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The coupling coordination relationship and promotion path of green economic efficiency and urban land development intensity: based on the case study of 283 prefecture-level cities

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The coordination and interaction of green economy efficiency (GEE) and urban land development intensity (ULDI) constitute a critical pathway toward achieving sustainable urban development. However, few studies have directly analyzed the coupling and coordinated mechanisms between GEE and ULDI, examining the coupling and coordinated relationship between GEE and ULD, and most have overlooked the interdependencies among the factors influencing their coordination. Focusing on 283 prefecture-level cities in China, this study constructs a comprehensive research framework, which includes analyzing interactive mechanisms between GEE and ULDI, evaluating the coupling and coordination degree between the two using a coupling coordination degree model, and identifying the driving factors and their configuration effects through the time-series qualitative comparative analysis (TSQCA) method. The results indicate that the coupling and coordination degree between GEE and ULDI in China increased from 0.479 in 2003 to 0.594 in 2019, with an average annual growth rate of approximately 1.34%, suggesting that China is currently in a transitional phase. The necessary condition analysis reveals that no single factor—whether governmental, market-based, or societal—constitutes a necessary condition for achieving high levels of coupling coordination. Five configurations promoting high coupling coordination and one configuration leading to non-high coupling coordination were identified. Based on these findings and the realities of Chinese cities, a Chinese paradigm of tripartite synergy among government, market, and society is proposed to promote the sustainable and coordinated development of GEE and ULDI.

KEYWORDS

China, coupling coordinated development, green economy efficiency, qualitative comparative analysis, urban land development intensity

1 Introduction

The dynamic interrelationship between economic development and land use has long stood at the forefront of debates on global sustainable development (Prabhakar, 2025). Despite striking disparities in development levels between developed and developing countries, both face acute sustainability challenges rooted in the inherent contradiction between the demand for economic growth and the finite capacity of urban land resources (Turok et al., 2023; Yanbo et al., 2023). Overcome the unsustainable trajectory of traditional growth models, the international community has collectively turned toward green economic strategies and more intensive modes of urban land utilization. For example, the Netherlands has been promoting the "compact city" policy, and managing idle land through land banks to prioritize its allocation to ecological projects (Bakker et al., 2015). Korea has taken a comprehensive strategy of compact urban development and territorial planning and land management, implementing land efficient use and low-carbon transition by regulatory mandates and market-based incentives (Cho et al., 2023). Singapore, meanwhile, has fused the green economy with land intensification by mandating vertical greenery and promoting multifunctional land use (Song et al., 2022). In China, a wide range of initiatives—such as the National Main Functional Zone Plan, low-carbon city pilots, new energy demonstration zones, and policies on green and low-carbon industrial land—have yielded notable progress in fostering both green economic transformation and intensive land use (Ma and Zhang, 2025; Nie et al., 2025; Wang and Chen, 2025). Compared to developed nations, China faces more severe challenges, as economic development has been accompanied by large-scale urban expansion and widespread inefficiencies in land use. This has led to the overconsumption of land resources, placing immense pressure on both the environment and urban infrastructure. During the process of urbanization, the expansion of cities often exceeds the land resources' carrying capacity, further intensifying the risk of unsustainable economic development. In this context, achieving effective coupling between green economic efficiency (GEE) and urban land development intensity (ULDI) becomes especially crucial. Moreover, China's land resources are relatively scarce, and regional disparities are pronounced. Therefore, promoting the coordination between these two factors requires tailored strategies for different regions, necessitating the exploration of driving pathways for their coordination development.

The green economic efficiency (GEE) reflects the economic efficiency of a country or region after considering resource depletion and environmental impacts (Zhao et al., 2020). The GEE can clearly demonstrate the relationship between economic development, resource consumption, and ecological environment impact, to support the development of green economy (Loiseau et al., 2016; Lorek and Spangenberg, 2014; Zhao et al., 2022). Previous studies have directly or indirectly measured GEE by constructing single factor GEE indicators or composite factor GEE indicator systems. Some scholars have constructed composite factor indicators to directly measure the efficiency of green economy. Pitt-man first included the cost of controlling environmental pollution as an unexpected output in the production function and used the Solow residual method to measure green economic productivity. In this way, scholars are gradually considering technology and other factors as new input factors, and haze, carbon emissions and other factors as new output factors to measure GEE (Chen et al., 2019). In terms of measurement methods, the DEA model can measure the efficiency of green economy under multiple input factors and multiple input–output scenarios, but due to the inability to consider the impact of input–output relaxation variables, the results can easily be biased (Liu et al., 2023). In recent years, scholars have mostly used the relaxation variable based SBM model (SBM) proposed by Tone and the super efficiency SBM model that can compensate for the problem of ranking decision units with multiple efficiency values of 1 in the SBM model to measure GEE (Liu B., 2023; Yang H. et al., 2023).

The urban land development intensity (ULDI) is a comprehensive evaluation of the current status of urban land development and utilization, which is often used as an important indicator to characterize the intensive use of urban land. Previous research has achieved certain results in terms of the conceptual connotation and quantitative measurement of ULDI. Some scholars define the concept of urban land development intensity from the perspective of the relationship between urban development and spatial control of construction land (Fu et al., 2025; Wang M. et al., 2025). Scholars are constantly expanding the connotation of ULDI based on the changing requirements of socio-economic development for urban land use, and selecting indicators from different perspectives to comprehensively evaluate ULDI. Some studies use a single indicator to measure the ULDI, such as the proportion of regional construction land area to regional land area (Fan, 2013), building density (Tang and Yiu, 2010), compactness (Yu P. H. et al., 2023), and plot ratio (Qiao et al., 2015). Some studies have constructed a composite indicator system from multiple levels to comprehensively evaluate the ULDI based on the functions and characteristics of urban land development in urban development (Chakrabortty et al., 2025; Luo et al., 2025). In summary, the concept connotation and evaluation index system construction of ULDI reflect the practical performance of urban land development. The practical manifestation of urban land development is that with the expansion of the quantity and scale of construction land, the reduction of arable land, forest land, water bodies, etc. meets the needs of social and economic activities (Yu et al., 2025). Socio economic activities can lead to changes in the level of urban land development, further altering the structure of construction land types (Fu et al., 2025). Based on existing literature and the practical performance of urban land development, ULDI includes a comprehensive representation of the scale of land space development based on breadth perspective, the benefits of land space development based on depth perspective, and the structure of land space development based on limit perspective.

Coupling coordination refers to the process of multiple systems interacting and influencing each other, ultimately tending towards a coordinated development state. The coupling coordination theory was first applied in the field of economic and social problem research, and gradually expanded to study the interactions and influencing relationships between various systems such as ecological environment, society, and economy (Cheng et al., 2023). Urban land is both the material and spatial carrier of production, living and ecological activities in economic development, and the most basic input element to promote urban economic development (Guo et al., 2025). The content of urban economic development will also be reflected in land development and utilization, which is manifested in the increase of construction land and the expansion and interaction of regional spatial scope (Zhou, 2025). There is a coupling coordination relationship between urban land development and utilization and green economic development

theoretically. Quantitative evaluation methods for coupling coordination relationships mainly include correlation analysis (Koçak and Şarkgüneşi, 2017), impulse response analysis (Guan and Jin, 2020), and coupling degree and coupling coordination degree models (Lu et al., 2016). With the increasingly severe problems of land resource depletion and environmental pollution in traditional economic growth, the application research field of coupling and coordination in the relationship between urban land and utilization and green economic development is expanding. The application of coupling coordination in the field of the relationship between urban land and utilization and green economic development has focused on exploring the relationship between economic growth and resource environment (Zhou et al., 2017), urbanization and resource environment (Reid et al., 2010), and urban land development and resource environment carrying capacity (Nakajima and Ortega, 2016; Ye et al., 2016). Furthermore, scholars have identified external factors that affect the coupling coordination relationship. It has been shown that the urbanization level, economic development level, population size, industrial development level and the level of opening to the outside world are the key influencing factors (Li et al., 2025; Yao et al., 2025). As such, three significant research challenges may be identified:

(1) Is there a coupling and coordination relationship between GEE and ULDI? How to measure the coupling and coordination relationship between the two? The existing literature has shown that there is a coupling and coordinated relationship between GEE and ULDI, but these literature only analyzed the one-way causal between GEE and ULDI. The research that directly explores the interaction between the two based on the coupling coordination theory is missing. Although there are also studies that have used the impulse response analysis method to verify the interactive relationship between the two (Hou et al., 2022), the theoretical discussion of the coupling and coordination mechanism between GEE and ULDI has been neglected.
(2) What are the key paths to promote the coupling and coordinated development between GEE and ULDI? The coupling and coordinated development between GEE and ULDI is a complex process, which is the result of the interaction of multiple external driving factors. Previous research has identified influencing factors of the coupling coordination degree (Gao et al., 2025; Zhang P. X. et al., 2025). But the ignorance of the concurrent mechanism of these factors to the coupling and coordination between GEE and ULDI is not conducive to exploring the specific path of urban sustainable development.

