Interactions Among socio-economy Systems, Urban Green Spaces, and Ecological Corridors: A Case Study of Kunming Using Entropy Weight and Coupling Coordination Models

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Abstract. Kunming City in Yunnan Province, China, is currently undergoing development as the "Plateau Pearl and Green & Beautiful Spring City." The rapid growth of its socio-economy development increasingly conflicts with ecological conservation. Rationally assessing and enhancing the coordinated development among the three major subsystems socio-economy, urban green space, and ecological corridors,is an urgent issue requiring resolution for high-quality socio-economy development. This study adopts a dual perspective of ecological civilization and spatial governance, employing the entropy weight method and coupling coordination degree model to construct an evaluation framework. This approach addresses limitations in traditional research, such as subjective weighting and insufficient dynamic analysis, enabling objective and quantifiable assessment of coordination levels. This study employs the entropy weight method to calculate objective weighting for 26 indicators across Kunming's socio-economy system, urban green space system, and ecological corridor system from 2018 to 2024. Annual coupling coordination scores are computed to reflect developmental changes in these three systems, yielding comprehensive scores and coordination levels. Data primarily sourced from the Kunming Statistical Yearbook and the 14th Five-Year Plan for Biodiversity Conservation Implementation. and the 2024 China Natural Resources Bulletin. The study found that from 2018 to 2024, the comprehensive development level of Kunming's three systems exhibited a "fluctuating upward trend," with the comprehensive score rising from 0.199 to 0.699, indicating a significant enhancement in overall system resilience. The socio-economy system maintained its leading position, while the urban green space system faced the issue of meeting aggregate targets but lacking spatial equity, and the ecological corridor system grappled with the dilemma of "sound baseline conditions but poor connectivity." Finally, the study proposes a dual-track optimization s trategy of targeted green space enhancement, corridor network weaving: First, densify 5-minute green zones in new districts like Guandu and Chenggong to improve service equity.Second, prioritize restoring 75 high-density ecological corridor areas to connect urban parks with core ecological sources like Dianchi Lake and Jiaozi Mountain, forming an integrated ecological network of urban greenery, corridor connectivity, suburban greenery.

1 Introduction

Against the backdrop of China's rapid urbanization, harmonious coexistence between humans and nature constitutes a critical issue for sustainable ecological and economic development[1].China's 14th Five-Year Plan for New Urbanization Implementation advocates coordinating production, living, and ecological spaces, providing guiding principles for Kunming's Green and Beautiful Spring City initiative[2].Therefore, examining the interactions among Kunming's three major systems socio-economy, urban green spaces, and ecological corridors, can offer theoretical foundations and practical insights for regional high-quality development.Current academic research on urban system coordination predominantly employs entropy-based methods and coupling coordination degree models. For instance, Chen Lan et al. (2025) applied this model to examine the coordination between Kunming's agricultural economy and ecology[3] Zhang Xueke (2024) referenced ecological service value indicators in regional economic coordination studies, noting Kunming's 2020 coordination level as

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"barely coordinated"[4]. Existing studies predominantly focus on single ecosystems or dual-system coordination integrating agricultural economies[5, 6], lacking comprehensive research on socio-economy factors, urban green spaces, and ecological corridors. Indicator frameworks exhibit insufficient attention to spatial structural characteristics of ecological corridors specifically ecological source areas and corridor metrics[7]. Internationally, Forman (2014) proposed the theory of 'ecological corridor connectivity thresholds,' and Haase et al. (2014) developed a spatial measurement framework for the equity of green space services, providing important methodological support for this type of multi-system collaborative research [17,18]. This study analyzes the development of Kunming's socio-economy system, urban green space system, and ecological corridor system based on the entropy weight method and coupling coordination degree model. Using 2018–2024 as the sample period, it examines their integrated development status and internal coupling to provide decision-making support for synergistic optimization of Kunming's three-life spaces and achieving the Green and Beautiful Spring City goal[8].

