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Impact of Urban Green Spaces on Sustainable Development: Empirical Evidence from Chinese Cities

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Abstract: Rapid urbanization has continuously exacerbated the ecological systems and resource-environment issues. Urban green spaces (UGS) are crucial for ecological balance, improving living environments, and promoting sustainable development. Using the panel data of 249 cities in China from 2006 to 2022, this work examines the impact of UGS on sustainable development. The findings reveal: firstly, UGS significantly promote sustainable development; secondly, the mechanisms primarily manifest in ecosystem services and industrial upgrading; lastly, the impact exhibits notable spatial heterogeneity, with more pronounced effects in resource-dependent cities, central-western regions, and areas with lower economic development levels. This study underscores the importance of UGS in sustainable development and proposes scientifically planned resource utilization to fully realize its potential in enhancing urban ecosystem functions, improving living environments, and fostering socio-economic sustainability, ultimately achieving urban sustainable development goals.

Keywords: UGS; sustainable development; ecosystem services; comprehensive industrial upgrading

1. Introduction

In recent years, the environmental, resource and social pressures brought about by industrialization and urbanization have made the issue of sustainable urban development become a public focus. Climate change has become a increasingly serious problem, which urgently requires mankind to find a sustainable path. According to the "Big Data for the Planet Supporting the Sustainable Development Goals (2024)" report released by the International Research Center for Big Data for Sustainable Development (SDG Center), if UGS coverage is increased to 30% in earth, it is expected to reduce carbon emissions by 15% and reduce public health expenditure by 10%. This shows that green space not only contributes to a clean urban environment, but also has economic and social value. Under the contradiction and conflict between ecological environment and economy and society, optimizing green space has become important for UGS.

The concept of "green space" originates from the "garden city", which advocates the improvement of urban environment through systematic planning of green space [1]. With the development of urbanization, the concept has diversified definitions in different regions: The World Health Organization (WTO) defines UGS as "land partially or completely covered with grass, trees, shrubs or other vegetation reserved for public use within the city limits" [2], emphasizing its vegetation-covered attributes. The United Nations (UN) describes urban green space as "public and private Spaces that contain natural elements such as trees, water, and other vegetation within city limits [3].The European Union (EU) defines urban green space as "all publicly accessible open green areas in urban areas, including parks, nature reserves, green corridors, playgrounds and gardens" [4]. Although there are differences in the above definitions, the core of the definition involves the two parts of "public access" and "natural elements".

With the establishment of the category of UGS, the academic circle's understanding of its connotation is also deepening. UGS has multiple ecological functions such as carbon fixation and

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cooling [5–12], and is crucial to the urban ecological environment. On top of ecological functions, the connotation of urban green space should also take into account the adaptability to economic and social development, and expand the more dynamic three-layer connotation: first, the construction of a comprehensive "green network system" covering garden green space, urban forest, water wetland and three-dimensional greening [13]; The second is to highlight the multi-functional attribute, which not only assumes the function of ecological regulation (carbon sequestration, cooling), but also has the function of social service (leisure, disaster prevention) and economic adaptation (urban-rural coordination) [14]. The third is to emphasize the systematic linkage between space, community and region, and strengthen publicity and openness by breaking through traditional natural boundaries [15]. It is a green space system with the characteristics of public, non-exclusive, scarce and open.

Urban green space promotes people's well-being. It provides people with access to nature, actively promotes people's physical health and relieves anxiety [16,17]. However, with the acceleration of urbanization, the competition for urban land use becomes increasingly fierce, especially in cities and neighboring areas where space is limited and land value premium is serious [18]. A large amount of green space is transformed into other land uses with more economic value, which reduces the opportunities for urban residents to contact with nature and thus weakens the various benefits they get from it.

In 1987, the World Commission on Environment and Development proposed sustainable development in Our Common Future [19]. In order to meet the needs of contemporary people and the welfare of future generations, scholars have discussed the connotation and path of sustainable development from three aspects. First, sustainable development requires policies to contain environmental costs and ensure economic efficiency [20]. Secondly, efficient use of resources is an important way to achieve sustainable development [21]. Finally, nature can sustain human welfare, and interest groups need to protect environment when using natural resources. Although the way of elaboration is different, the understanding of sustainable development gradually forms the core framework of the trinity of "environment-economy-society", emphasizing intergenerational equity, resource carrying capacity and system balance. Cities are major carriers of resource consumption and carbon emissions, and need sustainable development.

