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Barriers to sustainable urban green space development: A case study of Chengdu, China

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Abstract

This study aims to identify the key obstacles impacting the sustainable development of urban green spaces (UGS) in China, using Park City Chengdu as a case study. The research employs the entropy-weight method and the coupling coordination degree model (CCDM) to assess the relationship between UGS development and economic growth. The obstacle degree model identified the key barriers, while interviews with university researchers, registered urban planners, landscape architects, government officials, and UGS management staff, along with policy document analysis, provide additional insights. Results show an upward trend in UGS and economic development with indirect, reinforcing effects. The degree of coordination has gradually improved, indicating better UGS sustainability. Key obstacles include pressure on UGS, maintenance challenges, land use conflicts, and spatial distribution imbalances. To address these issues, this study recommends several strategies, including enhancing policy coherence and interdepartmental collaboration, strengthening pollution control, and optimizing the distribution and quality of green spaces, introducing diverse funding sources, facilitating value transformation, ensuring adequate green space construction and maintenance funding, and integrating new technologies to improve management efficiency for long-term sustainability. This research highlights the urgent need for empirical research on sustainable UGS development in rapidly urbanizing areas and provides actionable strategies for local policymakers and supports global urban sustainability.

Keywords: Coupling coordination, Ecology, Economic, Obstacle, Sustainability, Urban green space.

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1. Introduction

The United Nations' 2030 Agenda for Sustainable Development outlines 17 Sustainable Development Goals (SDGs), with SDG 11 specifically emphasizing the need for inclusive, safe, resilient, and sustainable cities [1]. UGSs play a crucial role in achieving sustainable urban development, offering significant ecological, social, and economic benefits, contributing to cities' overall sustainability and livability [2]. However, rapid global urbanization also poses numerous obstacles to the sustainable development of UGS, and empirical research is required to identify them.

In 2018, Chengdu introduced the Park City concept, emphasizing the importance of integrating ecological values into urban planning to create a beautiful and livable environment aligned with SDG 11 [3]. This approach highlights UGSs and parks as key elements of sustainable development, optimizing the relationship between citizens, parks, and cities, and providing high-quality ecological products. Chengdu's Park City model offers innovative urban planning solutions for China and globally, guiding sustainable urban development. From 2018 to 2022, the number of parks in Chengdu increased from 113 to 177, and the area for parks and UGSs expanded from 11,173 to 14,763 hectares, while the city's GDP grew from 153.43 billion yuan to 208.18 billion yuan [4]. Thus, Chengdu is a highly typical and representative case for this study.

Sustainable urban green spaces (UGSs) are crucial for urban development, and their impact on urban economic growth is widely acknowledged in academia, but the interaction between them has not been demonstrated yet. Moreover, the specific factors hindering the development of sustainable UGSs remain unclear, and there is a lack of empirical evidence to address these issues. In light of this, the research objectives of this study are:

1 To investigate the current status and trends of sustainable development of UGS in Chengdu.
2 To examine the interaction relationship between UGS and economic development.
3 To identify the key obstacles to UGS sustainability in Chengdu and provide insights for policy improvement.

To achieve these goals, this study adopted a mixed approach, combining quantitative and qualitative methods. Using Chengdu as an empirical case, it analyzed the interaction between UGS development and economic growth over the past 15 years based on longitudinal data. Afterward, the key barriers hindering the sustainable development of UGSs were further investigated. This timely and important research addresses the urgent need for empirical data on sustainable UGS development in rapidly urbanizing areas and advancing high-quality economic growth. Insights will offer actionable strategies for local policymakers and contribute to global urban sustainability efforts.

2. Literature Review

2.1. UGSs and Their Role

UGSs are critical in enhancing urban sustainability by providing essential ecosystem services such as air purification, climate regulation, and recreational opportunities [5]. They also contribute to urban residents' social cohesion and mental well-being [6, 7]. In recent years, more and more people have become concerned about the relationship between UGS and economic development. For example, Samad et al. [8] measured the impact of UGS on the economy by using house prices as a proxy factor and concluded that UGS creates great economic value.

Zeng et al. [9] argued that the construction of green eco-spaces enhances the value of the surrounding land. Recently, the issue of transforming the value of ecological spaces such as UGS has become a hotspot Yu et al. [10]. Zhang et al. [11] argued that transforming Park City's ecological advantages into development benefits is key to optimizing the city's overall value. However, despite their recognized importance, integrating UGSs with the economy and urban sustainable development planning remains challenging due to institutional, financial, and technical barriers [12].

2.2. Theoretical Framework

This study utilized three theoretical models. The entropy-weighted evaluation model assessed the relative significance of indicators for UGS sustainability. The coupling coordination degree model (CCDM) quantified the interaction and coordination between UGS development and economic growth. Lastly, the obstacle model identified key factors impeding sustainable UGS development through their impact on system performance.

2.2.1. Entropy-Weighted Evaluation

Establishing indicator weights is essential for comprehensively evaluating UGS construction and economic development. The entropy-weight method determines these weights by analyzing each indicator's interaction degree and information content, effectively reducing subjectivity. This method has been widely adopted across various academic fields [13]. It provides a scientific basis for decision-making by systematically reflecting underlying patterns in the data [14]. It is highly efficient and accurate for large datasets and adaptable to diverse research contexts, making it suitable for comprehensive evaluations and integration with other analytical techniques [15].

2.2.2. Coupling Coordination Degree Mode l(CCDM)

The Coupling Coordination Degree Model (CCDM) is a widely used tool that reflects the intensity of cooperative development based on the degree of coupling [16]. It is extensively applied in ecology, geography, and economics to study the coordination and coupling effects between systems such as ecology, economy, industry, technology, infrastructure, and health. "Coupling" describes the interaction and influence between complex systems through various subsystems, shifting from disorder to order and determining the system's phase transition characteristics [17, 18]. CCDM, comprising the coupling degree and coordination degree models, assesses the coupling coordination between systems [19, 20]. It is favored in academia for its clear meaning, simple calculation, and maturity as a research method [21, 22]. This method has also been widely used in the UGS research [23, 24].

2.2.3. Obstacle Model

The Obstacle Model is a widely used data analysis method for assessing the degree of obstruction that each indicator poses to the coordination of a system by analyzing the indicators [25]. This model encompasses three key indicators: factor contribution, indicator deviation, and obstacle degree [26].