2 Research Design

2.1 Study Area and Data Sources

This study examines Kunming City, Yunnan Province, from 2018 to 2024, analyzing the interactive relationships among the socio-economy system, urban green space system, and ecological corridor system. Research data were obtained from official databases such as the Kunming City 2022 Statistical Data, Kunming City 2024 National Economic and Social Development Statistical Bulletin, and Kunming City Biodiversity Conservation 14th Five-Year Plan Implementation Plan. Some data were sourced from the 2024 China Natural Resources Bulletin and the Study on Spatial Equity of Urban Public Green Spaces Based on Spatial Syntax.

2.2 Research Methodology

2.2.1 Entropy Weighting Method

The entropy weight method is an objective weighting approach derived from the concept of information entropy to eliminate biases caused by human factors. It assigns weights based on the amount of information contained within different indicator data. The fundamental principle is that an indicator with greater variability indicates a higher volume of information obtained, thereby warranting a correspondingly larger weight in the comprehensive evaluation.

The specific calculation steps are as follows:

(1) Data Standardization

Assume the number of research samples is m (i.e., the number of years, m=11) and the number of indicators is n (i.e., the total number of secondary indicators). Let X_{ij} denote the standardized value of the jth indicator for the ith sample (year) (i=1,2,...,m; j=1,2,...,n). Here, $\max X_{ij}$ and $\min X_{ij}$ represent the maximum and minimum values of the jth indicator, respectively. To avoid non-positive values, the normalized data requires a shift with a distance of 0.0001.

Positiveindicators :

$$X_{ij}=\frac{x_{ij}-\min(x_j)}{\max(x_j)-\min(x_j)} \quad (1)$$

negativeindicators :

$$X_{ij}=\frac{\max(x_j)-x_{ij}}{\max(x_j)-\min(x_j)} \quad (2)$$

Calculate the indicator value for the i-th sample of the j-th indicator:

$$p_{ij}=\frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \quad (3)$$

Calculate the entropy value for the jth indicator:

$$e_j=-k\sum_{i=1}^{m} p_{ij}\ln\left(p_{ij}\right),k=\frac{1}{\ln(m)} \quad (4)$$

Calculate the coefficient of variation for the jth indicator:

$$g_j=1-e_j \quad (5)$$

Calculate the weight for the jth indicator:

$$w_j=\frac{g_j}{\sum_{j=1}^{n} g_j} \quad (6)$$

Calculate the composite score for each year:

$$s_{ij}=\sum_{j=1}^{n} w_j \times p_{ij} \quad (7)$$

2.2.2 Coupling Coordination Model

The coupling coordination model is a framework for measuring the degree of interaction and coordinated development between two or more systems. This study references the coupling coordination model to evaluate the coordination level among Kunming City'seconomic and social system, urban green space system, and ecological corridor system.

The calculation formula is as follows:

(1) Calculate the coupling degree (C):

$$C=\sqrt{\frac{C_1\times C_2\times C_3}{\left(\frac{C_1+C_2+C_3}{3}\right)^3}} \quad (1)$$

(2) Calculate the comprehensive evaluation index (T):

$$T=\alpha C_1+\beta C_2+\gamma C_3 \quad (2)$$

(3) Calculate the coupling coordination degree (D):

$$D=\sqrt{C\times T} \quad (3)$$

In this study, the three major systems—socio-economy, urban green space, and ecological corridor are considered equally important. Therefore, $\alpha=\beta=\gamma=1/3$. Referencing existing research[9]and , the coupling coordination degree is categorized into 10 levels. The specific classification criteria are presented in Table 1.