Urban sustainable development is based on ecology and economic development theory, and also seeks the benefits of urban society, economy and environment [22–29]. Its realization path presents the characteristics of diversification. At the macro level, urban agglomerations have become an important carrier, forming a close network through industrial agglomeration and diffusion. Urban agglomerations such as China's Yangtze River Delta have significantly improved their ecological efficiency through green urbanization [30,31]. At the medium level, smart cities and low-carbon technologies become the key to transformation [32], such as big data policies to promote industrial upgrading by optimizing resource allocation. At the micro level, innovative designs such as sponge cities and ecological infrastructure reduce ecological loads through stormwater management and energy recycling [33,34]. It is worth noting that urban expansion leads to the loss of arable land and the decline of biodiversity, highlighting the contradiction between economic and ecological goals in spatial planning.

Existing studies mostly emphasize the ecological function of UGS in improving urban environmental quality and residents' well-being [35–37]. Subsequent scholars further expanded the connotation of UGS, the World Health Organization, the United Nations and other agencies defined it as a public natural space covered by vegetation, and confirmed that it can directly promote ecological balance through ecosystem services (such as carbon sink and air purification). In recent years, the research perspective has gradually turned to the synergistic effect between UGS and economic and social development. For example, the SDG Center (2024) notes that increasing urban green space coverage can significantly reduce carbon emissions and public health expenditures, highlighting the multi-dimensional value of UGS. Existing studies have not systematically analyzed the action mechanism of UGS on sustainable development, and most of them are case studies, failing to solve the contradiction between UGS and land economic value. In this study, a sample of 249 cities in China from 2006 to 2022 is used to assess the impact of UGS on sustainable development by using a fixed-effect model, while a moderating effect model was used to examine the underlying mechanism and further analyze heterogeneity. This study breaks through the intersection of urban ecology and sustainable development, expands the research content of urban green space, and explores its role and formation mechanism in promoting sustainable economic and social development.

2. Theoretical Mechanism

2.1. Green Space and Sustainable Urban Development

This section uses ecological theory and sustainable development theory to build the theoretical framework of green space's impact on urban sustainable development. Ecological theory emphasizes the fundamental role of ecosystems in human development. UGS are major part of urban ecosystems, which affect the sustainable development.

According to ecological theory, healthy ecosystems provide irreplaceable "natural capital" for human beings through carbon sink regulation, water conservation, soil conservation and other functions. First the stable operation of ecosystems is an indispensable prerequisite for the sustainable development of human social and economic systems. When ecosystems are unstable, such as rising sea levels and frequent extreme weather events, social systems and economic systems pay a heavy price. Secondly, UGS is the main part of urban ecosystem. It maintains the stability of the urban ecosystem and indirectly protects the economic and social security. People live in and are affected by urban ecosystems and need them to provide healthy products, clean oxygen and suitable temperatures. UGS provides basic ecosystem services for the city through ecological elements such as vegetation and water. Finally, UGS can optimize the urban ecosystem, increasing the supply of ecological services. The network layout of green space, such as ecological corridors and green patches, enhances the connectivity of the urban ecosystem, promotes species migration and gene flow, and thus improves the anti-interference ability of the system, which is the ecological basis for sustainable development.

Sustainable development pursues the coordinated and unified development of ecology, economy and society. The three are interdependent and mutually restricted, and the isolated development of any single dimension may destroy the balance of the overall system, making development unsustainable. Urban green space is part of the ecosystem and plays the function of ecological security. At the same time, urban green space has a welfare effect, which promotes economic and social development. Therefore, urban green space is the link between ecology, economy and society.

At the ecological level, ecological infrastructure such as urban forest system, wetland park, and ecological corridor have effectively alleviated atmospheric environmental problems such as PM2.5 and ozone pollution, and improved the urban heat island effect. In the process of urbanization, population, industry and economic activities gather in cities on a large scale, which brings many aspects of environmental impact, and ultimately leads to the intensification of environmental pollution. Urban green space innovatively uses green buildings, vertical greening, urban forest construction, community gardens, green transportation planning and other ecological tools to provide diversified ecosystem services for sustainable urban development, thus vigorously promoting urban green transformation.

