Miyun	4.3000	4.8267	4.5944	4.3133	4.4416
Pinggu	4.1821	3.5255	3.6240	3.6116	3.9112
Shijingshan	4.5917	4.0441	4.0545	4.3177	4.3639
Shunyi	4.1917	4.5702	4.3489	4.4176	4.2972
Tongzhou	4.1500	4.1904	4.0462	3.8573	4.1044
Xicheng	4.8750	3.9236	4.5960	4.8223	4.6817
Yanqing	4.2000	4.6313	4.0636	4.0855	4.2089

3.4. Spatial analysis and policy diagnosis visualization

The methodological innovation of this study lies not only in assessment but also in diagnosis. Based on the comprehensive score at the district level and the scores of the four dimensions, we conducted spatial visualization analysis using GIS (Geographic Information System) technology.

Spatial differentiation identification: By mapping the numerical results to the geographical space, it clearly reveals the “high center and low periphery” banded distribution pattern of the governance level of the 16 districts in Beijing (as shown in Fig. 2), as well as the different spatial correlations and polarization phenomena in each dimension (security, construction, service, culture).

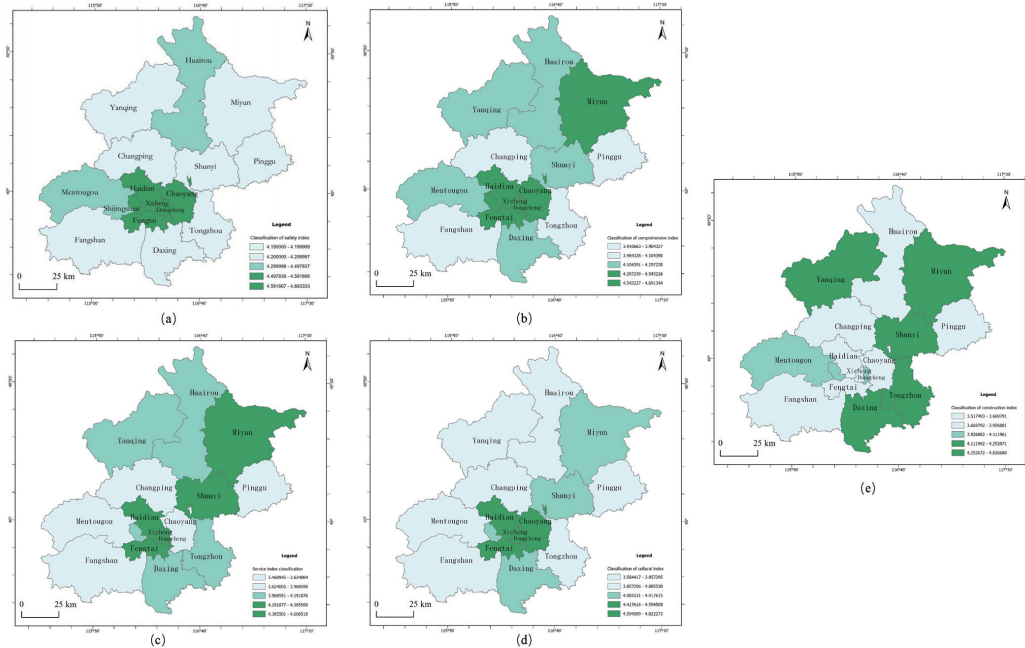


Fig. 3. The level of CHSE governance in Beijing.

Policy diagnostic function: This spatial visualization elevates the research method from an assessment model to a policy diagnostic system. For instance, the “double tail distribution” and significant differences

(standard deviation 0.36) in the construction dimension scores directly point to the shortcomings of infrastructure co-construction in the peripheral regions, suggesting the need for innovative financing policies. The high similarity between the dimensions of service and culture implies the necessity of coordinated policy supply. This approach can provide decision-makers with an intuitive “governance level heat map”, accurately identifying governance blind spots and policy priorities.