2.3. Previous Studies on UGS Sustainability

Recent global studies have highlighted the importance of UGSs in urban sustainability, but often focus narrowly on ecological or social aspects [7]**.** For example, research on green infrastructure in cities has shifted from addressing water-related issues to tackling air pollution and urban heat islands [27]. In China, studies have examined the coupling coordination between urbanization and ecological resilience, emphasizing the need for integrated planning [28]. However, research focusing on the interactive relationship between UGSs and the economy is relatively scarce.

2.4. Challenges to UGS Sustainability

Challenges to sustainable UGS development include limited funding, lack of stakeholder engagement, and insufficient policy support [29]. Additionally, rapid urbanization and economic development can lead to the degradation of green spaces if not properly managed [30]. These challenges highlight the need for a comprehensive approach that integrates economic growth with UGS development.

2.5. Research Gaps

Current research on UGS sustainability predominantly emphasizes ecological values and environmental protection, with limited integration of economic factors. Although numerous macro-level studies exist, empirical case studies at the city scale are scarce. Moreover, most existing studies are confined to analyzing the coupled coordination between systems, with a paucity of research dedicated to identifying obstacle factors. This study aims to fill these gaps by providing empirical insights into the case of Park City Chengdu and conducting an integrated analysis of UGS and the economic system to identify factors hindering the sustainable development of green spaces.

3. Materials and Methods

3.1. Research Design

Unlike previous studies that primarily employed a single research method, this study adopted a mixed-methods research design. It took Chengdu as a case study and employed a mixed approach to analyze the coupling coordination between UGS and the economic system and assess sustainable development trends. It analyzed 15-year-long data on UGS construction and economic development and explored their interactions and coordination characteristics to reveal the relationship between them and sustainable development trends. An entropy weight method was used to determine indicator weights. It integrated the coupling coordination degree model to show the coordinated development trend between the two systems. An obstacle model was employed to identify the main factors hindering this coordination and green space sustainability. Finally, qualitative interviews and policy document analysis addressed the study's objective. The research framework of the study is shown in Figure 1.

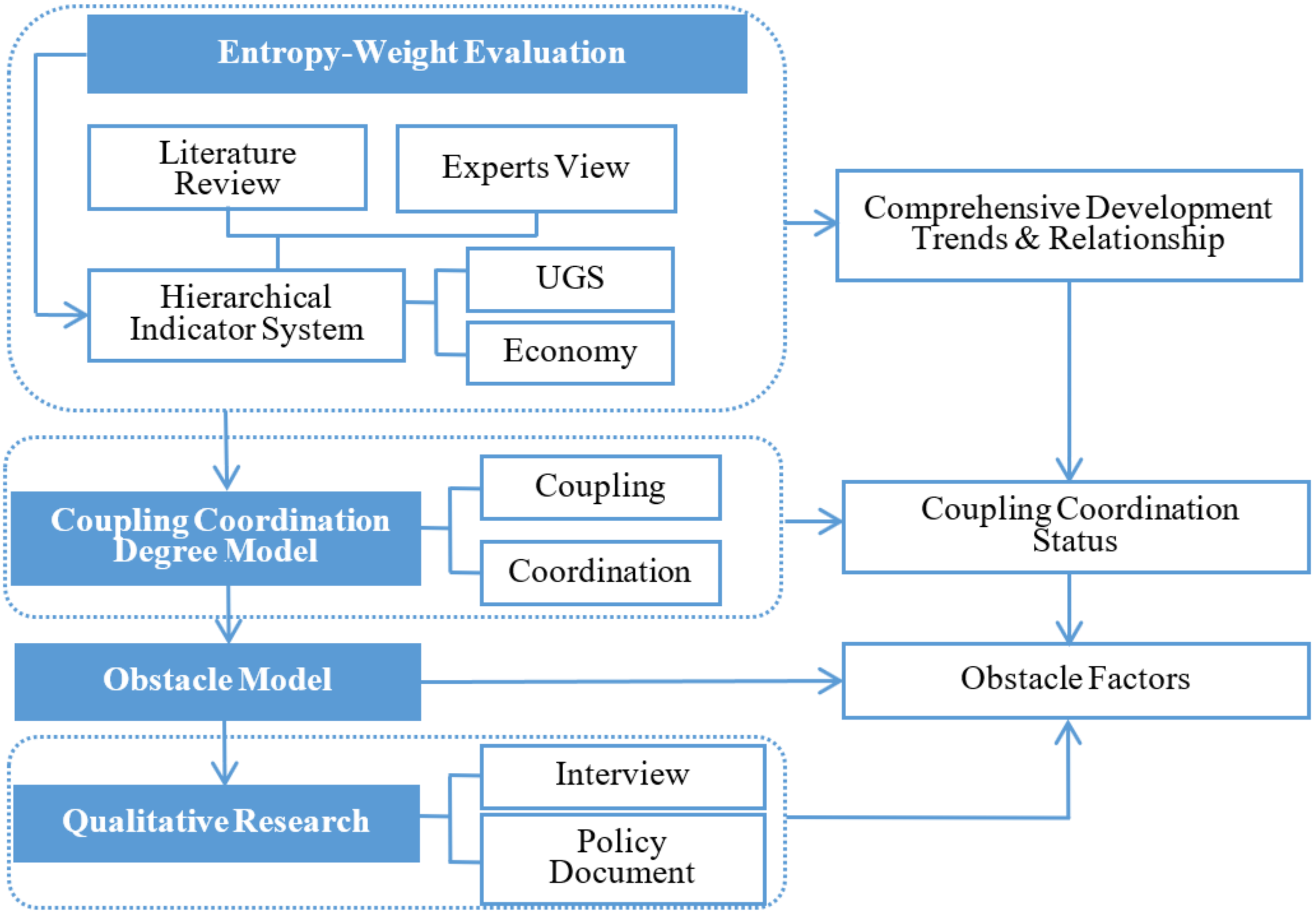

Figure 1.
Research Framework.

3.2. Data Collection

3.2.1. Quantitative Data

The UGS and economic systems encompass diverse, complex factors, and a hierarchical indicator system was constructed, with the overall objective positioned at its apex. Based on prior studies, the most representative indicators and expert consultation were selected [31]. Ultimately, the system was defined to include two overarching systems, five core elements, and 17 specific indicators informed by data accessibility. Table 1. Most of the quantitative data was obtained from the Chengdu Statistical Yearbook [4]. In addition, UGS pressure data were sourced from the China Environmental Statistics Yearbook[32] and the Chengdu Environmental Bulletin [33].