At the economic level, green space can enhance the economic vitality of the city. Only with thriving industrial clusters, emerging innovative enterprises, and a positive and open market environment can a city have sufficient employment opportunities, continuous growth of fiscal revenues, and the ability to attract talent and capital to achieve sustainable development. At the same time, through the linkage of ecological value transformation and industrial upgrading, green space has become the fulcrum of economic green transformation. Its ecological function can be directly transformed into economic benefits through carbon trading and other mechanisms to enhance land

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value and attract low-carbon industries. By catalyzing new forms of business such as clean energy and eco-tourism, green space drives the low-carbon industrial chain; Attract talents and innovative resources through livable environment to support urban development and upgrading.

At the social level, urban green space can alleviate the unequal distribution of resources and promote social welfare and equity and justice. Urban green space can not only maintain the ecological system and economic and social stability, but also benefit people's physical and mental health. A study by University College London found that low-income people living within 500 metres of green space had a 14 per cent lower incidence of type 2 diabetes than those with no access to green space. The free exercise scene provided by the green space effectively replaces the paid health resources such as the gym. Urban green space has the nature of public goods, and because of the inseparable nature of natural space, it has the property of universal benefit. Every resident of the city can enjoy the ecological, health and social benefits of green space.

UGS has ecological, economic and social benefits to promote sustainable development. UGS are part of the ecosystem. Improving the supply of UGS is to optimize the urban ecological environment. The stability of ecological environment is the basis of economic and social stability, and the cleaning and beautifying functions of UGS are conducive to human development. At the same time, green space has public attributes and indivisibility, giving people the same right to development. This paper proposes hypothesis 1.

Hypothesis 1: UGS can promote sustainable urban development.

2.2. Impact Mechanism

2.2.1. Ecosystem Service Optimization

According to the theory of urban ecology, the development of ecology, economy and society can be achieved by exerting the function of ecosystem service. According to the above analysis, UGS are important parts of urban ecosystem. On the one hand, expanding the supply of UGS improves the urban ecosystem and increases its output capacity and quantity. On the other hand, UGS enhance the stability of the urban ecosystem and ensure the sustainable output of the ecosystem.

As a natural ecosystem and its biological community provide various functions and values for human society, ecosystem services not only maintain the stability of the ecosystem, but also directly or indirectly meet the needs of human survival and development, their role is irreplaceable. Sustainable urban development not only requires economic vitality, but also depends on ecosystem services. Green space is closely related to ecosystem service mechanism. Urban green space provides a variety of services such as carbon reduction, air pollutant purification, microclimate regulation, biodiversity protection, and recreation. Specifically, in terms of carbon emission reduction, urban green space effectively absorbs carbon dioxide in the atmosphere through the photosynthesis of vegetation and fixes it in the plant body, thus achieving carbon emission reduction. The purification of air pollutants is to reduce the concentration of suspended particles, sulfur dioxide and other harmful gases through the adsorption of tree leaves, soil and vegetation surfaces, and improve air quality. In terms of microclimate regulation, urban greening can reduce surface temperature, mitigate heat island effect, increase air humidity through plant transpiration, and optimize urban microclimate. In terms of biodiversity conservation, urban green Spaces provide habitats for various types of plants and animals and maintain the balance of urban ecosystems. In addition, urban green space also provides residents with leisure and entertainment space, enhances physical and mental health, and improves residents' quality of life and happiness.

Ecosystem services have a profound impact on multiple dimensions of urban sustainable development through multiple functional approaches such as supply, regulation, culture and support.

First, ecosystems provide the basic guarantee for the normal operation of cities. People need clean water, fresh air, food and other services from the ecosystem. These products and services