Table 1. Coupling Coordination Level Table

Coupling Coordination Degree D Value Range	Coordination Level	Degree of Coupling Coordination
[0.0~0.1)	1	Extremely Uncoordinated
[0.1~0.2)	2	Severe imbalance
[0.2–0.3)	3	Moderate imbalance
[0.3–0.4)	4	Mild imbalance

[0.4–0.5)	5	Borderline imbalance
[0.5–0.6)	6	Barely Coordinated
[0.6–0.7)	7	Basic coordination
[0.7–0.8)	8	Intermediate Coordination
[0.8–0.9)	9	Good Coordination
[0.9–1.0]	10	Excellent coordination

2.2 Development of the Evaluation Index System

The evaluation indicator system constructed in this paper quantitatively assesses the coupling coordination among Kunming's three systems: socio-economic development, urban green spaces, and ecological corridors. It comprises 26 secondary indicators organized around three dimensions development level, spatial structure, and functional services exhibiting comprehensive coverage and strong operational feasibility, as shown in Table 2.

(1) socio-economy System: Drawing on studies by Chen Lan (2023), Zhang Xueke (2024), and others on regional economic coordination, nine core indicators were selected,total GDP, per capita GDP, tertiary industry share, per capita disposable income of urban residents, permanent resident population, urbanization rate, etc. to reflect regional economic vitality and public welfare levels.

(2) Urban Green Space System: Drawing upon Zhang Yuzheng's (2021) research on accessibility and equity of urban public green spaces[10]and landscaping data from the Kunming City 2024 Statistical Bulletin, we selected eight indicators: green coverage rate in built-up areas, per capita park green space area, total park green space area, free access rate of parks, urban road green space coverage rate, and investment in landscaping construction. These quantify the scale, quality, and service level of urban green infrastructure.

(3) Ecological Corridor System: Based on studies by Liu Fenglian (2023), Liang Qiuyan (2025), Li Zhiying (2023), and others on the ecological security patterns of plateau cities[11-13] and the Kunming Municipal 14th Five-Year Plan for Biodiversity Conservation, ten indicators were selected: ecological protection red line area, general ecological space area, number of nature reserves, forest coverage rate, soil erosion control area, and number of ecological restoration projects. These focus on regional ecological baseline protection, spatial connectivity, and restoration effectiveness.

The weights for all indicators were objectively calculated using the entropy weight method.

The specific steps are as follows: First, the raw data undergoes Min-Max normalization. Second, the information entropy value of each indicator is calculated using the formula: $e_j=-k\sum_{i=1}^{m} p_{ij}\ln(p_{ij})$. Third, the coefficient of variation is obtained based on: $g_j=1-e_j$. Finally, the final weight of each indicator is calculated through: $w_j=\frac{g_j}{\sum_{j=1}^{n} g_j}$. This method effectively avoids the bias caused by subjective weighting, ensuring the scientific rigor and impartiality of the evaluation results.

Table 2. Construction of the "socio-economy-Urban Green Space-Ecological Corridor" Three-System Indicator Framework

Primary indicators	serial number	Secondary indicators	unit	Indicator Attributes	Weight
socio-economy system	X1	Gross Regional Product (GDP)	100 million yuan	positive	0.087
	X2	GDP per capita	Yuan	positive	0.085
	X3	General public budget revenue	100 million yuan	positive	0.090
	X4	Primary industry share	%	negative	0.097
	X5	The proportion of secondary industry	%	positive	0.117
	X6	The proportion of the tertiary industry	%	positive	0.095
	X7	resident population	10,000 people	positive	0.082
	X8	urbanization rate	%	positive	0.086
	X9	per capita disposable income of residents	Yuan	positive	0.088
	X10	Growth rate of value added in high-tech manufacturing	%	positive	0.090
	X11	Growth rate of added value of equipment manufacturing industry	%	positive	0.083
socio-economy system	Y1	Forest coverage	%	positive	0.068
	Y2	forest area	10,000 mu/10,000 hectares	positive	0.039
	Y5	Number of scenic spots	indivual	positive	0.157
	Y6	Number of Geoparks	indivual	positive	0.116
	Y7	Number of national wetland parks	indivual	positive	0.041
	Y8	Number of species of higher plants	Ten thousand kinds	positive	0.088
	Y9	Number of vertebrate species	kind	positive	0.088
	Y10	Number of national key protected plant species	kind	positive	0.067
	Y11	Number of national key protected animal species	kind	positive	0.067
	Y12	park green space area	10,000 mu/10,000 hectares	positive	0.049
	Y13	Green coverage rate of built-up areas	%	positive	0.048
	Y14	Green space ratio in built-up areas	%	positive	0.048