Therefore, this study takes 283 cities in China as the research unit, and on the basis of analyzing the coupling and coordination mechanism between GEE ULDI, the coupling and coordination relationship between GEE and ULDI is examined empirically by using the coupling and coordination model, and the spatial–temporal evolution characteristics of the and coordination degree are analyzed. In addition, the time series qualitative comparative analysis method is used to identify the key factors and their paths affecting the coupling and coordination degree from the perspective configuration.

This paper makes several theoretical and practical contributions. First, from the perspective of research innovation, it explores the interactive mechanism between GEE and ULDI through coupling coordination theory, revealing the driving factors and configurational mechanisms underlying their coordinated development. Second, in terms of research scale, unlike previous studies that focused on nations, regions, provinces, or individual cities, this paper examines all prefecture-level cities in China, providing a more comprehensive understanding of the spatial–temporal evolution of GEE–ULDI coordination. Third, methodologically, it breaks through traditional linear analytical frameworks by introducing the qualitative comparative analysis approach, identifying driving factors and their configurational paths from a multi-dimensional perspective.

2 Literature review and theoretical logic

2.1 Coupling and coordination mechanism between GEE and ULDI

Coupling coordination refers to the dynamic process in which multiple systems interact and influence each other, ultimately achieving a state of synergistic development. Theoretical and empirical evidence suggests that ULDI plays a crucial role in enhancing GEE, while green economic development, in turn, exerts a reciprocal influence on ULDI.

Firstly, ULDI exerts a significant impact on GEE. Urban land development serves as a fundamental driver of the spatial concentration of human and economic activities (You and Yang, 2017). The purpose of improving GEE is to achieve a virtuous cycle of economic growth and resource and environmental protection, ultimately achieving the unity of economic benefits, ecological benefits, and social effects (Wang Q. et al., 2025). Urban land development and utilization are the internal driving force behind the agglomeration of human social production activities in urban space (Sheng and Huang, 2025). At a certain level of ULDI, humans can achieve economic, social, and ecological benefits (Song et al., 2025). When optimized, ULDI generates synergies across economic, social, and ecological dimensions, yielding substantial efficiency and sustainability gains (Panagopoulos et al., 2016). As the material and spatial foundation for production, livelihoods, and ecological processes, urban land resources are indispensable for improving GEE (Shao and Deng, 2016; Shu et al., 2018). Moreover, ULDI enhances efficiency through agglomeration effects and economies of scale, fostering more effective resource utilization (Peng et al., 2017; Zhong et al., 2020). However, extensive and inefficient land use, along with pollution from industrial waste and carbon emissions, can seriously constrain the improvement of GEE (Cui et al., 2019; Guan et al., 2018).

Secondly, GEE also shapes the evolution of ULDI. The transformation of ULDI requires the conceptual and methodological guidance of green development. On one hand, GEE exerts a factor-driven effect, providing financial, technological, and resource support that facilitates efficient urban land utilization (Liao et al., 2023). Specifically, the improvement of GEE provides necessary financial support for urban land development and utilization, which constitutes the basic investment element of urban land development. The improvement of GEE mainly comes from the technological innovation of enterprises and the capital investment of local governments in innovation and research and development of enterprises (Liao and Li, 2023). With the improvement of GEE, these technologies, knowledge, and human capital have been continuously accumulated, providing superior technical support and financial support for urban land development (Hasan et al., 2023). The improvement of GEE has brought

new impetus to urban land development and utilization. On the other hand, the technological progress underpinning GEE enhances ULDI through efficiency improvement and environmental optimization. Essentially, technological innovation reconfigures resource allocation and optimizes industrial structures (Rehman Khan et al., 2023), thereby improving urban land use efficiency and mitigating environmental externalities (Fan et al., 2023; Liu Y., 2023; Wang, 2023). Furthermore, GEE promotes the structural upgrading and spatial optimization of urban land development through the rational adjustment of industrial structure and regional resource allocation (He et al., 2023; Wang, 2023). Consequently, GEE exerts a sustained positive effect on ULDI.

In summary, there exists a theoretically grounded coupling and coordination relationship between GEE and ULDI, reflecting their mutual promotion and synergistic development.

2.2 Factors influencing the coupling and coordination between GEE and ULDI

The coupling and coordinated development between GEE and ULDI is shaped by a variety of external environmental factors. According to configurational theory, outcomes arise from the joint and interdependent influence of multiple conditions, rather than a single determinant. In this context, various external factors may collectively enhance the degree of coupling coordination between GEE and ULDI. Meanwhile, the new institutional economics theory emphasizes the influence of government and market mechanisms on the efficiency of resource allocation, while social factors regulates the operation effect of government and markets (Keefer, 2025). Guided by these theoretical perspective, this study first identifies the governmental, market, and social environmental factors that influence the GEE–ULDI coupling system, based on a comprehensive review of existing research. Building upon this, an analytical framework grounded in configurational theory is constructed to examine the configuration effects of these external factors on the coupling and coordination between GEE and ULDI, as illustrated in Figure 1.

2.2.1 The relationship between governmental factors and the coupling coordination degree between GEE and ULDI

In the governmental dimension, the coupling and coordinated development of GEE and ULDI is primarily influenced by two aspects: fiscal support and environmental regulation.

Government fiscal support reflects the behavioral responses of local governments shaped by their fiscal conditions (Campos-Alba et al., 2021). On the one hand, local governments attract investment through land supply, expanding ULDI to generate fiscal revenue and economic growth, which in turn affects the coupling and coordination between GEE and ULDI (Tong D. et al., 2023). On the other hand, fiscal capacity determines public investment in infrastructure, which is essential for enhancing both urban efficiency and sustainability, thereby facilitating GEE–ULDI coordination (Yang R. X. et al., 2023; Zhou et al., 2023).

Environmental regulations exert a direct and profound influence on urban green economic development and land use dynamics (Xu et al., 2021). In China, imperfect market mechanisms and institutional frameworks often result in problems such as land underutilization, overdevelopment, and environmental degradation (Guo et al., 2023). Consequently, the government engages in macro-level regulation of construction land scale, land-use structure, and economic growth to guide sustainable land development and improve GEE, thereby shaping the degree of coupling coordination between GEE and ULDI (Niu et al., 2023).

2.2.2 The relationship between market-based factors and the coupling coordination degree between GEE and ULDI

The coupling and coordination between GEE and ULDI are practically manifested in the efficient allocation of urban land resources (Xie et al., 2021). The market plays a fundamental role in this allocation process. Among market environmental factors, domestic financial market development and foreign capital inflows are key forces that stimulate market dynamism and influence GEE–ULDI coordination (Sun and You, 2023).