3.2.2. Qualitative Data

The data for qualitative research were obtained through semi-structured interviews. The interview guide was initially prepared in Chinese. After expert review, further amendments were made. Five experts were recruited using purposive sampling. The interviewees included university researchers, registered urban planners, landscape architects, government officials, and UGS management staff. All participants had more than five years of professional experience, as this was one of the inclusion criteria [34].

All interviews were conducted in Chinese. After the data were transcribed and analyzed, the analysis was translated into English. To ensure the accuracy of the translation and that the original meaning was preserved, contact was made with the relevant experts for validation. Those who had previously validated the interview guide confirmed the analysis outcomes, and the translation was standardized accordingly, which was used in the results. Furthermore, all interviews were audio recorded with participants' permission. Written informed consent was obtained. All ethical considerations were fulfilled for this study. Numerous policy and planning documents related to UGS construction in Chengdu over the past 15 years were collected via online platforms (Table 2).

Table 1.
Evaluation Indicator System for coupling the coordination of UGS and the Economy

System-level	Element level （weight）	Indicator level	Code	Unit	Source	Indicator attribute	Indicator weight
UGS	UGS Quality	Per capita park green area	X1	square meters	Chengdu Statistical Yearbook	Positive	0.1113
	-0.2336	Green area ratio of built-up areas	X2	%	Chengdu Statistical Yearbook	Positive	0.0481
		Green coverage ratio of built-up areas	X3	%	Chengdu Statistical Yearbook	Positive	0.0742
	UGS scale	Green space area	X4	hectares	Chengdu Statistical Yearbook	Positive	0.2243
	-0.6214	Park area	X5	hectares	Chengdu Statistical Yearbook	Positive	0.1744
		Green coverage area	X6	hectares	Chengdu Statistical Yearbook	Positive	0.2227
	UGS Pressure	Industrial sulfur dioxide emissions	X7	tons	China Environmental Statistics Yearbook	Negative	0.0786
	-0.145	Industrial solid waste generation	X8	millions of tons	Chengdu Environmental Bulletin	Negative	0.0664
Economy	Economic scale	Gross domestic product (GDP)	Y1	billions of yuan	Chengdu Statistical Yearbook	Positive	0.0991
	-0.4479	Total retail sales of consumer goods	Y2	billions of yuan	Chengdu Statistical Yearbook	Positive	0.1247
		General public budget revenue	Y3	billions of yuan	Chengdu Statistical Yearbook	Positive	0.0885
		Total fixed asset investment	Y4	billions of yuan	Chengdu Statistical Yearbook	Positive	0.1357
	Economic Structure	Proportion of the tertiary industry in GDP	Y5	%	Chengdu Statistical Yearbook	Positive	0.2345
	-0.3174	Labor productivity of the tertiary industry	Y6	yuan/person	Chengdu Statistical Yearbook	Positive	0.0829
	Economic quality	Regional GDP per capita	Y7	yuan/person	Chengdu Statistical Yearbook	Positive	0.0735
	-0.2347	Fiscal revenue per capita	Y8	yuan/person	Chengdu Statistical Yearbook	Positive	0.069
		Per capita disposable income of urban residents	Y9	yuan/person	Chengdu Statistical Yearbook	Positive	0.0922

Table 2.
Major Policy and Planning Documents Reviewed in the Study (by authors).

No.	Title	Issuing Body	Year	Stage
P1	Opinions of the Chengdu Municipal People's Government on Building an Eco-city	Chengdu Municipal People's Government	2008	Ecological garden city construction stage
P2	Chengdu Urban Green Space System Plan (2013–2020)	Chengdu Forestry and Garden Administration	2013	
P3	Chengdu City Master Plan (2016 - 2035)	Chengdu Planning and Natural Resources Bureau	2016	
P4	Action Plan for Implementing the "Ten Measures for Increasing Green Spaces in Chengdu" to Promote City-wide Greening	Chengdu Forestry and Gardening Bureau	2017	
P5	Chengdu Urban Road Greening Construction Guidelines	Chengdu Housing and Urban-Rural Development Bureau	2017	
P6	Chengdu Residential Community Garden Green Space Management Measures	Chengdu Housing and Urban-Rural Development Bureau	2017	
P7	Chengdu Park City Green Space System Plan (2019 - 2035)	Chengdu Park City Construction and Management Bureau	2019	Park City construction stage
P8	General Plan for Chengdu to Build a Park City Demonstration Zone That Implements New Development Concepts	Chengdu Development and Reform Commission	2022	
P9	Notice on Strengthening the Management of Land Approval for Urban Park Green Spaces in Chengdu	Chengdu Planning and Natural Resources Bureau	2022	
P10	Chengdu's "14th Five-Year Plan" for the Development and Construction of Park Cities	Chengdu Park City Construction Management Bureau	2022	
P11	Chengdu 14th Five-Year Plan for Ecological Environment Protection	Chengdu Environmental Protection Bureau	2022	
P12	Beautiful Chengdu Construction Strategic Plan	Chengdu Development and Reform Commission	2024	
P13	General Plan for the Territorial Space of Chengdu (2021 - 2035)	Chengdu Planning and Natural Resources Bureau	2024	
P14	Chengdu Urban Renewal Action Plan	Chengdu Housing and Urban-Rural Development Bureau	2025	

3.3. Indicator Explanation

This study identified 17 indicators across two systems (UGS and Economic), each with three elements. Under the UGS system, the UGS Quality element included indicators such as Per Capita Park Green Area (X1), Green Area Ratio of Built-Up Areas (X2), and Green Coverage Ratio of Built-Up Areas (X3). The UGS Scale focuses on Green Space Area (X4), Park Area (X5), and Green Coverage Area (X6).

UGS Pressure covers Industrial Sulfur Dioxide Emissions (X7) and Industrial Solid Waste Generation (X8). In the Economic Development system, the Economic Scale includes indicators such as Gross Domestic Product (GDP) (Y1), Total Retail Sales of Consumer Goods (Y2), General Public Budget Revenue (Y3), and Total Fixed Asset Investment (Y4). The Economic Structure element includes the Proportion of the Tertiary Industry in GDP (Y5) and the Labor Productivity of the Tertiary Industry (Y6). Economic Quality encompasses Regional GDP per Capita (Y7), Fiscal Revenue Per Capita (Y8), and Per Capita Disposable Income of Urban Residents (Y9).