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support the survival and health of urban residents. If the quality of these services is reduced or insufficient, it will directly reduce the quality of life of urban residents and aggravate social conflicts, thus hindering the healthy development of cities. Secondly, ecosystem regulatory services, such as climate regulation, flood storage, pollution purification, etc., are crucial for cities to cope with climate change, reduce the risk of natural disasters, and improve environmental quality. Perfect urban green space system, wetland protection and water management help to improve the city's flood control and drainage capacity, alleviate the urban heat island effect, improve air quality, thereby enhancing the city's environmental carrying capacity and ensuring urban ecological security. Thirdly, the cultural services provided by the ecosystem, such as leisure and recreation, aesthetic experience and cultural inheritance, can enrich the spiritual life of urban residents, enhance happiness and sense of belonging, and enhance urban cohesion. Urban parks, greenways, cultural landscapes and other ecological Spaces not only provide places of recreation for residents, but also carry the historical context and cultural memory of the city, helping to shape urban characteristics and enhance the image of the city. In addition, ecosystem support services, such as soil formation, nutrient cycling and biodiversity maintenance, are fundamental to maintaining ecosystem functions and providing other ecosystem services. Protecting biodiversity in and around cities, maintaining soil health, and promoting nutrient cycling contribute to the stability and resilience of ecosystems and the ability of cities to respond to environmental challenges.

In conclusion, ecosystem services are an important and indispensable support for sustainable urban development, and their impact runs through all aspects of urban society, economy and environment.

2.2.2. Promoting Comprehensive Industrial Upgrading

Urban green space promotes the coordinated development of economy and ecology by transforming ecological resources into economic momentum and using the dynamic balance mechanism of industrial upgrading to feed ecological protection. This process reflects the positive interaction between green space and the overall industrial upgrading, and provides an important support for the sustainable development of the city. The benign interaction between green space and overall industrial upgrading essentially reflects the synergistic symbiosis between ecological protection and economic development. This interaction can not only promote the transformation of the industry to green and high-end, but also feed the optimization of the ecological environment through industrial upgrading, forming a closed loop of "ecological - economic - social" sustainable development. In this process, green space as an important ecological resource, its value can be fully developed. It not only provides a good development environment for the industry, but also promotes the transformation of the industry to green and high-end through benign interaction with the industry. The overall upgrading of the industry also provides strong support for the optimization of green space. With the progress of technology and the upgrading of industry, the investment and application of green technology by enterprises are increasing, which helps to reduce environmental pollution in the production process and improve the efficiency of resource utilization, thus providing the material basis and technical guarantee for the protection of green space. For example, through the implementation of circular economy and green manufacturing, the closed cycle of the industrial chain can be achieved, the generation of waste can be reduced, and the reuse of resources can be improved. This interactive relationship is also reflected in the mutual promotion between ecology, economy and society. The UGS not only improves the health level of the ecosystem, but also provides a good ecological basis for economic development and further promotes social harmony and progress. At the same time, the continuous economic growth and the overall progress of society also provide material conditions and technical support for the protection.

In the process of the overall upgrading of UGS and industry, the two are not simple linear development, but through the four core dimensions of ecological carrying capacity enhancement, economic efficiency improvement, social welfare optimization and governance model innovation, to achieve deep integration and mutual promotion synergies, and jointly lead the city to the sustainable

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development goal. Specifically, the enhancement of ecological carrying capacity is not only reflected in the expansion of urban green space and the increase of biodiversity, but also through the construction of green infrastructure, effectively improve air quality, regulate microclimate, protect and conserve water resources, reduce flood risk, and provide solid ecological environment support for industrial development. For economic benefits, green space to rise green industry, promote the green transformation of traditional industries, and through green technology innovation to enhance industrial added value and market competitiveness, so as to promote the economic growth model to intensive transformation. For social welfare, UGS improve the quality of life of residents. UGS can provide leisure spaces that improve living conditions and promote physical and mental health. Building and maintaining green Spaces in cities creates jobs, which promoting social equity and shared prosperity. Finally, UGS require the participation of the whole society, which improves the social integrity and governance capacity. UGS governance model emphasizes collaborative governance involving government, enterprises and communities, advocates public participation in green planning and decision-making, and provides institutional guarantee and policy support for the coordinated development of green space and industry. This helps build a more open, transparent and efficient urban governance system.

These four dimensions are interdependent and mutually reinforcing, which together constitute an organic system of urban sustainable development and promote the comprehensive, coordinated and sustainable development of cities at the four levels of ecology, economy, society and governance.

Based on the above analysis, this paper proposes hypothesis 2 and 3.

Hypothesis 2: UGS can optimize ecosystem services and thus promote sustainable urban development.

Hypothesis 3: UGS can positively interact with the overall industrial upgrading, thus promoting sustainable urban development.