### 3.5. Methodology summary: an extensible model for policy innovation

In conclusion, the core advantage of the methodological combination of “AHP weight determination + multi-source data integration + GIS spatial analysis” constructed in this study lies in its scalability and diagnostic functions. It not only answers the question of “What is the level of governance”, but more importantly, it addresses the more practical proposition of “where are the problems” and “What should be the priority of policies”. This approach has successfully transformed the complexity of micro-communities into clear insights into district-level policies, providing a powerful scientific tool and decision support for achieving precise and differentiated governance of CHSE.

## 4. Empirical Findings: Spatial Heterogeneity as A catalyst for Policy Innovation

Based on the systematic analysis of the scalable evaluation model, this study reveals the spatial differentiation pattern of the sustainable governance level of the CHSE in Beijing. These empirical findings are not only descriptions of the current situation, but more importantly, they provide crucial evidence for understanding the driving mechanisms of governance effectiveness and formulating precise innovative policies. This section will present and interpret these findings in detail and clarify the policy implications behind them.

### 4.1. Overall layout: significant spatial differentiation at a relatively superior level

A comprehensive analysis of the 16 districts in Beijing shows that the average comprehensive score of sustainable governance of CHSE is 4.30 (out of 5), which is in the “relatively high level” range. This reflects that Beijing has made positive progress in modernizing grassroots governance. However, the difference in the comprehensive score (0.78) and the spatial distribution reveal significant internal imbalances.

The governance level exhibits a distinct strip-shaped spatial distribution pattern characterized by “high in the center and low in the periphery”. The governance level of the core areas (such as Dongcheng District, Xicheng District, and Haidian District) has reached the highest level, while the areas with a modestly high level (such as Miyun, Fengtai, Chaoyang, Shijingshan, Shunyi, and Mentougou) are distributed in a northeast-to-southwest direction in a band within the central urban area of Beijing (refers to the six urban districts: Dongcheng, Xicheng, Haidian, Chaoyang, Fengtai and Shijingshan). The comprehensive governance level of the CHSE in other districts is at a medium level. With the high-level community strip area as the dividing line, they are distributed in the southeastern and northwestern regions of Beijing. This spatial pattern is closely associated with Beijing’s urban functional orientation, the degree of resource agglomeration and its historical development foundation, which directly indicates that policy resources should move away from “egalitarianism” and be allocated in a differentiated manner.

#### 4.2. *In-depth analysis by dimension: from data discrepancies to policy signals*

An in-depth analysis of the four core dimensions can more accurately identify the shortcomings and strengths of governance and provide direction for classified policy guidance.

##### 4.2.1. *Institutional supply dimension: high-level homogeneity and insufficient flexibility*

The average score of the institutional supply dimension was the highest (4.44), and the scores of each district were all above 4.0, with a small regional difference (standard deviation 0.26). This indicates that in basic institutional fields such as policy guarantee, financial support, and power and responsibility division, Beijing has established a relatively homogeneous and effective policy system. Its spatial pattern is characterized by “high in the central urban area, moderate in the northern and southern regions, and low in the central area”. The policy signal of this discovery is that basic institutional policies are effective. The focus of future policy innovation should not remain at maintaining the existing level, but should shift to enhancing institutional flexibility and optimizing policy adaptability in response to the differentiated needs of various regions.

##### 4.2.2. *Multi-party co-construction Dimension: huge Regional differences call for innovation in investment and financing mechanisms*

The assessment results of the multi-party co-construction dimension most prominently reveal the shortcomings of governance. Although its average score (4.05) is at a relatively high level, the score differences are huge (with the largest hitting 1.31), the standard deviation is high (0.36), and it shows obvious “double-tail distribution” and spatial discrete characteristics. The high-level districts are mainly distributed outside the “six urban districts” of Beijing, showing a distinct polarization phenomenon. Casella *et al.* (2025) proposed a model for maximizing shared benefits in renewable energy communities, providing a reference for solving the polarization problem in this dimension. This indicates that there is an extremely uneven development among regions in terms of multi-subject collaborative participation and infrastructure co-construction. The significant differences in this dimension strongly suggest that the current single model relying on government fiscal input may no longer be able to meet the construction needs of the peripheral areas. There is an urgent need for policy innovation in the investment and financing mechanism.