3.4. Data Analysis

3.4.1. Comprehensive Development Trends Analysis

The weight and comprehensive development trends analysis were calculated based on the entropy weighting method, which consists of the following steps:

(1) Data standardization

Using the following formulas, all indicators were normalized using min-max standardization to eliminate dimensional effects. Data were drawn from 2008–2022. Missing data (<5%) were interpolated using linear trends.

Positive indicators：

$$X_i' = \frac{X_i - \min(X_i)}{\max(X_i) - \min(X_i)} \quad (1)$$

Negative indicators： $X_i' = \frac{\max(X_i) - X_i}{\max(X_i) - \min(X_i)}$ (2)

Where X_i' represents the standardized value of the i th indicator, denotes the original data, and signifies the minimum and maximum values of the i th indicator.

(2) Calculate the information entropy values of the indicators with the following formulas:

$$E_i = -\frac{1}{\ln n}\sum_{i=1}^{n} P_i \ln P_i \quad (3)$$

$$P_i = \frac{X_i'}{\sum_{i=1}^{n} X_i'} \quad (4)$$

E_i is the information entropy value of the i th indicator.

In order to avoid $\ln P_i$ being meaningless when $P_i = 0$, the calculation result should be corrected and its value should be assigned to 0.001 when $P_i = 0$ with reference to relevant research results.

(3) Calculate the indicator weight W_i, the formula is as follows, and the weight calculation results of all indicators are shown in Table 1.

$$W_i = \frac{1 - E_i}{\sum_{i=1}^{n}(1 - E_i)} \quad (5)$$

(4) Calculate the comprehensive evaluation indexes for the two systems with the following formulas:

UGS construction: $U_1 = \sum_{i=1}^{8} W_i \times X_i'$ (6)

Economic Development: $U_2 = \sum_{i=1}^{9} W_i \times Y_i'$ (7)

In the formulas, U_1 and represent the comprehensive development indexes of the UGS system and the economic development system, $U_1 \in [0,1]$, $U_2 \in [0,1]$. W_i is the corresponding indicator weight, and X_i' and Y_i' are the standardized values of the corresponding indicators of the UGS system and the economic development system.

3.4.2. Coupling Coordination Analysis

Following Huang et al. [35] and Yin et al. [24] the CCDM was applied to evaluate the strength of the interaction between UGS and economic development. This study employed a modified coupling model to analyze the coupling level between UGS construction and economic development [36]. The modified formulas are:

$$C = \sqrt{[1 - (U_i - U_j)] \times \frac{U_j}{U_i}} \quad (8)$$

$$D = \sqrt{C \times T} \quad (9)$$

$$T = \alpha U_1 + \beta U_2 \quad (10)$$

In the formulas, C represents the coupling degree, and $C \in [0,1]$, when U_1 is greater than U_2, i =1， j =2； when U_2 is greater than U_1, i =2， j =1. D is the coordination degree, $D \in [0,1]$. T is the comprehensive development index. α and β are weight coefficients $\alpha + \beta = 1$. In view of the difference in importance between the UGS and the economic systems, after referring to previous literature and soliciting expert opinions, α =0.4, β =0.6 [31].

Referring to the related literature [20, 37, 38] the degree of coordination was categorized into the following 10 different levels Table 3:

Table 3.
Coordination Level Classification Standards.

Coordination value	Coordination level	Coordination value	Coordination level
0~0.1	Extremely uncoordinated	0.5~0.6	Barely coordinated
0.1~0.2	Seriously uncoordinated	0.6~0.7	Mildly coordinated
0.2~0.3	Moderately uncoordinated	0.7~0.8	Moderately Coordinated
0.3~0.4	Mildly uncoordinated	0.8~0.9	Well-coordinated
0.4~0.5	On the verge of uncoordinated	0.9~1.0	Excellently coordinated

3.4.3. Obstacle Analysis
The relevant formulas are as follows:

$$I_i = 1 - X_i' \tag{11}$$

$$H_i = \frac{W_i I_i}{\sum_{i=1}^{n} W_i I_i} \times 100\% \tag{12}$$

Where I_i is the indicator deviation, X_i' is the standardized value of each indicator, W_i is the factor weight and H_i is the obstacle degree. Moreover, X_i' and W_i are both from the entropy weighting model.

3.4.4. Qualitative Analysis
The interview data collected were processed using the software ROST Content Mining-6 for word segmentation and thematic coding. This tool demonstrates significant advantages in processing text [39]. Five thousand seven hundred eighty-eight words were analyzed, and coding categories included 'funding,' 'policy,' 'land use,' 'distribution,' and 'maintenance.' This was combined with the summarization of planning policy documents Table 2 to further analyze the relevant obstacle factors.

4. Results
4.1. Current UGS State and Comprehensive Development Trends
During the study period, the comprehensive green space development of Chengdu City showed an upward trend. Figure 2 illustrates the trend of the comprehensive development index for Chengdu's UGS and economic development systems from 2008 to 2022. Overall, both systems exhibit an upward trajectory. The UGS composite index increased from 0.0522 to 0.8699, while the economic development index rose from 0.0010 to 0.9935. The specific evolutionary trends depicted in the figure indicate that UGS construction often outpaced economic development in most years (U1>U2).

Specifically, the comprehensive index of UGS in Chengdu has three relatively obvious growth phases: the first period was from 2008 to 2010, the second phase was from 2014 to 2016, and the third rapid growth phase was from 2018 to 2020. As for economic development, the overall growth trend was more stable and was characterized by a more pronounced acceleration after 2018.