	Y15	Forest and grassland ecological construction area	10,000 hectares/10,000 mu	positive	0.060
	Y16	artificial afforestation area	hectares	positive	0.064

Table 2. Construction of the "socio-economy-Urban Green Space-Ecological Corridor" Three-System Indicator Framework

Ecological Corridor System	Z1	Air quality good rate	%	positive	0.069
	Z2	Comprehensive Air Quality Index	Unit: mg/m³	positive	0.099
	Z4	Yangzonghai water quality category	kind	negative	0.124
	Z6	Average regional noise	dB(A)	negative	0.085
	Z7	Average traffic noise	dB(A)	negative	0.079
	Z9	Length of drainage pipes in built-up areas	10,000 kilometers	positive	0.080
	Z10	Built-up area	square kilometers	positive	0.073
	Z11	Density of drainage pipes in built-up areas	km/km²	positive	0.085
	Z12	Wastewater treatment rate	%	positive	0.082
	Z13	Centralized treatment rate of sewage treatment plants	%	positive	0.075
	Z15	Harmless treatment rate of domestic waste	%	positive	0.069
	Z16	clean energy power generation ratio	%	positive	0.080

3 Analysis of Coupling Characteristics Between socio-economy Development, Urban Green Spaces, and Ecological Corridor Systems

3.1 Measurement and Evaluation of the Comprehensive Development Level of the socio-economy-Urban Green Space-Ecological Corridor System

Overall, from 2018 to 2024, Kunming City's integrated development level across its three major subsystems socio-economy, urban green space, and ecological corridor exhibited an upward trend, with steadily improving system coordination. However, influenced by external environmental factors and internal structural adjustments, significant fluctuations were observed across different phases, as shown in Figure 1.

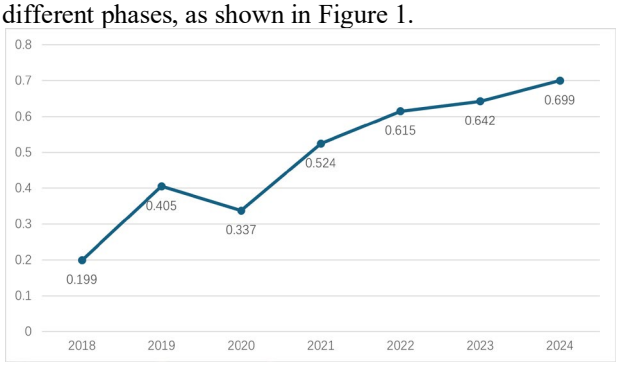

Fig. 1 Comprehensive Development Level of Kunming's "socio-economy-Urban Green Space-Ecological Corridor"three-subsystem, 2018–2024