##### 4.2.3. *Cultural cultivation dimension: high degree of synergy with the technological adaptation dimension*

The average score of the cultural cultivation dimension (4.22) is relatively high, with the smallest regional difference (standard deviation 0.23). Its spatial distribution pattern of “high in the middle and low around” is highly similar to that of the technological adaptation dimension. This profoundly reveals the close intrinsic connection between community cultural construction and technological application. Rich cultural cultivation activities provide a social foundation for the promotion of technological tools, while convenient technological applications provide an efficient carrier for cultural communication and resident participation. Charles *et al.* (2020) expounded the significance of community science to the governance of social-ecological systems, providing a theoretical basis for the cultivation of community culture. The policy significance of this discovery lies in that future cultural construction should not be an isolated “activity”, but should be policy-bound and coordinated with the promotion and application of technological tools, maximizing policy effectiveness through the linkage of “software” and “hardware”.

#### 4.2.4. *Technological adaptation dimension: highlights and collaborative opportunities under the aggregation of centers*

The average score of the technological adaptation dimension is 4.13, with relatively small regional differences (standard deviation 0.33), exhibiting an overall pattern of “high in the middle and low around the periphery”. It is worth noting that the technological adaptation levels of Miyun District and Shunyi District are higher than those of the surrounding areas, and they are adjacent to each other, showing a certain positive spatial correlation. This indicates that the allocation of technological resources is generally in line with the degree of population and economic agglomeration, but at the same time, a good technological application cluster effect has been formed in specific regions. Parappallil Mathew and Bangwal (2024) proposed a people-centric governance model for smart cities, providing a reference for the inclusive application of technology in this dimension. Policy makers can summarize and promote the experience of the “Miyun-Shunyi” model based on this. At the same time, they should pay close attention to areas with low technological application levels and promote the coordinated and balanced distribution of technological resources among regions through policy guidance.

#### 4.3. *Comprehensive policy diagnosis: spatial heterogeneity as a catalyst for policy innovation*

The above empirical findings all point to a core conclusion: Spatial heterogeneity is not a negative governance outcome, but rather a catalyst that inspires precise and innovative policy design. The evaluation model of this study successfully aggregated the complex information of micro-communities into clearly distinguishable policy signals at the district scale.

For the homogenization of high scores in the security dimension, policies can shift to more cutting-edge innovative pilot projects for resilient cities.

For the significant polarization in the construction dimension, the policy focus should be concentrated on the activation of financing mechanisms and market forces.

For high synergy in the dimensions of service and culture, policy design should emphasize cross-departmental integration and resource sharing. Honeybun-Arnolda *et al.* (2024) discussed the localization and democratization of goal-based governance for sustainability, providing a reference for the design of differentiated policies.

In conclusion, the spatial analysis in this section goes beyond simple ranking comparisons. It enables each district to clearly recognize its position in the city’s governance map and its corresponding relationship with various dimensions in the theoretical framework. This provides a solid empirical foundation for the next section to propose a highly targeted and operational governance path, achieving a closed loop from “identifying problems” to “understanding the causes of problems” and then to “guiding solutions”.

#### 4.4. *Causal mechanisms: unpacking the drivers of spatial heterogeneity*

The spatial analysis of this study not only reveals the distribution pattern of governance levels, but also points to the deep-seated causal mechanism. These mechanisms stem from the unique context of Beijing as a megacity, including the interaction between administrative hierarchy, financial capacity and historical planning heritage. Specifically:

The high score homogeneity (average score 4.44, standard deviation 0.26) in the dimension of institutional supply is mainly attributed to Beijing’s administrative hierarchy advantage. As the capital,

its policy resources are uniformly allocated by the central government, which leads to the long-term accumulation of a legal foundation in the central area, while the peripheral areas can also benefit from the top-down institutional diffusion. North (1994) studied the long-term economic performance from the perspective of institutional change, providing a theoretical basis for analyzing the institutional supply mechanism. However, this homogenization also reflects a lack of flexibility – historical planning legacies (such as the resource tilt during the planned economy era) make it difficult for the system to adapt to the differentiated demands of the peripheral areas (such as the new challenges brought about by population mobility). Bharathi *et al.* (2024) studied the relationship between status inequality and public goods, providing a reference for analyzing the fairness problem of institutional supply.