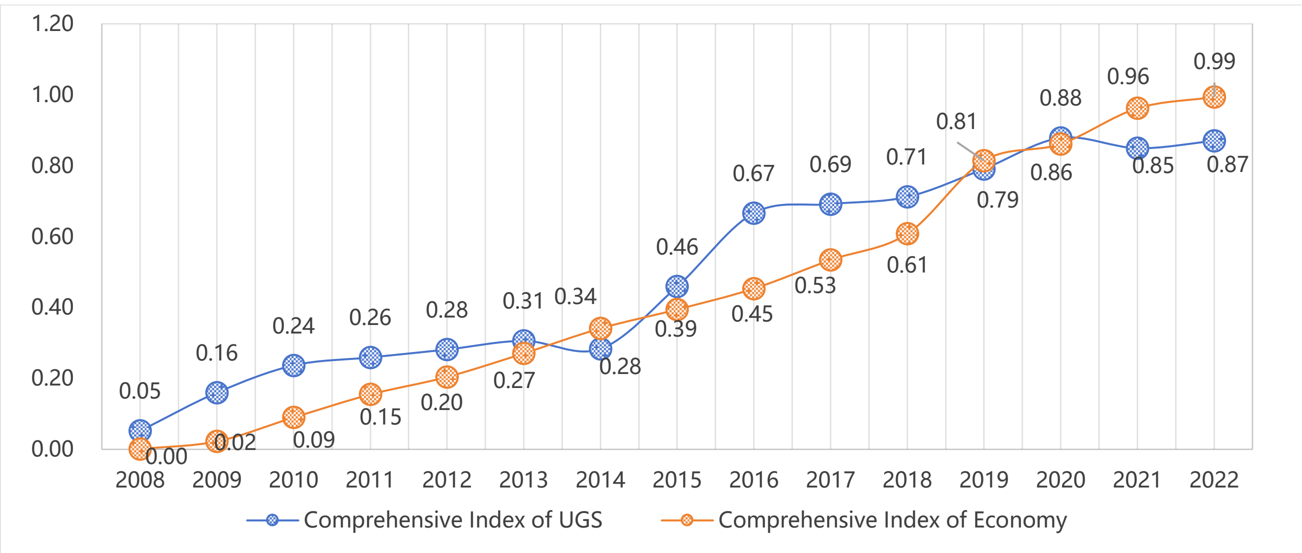

Figure 2.
Comprehensive Development Trend of UGS and Economy in Chengdu, 2008-2022.

4.2. Entropy-Weighted Evaluation Results

Following data standardization, the entropy-weight method was employed to assign weights, facilitating the sequential calculation of the comprehensive development index for both systems from 2008 to 2022. The coupling degree C and the coordination degree D for each year were determined using the coupling coordination degree model (CCDM). The results of these calculations are presented in Table 4.

Table 4.
Comprehensive Development Index and Coupling Coordination Level Classification.

Years	Comprehensive UGS index U_1	Comprehensive Economic Index U_2	Coupling C	Coordination D	Coordination level
2008	0.0522	0.0010	0.1348	0.0538	Extremely uncoordinated
2009	0.1600	0.0226	0.3488	0.1644	Seriously uncoordinated
2010	0.2367	0.0899	0.5692	0.2909	Moderately uncoordinated
2011	0.2593	0.1548	0.7312	0.3792	Mildly uncoordinated
2012	0.2815	0.2041	0.8179	0.4385	On the verge of uncoordinated
2013	0.3059	0.2706	0.9237	0.5129	Barely coordinated
2014	0.2834	0.3411	0.8848	0.5304	Barely coordinated
2015	0.4590	0.3945	0.8967	0.6139	Mildly coordinated
2016	0.6663	0.4533	0.7317	0.6277	Mildly coordinated
2017	0.6916	0.5341	0.8066	0.6940	Mildly coordinated
2018	0.7120	0.6080	0.8747	0.7538	Moderately Coordinated
2019	0.7910	0.8142	0.9742	0.8855	Well-coordinated
2020	0.8783	0.8611	0.9816	0.9230	Excellently coordinated
2021	0.8492	0.9617	0.8853	0.9009	Excellently coordinated
2022	0.8699	0.9935	0.8759	0.9094	Excellently coordinated

4.3. Correlation Analysis Results

A correlation test on the comprehensive development index of UGS and economic development yielded a Pearson correlation coefficient of 0.962, which is significant at the 0.01 level ($p \leq 0.01$). This indicates a strong correlation between UGS construction and economic development, consistent with findings from previous studies [8]. Subsequently, through linear regression analysis to further test, with the index of UGS as the independent variable x, economic development as the dependent variable y, to get the linear fitting equation $y = 1.123x - 0.114$, and then swap the position of the dependent variable and independent variable, to get the fitting equation $y = 0.824x + 0.131$.

The R-squared value is 0.926, indicating a high degree of fit. This further supports the positive correlation between UGS and economic development and their mutual influence. From the fitting equations, it can be inferred that for every 1-unit increase in UGS, economic growth increases by 1.123 units; conversely, for every 1-unit increase in economic growth, the UGS system is expected to increase by 0.824 units.

4.4. Cointegration Test and Granger Test Results

Cointegration and Granger tests were conducted to verify the dynamic coordination characteristics and causality between the two systems. Before testing, heteroskedasticity was addressed by taking logarithms, and the smoothness of the data was assessed using the ADF test. Non-smooth sequences were subsequently processed through differencing. The Johansen cointegration testing method revealed cointegration at the 10% significance level, indicating a relatively stable long-term relationship between the two systems.

Further analysis using the Granger test (lag 1 order) showed P values of 0.619 and 0.300, respectively, exceeding 0.05. This suggests that the two systems do not serve as Granger causes for each other, indicating a lack of direct causal correlation between them. Therefore, the influence of UGS on the economy is indirect.

4.5. Coupling Coordination Degree Analysis Results

4.5.1. Coupling Degree

The coupling degree exhibits a fluctuating growth trend Figure 3 increasing from 0.1348 at the beginning of the study to 0.8759 by the end. From 2008 to 2013, the coupling degree rose rapidly, reaching its first peak at 0.9237. However, the subsequent three years witnessed a significant decline, culminating in a trough of 0.7317 in 2016. Following this low point, the coupling degree rises again, achieving a second peak of 0.9816 in 2020, after which a gradual yearly decrease occurs. These observations suggest that the coupling degree between the two systems is dynamic and fluctuating, displaying instability despite an upward trend.

4.5.2. Coordination Degree

The degree of coordination between UGS and economic development demonstrates a relatively stable growth trend, with its value increasing from 0.0538 at the beginning of the period to 0.9094 at the end. Analyzing the phases of this relationship, as detailed in Table 4, reveals that the system was characterized by uncoordinated development before 2012

(D<0.5). Subsequently, it transitioned into a period of coordinated development after 2013 (D≥0.5). Following two years of barely coordinated development and three years of mild coordination, the system entered a moderately coordinated stage in 2018. Notably, between 2018 and 2019, the degree of coordination increased by 0.1317, or 17.47%, marking a significant rise. This improvement propelled the system into an excellently coordinated stage in 2020, reaching a maximum value of 0.9230. Although there was a slight decline thereafter, the system remained in excellent coordination.