From 2018 to 2020, Kunming's socio-economy system development level first experienced a slight decline before recovering rapidly. The comprehensive score reached 0.405 in 2019, a significant increase from 0.199 in 2018, but fell back to 0.337 in 2020. In 2020, the city's GDP growth rate slowed to 2.3%[16] , total retail sales of consumer goods decreased by 3.6% year-on-year, and the growth rate of fixed-asset investment shifted from 2.8% in 2019 to -13.6%[16] . However, thanks to the targeted implementation of the Six Priorities and Six Guarantees policies, the economy rebounded rapidly in the second half of the year. The tertiary sector's share of the economy rose against the trend to 64.2%, laying the foundation for subsequent growth. From 2020 to 2022, the composite score of the three systems surged from 0.337 to 0.615, demonstrating a sustained rapid upward trend. The socio-economy system performed particularly strongly, with GDP reaching 754.137 billion yuan in 2022 and the added value of high-tech manufacturing growing by 27.6%[16] . During 2022-2024, the composite score rose from 0.615 to 0.699, but the growth rate sharply declined, entering a high-level plateau phase. Although socio-economy development momentum remained strong, the overall coordinated development level remained low due to lagging development of the urban green space and ecological corridor system—comprising urban green areas and ecological corridors. The green coverage rate within Kunming's main urban area 5-minute living circles is only 57.26%[14] , failing to fully leverage the ecological network effects of green spaces. Furthermore, with fixed-asset investment declining by 12.0% year-on-year[16] , this indicates that following economic transformation, the city's traditional investment-driven growth model has reached its limits, necessitating a shift in strategy.

(1) Integrated Analysis of Three Systems

From 2018 to 2024, the integrated development level of Kunming's socio-economy system, urban green space system, and ecological corridor system exhibited an overall fluctuating upward trend. The coupling coordination index rose from 0.143 (severe imbalance) in 2018 to 0.983 (excellent coordination) in 2024, transitioning from imbalance to coordination and achieving leapfrog development. This transformation primarily resulted from substantial policy interventions and structural adjustments implemented after 2022: In 2022, the composite score for the three systems reached 0.615, with a coupling coordination index of 0.925 (primary coordination). By 2023, the composite score increased to 0.642, and the coupling coordination index rose to 0.889 (intermediate coordination). After 2020, Kunming began to implement an integrated governance approach at the spatial level, through measures such as ecological protection redline demarcation and optimized

territorial spatial planning, which effectively alleviated spatial conflict hotspots within its production-living-ecological spaces under the "Green and Beautiful Spring City" initiative [15] . However, despite rapid improvements in coordination levels, imbalances persist. Economic and social development shows strong momentum (2024 score: 0.145), while urban green space systems (score: 0.349) and ecological corridor systems (score: 0.206) underperform. Kunming's development coordination remains dominated by economic unilateralism. The mutually reinforcing effects between green veins and green networks require further amplification, with the entire system still operating at an early developmental stage characterized by high economic performance, moderate ecological status, and low equity.

(2) Analysis of Each Subsystem

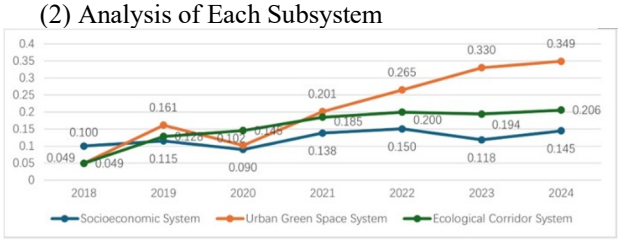

Fig. 2. Comprehensive Development Level of Kunming's "socio-economy-Urban Green Spaces-Ecological Corridors" Subsystems, 2018–2024