The polarization phenomenon in the multi-party co-construction dimension (standard deviation 0.36) is directly linked to the disparity in fiscal capacity. The central area, with its high-density commercial activities, can attract market capital to participate in governance, while the peripheral area, constrained by local fiscal revenue, falls into a “free-rider” predicament. GIS spatial analysis shows that the low-level co-construction zones highly overlap with regions with a relatively low level of economic development, confirming the crucial role of fiscal capacity. Salmaso (2024) studied the welfare maximization of stable sharing services, providing a reference for the design of benefit sharing mechanisms in multi-party co-construction.

The synergy between cultural cultivation and technological adaptation ( $r > 0.8$ ) reflects historical path dependence: As a science and technology center, Haidian District’s technological cluster effect has promoted the technological empowerment of cultural activities, while the peripheral areas, due to lagging infrastructure, find it difficult to achieve similar synergy.

## 5. Pathways to Innovative Policy: A Mechanism-based Framework

Building on the systematic assessment and spatial diagnosis of Beijing's CHSE governance levels, this section constructs a mechanized, four-dimensional collaborative policy innovation framework, moving beyond traditional countermeasure lists. The framework directly addresses the core issues identified in empirical findings, converting governance challenges into specific institutional arrangements, action paths, and policy tools, aiming to promote the transformation of CHSE governance from “campaign-style rectification” to “institutional sustainability”.

**Table 7**

The policy mechanism mapping table based on the empirical findings in Part 4.

Governance dimension	Empirical discovery	Core issue	Corresponding mechanism	Key policy actions
Institutional Supply	The average score was 4.44 (the highest), and the standard deviation was 0.26 (the lowest), showing “high score homogenization”.	Insufficient policy rigidity makes it difficult to adapt to differentiated risks (such as climate change).	Mechanism I: Innovate institutional supply	Legal guarantee; Diversified financing mechanism; Multi-subject collaborative network
Multi-party Co-construction	The standard deviation is 0.36 (maximum), and the scores in the peripheral areas (such as Fangshan) are significantly lower.	The disparity in fiscal capacity leads to “center-periphery” polarization and the failure of collective actions	Mechanism II: Improve the co-construction mechanism	Vertical and horizontal institutional innovation; Benefit sharing and cost sharing; Establish a win-win incentive mechanism

Table 7. (continued)

Governance dimension	Empirical discovery	Core issue	Corresponding mechanism	Key policy actions
Cultural Cultivation	The high degree of synergy with the cultural and technological dimensions ( $r > 0.8$ ), but the resident participation rate is low.	Cultural governance overly relies on technology-driven approaches, and residents' subjectivity is lacking	Mechanism III: Cultivate a culture of participatory governance	Institutional empowerment and platform construction; Multi-level capacity cultivation system; Cultivation of community consciousness
Technological Adaptation	The "high center and low periphery" pattern (standard deviation 0.33) makes the elderly population face digital exclusion	The uneven distribution of technological resources exacerbates the problem of social equity	Mechanism IV: Deepen the adaptability of technology empowerment	Data-driven governance support; Build a "government-enterprise-public" collaborative platform; Inclusive technology application

### 5.1. Mechanism I: innovate institutional supply for safe and resilient communities

Guided by multi-center governance theory, institutional supply sustainability requires transcending short-term projects to address collective action dilemmas. Corresponding to the high homogeneous scores in Beijing's institutional supply (4.44), the key issue lies in insufficient policy flexibility. This mechanism aims to upgrade the system from a "guarantee" to a "resilience engine" through legal and financing innovations:

**Legal guarantee:** Promote the compilation and implementation of the "Ecological Environment Code", solidify reform achievements into legal systems, and strengthen institutional links between environmental legislation, urban renewal, and CHSE governance. Nachmany and Hananel (2023) proposed the urban renewal matrix, providing a reference for the connection between institutional supply and urban renewal.