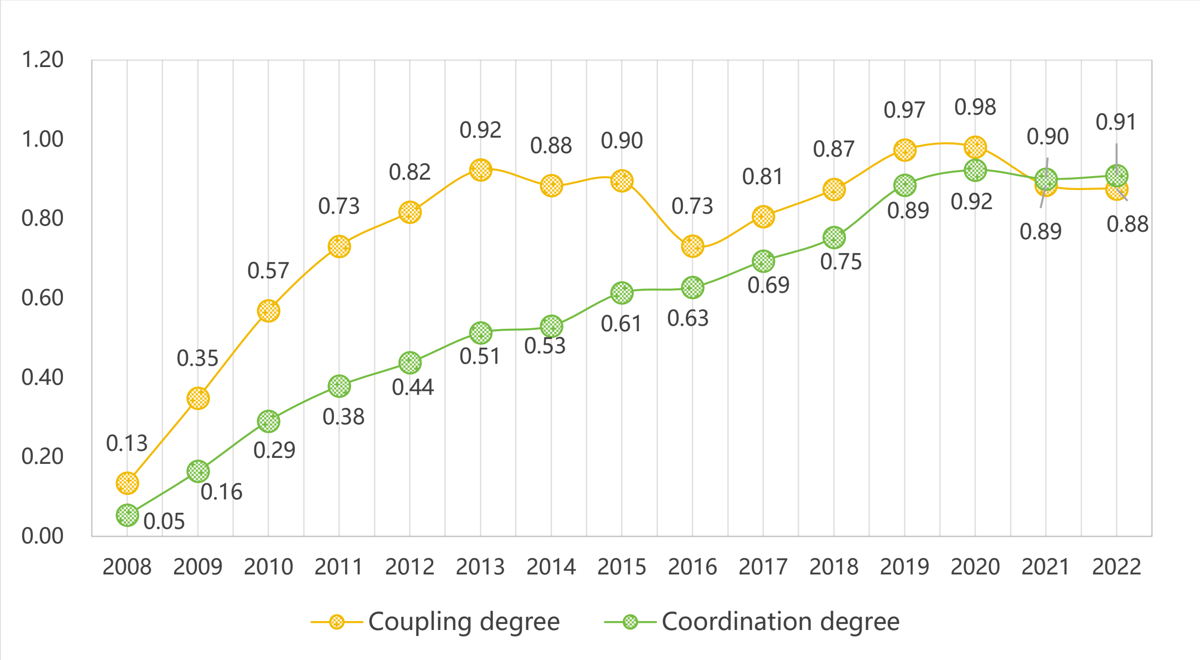

Figure 3.
Trend of Coupling and Coordination of UGS and Economy in Chengdu, 2008-2022 (by authors).

4.6. Obstacle Model Results

Model robustness was tested via phased validation. Years were split into two phases: 2008–2015 and 2016–2022. Obstacle degrees were calculated for each phase, with the top three factors selected annually. Twelve obstacles were identified in 2008–2015 and thirteen in 2016–2022. Nine obstacles remained consistent (X1, X2, X3, X4, X7, X8, Y5, Y7, Y8), indicating overall stability. In the later phase, Y2, Y4, and Y9 were replaced by X5, X6, Y3, and Y6. The reasonable trend suggests the model's results are robust. As shown in Figure 4 the overall obstacle degree exhibits a declining trend over the study period, decreasing from 223.11 in 2008 to 23.23 in 2022. Table 5 lists the top three obstacle indicators and their values for each year, highlighting dynamic changes and relative stability, collectively accounting for 28.38% of the total obstacle degree.

Table 5.
Top Three Obstacles and Their Obstruction Degree.

Years	First		Second		Third		Years	First		Second		Third	
2008	X7	19.38	X8	17.98	X1	16.68	2016	Y5	7.77	Y8	7.33	Y4	6.52
2009	X7	16.78	Y7	14.72	Y8	13.64	2017	Y5	7.77	Y4	5.41	Y9	5.31
2010	Y7	13.31	Y3	12.35	Y6	11.93	2018	Y5	7.37	X1	6.59	X3	5.48
2011	Y7	11.39	Y3	10.76	Y6	10.74	2019	X8	6.60	X2	3.77	Y6	3.68
2012	X8	12.16	X4	10.14	X6	10.13	2020	Y7	2.92	X5	2.53	Y1	2.27
2013	X8	10.00	X6	9.94	X4	9.89	2021	X1	14.91	X8	1.70	X5	1.26
2014	X2	20.21	X3	16.39	X4	9.59	2022	X1	16.89	X8	4.57	Y8	0.78
2015	X2	8.93	X6	8.66	X4	8.63							

The most significant obstacle is X8 (Industrial Solid Waste Generation), contributing 69.69, followed by Y7 (Regional GDP Per Capita) at 42.34 and X1 (Per Capita Park Green Area) at 38.39. Notably, the obstacle degrees of the two indicators, X1 (Per Capita Park Green Area) and X8 (Industrial Solid Waste Generation), exhibit a pattern of initially decreasing followed by an increase over time, highlighting their roles as significant obstacles to coordinated development in recent periods.

At the element level, the ranking of obstacles is as follows: UGS pressure (105.85) > UGS quality (93.17) > UGS scale (70.77) > economic quality (64.09) > economic structure (49.26) > economic scale (37.31).

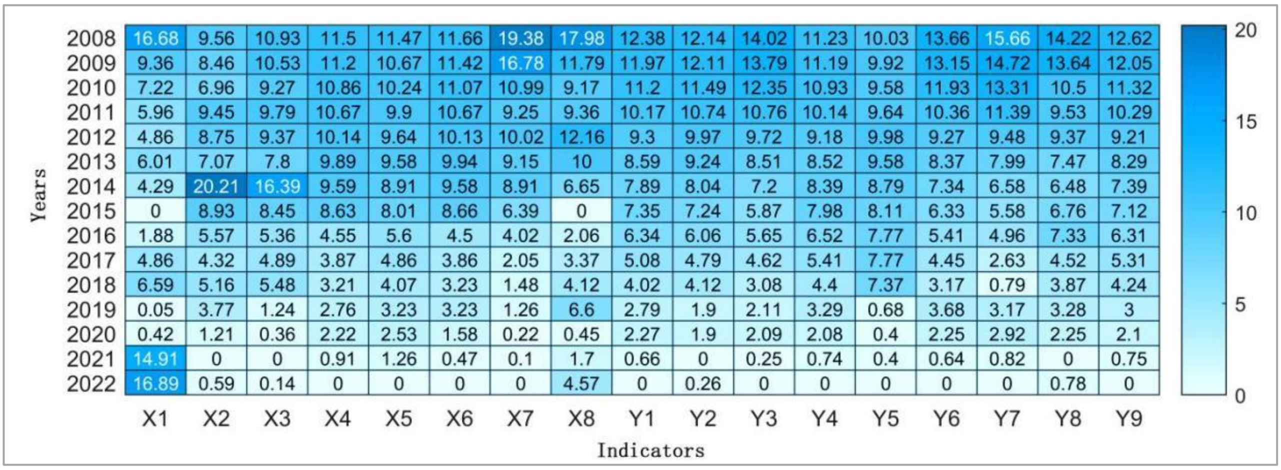

Figure 4.
Heat Map of Obstacles to UGS-Economy Coordination in Chengdu, 2008-2022.