3. Research Design

3.1. Model Construction

In order to test whether green space promotes sustainable urban development, this paper constructs a bi-directional fixed model of time and region:

$$SD_{it} = \alpha_0 + \alpha_1 UGS_{it} + \sum \alpha_j X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

Where: i denotes the city, t represents the year; SD_{it} stands for sustainable development; UGS_{it} stands for green space; X_{it} denotes control variables that the level of economic development (PGDP), government intervention (GOV), green innovation (INN), environmental regulation (ENV), level of foreign investment (FDI), and population concentration (POP); α_0、 α_1 and α_j represent the parameters to be estimated. μ_i symbolizes a constant regional effect. δt r symbolizes the constant effect over time; ε_{it} denotes the term for random disturbance.

3.2. Model Construction

3.2.1. Explained Variable

This paper agrees that sustainable development involves three aspects: economy, society and ecology. A comprehensive evaluation index system was constructed by referring to relevant studies [38–40], as depicted in Table 1.

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Table 1. System for assessing urban sustainability in development.

Primary index	Secondary index	Unit of measurement	Stats
Economic development level	Per capita GDP growth rate	%	+
	The contribution of tertiary industry value in relation to GDP	%	+
	The ratio of spending on science and technology within government spending	%	+
	The proportion of education expenditure in government expenditure	%	+
	Financial deposit balance/financial loan balance	%	+
	Per capita disposable income	yuan	+
Social development level	Sales of consumer goods per person in retail	yuan	+
	Count of buses per 10,000 individuals	Vehicles per 10,000 people	+
	Public publications for every 100 individuals	Pieces per 10,000 people	+
	Inclusive TFP Index	/	+
	Per capita expenditure on education	Ten thousand yuan per person	+
Ecological environment level	Green coverage rate of construction area	%	+
	Water use intensity	m3/ 10,000 yuan	-
	Energy intensity	Tons of standard coal / 10,000 yuan	-
	The rate of industrial wastewater release per GDP unit	t/ 10,000 yuan	-
	Emissions of sulfur dioxide as a percentage of GDP	kg/ 10,000 yuan	-
	Emissions of industrial smoke and dust per unit of GDP	kg/ 10,000 yuan	-
	Rate of centralized sewage treatment	%	+

3.2.2. Core Explanatory Variable

To assess the extent of urban green space, this study focused on parkland area as the primary indicator. The selection was informed by both the conceptual framework of urban green spaces and relevant regulatory guidelines, including the CJJ/T85-2017 Urban Green Space Classification Standard and GB/T51346-2019 Urban Green Space Planning Standard. This approach aligns with established methodologies while ensuring practical applicability for urban planning purposes.

3.2.3. Control Variable

The aim is to minimize bias in estimations due to absent variables and to more precisely assess how green spaces affect urban sustainable growth, the following control variables are introduced in this paper based on previous studies [41,42]: The economic growth measure (PGDP) is depicted through per capita GDP; government involvement (GOV) is quantified as the ratio of local public budget revenue to GDP; green technological advancements (INN) are indicated by the cumulative green patent filings. To mitigate the disparity in scale among these variables and to counteract any bias resulting from unequal variances, the INN variable is transformed into its logarithmic form in

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this study. Environmental oversight (ENV) is assessed by analyzing the frequency of environmental-related terms in government statements; and the foreign direct investment (FDI) metric is presented as the percentage of utilized FDI relative to GDP; Population agglomeration (POP) : population density is used. The GDP of the above control variables is the real GDP excluding price effects based on 2006.

3.3. Data Sources and Descriptive Statistical Analysis

The data used in this paper are sourced from a variety of publications, including the China Urban Statistical Yearbook, the China Regional Economic Statistical Yearbook, and various provincial and municipal statistical yearbooks. We also utilized the EPS database to gather information. Where data were missing, we filled in the gaps using interpolation techniques. Given data availability, our research sample consists of 249 cities at the prefecture level and above in China, spanning the years 2006 to 2022. Table 2 presents a summary of the descriptive statistics for each variable.

Table 2. Descriptive statistical analysis.