**Diversified financing:** Break fiscal dependence by establishing a model of "fiscal guidance + social capital participation + reasonable resident payment", including special central transfer payments, Public-Private-Partnership (PPP) projects, and market-oriented tools like tiered water pricing. Huang *et al.* (2023) explored the long-term performance-oriented incentive mechanism for balancing environmental and economic policies, providing a reference for the design of diversified financing mechanisms.

**Multi-subject collaboration:** Build a network of "government coordination - market operation - resident self-governance - social participation", clarify departmental responsibilities via action plans, and explore ecological compensation and resident convention-based incentive mechanisms. Lu *et al.* (2024) explored the adaptive governance of urban community renewal, providing a reference for the design of multi-subject collaboration mechanisms. Asibey *et al.* (2025) studied the climate resilience of urban socio-ecological systems, providing support for the construction of safe and resilient communities. Oxley (2013) proposed a people-centered framework for enhancing community resilience, providing an international experience reference.

### 5.2. Mechanism II: improve the multi-party co-construction for livable communities

This mechanism responds to the significant regional disparities in multi-party co-construction (standard deviation: 0.36), with peripheral areas scoring over 20% lower than central regions due to weak fiscal capacity and insufficient market participation. Drawing on Ostrom's multi-center governance theory (1990), the focus is on constructing a closed-loop system of shared responsibilities and benefits through vertical and horizontal institutional innovations:

**Vertical and horizontal coordination:** Establish a "central-local-grassroots" three-level linkage mechanism and cross-departmental/cross-regional coordination bodies, while clarifying enterprise environmental responsibilities via legislation. Chen *et al.* (2025) proposed a collaborative mobile government participation framework, providing a reference for the design of coordination mechanisms.

**Benefit and cost sharing:** Transform environmental governance into economic benefits for enterprises (via green credit), livelihood improvements for residents, and support for social organizations through government procurement and public welfare venture capital. Sánchez *et al.* (2025) studied social equity and community well-being in regional planning, providing a reference for the design of benefit sharing mechanisms.

**Win-win incentives:** Forge interest-based connections to enable all parties to realize value in co-construction, forming sustainable internal driving forces.

### 5.3. Mechanism III: cultivate a participatory governance culture for civilized communities

Empirical findings show a high correlation between cultural cultivation and technological adaptation ( $r > 0.8$ ) but insufficient endogenous motivation among residents. Guided by cultural sustainable design theory, this mechanism aims to transform residents from "passive recipients" to "value co-creators":

**Institutional empowerment and platforms:** Clarify legal participation procedures for residents in environmental planning and evaluation, and build an "online + offline" integrated participation platform to reduce participation costs.

**Capacity building:** Conduct community environmental education activities and train grassroots environmental supervisors with government subsidies.

**Community consciousness cultivation:** Foster cultural identity and value consensus through participatory activities, building an "emotional bond" for CHSE governance. Neuhoff *et al.* (2023) studied the forms of participatory future planning for urban sustainability, providing a reference for the cultivation of participatory governance culture.

### 5.4. Mechanism IV: deepen the adaptability of technology adaptation for smart communities

Technological adaptation exhibits a "high center and low periphery" pattern (average score: 4.13; standard deviation: 0.33), with risks of exacerbating the digital divide. Based on digital governance theory, technology is positioned as an "enabler" embedded in multi-party collaboration and cultural identity:

**Data-driven governance:** Build a "Digital Twin Community" platform integrating BIM and GIS technologies, and establish predictive models using meteorological, traffic, and environmental data. Bibri *et al.* (2024) analyzed the synergistic application of artificial intelligence and digital twin in smart cities, providing a reference for the construction of digital twin communities.