The comprehensive score of the economic subsystem steadily increasedsteadily increased from 0.100 in 2018 to 0.145 in 2024, achieving an average annual growth rate of 6.3%. Data indicates that the growth rate of high-tech manufacturing value-added reached 43.1% in 2020 and surged to 107.6% in 2022; By 2024, high-tech manufacturing accounted for 17.7% of added value, while equipment manufacturing represented 16.8%[16] . This confirms Kunming's transition from a traditional resource-dependent economy to a high-quality development model driven by new productive forces, as illustrated in Figure 2. However, due to systemic internal issues, GDP declined to 2.3% in 2020, with general public budget revenue plummeting by 26.7%, indicating high sensitivity to global economic shocks. Yet recovery accelerated rapidly in 2023, with GDP rebounding to 786.476 billion yuan. Nevertheless, fixed-asset investment in 2024 remained at -12.0%[16] . Table 2 clearly shows that the urban green space subsystem score increased from 0.049 in 2018 to 0.349 in 2024, a 612% rise, making it the fastest-growing among the three major systems. This primarily resulted from Kunming's sustained investment in landscaping and green space. By 2024, the green coverage rate in built-up areas reached 44.1%, with per capita park green space area at 13.9m^2, meeting all requirements for a national garden city. Research indicates that the green space coverage rate within a 5-minute living circle in Kunming's main urban area is only 57.26%, meaning most residents cannot conveniently enjoy the benefits of green space[14] . Further categorizing residents based on green space accessibility into highly coordinated[10] and accessibility-lagging groups reveals significant spatial inequity in green space distribution. This overall compliance with standards yet localized shortages issue hinders coordinated socio-economy and systemic development, emerging as a critical bottleneck in enhancing overall coordination levels. The ecological corridor subsystem score ranged from 0.049 to 0.206, increasing year by year; Kunming City has a relatively good ecological foundation: the forest coverage rate reached over 45.27%; the area of ecological protection zones was 4274.7 km^2 (accounting for 20.34% of the land area), and the number and area of nature reserves ranked among the top in the province. However, the ecological network exhibits structural weaknesses. Existing ecological risk assessment studies indicate that the Dianchi Lake basin is a high-risk area, with low-safety zones expanding in a ring-shaped pattern[9].

3.2 Analysis of Coupling Coordination Between socio-economy Development, Urban Green Spaces, and Ecological Corridors

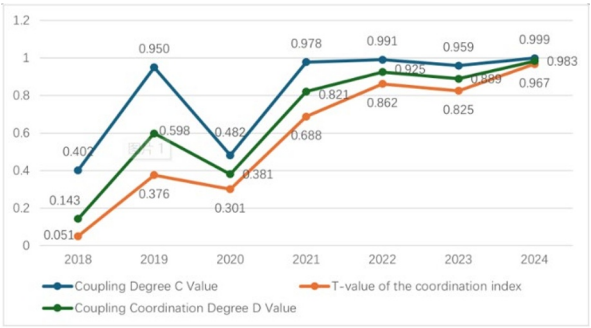

Fig. 3.g Coordination Analysis Results for Kunming City's "socio-economy Urban Green Space-Ecological Corridor" System (2018–2024)

From 2018 to 2020, Kunming's three systems experienced profoundly imbalanced coordinated development. with the coupling coordination index (D) marginally increasing from 0.143 (severe imbalance) in 2018 to 0.598 (barely coordinated) in 2019, only to plummet back to 0.381 (mild imbalance) in 2020. This reflects significant fluctuations and instability in system development during this period. These fluctuations occurred alongside the dual shocks of the COVID-19 outbreak and economic restructuring: GDP growth plummeted to 2.3% in 2020[16], fixed-asset investment declined sharply, and socio-economy development became severely sluggish. Compounded by delays in constructing urban green spaces and ecological corridor systems, the coupling relationships between systems were disrupted, driving coordination to its lowest point, as shown in Figure 3. By 2024, Kunming's three major subsystems entered a high-level coordination phase in the Green and Beautiful Spring City initiative, with coupling coordination rising from 0.821 (good coordination) in 2021 to 0.983 (excellent coordination) in 2024. This marked a significant leap in the Green and Beautiful Spring City initiative, demonstrating the remarkable effectiveness of its targeted strategic implementation. There are three core driving forces behind this: First, the top-level design and policy system have been effectively promoted. The 14th Five-Year Plan for Biodiversity Conservation in Kunming has delineated an ecological red line of 4,274.7 km^2, and the Overall Plan for the Ecological Corridor around Dianchi Lake has vigorously carried out ecological breakpoint restoration