Variable type	Variable	Sample	Mean value	Standard deviation	Minimum value	Maximum value
Explained variable	*SD*	4233	0.0030	0.0055	0.002	0.0595
Explanatory variable	*UGS*	4233	0.1777	0.3333	0.0192	3.6397
	PGDP	4233	0.5233	0.5089	0.0001	6.0906
	GOV	4233	0.2784	13.0713	0.0070	828.529
Control variable	*INN*	4233	4.5264	1.8855	0	10.3007
	ENV	4233	0.0033	0.0014	0.0008	0.0124
	FDI	4233	0.0211	0.0251	0.00001	0.4686
	POP	4233	0.0462	0.0353	0.0005	0.3160

4. Results and Analysis

4.1. USG and Urban Sustainable Development

Table 3 shows the baseline regression results of green space and urban sustainable development, Model (1) shows the baseline regression absent any control variables; Model (2) is the regression result of introducing control variables based on model (1). The positive estimated coefficients for both columns of core explanatory variables suggest that green space greatly enhances urban sustainable development, it proved H1 is valid.

Table 3. Results of baseline regression model.

Variable	(1) No control variables	(2) Add control variables
UGS	0.0003*	0.0005**
	(1.6400)	(2.2900)
PGDP		0.0025***
		(9.1300)

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GOV		-0.0000
		(-0.0100)
INN		0.004***
		(6.0000)
ENV		0.0538**
		(2.4100)
FDI		0.0020
		(1.2400)
POP		-0.0251***
		(-4.5300)
Individual fixed effect	YES	YES
Year fixed effect	YES	YES
N	4233	4233
R^2	0.0834	0.1638

Note: Asterisks *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels respectively, with t-statistics reported in parentheses throughout the tables. The same convention applies to subsequent tables.

4.2. Endogeneity and Robustness Analysis

4.2.1. Endogeneity Test

To avoid potential endogeneity issues, this study uses system GMM estimation and selects the urban sustainable development level with a single-period delayed variable as the instrument. Table 4 presents the GMM estimation results of the system. The AR(1) test outcomes are below 0.1, demonstrating first-order autocorrelation exists in the disturbance term's differential. The AR(2) test statistic exceeding 0.1 suggests that second-order serial correlation isn't present in the first-differenced error terms, while the Hansen test outcomes confirm the instrumental variables' appropriateness. GMM estimates indicate a significantly positive urban green space coefficient, aligning with benchmark regression findings.

Table 4. Endogeneity test.

Variable	GMM estimate
UGS	0.0009***
	(8.2500)
Control variable	YES
Individual fixed effect	YES
Year fixed effect	YES
N	4233
AR(1)	0.0020
AR(2)	0.1140

HANSEN	0.1920

4.2.2. Robustness Analysis

Table 5 presents findings from the study's three applied robustness checks.

(1) Change explanatory variables. The green space measured by remote sensing method replaced the initial explanatory variable. Remote sensing technology can accurately extract vegetation coverage information through image analysis to avoid subjective bias, and this method can effectively distinguish between real vegetation and artificial landscape, and accurately reflect the ecological status. The alternative variable regressions align with baseline findings.

(2) Change the explained variable. Green total factor productivity now serves as the explanatory variable. Integrating energy use, environmental contaminants, and other less-than-desirable byproducts into the traditional TFP model allows for a more holistic view of the resource and environmental limitations, as well as the enhancement of economic efficiency, during the urbanization process. In this paper, green total factor productivity which calculated by super-efficiency SBM-GML model is selected to index urban sustainable development levels. Select capital, labor and energy as input indicators; Gross regional product is the expected output index, wastewater, emissions, and solid waste comprise the undesired output indicators. Specifically, prefecture-level cities' fixed capital assets is used to represent capital input, province's constant asset investment value indicator where the cities at the prefecture level are situated is reduced to the constant price in 2006, the capital stock is calculated using the perpetual inventory method, and the 9.6% depreciation rate, established by Zhang Jun et al. (2004) is applied. Labor input is represented by workforce size in each prefecture-level city, covering the total workforce in organizations and the city's private and freelance workers. Energy input is represented by each prefecture-level city's total societal electricity usage. The output of economic benefit is represented by the gross regional product of each prefecture-level city, and the deflator index of the province is used to deflate and processed at the constant price in 2006. Industrial byproducts including effluents gas emissions and solid waste were characterized by discharge of industrial waste water, sulfur dioxide and industrial smoke and dust from each prefecture level city. Regression outcomes with alternative dependent variables are basically consistent with the baseline regression results.