**Collaborative platforms:** Develop an environmental issue crowdsourcing APP to enable real-time

problem reporting and rectification progress tracking.

Inclusive application: Prioritize low-cost, easy-to-operate tools in peripheral areas, develop elderly-friendly smart devices, and establish digital inclusion guarantees to avoid social exclusion.

### 5.5. Comprehensive Implementation: a four-dimensional collaborative system

The four mechanisms form an interdependent organic whole: institutional supply as the guarantee, multi-party co-construction as the engine, cultural cultivation as the soul, and technological adaptation as the tool. Policy innovation requires their coordinated resonance—e.g., synchronizing resident capacity training with smart technology promotion, and clarifying supervision rules when introducing social capital. The implementation strategy of “pilot-summary-promotion” is recommended to verify the framework’s effectiveness and promote qualitative improvement in CHSE governance.

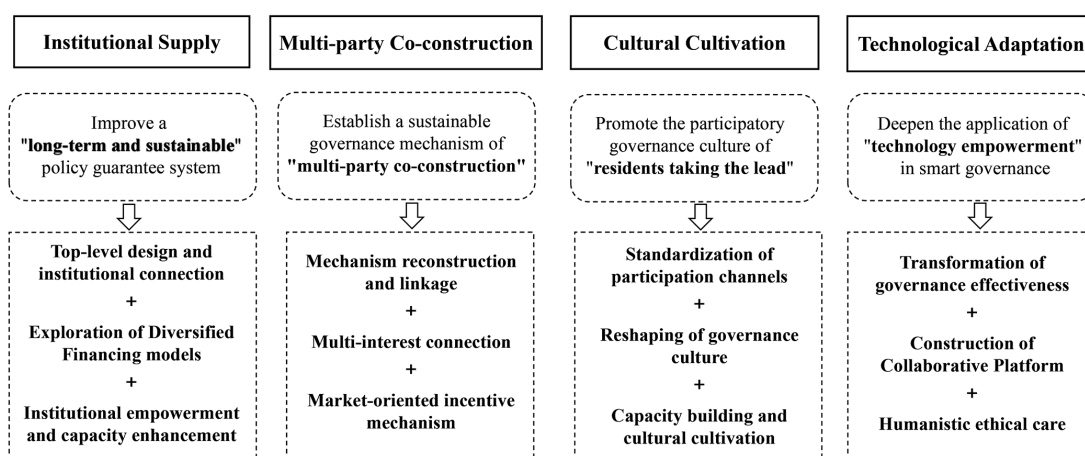


Fig. 4. Four-dimensional collaborative policy innovation framework for CHSE governance.

## 6. Conclusion and Policy Implications

This study has conducted scientific measurement and in-depth diagnosis from micro-community data to district-level governance levels by constructing a four-dimensional collaborative governance framework of “institutional supply - multi-party co-construction - cultural cultivation - technological adaptation”, and adopting a hybrid evaluation model combining AHP and spatial analysis. Based on the empirical research of 16 districts in Beijing, not only has the explanatory power of this framework been verified, but also the spatial differentiation law of CHSE governance and its profound policy implications have been revealed.

### 6.1. Theoretical contribution and innovative value

The theoretical contributions of this research are mainly reflected in three aspects:

Firstly, in terms of theoretical construction, it has broken through the limitations of traditional single-dimensional research, innovatively integrating human settlement science, sustainable development theory and multi-center governance theory, and proposed a systematic and operational four-dimensional

collaborative governance framework. This framework provides a new theoretical perspective for understanding “value co-creation” at the community scale.

Secondly, in terms of methodology, by integrating the AHP with GIS, an extensible evaluation model has been established, achieving a scientific transformation from micro-perception to macro-policy. This scale transformation method provides a new analytical tool for public policy research, especially having methodological innovation value in addressing the “scale paradox” of governance.