work to ensure the connectivity of the ecological corridor. Second, accelerated development of new-quality productive forces. In 2024, the city's high-tech manufacturing output value grew by 47.3%[16], driving industrial transformation toward greener and higher-end sectors. This fundamentally alleviated the ecological constraints imposed by economic growth. Third, the service functions of urban green spaces have been precisely enhanced. Research indicates that after spatial optimization, Kunming's main urban area has extended its high-level coordinated public green spaces to the northern and southern new districts, improving coverage of previously underserved areas. This creates a virtuous cycle between green spaces and the economy, strengthening the synergistic effect of green space services on economic vitality and playing a crucial role in system coordination[10]. It is the combined effect of these three aspects that has propelled Kunming's three major systems from passive adaptation" to active coordination, achieving a crucial leap from quantitative to qualitative change in their coupling coordination.

4 Research Findings and Discussion

4.1 Research Findings

This study employs the entropy weight method and the coupling coordination degree model to measure the interactive relationships among Kunming's three major subsystems—socio-economy, urban green spaces, and ecological corridors—based on data from 2018 to 2024. Results indicate that the comprehensive development level of the three systems exhibits a fluctuating upward trend, with the coupling coordination index D value steadily increasing from 0.143 in 2018 (approaching imbalance) to 0.983 in 2024 (high-quality coordination), reflecting significantly enhanced inter-system synergy. However, development imbalances remain prominent: The continues to lead the way, with GDP reaching 827.522 billion yuan in 2024 and an urbanization rate of 83.54%. Although the total amount of urban green space meets the standards, spatial equity is insufficient, with the coverage rate of the 5-minute living circle being only 57.26%.[14]; The ecological corridor subsystem possesses a strong baseline but contains 75 ecological bottlenecks and 4 barrier points[11], which constrain the overall functionality of the ecological network.

4.2 Discussion

Zhang Xueke's (2023) evaluation of Kunming's increased coordination level was supported by this study, and it also highlighted the structural hazards that are at the root of the high level of coordination[4]. First, the ecological protection redline's strict limitations of 4,274.7 km^2 and the effective use of territorial spatial planning have all contributed to the successful mitigation of spatial problems[15].Second, the 47.3% increase in high-tech manufacturing output value in 2024, which has caused the accelerated development of new-quality productive forces, has shown that the economy is being decoupled from environmental pressure, which is why the industry is developing more economically than it would otherwise be.Third, spatial equity has increased thanks to targeted improvements in green space services[10].Therefore, the observed high coordination level reflects these synergistic developments.

5 Conclusion

In this study, the socioeconomic development, urban green spaces, and ecological corridors were combined in the athree-subsystem coupling coordination model, which was built and used for empirical analysis based on data from 2018 to 2024.The development of an objective entropy-weighted indicator system that fully covers the development level, spatial structure, and functional services that address subjectivity and static bias in conventional frameworks is the main source of its methodological innovation. It successfully addressed the research goals described in the introduction:

(1)Indicator system construction objective reached 26 indicators were integrated across three dimensions development level, spatial structure, and functional services systematically covering economic vitality, green space equity, and ecological connectivity.(2) The goal of identifying interactive relationships was achieved: Kunming's coordination level has improved from severe imbalance to high-quality coordination, despite ongoing challenges in green space spatial equity and ecological network connectivity that present opportunities for further optimization.(3) Bottleneck Diagnosis Objective Achieved: Identified insufficient 5-minute green coverage and 75 ecological bottlenecks. Future implementation should adopt a dual-track strategy of targeted green space enhancement,corridor network weaving: First, densify 5-minute green zones in new districts like Guandu and Chenggong; second, prioritize restoring areas with the highest species passage probability within ecological corridors, connecting urban parks to core ecological sources like Dianchi Lake and Jiaozi Mountain to build an integrated ecological network. This study still has room for improvement; for example, real-time remote sensing or point-of-interest indicators could be incorporated for more in-depth analysis.Future research may integrate land-use simulation scenarios from Liang Qiuyan(2025) to predict long-term coordinated evolution trends across three systems under diverse policy pathways[12], providing dynamic decision support for territorial spatial planning.

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