(3) Exclude municipalities. In the previous test, this paper considers that the administrative levels of Beijing, Tianjin, Chongqing and Shanghai are different from those of other prefecture-level cities, so they are excluded to verify result robustness. Excluding the municipalities, the regression model's outcomes largely align with those of the standard regression model.

Table 5. Robustness test.

variable	Alternate explanatory variable	Change the explained variable	Exclude municipalities
UGS	0.0079***	0.0503***	0.0007***
	(5.0500)	(6.8600)	(3.1800)
Control variable	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
N	4233	4233	4165
R^2	0.1690	0.1615	0.1978

4.3. Heterogeneity Analysis

4.3.1. Regional Heterogeneity

China boasts an expansive landscape with an uneven allocation of natural resources across its regions. Given the disparities in regional development conditions, this study categorizes the selected samples into eastern, central, and western zones for grouped regression analysis. The findings, as illustrated in Table 6, highlight distinct regional variations in the outcomes.

Urban green spaces play a crucial role in advancing sustainable development, particularly in central and western cities, though their impact is less pronounced in eastern urban areas. This disparity stems from several factors: the eastern region boasts stronger economic growth, more rapid urbanization, and a more stabilized urban layout, all of which diminish the marginal benefits of additional green spaces. Essentially, these areas have already reached a point where further green infrastructure yields diminishing returns.

As urbanization kicks into high gear in the central and western regions, the clash between urban sprawl and preserving the environment becomes even more glaring. Green spaces play a much bigger role there in tackling the urban heat island effect and cleaning up the air. Meanwhile, in the eastern regions, folks are already pretty eco-conscious and put a lot of money into environmental cleanup, so the added benefits of green spaces aren't quite as noticeable. But, because the central and western areas are lagging behind when it comes to environmental infrastructure, green spaces really stand out in improving the environment.

Table 6. Location heterogeneity test.

variable	East region	Central region	Western region
UGS	-0.0005	0.0029***	0.0035***
	(-1.5900)	(9.4900)	(20.56)
Control variable	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
N	1632	1666	935
R^2	0.2520	0.3263	0.5525

4.3.2. Economic Development Stage Heterogeneity

Since the inception of the post-reform and opening era, China's socio-economic fabric has undergone a period of profound and multifaceted transformation. Sweeping economic reforms, while fostering unprecedented growth and prosperity, have also inadvertently precipitated significant regional development disparities, creating a heterogeneous landscape of economic achievement across the nation. Recognizing these inherent divergences in urban economic advancement, this study adopts a differentiated approach by categorizing cities into distinct tiers based on their relative levels of development: a dichotomy primarily delineating between cities characterized by high-level economic performance and those exhibiting comparatively lower levels of economic attainment. In this study, we're using real GDP per capita as a yardstick for economic development. We crunched the numbers to get an average level of economic development. Then, we split the cities into two groups: those performing above the average, which we're calling "higher economic development," and those lagging behind the average, which we're calling "lower economic development." The table displaying grouping regression outcomes is located in Table 7.

Urban green spaces play a more substantial role in boosting sustainability for economically disadvantaged cities compared to their wealthier counterparts. This disparity stems from the fact that less developed urban areas typically grapple with resource scarcity and constrained environmental thresholds. Consequently, the strategic development of green infrastructure becomes critical for

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enhancing ecological conditions and elevating residents' standard of living. Such pressing needs compel local governments to prioritize green space allocation and optimization in urban planning, leading to more immediate and noticeable gains in a city's sustainable growth potential.

However, wealthier urban areas often encounter greater difficulty administering and maintaining parkland. For example, the land resources in these cities are relatively tight, and how to realize the reasonable layout of green space on the limited land has become a difficult problem. As cities grow and economies hum, so too does the need for green spaces. Juggling this demand with the vital ecological roles these spaces play is a challenge that calls for some serious thought.

Table 7. Heterogeneity test of economic development stage.

Variable	High economic level areas	Low economic level areas
UGS	-0.0002	0.0004***
	(-0.5300)	(2.7800)
Control variable	Yes	Yes
Individual fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
N	2618	1615
R^2	0.2357	0.1886

4.3.3. Heterogeneity of Resource-Based Cities

Varied resource cities require distinct developmental strategies and trajectories. Considering the differences in city types, this study categorizes the sampled cities into two groups-non-resource-based and resource-based-following the classification framework outlined in the National Plan for Sustainable Development of Resource-Based Cities (2013–2020). A regression analysis was conducted for each subgroup, with the findings presented in Table 8.