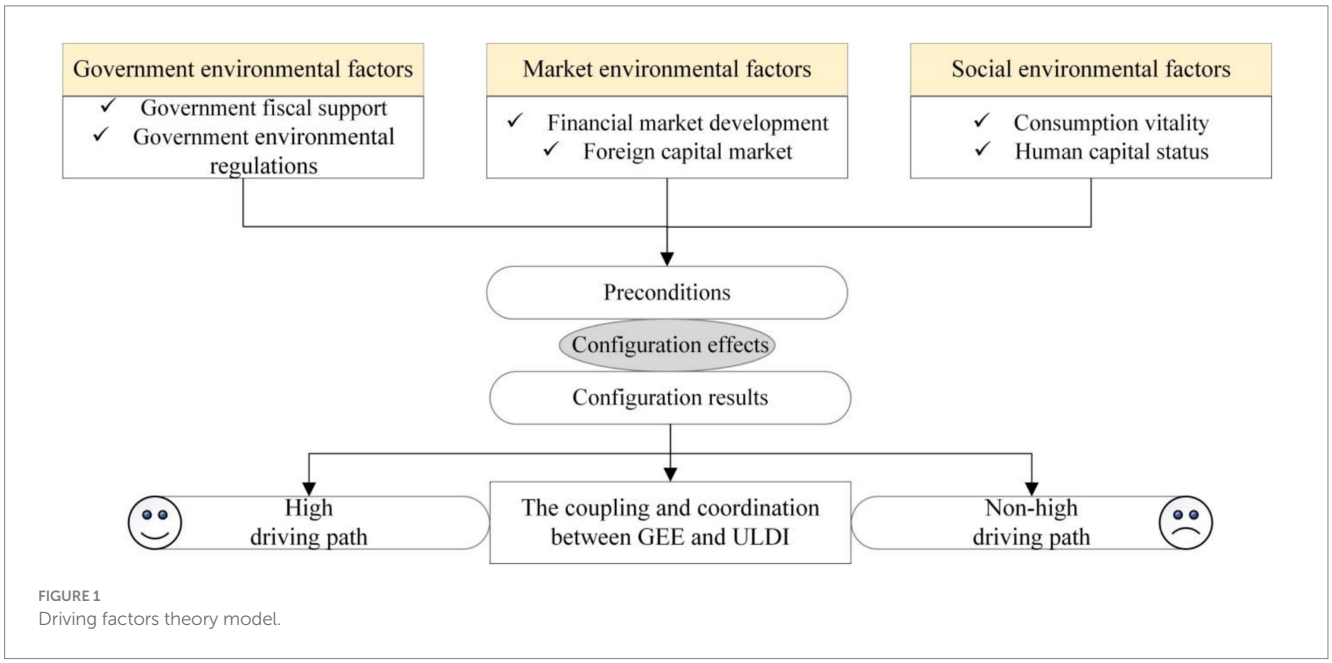

FIGURE 1
Driving factors theory model.

The development of domestic and foreign capital markets promotes GEE–ULDI coordination by shaping price mechanisms and supply–demand relationships. Market fluctuations alter production costs and resource allocation decisions of economic entities, leading to changes in land demand and supply dynamics (Cheng et al., 2023; Fan et al., 2023). The continuous interaction between land prices and market demand–supply relations fosters the spontaneous optimization of urban land allocation, thus advancing the coordinated development of GEE and ULDI (Haque and Asami, 2014; Desbordes and Wei, 2017).

2.2.3 The relationship between societal factors and the coupling coordination degree between GEE and ULDI

Social development constitutes the broader external environment underpinning both green economic transformation and urban land development (Cheba et al., 2023; Hong et al., 2023). With ongoing institutional reforms and policy innovation, China's social environment continues to improve (Shi and Mu, 2023). Two critical social environmental factors are consumption vitality and human capital conditions.

Changes in household consumption patterns and structures alter both the total demand and spatial structure of urban land development, providing momentum for land use optimization (Tong Y. et al., 2023; Yu S. et al., 2023). Rising income levels further drive demand for education, health, culture, and ecological services, fostering GEE improvement (Cheba et al., 2023). Therefore, consumption vitality serves as a key driver of the coupling coordination between GEE and ULDI.

Human capital, reflected in the size and quality of the urban labor force, is an intrinsic force shaping the GEE–ULDI coupling relationship (Xie et al., 2023; Yue et al., 2023). Rapid population growth influences urban land scale and spatial structure, while greater human participation in production and distribution enhances both land use efficiency and green economic output (Li et al., 2023) (de Oliveira et al., 2013). Thus, the quality and quantity of human capital are fundamental determinants of GEE–ULDI coordination.

2.2.4 The relationship between configurations of influencing factors and the coupling coordination degree between GEE and ULDI

Overall, the coupling and coordination between GEE and ULDI are shaped by the interplay of governmental, market-based, and societal factors. Importantly, these factors do not operate in isolation but rather interact synergistically through mechanisms of linkage and complementarity. Specifically, different configurations of these conditions may reinforce each other through mutual fit or offset one another through substitution, ultimately determining the degree and trajectory of GEE–ULDI coupling coordination.

3 Data sources and methodology

3.1 Research area and data sources

This study selects prefecture-level cities in China as the research sample, as illustrated in Figure 2. Considering data availability and completeness, a total of 283 prefecture-level and above cities are included in the final sample. The study period spans from 2003 to 2019.

Except for green patent data, which are obtained from the China Research Data Service (CNRDS) platform, all other indicator-related data are derived from authoritative statistical sources, including the China Urban Statistical Yearbook (2004–2020), the China Urban Construction Statistical Yearbook (2003–2019), various provincial and municipal statistical yearbooks, and the National Economic and Social Development Statistical Bulletins published during the study period. For a small number of cities with missing data in certain years, interpolation methods were applied to ensure the continuity and reliability of the dataset.

3.2 Method for measuring GEE

3.2.1 Indicators selection of the GEE

GEE is a measure of economic efficiency that comprehensively considers resource utilization and environmental losses (Zhao et al., 2020). Referring to existing literature (Hao et al., 2023; Liao et al., 2020), this study employed an "input-expected output-unexpected output" indicators framework for GEE measurement (Figure 3).

3.2.2 The super-efficient SBM model

The super-efficient SBM model is used to measure GEE. The formula is as follows:

$$p^* = \min \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1+\frac{1}{p_1+p_2}\left\{\sum_{r=1}^{p_1}\frac{s_i^+}{y_{rk}}+\sum_{h=1}^{p_2}\frac{s_h^{b-}}{b_{hk}}\right.} \tag{1}$$

$$s.t.\begin{cases} x_k = X\lambda + s^- \\ y_k = Y\lambda - s^+ \\ b_k = B\lambda + s^{b-} \\ \lambda \geq 0, s^- \geq 0, s^+ \geq 0, s^{b-} \geq 0 \end{cases} \tag{2}$$

where p^* is GEE. Supposing that there are n decision-making units in a green economy production system, and each unit is composed of m inputs, p_1 expected outputs, and p_2 unexpected outputs. s^-, s^+, and s^{b-} refer to the slack variables of inputs, expected outputs, and unexpected outputs, respectively. X, Y, and B represent the input matrix, the expected output matrix, and the unexpected output matrix, respectively. λ is a weight vector.

3.3 Method for measuring ULDI

3.3.1 Indicators selection of the ULDI

The ULDI is a comprehensive representation of the urban land development scale, urban land development benefits, and urban land development structure. Based on the concept of ULDI, a comprehensive indicator system is constructed from the above three levels to measure ULDI, as detailed in Figure 4.