Finally, in terms of research findings, it goes beyond a simple description of the current situation and reveals the intrinsic connections and policy implications among various governance dimensions through spatial heterogeneity analysis. For instance, the “double-tail distribution” in the construction dimension reveals the urgency of financing mechanism innovation, while the high degree of synergy between the service and cultural dimensions provides empirical evidence for policy integration.

### *6.2. Policy implications and practical significance*

Based on the research findings, this study provides operational policy implications for governance subjects at different levels:

**Differentiated governance strategy:** Precise policy plans should be formulated based on the performance characteristics of each region in the four dimensions. For regions that are weak in the construction dimension, the focus should be placed on innovating investment and financing mechanisms; For those weak in the dimensions of service and culture, promote the coordinated development of facility construction and cultural activities.

**Long-term mechanism construction:** Promote the shift from “campaign-style governance” to “institutionalized governance”, especially by establishing stable and sustainable mechanisms in terms of financial guarantee, multi-party participation, and technological application.

**Digital governance Innovation:** Promote the construction of “Digital Twin Communities”, but it is necessary to pay attention to the adaptability of technology, avoid falling into the trap of “technology supremacy”, and ensure that the achievements of smart governance benefit all residents.

The evaluation framework and governance pathways constructed in this study are scalable and transferable. Other cities can draw on the indicator system, assessment methods and four-dimensional collaborative framework of this study, and carry out application innovation in combination with local realities to provide a practical toolkit for promoting the modernization of grassroots governance.

### *6.3. Research limitations and future directions*

This study has the following limitations, which also point out the direction for future research:

**Data timeliness:** Mainly based on cross-sectional data, it is difficult to capture the dynamic evolution process of governance effectiveness. In the future, it is necessary to establish a long-term tracking mechanism and conduct longitudinal research.

**Group diversity:** Insufficient attention has been paid to the differentiated needs of vulnerable groups such as the elderly and the floating population. Subsequent research should enhance inclusive governance innovation.

**Mechanism verification:** Although a theoretical framework of four-dimensional collaboration has been proposed, its interaction mechanism still needs to be verified and improved through more cases.

#### 6.4. Generalizability and transferability: from Beijing to global megacities

The four-dimensional governance framework and methodology design of this study are both transferable and context-sensitive. The universality of the framework stems from its theoretical foundation: the collaborative logic of institutional supply - multi-party co-construction - cultural cultivation - technological adaptation, rooted in the theories of sustainable development and multi-center governance (as described in Section 2.2), and can be applied to any high-density city facing the “scale paradox” (such as Shanghai, Mumbai or Sao Paulo). For instance, the localization requirements of SDG 11 have made the framework a bridge connecting global goals with community practices. Methodically, the scalability of the AHP-GIS model allows other cities to replace local indicators (such as replacing Beijing’s POI data with New York’s community facility data) for scientific assessment.

However, the particularity of the Beijing case lies in its administrative hierarchy and historical planning heritage—the capital’s functions lead to a higher concentration of resources than in ordinary cities. Therefore, parameters need to be adjusted when policies are transferred: In fiscally decentralized cities (such as the metropolitan areas in the United States), the multi-party co-construction dimension may rely more on market mechanisms rather than government dominance. A brief comparison shows that the flexibility of the framework supports differentiated applications. Future research can further verify its boundary conditions through cross-case comparisons (such as benchmarking analysis between Beijing and Shanghai).

In addition, Future research directions should include: Strengthening interdisciplinary integration and building a more complete human habitat system science; Explore community resilience governance in sudden scenarios such as climate change and public health events; Conduct global comparative studies to analyze the similarities and differences in governance models under different institutional backgrounds. Only by pooling efforts via multi-party governance, improving efficiency through intelligent technologies, laying a solid foundation through resident participation, and stabilizing expectations through policy guarantees can a profound transformation be achieved—specifically, the transformation of the human settlement environment from “survival-oriented” to “quality-oriented”, and that of communities from “unsustainable” to “resilient, symbiotic, and sustainable”, contributing practical wisdom at the community scale to global sustainable development.

#### Conflicts of Interest

The authors declare no conflict of interest.

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