4.7. Results of Qualitative Research

Analysis of interview transcripts and policy documents shows that Chengdu's sustainable green space development is primarily due to strong government policy, financial, and technical support.

Firstly, from 2008 to 2017, Chengdu's UGS construction policy centered on building an Eco-Garden City. Since 2017, the focus has shifted to constructing a National Park City Table 2. These policies have distinct periodicity characteristics, aligning with data trends in quantitative analysis. This indicates that Chengdu's UGS sustainable development is policy-driven. Chengdu emphasizes establishing urban green ecological infrastructure, positioning UGSs as central components of its long-term development strategy. Chengdu stipulates the basic principles and requirements for the planning, construction, protection, and management of UGSs, providing policy support for green space construction [40].

Secondly, Chengdu has provided significant financial backing for UGS construction. The government allocates special funds annually for projects such as park construction, greenway development, and ecological restoration. Chengdu has also established a Green Development Fund to attract social capital and diversify funding sources. This financial support has been crucial for the rapid advancement of green space projects.

Moreover, Chengdu's green space construction emphasizes ecological protection and value conversion, highlighting the enhancement of ecosystem services and biodiversity protection. Additionally, Chengdu has actively explored the "ecology +" model, integrating green spaces with cultural tourism, sports, and other industries [33].

Despite the enabling factors for the sustainable development of Chengdu's UGS, the study also identified the following obstacles:

4.7.1. Budget Pressure

Chengdu has invested heavily in green space construction and protection. As green space-related tasks grow, so do financial needs. The five respondents mentioned the terms "funding," "budget," and "finance" a total of 38 times. UGS construction and maintenance require ongoing funding. With rapid urban expansion and population growth, government finance alone cannot meet all green space-related demands.

4.7.2. Land-Use Conflicts

Land-use competition in urban construction causes conflicts between green space and other development projects. Although Chengdu has optimized its spatial structure by reducing construction land for industrial use and increasing ecological space, improved land-use planning is still necessary to address land-use conflicts. Considering the development positioning of the Tianfu Granary, coordinating the relationship between urban green spaces (UGS) and high-quality farmland remains a significant challenge for the sustainable development of UGS in Chengdu [41].

4.7.3. Spatial Distribution Imbalance

The unequal distribution of green space in Chengdu hampers the maximization of its ecological and service functions. Research indicates that the connectivity of the ecological network of green space in this city decreases from the west to the east and from the periphery to the center. There is poor connectivity in the city center and the area to the northeast. In addition, green spaces are mainly concentrated in the west, suburbs, and scenic spots, while other urban localities, particularly the north, have less greenery [41]. As a result, some urban residents may be denied the benefits associated with green spaces, which is bad for cities.

4.7.4. Growing Maintenance Difficulty

With Chengdu's green spaces expanding, maintenance becomes more challenging. Larger green areas require more staff and equipment for upkeep. Additionally, as green spaces diversify in types and functions, their varying maintenance needs demand higher-level professional management.

In addition, there are issues caused by changes in green space functions due to adjustments in development positioning and untimely communication of policies between departments.

4.8. Key Findings

The findings indicate an overall upward trend in the UGS and economic development, with mutually reinforcing yet indirect effects. The degree of coordination has steadily improved, indicating a gradual enhancement in UGS sustainability. Key obstacle factors identified are UGS pressure and quality. Barriers hindering the UGS's sustainable development include budget pressure, increased difficulties in green space maintenance, land use conflicts, and imbalanced spatial distribution.

5. Discussion

5.1. Interpretation of Results

This study employs quantitative and qualitative methods to analyze the sustainable development trends and major obstacles facing UGSs in Chengdu. Results show that during the study period, the comprehensive development of UGSs in Chengdu has improved, with growth in scale and quality, aligning with Li et al. [41]. Additionally, a significant positive correlation between UGSs and economic development was found, consistent with prior research [42]. This relationship is stable and long-term, although no direct causality exists; the interaction between UGSs and the economy is indirect.

UGS benefits the local economy through various social and environmental mechanisms [43-45]. These mechanisms include optimizing the ecological environment and promoting residents' health [46]. Enhancing the value of surrounding assets, providing ecological services, attracting talent, and bolstering the city's competitiveness [47]. These benefits can, in turn, feed back into the input and operation of UGS [9], creating a virtuous cycle that facilitates spiral growth to promote the UGS's sustainable development, as illustrated in Figure 5.

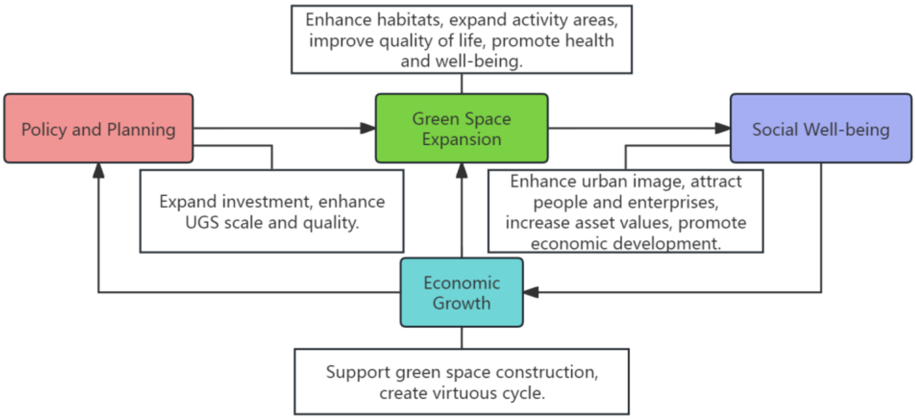

Figure 5.
Mechanisms of Interaction Between UGS and Economic Development.