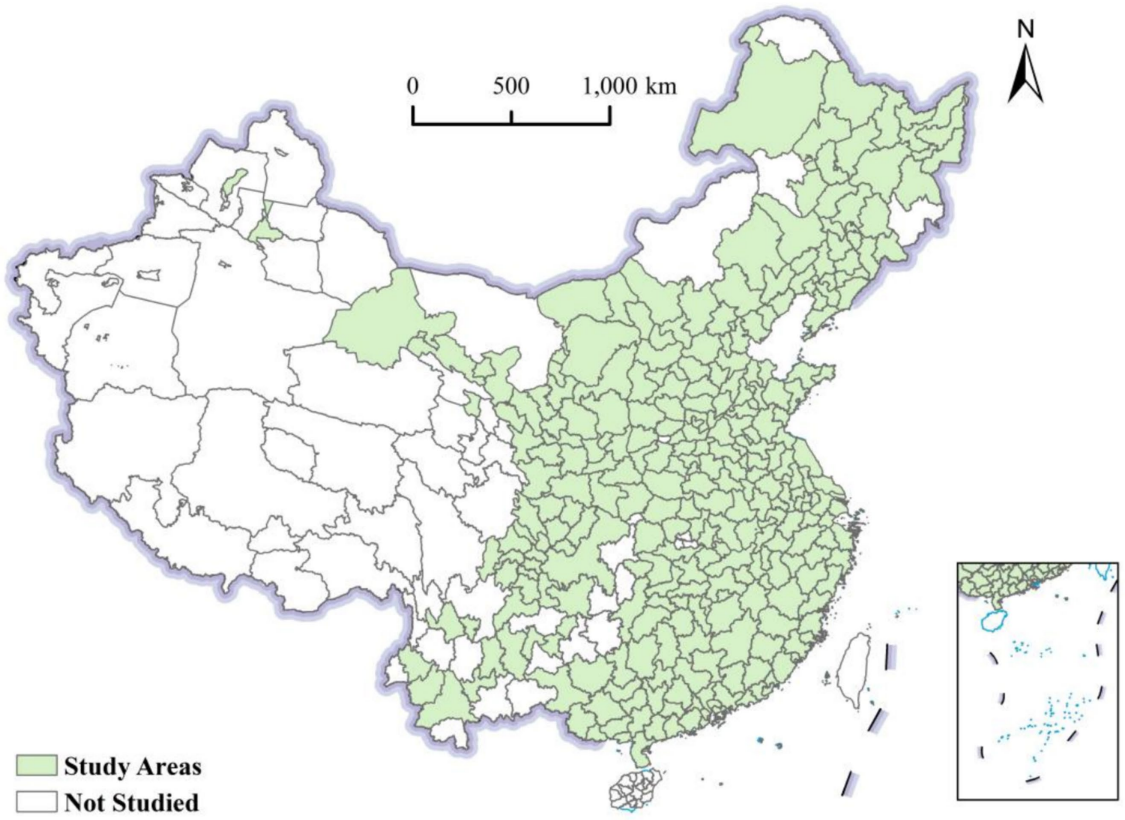

FIGURE 2
Research area.

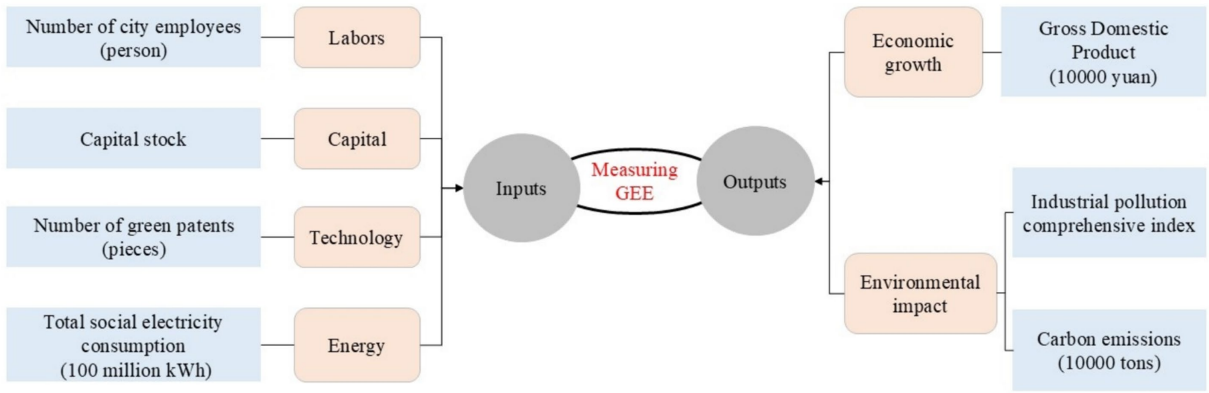

FIGURE 3
Evaluation index system for GEE.

3.3.2 The panel entropy method

Referring to existing research (Wu et al., 2019), we use the panel entropy method that introduces time to measure the intensity of urban land development. The evaluation model is as follows:

The first step is to select indicators.

If there are m cities, t years, and n indicators, then x_{ijk} represents the value of the k indicator in the j year of the i city.

The second step is to standardize the indicators.

Select the extreme value method to standardize different indicators with differences in dimensions and units. The standardized processing formula for positive and negative indicators is different.

The formula for standardizing positive indicators is as follows:

$$x`_{ijk} = \frac{x_{ijk} - x_{\min k}}{x_{\max k} - x_{\min k}} \quad (3)$$

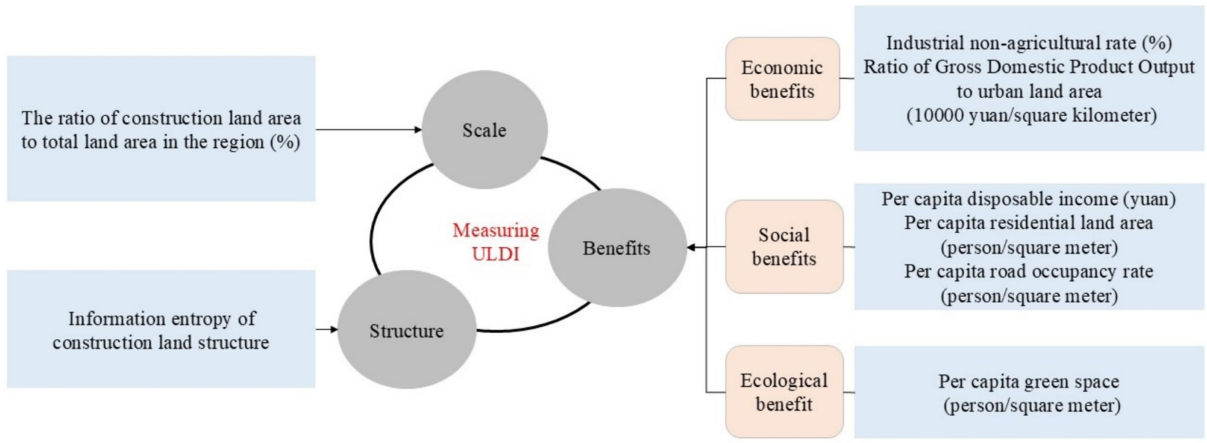

FIGURE 4
Evaluation index system for ULDI.

The formula for standardizing negative indicators is as follows:

$$x`_{ijk} = \frac{x_{\min k} - x_{ijk}}{x_{\min k} - x_{\max k}} \tag{4}$$

Where $x_{\min k}$ and $x_{\max k}$ represent the minimum and maximum values of the k indicator in the j year of the i city, respectively. The $x`_{ijk}$ obtained after standardization represents the relative size of x_{ijk} in m cities and t years, with values ranging from 0 to 1.

The third step is to determine the weight of the indicators. The formula is as follows:

$$y_{ijk} = x`_{ijk} / \sum_i \sum_j x`_{ijk} \tag{5}$$

The fourth step is to calculate the entropy value of the kth indicator. The formula is as follows:

$$e_k = -\frac{1}{\theta} \sum_i \sum_j y_{ijk} \ln\left(y_{ijk}\right) \tag{6}$$

Where $\theta > 0$, and $\theta = \ln\left(mt\right)$.

The fifth step is to calculate the information utility value of the k -th indicator. The formula is as follows:

$$g_k = 1 - e_k \tag{7}$$

The sixth step is to calculate the weight of the k-th indicator. The formula is as follows:

$$w_k = g_k / \sum_k g_k \tag{8}$$

The seventh step is to calculate the comprehensive score of ULDI for each city. The formula is as follows:

$$\mathrm{ULDI}_{ij} = \sum_k w_k x`_{ijk} \tag{9}$$

3.4 Method for measuring coupling coordination degree

The coupling coordination model is used to measure the coupling coordination degree between GEE and ULDI. The coupling coordination model is as follows:

$$\begin{cases} D = \sqrt{C \times T} \\ C = \sqrt{\dfrac{GEE \times ULDI}{\left(GEE + ULDI\right)^2}} \\ T = \alpha \mathrm{GEE} + \delta ULDI \end{cases} \tag{10}$$

where D is the coupling coordination value, representing the degree of GEE and ULDI. C is the coupling degree, which quantifies the degree of interaction and constraint between two systems. It is calculated using existing capacity coupling and capacity coefficient models for reference. T is the coordination degree, representing the comprehensive coordination index between GEE and ULDI, reflecting the overall synergistic effect of the two. Both α and δ are the undetermined coefficient. Considering that both are equally important in the relationship between GEE and ULDI, $\alpha = \delta = 0.5$ is set in the calculation process.

Referring to existing research, the coordinated development status of GEE and ULDI is divided into three stages and 10 levels based on the degree of coupling coordination, as detailed in Table 1.

3.5 Method for measuring configuration effects

3.5.1 Indicators selection of the influencing factors

The driving factors affecting the coupling and coordination between GEE and ULDI include a total of six secondary conditions under the three levels of governmental factors, market-based factors, and societal factors, as detailed in Figure 5.

3.5.2 The time series qualitative comparative analysis

Drawing on Hino (2009), this study employs the time-series qualitative comparative analysis (TSQCA) method to explore the configurational pathways through which government, market, and social environmental factors jointly promote the coupling and coordinated development between GEE and ULDI. TSQCA transforms time-series data into a QCA-compatible format, enabling the analysis of dynamic configurational evolution over time. According to the treatment of condition values, TSQCA can be classified into three types: summary-type QCA, solid-effect QCA, and time-lag QCA. Traditional QCA approaches—such as fuzzy-set QCA (fsQCA), crisp-set QCA (csQCA), and multi-value QCA (mvQCA)—are generally used to handle continuous, binary, nominal, or ordinal variables. Among these, the summary-type fuzzy-set TSQCA method, which is grounded in Boolean algebra, compares the configurational effects of individual cases while simultaneously accounting for temporal characteristics. This approach effectively captures complex causal relationships through set intersection logic and minimizes issues of case loss and contradictory configurations commonly observed in crisp-set TSQCA. Accordingly, this study adopts the summary-type fsQCA as the primary analytical method.

4 Spatiotemporal evolution characteristics of the coupling and coordination between GEE and ULDI

4.1 Temporal evolution characteristics of the coupling coordination degree between GEE and ULDI

This section shows the temporal evolution and trend characteristics of the coupling coordination between GEE and ULDI. Based on Equation 1–Equation 2, the GEE in China from 2003-2019 are calculated. Based on Equation 3–Equation 9, the ULDI in China from 2003-2019 are calculated. Based on Equation 10, the coupling and coordination results between GEE and ULDI in China from 2003 to 2019 are calculated, as detailed in Figure 6, and their temporal evolution characteristics are analyzed.

As shown in Figure 6, the average coupling coordination degree between GEE and ULDI ranges from 0.4 to 0.6, indicating that China is currently in a transitional stage of coordinated development. From 2003 to 2019, the CCD rose steadily from 0.479 to 0.594, reflecting a remarkable upward trend and suggesting that the overall coupling relationship between the two systems is improving. Specifically, most cities have shifted from a state of mild disequilibrium to basic coordination. Overall, the coupling process has experienced a cross-stage transformation—from a period of disordered interaction to a transitional phase—followed by continuous enhancement. During 2003–2019, China's GEE and ULDI entered an increasingly synergistic stage, characterized by the simultaneous advancement of both subsystems.

TABLE 1 Classification criteria for coupling coordination level.

Coupling coordination degree	Coupling coordination type	Coupling coordination stage
(0, 0.1)	Extreme imbalance	Dysfunctional decline period
(0.1, 0.2)	Serious imbalance	
(0.2, 0.3)	Severe imbalance	
(0.3, 0.4)	Mild imbalance	
(0.4, 0.5)	Near imbalance	Transition period
(0.5, 0.6)	Barely coordinated	
(0.6, 0.7)	Primary coordination	
(0.7, 0.8)	Intermediate coordination	Coupling coordination period
(0.8, 0.9)	Good coordination	
(0.9, 1.0)	High quality coordination	

4.2 Spatial dynamic variation characteristics of the coupling coordination degree between GEE and ULDI

We also used ArcGIS 10.2 software to visualize the spatial distribution of the coupling coordination degree between GEE and ULDI in 285 cities in China in 2003, 2009, 2014, and 2019, for analyzing the spatial reality pattern characteristics of the coupling coordination degree between GEE and ULDI, as shown in Figure 7.

As shown in Figure 8, the spatial distribution of the CCD between GEE and ULDI exhibits a clear east–west and south–north gradient, with higher values in the eastern and southern regions and lower values in the western and northern regions. Spatially, the coupling and coordination have formed structural cores around major urban clusters, including the Yangtze River Economic Belt, the Beijing–Tianjin–Hebei urban cluster, and the Guangdong–Hong Kong–Macao Greater Bay Area, gradually diffusing and diminishing toward surrounding areas. Cities in these regions have promoted the transformation and upgrading of economic structure by increasing the input of innovative elements, thus realizing the high-quality and specialized of industrial structure (Dong et al., 2022; Wu et al., 2025). In particular, the expansion and agglomeration of the tertiary industry and the gradual reduction of the secondary industry such as industry have led to a decrease resource consumption and environmental pollution, which has promoted the development of a green economy (Pu and Xia, 2025). At the same time, urban technological innovation, transformation and upgrading of industrial structure, and service industry agglomeration have also promoted the intensive and economical use of urban land and have promoted the improvement of ULDI (Zhang E. et al., 2025). Ultimately, it is manifested as an improvement in the coupling coordination between GEE and ULDI.

In terms of temporal evolution from 2003 to 2019, cities at different coordination levels exhibited distinct spatial trends. Cities classified as barely coordinated, primarily coordinated, or intermediate coordinated expanded spatially, whereas cities in the near-imbalance category exhibited a convergent pattern. Specifically, in 2003, only two

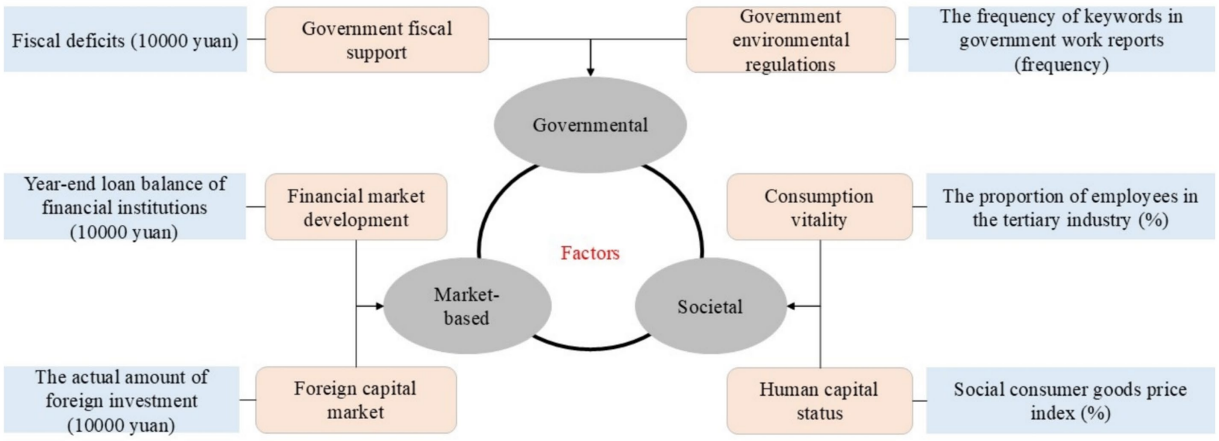

FIGURE 5
Evaluation index system for influencing factors.