In the quantitative analysis, the obstacle model identified green space pressure and quality as the most significant barriers, with environmental stress negatively impacting sustainable development. Qualitative research revealed that, while policies, finances, and technology support Chengdu's green space development, key obstacles include budget pressure, land-use conflicts, spatial distribution imbalance, and increasing maintenance difficulties. The spatial distribution imbalance corresponds to the green space quality barrier identified quantitatively. Although land-use conflicts and financial pressure are widely recognized [48], this study highlights that ongoing management and maintenance pressures are also significant barriers to sustainable development.

5.2. Land-Use Conflicts

In urbanization, land-use conflicts are one of the significant factors affecting the sustainable development of UGSs [49]. As a vital component of urban ecosystems, UGSs face competitive pressures from urban development, infrastructure construction, and real estate development [50]. With urban expansion, encroachment on green spaces occurs frequently, resulting in a reduction of green space area and uneven distribution, which compromises the integrity of urban ecosystems and their ecological service functions.

5.3. Policy Gaps and Implementation Challenges

Policies play a prominent guiding role in the development of UGSs, and Chengdu has assigned a high policy priority to green space construction since the 21st century. Despite implementing a series of greening policies in Chengdu, there are still significant shortcomings in long-term planning and policy integration [41]. Moreover, formulating and implementing UGS policies typically involve multiple departments whose differing objectives and priorities may lead to contradictions and conflicts in policy enforcement [51].

5.4. Economic Constraints and Resource Allocation

Another major restriction to the sustainable development of UGSs is economic constraints. Scarcity of resources and lack of investment undermine the quantity and quality of UGSs [52]. The rapid urbanization in many countries often results in municipal governments focusing heavily on economic development and construction work, with relatively less investment allocated to UGSs [51]. The disproportionate allocation of resources results in a smaller area of green space and decreased performance of ecological service functions, causing further implications for urban ecology.

5.5. Public Participation and Community Engagement

Public participation plays a significant role in managing UGS, yet community involvement faces numerous barriers [53]. Public participation can enhance the transparency and democracy of UGS management and strengthen community residents' sense of identity and belonging to green spaces, thereby promoting long-term maintenance and sustainable use [54]. However, information asymmetry, inadequate participation channels, and insufficient community capacity building often constrain public participation.

5.6. Technological Innovation and Smart Green Space Management

High investment of resources in the continuation of UGSs is a significant concern for sustainable development. New solutions are devised for UGSs, with technological innovation applications such as artificial intelligence (AI), smart monitoring systems, and geospatial information systems (GIS) that significantly enhance management efficiency and accuracy [55, 56]. Monitoring in real time of ecological conditions and usages allows managers to reassess and modify strategies. With ongoing technological advancements, smart green space management is becoming a key direction for the sustainability of UGS [57] .

5.7. Policy and Practical Recommendations

5.7.1 Enhance Policy Coherence and Interdepartmental Collaboration

The coherence and stability of policies on UGSs are necessary for fulfilling future aims. Ensuring continuity in time and space of policies is essential. Various departments of planning, construction, environmental protection, landscaping and others work to develop UGSs. The departments should establish efficient communication channels and collaborative mechanisms. It is possible to maintain consistency and break barriers between departments through the sharing of information and data, and mutual implementation of projects.

5.7.2. Introduce Diverse Capital to Facilitate Value Transformation

To address the funding bottleneck in sustainable urban green spaces (UGSs), the government should introduce diverse sources of capital and implement policies aimed at attracting private sector participation in UGS construction and management. Engaging enterprises and social organizations to donate funds for green space development will broaden funding channels. Utilizing appropriate commercial formats and developing alternative models to convert value into direct economic benefits can enhance support for the sustainable development of green spaces.

5.7.3. Alleviate Environmental Pressure on Green Spaces

Industrial pollution severely threatens the ecological environment of UGSs [58, 59]. Controlling industrial waste and pollution emissions is an important measure to promote the sustainability of UGSs. The government should strengthen the supervision of industrial enterprises, strictly enforce environmental standards, and reduce the impact of industrial pollution on green spaces. Meanwhile, promoting green production technologies and encouraging enterprises to reduce pollutant emissions and enhance recycling can mitigate pressure on green spaces at the source [60].

5.7.4. Optimize Green Space Layout and Improve Green Space Quality

The quality and distribution of green spaces significantly impact sustainable development. Optimizing the layout of green spaces is an important means to enhance the comprehensive benefits of urban green spaces, with population distribution being the most critical factor [61]. UGS layout should be planned reasonably based on population distribution and urban functional zoning to improve accessibility and equity [62]. Additionally, efforts should be made to improve UGS quality by increasing vegetation diversity and enhancing soil quality to boost ecological service functions.

5.7.5. Integrate New Technologies to Enhance Maintenance Capabilities

The efficiency and scientific basis of UGS management can be benefited by introducing modern technologies such as AI and GIS, which will result in reducing the dependence on human and financial resources [55-57]. For instance, smart monitoring systems can monitor the environmental situation of UGS in real time to address issues efficiently. Smart irrigation systems effortlessly water and care for plants. The integration of innovative technologies can contribute to reducing management and maintenance costs, enhancing resource utilization efficiency, and providing strong technical support for sustainable urban development.

6. Conclusions

UGS development in Chengdu has increased annually and is closely correlated with economic growth. Key obstacles include ecological pressure from industrial pollution, green space distribution and quality, funding, land-use conflicts, and maintenance management pressures. These findings are significant for urban planning and management, suggesting that relevant departments should effectively address these obstacles.

6.1. Recommendations

The study recommends enhancing policy coherence and interdepartmental collaboration, controlling pollution, optimizing green space distribution, improving quality, introducing diverse capital sources, facilitating value transformation, and ensuring adequate green space construction and maintenance funding. Integrating new technologies to improve management efficiency is essential for long-term sustainability and ecological benefits.

6.2. Limitations and Future Research

This study provides in-depth insights into UGS sustainability, but has limitations. First, focusing only on Chengdu limits the generalizability of conclusions. Future research should conduct comparative studies across multiple cities. Second, the indicator selection remains subjective, based on expert opinions and literature. Future studies could include ecological dimensions such as biodiversity and climate for a more comprehensive system. Third, the study analyzed 15 years of data and policies. Future research should explore long-term mechanisms affecting green space sustainability. Lastly, it only focuses on the coupling coordination between UGS and economic development systems. It does not include data from other systems, such as ecological, microclimate, and the geographic specificity of Chengdu. Additionally, the small number of respondents in the qualitative interviews represents another limitation. Despite these limitations, this study contributes valuable insights into UGS sustainability theory and practice.

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