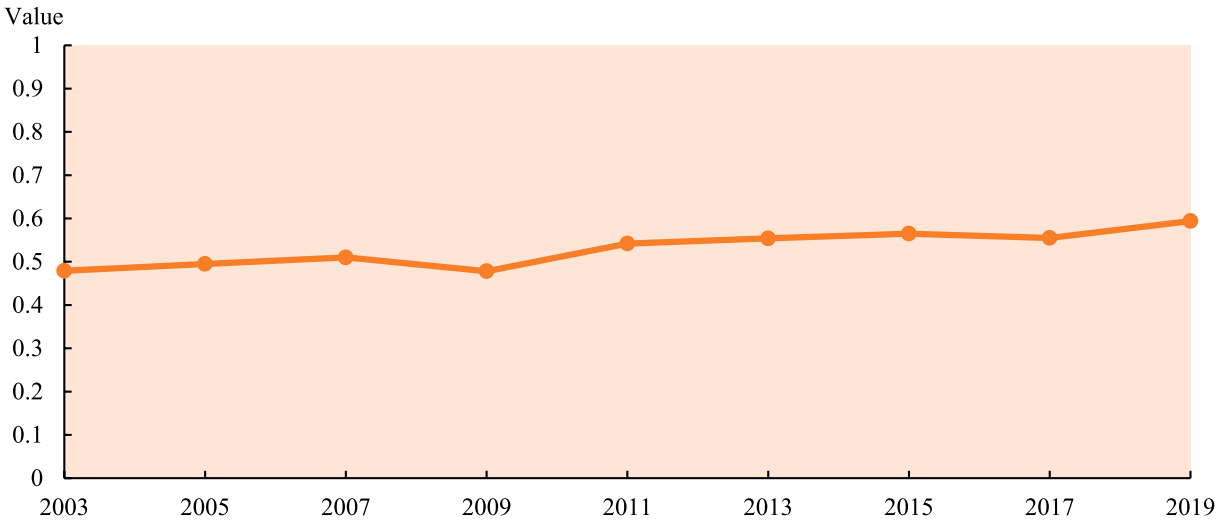

FIGURE 6
Measurement results of GEE-ULDI coupling coordination from 2003 to 2019.

cities were at the intermediate coordination level and one city achieved good coordination. The remaining cities included 161 near-imbalance cities, 78 barely coordinated cities, and 10 primarily coordinated cities. By 2019, the near-imbalance category had reduced dramatically to 16 cities, 154 cities reached a barely coordinated level, 92 cities were primarily coordinated, 15 were intermediate coordinated, three achieved good coordination, and three attained high-quality coupling. Notably, no city remained in the mild imbalance category by 2019, indicating a substantial upgrade in CCD across most Chinese cities.

5 Configuration analysis

5.1 Variable calibration

The first step in fsQCA analysis is to conduct variable calibration to determine the membership of each sample in each variable. Following existing studies (Fiss, 2011), this paper employs a direct calibration method to convert the original data into fuzzy-set membership scores. The key to the direct calibration method lies in the determination of the anchor point. In this paper, the anchor point is selected based on the frequency distribution of the data by referring to the existing research (Greckhamer, 2016). Ultimately, three calibration thresholds are defined: the full membership point, the crossover point, and the full non-membership point. The full membership point corresponds to the upper quartile (75th percentile) of the sample data, the crossover point is set at the median (50th percentile), and the full non-membership point corresponds to the lower quartile (25th percentile). Specifically, for each variable, we first calculates the mean value of the scores of each item, and then determines the anchor points and calibrates them according to the above criteria. At the same time, in order to avoid missing data caused by the fsQCA software excluding samples due to the complete equality of variable values and membership, we also refer to the methods

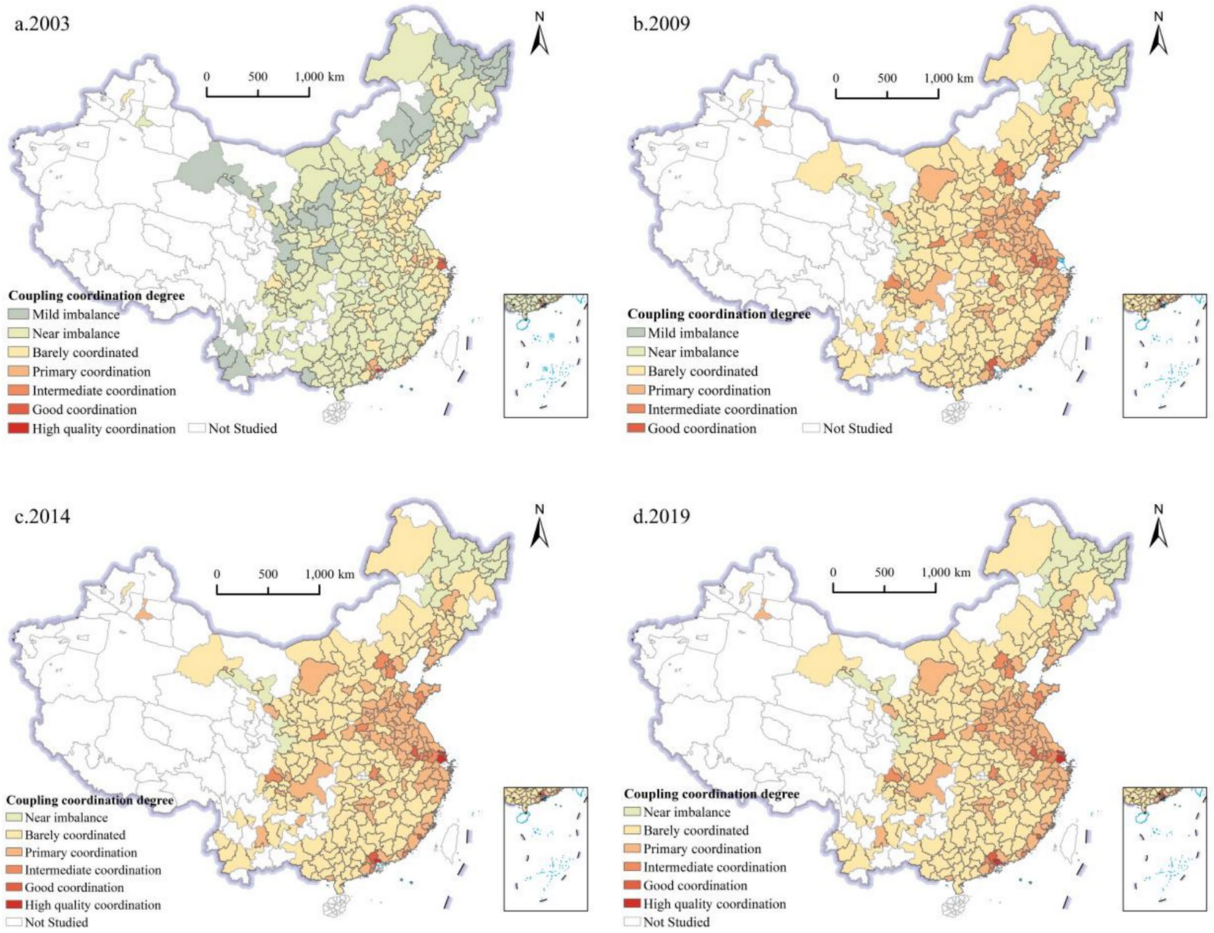

FIGURE 7
Geographical spatial pattern distribution of GEE-ULDI coupling coordination.

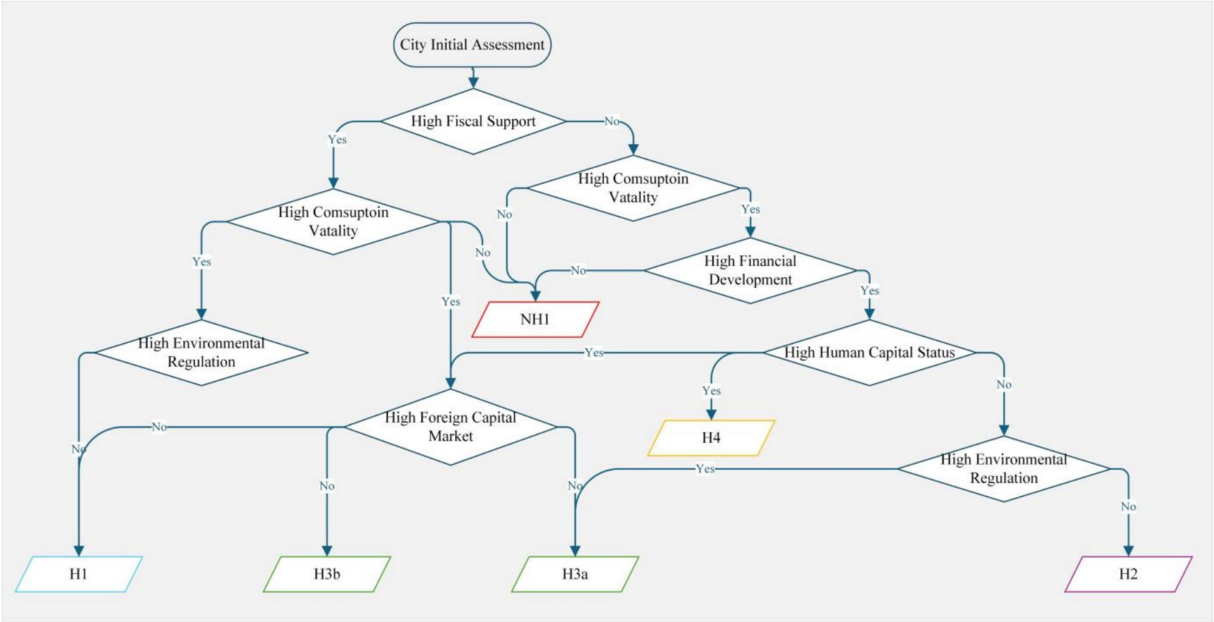

FIGURE 8
Decision tree model of realizing the GEE-ULDI coupling coordination.

adopted in existing research (Greckhamer, 2016), and adjust overlapping membership points (plus or minus 1‰) according to the actual distribution of the data.

5.2 Necessary condition analysis of single condition

Prior to the configurational analysis, it is essential to assess the necessity of individual conditions, i.e., to examine whether single government, market, or social environmental factors—or their negations—constitute necessary conditions for driving the coupling and coordination between GEE and ULDI (Table 2). The consistency value serves as the key indicator, with a typical threshold set at 0.9. As shown in Table 2, the consistency values for all individual conditions are below 0.9, indicating that none of these single factors alone can account for the necessary conditions of either high or non-high CCD between GEE and ULDI. This finding highlights the need to investigate the configurational effects of government, market, and social environmental factors, as it is their combination, rather than any individual factor, that drives the coupling and coordinated development.

5.3 Configuration analysis

This study employs fsQCA 3.0 to examine the various configurational combinations of multiple conditional variables that lead to either high or non-high coupling coordination between GEE and ULDI, representing distinct key pathways to the same outcome. Given the number of cases involved 283 cities, this paper set the original consistency threshold at 0.8, PRI consistency threshold at 0.7, and the case frequency threshold at least one case.

Table 3 shows that there are five configurations that promote high coupling coordination degree, including H1, H2, H3a, H3b, and H4. Because their core conditions are the same, H3a and H3b constitute a second-order equivalent configuration (Fiss, 2011). Each configuration path that influences high coupling coordination degree is analyzed in detail below. Table 3 presents five configurations that promote high coupling coordination: H1, H2, H3a, H3b, and H4. Since H3a and H3b share identical core conditions, they constitute a second-order equivalent configuration.

H1 demonstrates that high government fiscal support, high government environmental regulation, high financial market development, and high consumption vitality as core conditions, combined with non-high human capital status as a marginal condition, can achieve a high CCD between GEE and ULDI.

H2 shows that high government fiscal support, high financial market development, and high consumption vitality as core conditions, with non-high human capital status as a marginal condition, also lead to high CCD. Compared with H1, H2 lacks the core condition of government environmental regulation, illustrating the partial substitutability of regulation. This effect arises from two sources: (i) synergistic effects of financial market development and consumption vitality—financial markets can price environmental risks via green credit rates, while consumers' green preferences can partially compensate for weaker regulation (Raberto et al., 2019);(Tan et al., 2025); (ii) implicit environmental constraints embedded in fiscal support, e.g., subsidies or preferential land transfer for low-carbon projects, which replicate the effect of environmental regulation (Ahmed et al., 2023; Zhang J. et al., 2023).

H3a indicates that high government environmental regulation, high financial market development, and high consumption vitality as core conditions, together with non-high human capital status as a marginal condition, achieve high CCD. H3b has the same core conditions, but non-high foreign capital market serves as the marginal condition. Despite differences in marginal conditions, both configurations produce equivalent outcomes, demonstrating that as long as the action framework includes strong government regulation, robust market support, and demand pull from consumption vitality, cities can overcome limitations in marginal resources and achieve coordinated development.

H4 shows that even under high financial market development and high consumption vitality as core conditions, with non-high human capital and non-high foreign capital market as marginal conditions, high CCD can still be realized. Here, the synergy

TABLE 2 Necessary condition analysis results.

Conditional variables	High coupling coordination degree		Non-high coupling coordination degree	
	Consistency	Coverage	Consistency	Coverage
Government financial support	0.575	0.745	0.447	0.339
~ Government financial support	0.490	0.603	0.663	0.477
Government environmental regulations	0.535	0.771	0.382	0.322
~ Government environmental regulations	0.530	0.595	0.728	0.477
Financial market development	0.618	0.783	0.414	0.306
~ Financial market development	0.452	0.569	0.707	0.520
Foreign capital market	0.535	0.679	0.546	0.405
~ Foreign capital market	0.531	0.667	0.567	0.416
Human capital status	0.503	0.632	0.618	0.453
~ Human capital status	0.565	0.717	0.499	0.370
Consumption vitality	0.625	0.785	0.411	0.301
~ Consumption vitality	0.444	0.563	0.708	0.524

TABLE 3 Results of configuration analysis.

Conditions	High coupling coordination degree					Non-high coupling coordination degree
	H1	H2	H3a	H3b	H4	NH1
Government financial support	●	●				⊗
Government environmental regulations	●		●	●		
Financial development		●	●	●	●	●
Foreign capital market	●					●
Human capital status	⊗		⊗			●
Consumption vitality	●	●	●	●	●	⊗
Consistency	0.867	0.837	0.868	0.894	0.874	0.804
Raw coverage	0.131	0.241	0.251	0.211	0.174	0.078
Unique coverage	0.007	0.037	0.046	0.082	0.015	0.078
Overall solution consistency	0.853					0.804
Overall solution coverage	0.422					0.078

[a]● Indicates the existence of core conditions; [b]⊗ indicates the absence of core conditions.

between the two core conditions drives GEE improvement and ULDI optimization, creating a positive feedback loop between funds and demand. This configuration can compensate for deficiencies in human capital and foreign investment, enabling cities to achieve sustainable development.

Table 3 also indicates a single configuration (NH1) leading to non-high coupling coordination between GEE and ULDI. NH1 shows that in the absence of high government fiscal support and high consumption vitality, even when financial market development, foreign capital market activity, and human capital are high, the coupling and coordination between GEE and ULDI remain low. This underscores the irreplaceable role of government leadership in promoting coordinated development. While financial capital, foreign investment, and human resources contribute to the process, their effectiveness is limited without government guidance.

6 Discussion

This study aims to theoretically explore the coupling and coordination mechanism between GEE and ULDI, assess their current level of interaction, and empirically identify the key external driving factors and their configurational effects on the coupling and coordinated development between the two. Based on this analysis, the study examines both pathways that promote coupling and coordination as well as those that may hinder it, with a view to achieving sustainable urban development.

First, the results indicate that, by 2019, the coupling and coordination degree between GEE and ULDI in China was barely coordinated, still in a transitional phase. The coupling and coordinated development reflects the dynamic balance between socio-economic demand and natural resource supply (Hou et al., 2022). This essentially reflects that the inertia of the traditional extensive development path is still continuing, and the speed and scale of land development have not yet been fully converted into green intensive and efficient output. To crack this dilemma and promote the two to evolve to a higher level of synergy is an important goal for the sustainable development of Chinese cities in the future. In practice, China has put forward Ecological Civilization Construction and People-centered New-type Urbanization strategy, in which the overall planning of production, living and ecological spaces is clearly proposed. The establishment and implementation of this territorial spatial planning system, the disorderly expansion of urban development is constrained from the source (Fang and Yu, 2016; Pan, 2018). Meanwhile, the continuous investment in green technology innovation in China under the goal of achieving "double carbon" is encouraging various cities to explore a new model of industrial that is "low land consumption and high value-added output" (Zhang Y. et al., 2023). China is transforming the binding constraints of urban land resources into a reverse incentive mechanism for economic transformation through these institutional designs, guiding the green development of the urban economy. And China is moving towards a higher level of dynamic equilibrium between GEE and ULDI through governance and innovation-driven development, which is an important practice path for to enter a stage of high-quality development.

Second, we used necessary condition analysis and the single-factor necessity test in fsQCA to determine whether a single influencing factor-governmental, market-based, or societal factors would affect the coupling coordination degree between GEE and ULDI. The necessary condition analysis shows that no single governmental, market, or societal factor alone can explain either high or non-high levels of coupling coordination. While previous research has used conventional econometric regression methods such as the panel model, spatial statistical models, and geographically and temporally weighted regression to identify influencing factors of the coupling coordination degree (Gao et al., 2025; Zhang C. H. et al., 2025). Moreover, these studies mainly focused on the impact of a single factor on the coupling and coordinated development and used quantitative analysis methods to identify their independent impact and quantify their net effect. Thus, the findings of this paper are complementary to existing research.

Third, according the results of configuration analysis, this study refines a Chinese paradigm of tripartite synergy—government, market, and society—for driving GEE and ULDI coupling and

coordination. This paradigm can be summarized in four dimensions: first, establishing a regulatory bottom line through government environmental regulation; second, providing development momentum via government fiscal support and financial market development; third, enabling value transformation through consumption vitality; and fourth, defining the potential boundaries of exogenous resource substitution under "non-high" conditions of foreign capital markets and human capital. For sustainable urban development in China, this paradigm offers a systematic approach to escape the "pollute first, treat later" trap and overcome resource constraints, providing valuable insights for other countries seeking sustainable pathways by enhancing GEE and optimizing ULDI. Moreover, this paradigm also allows for diversity and differentiation in specific combination pathways, serving as a guide for urban sustainability. Only by accurately matching urban endowments with pathway conditions can cities leap from a "low-coordination trap" to "high-quality coupling." Accordingly, this study further examines city types and their corresponding enabling configuration pathways, applying the five high-coupling configurations and one non-high coordination configuration, and proposes differentiated policy combinations tailored to local development conditions (Figure 8).

(1) The coupling and coordination pathways between China's GEE and ULDI highlight the crucial role of endogenous government policies and consumer demand. Without effective government fiscal support and consumption vitality, high-level coordination is difficult to achieve, as illustrated by the NH1 pathway—even when foreign investment, financial capital, and human capital are present. H1 shows that in cities with low human capital but strong government fiscal support, environmental regulation, foreign investment, and consumption vitality, financial development is not essential for achieving high coupling and synergy between GEE and ULDI. Typical examples include first-tier or new first-tier cities such as Beijing, Shanghai, and Shenzhen. In practice, these cities promote sustainable development by: establishing green infrastructure funds to subsidize low-carbon urban land development; enforcing "dual carbon" land transfer standards; issuing green REITs; and stimulating consumption vitality through mechanisms like carbon credit systems, allowing property tax deductions for purchasing green buildings.
(2) H2 indicates that in cities with low human capital but high fiscal support, financial development, and consumption vitality, both government environmental regulation and foreign capital markets are unnecessary for achieving high coupling and coordination. Such cities, typically high-income coastal cities like Hangzhou or Xiamen, face relatively low environmental pressure and rely on targeted fiscal subsidies, consumption guidance, and financial instruments for green development, alongside self-regulating market mechanisms such as voluntary carbon trading.
(3) H3a demonstrates that in cities with low human capital, high environmental regulation combined with strong financial services and consumption vitality can achieve high coupling coordination, without the need for fiscal support or foreign capital. H3b similarly shows that in cities with limited foreign capital, high government environmental regulation and strong financial and consumption conditions can achieve the same outcome, independent of fiscal support and human capital. Examples include Lanzhou and Taiyuan, which, despite brain drain and limited human and foreign capital, leverage strong policy enforcement to promote urban green upgrading. Conversely, cities such as Tangshan and Xuzhou, with low coupling coordination, should intensify environmental regulation to address historical industrial pressures, insufficient human capital, and limited foreign investment.
(4) H4 illustrates that cities with low human capital and foreign capital markets can achieve high coupling coordination through robust financial development and consumption vitality, without relying on government fiscal support or regulation. Typical examples are third- and fourth-tier cities such as Luoyang and Xiamen. These cities can bypass traditional high-cost policy instruments and achieve positive feedback between green economy and urban land development through a dual-engine model of financial development and consumption vitality.

In summary, this study offers valuable theoretical and practical insights but has certain limitations that point to future research directions. First, the GEE and ULDI index systems require further refinement. While this study establishes evaluation frameworks based on existing literature and Chinese practice, there is currently no unified authoritative measurement system. Future research should incorporate additional indicators to create a richer, more practically aligned evaluation system. Second, government, market, and social factors were identified as core conditions, and this result remains robust across different calibration points and case frequency thresholds, reinforcing prior findings regarding drivers of GEE-ULDI coupling. However, the large sample size may contribute to this robustness, which warrants further investigation. Finally, updating GEE and ULDI data in future research is essential to capture the latest trends in urban sustainability.

7 Conclusion

Realizing the coupling and coordinated development of GEE and ULDI is a critical pathway toward sustainable urban development. Building on an analysis of the coupling and coordination mechanism between GEE and ULDI, this study employs a coupling coordination model to quantitatively measure the degree of coupling and coordination, and utilizes the time series qualitative comparative analysis (TSQCA) method to identify the key driving factors and their configurational effects on the coupling and coordinated development of China's GEE and ULDI. The main findings are as follows.

First, using the coupling coordination model, the spatio-temporal patterns of the coupling coordination degree between GEE and ULDI were calculated and analyzed. The results show that the mean coupling coordination degree ranges from 0.4 to 0.6 during the study period, indicating that China remains in a transitional stage of coupling and coordinated development. Spatially, the coupling coordination degree exhibits a clear pattern of "high in the east and low in the west" and "high in the south and low in the north."

Second, the study theoretically analyzes the direct effects and configuration effects of governmental, market-based, and societal factors on GEE-ULDI coupling and coordination, and tests these relationships empirically using fsQCA. The necessary condition analysis shows that no single governmental, market, or societal factor alone can explain either high or non-high levels of coupling coordination. Rather, the observed coupling coordination outcomes are attributable to the synergistic configuration of these factors. Specifically, five configurations (H1, H2, H3a, H3b, H4) were identified as promoting high coupling coordination, while one configuration (NH1) leads to non-high coupling coordination.

Finally, based on the theoretical and empirical findings, a Chinese paradigm of tripartite synergy—government, market, and society—can be refined for promoting GEE-ULDI coupling and coordination. This paradigm involves: setting the bottom line through government environmental regulation, providing development momentum through fiscal support and financial market development, and achieving value transformation through consumption vitality. Meanwhile, external resources such as the foreign capital market and human capital status play a substitutable role in achieving coupling coordination. Ultimately, only by accurately matching urban endowments with appropriate pathways can cities break free from the "low coordination trap" and achieve high-quality coupling.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: http://www.tjcn.org/.

Author contributions

JH: Writing – review & editing, Writing – original draft. XZ: Conceptualization, Writing – review & editing, Funding acquisition. ZQ: Visualization, Software, Writing – review & editing. ZM: Writing – review & editing, Software, Data curation, Methodology. XL: Supervision, Conceptualization, Investigation, Writing – review & editing. ML: Writing – review & editing, Funding acquisition, Methodology. XC: Writing – review & editing, Software, Methodology. MC: Resources, Writing – review & editing, Software, Formal analysis. XF: Formal analysis, Visualization, Writing – review & editing, Supervision, Conceptualization.

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Conflict of interest

ZQ was employed by Hontye Inteliigence Land Technology Consulting Co., Ltd.

The remaining author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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