Green spaces within urban settings can significantly contribute to the eco-friendly growth of cities that rely on natural resources. However, their influence is typically less pronounced in cities that don't depend on such assets. The rationale boils down to the fact that resource-rich towns are often home to robust industrial sectors that have a more considerable environmental footprint. A boost in green spaces can go a long way in mitigating the pollution stemming from industrial discharges, enhancing the overall living standards for city dwellers, and even serving as a magnet for eco-friendly and tech-forward sectors. This, in turn, spurs the city's economy to evolve and modernize.

In contrast, cities that aren't sitting on a pile of natural resources tend to lean heavily on service and high-tech sectors. These industries generally have a lighter environmental footprint. Because of this, it can be tough to see the immediate payoff of green spaces in those urban areas. In other words, the environmental advantages aren't always obvious right away.

Table 8. Heterogeneity test of resource-based cities.

Variable	Non-resource-based city	resource-based city
UGS	0.0002	0.0008***
	(0.7400)	(2.5800)
Control variable	Yes	Yes
Individual fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
N	1666	2567
R^2	0.2291	0.1690

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4.4. Influence Mechanism Analysis

Based on baseline regression, this paper introduces the interaction term between urban green space and institutional variables, and examines how urban green space promotes urban sustainable development through ecosystem services and overall industrial upgrading. To this end, the following model is constructed:

$$SD_{it} = \beta_0 + \beta_1 UGS_{it} + \beta_2 ECO_{it}/STR_{it} + \beta_3 UGS_{it} \times ECO_{it}/STR_{it} + \sum \beta_j X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

Where: ECO_{it} and STR_{it} respectively represent the value of ecosystem services and the overall upgrading of the industry; $ECO_{it}/STR_{it} \times UGS_{it}$ is the interaction item between the two and green space respectively, and β3 is the focus object, which represents the impact of green space and ecosystem service value, overall industrial upgrading interaction and superposition on sustainable development.

Based on baseline regression, this paper introduces the interaction term between urban green space and institutional variables, and examines how urban green space promotes urban sustainable development through ecosystem services and overall industrial upgrading. The ecosystem services are calculated by referring to the research of Liu, H.M.; et al [43]. Based on the research of Hu, Y.D. and Xu, Y.D. [44], the overall upgrading of the industry is given a weight of 1 to 3 times for the proportion of output value of the primary industry, the proportion of output value of the secondary industry and the proportion of output value of the tertiary industry respectively, and the sum is concluded. The larger the value, the higher the overall level of the industry.

4.4.1. Ecosystem Service Optimization

The regression results in Table 9 show that the interaction coefficient between urban green space and ecosystem services is significantly positive, indicating that urban green space can not only directly provide ecosystem services, such as purifying air, regulating climate, maintaining biodiversity, etc., but also further strengthen the contribution of these services to urban sustainable development by improving the overall efficiency of ecosystem services.

Table 9. Ecosystem service optimization.

Variable	Ecosystem service
UGS	-0.0003
	(-1.1300)
UGS×ECO	0.0001***
	(5.3000)
Control variable	Yes
Individual fixed effect	Yes
Year fixed effect	Yes
N	4233
R^2	0.1709

4.4.2. Overall Industrial Upgrading

The regression results in Table 10 show that the interaction coefficient between urban green space and overall industrial upgrading is significantly positive, indicating that there is a synergistic promotion effect between urban green space and overall industrial upgrading, that is, reasonable planning and construction of green space can effectively enhance the positive impact of industrial upgrading on sustainable development.

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Table 10. Overall industrial upgrading.

Variable	Overall industrial upgrading
UGS	0.0331***
	(14.3300)
UGS×STR	0.0001***
	(14.1900)
Control variable	Yes
Individual fixed effect	Yes
Year fixed effect	Yes
N	4233
R^2	0.1369

5. Conclusions and Suggestion

Using environmental date from 249+ Chinese cities (prefecture-level and above) spanning 2006-2022, This study examines how urban green spaces influence sustainability, their underlying mechanisms, and regional variations. The findings indicate: (1) Urban greenery strongly enhances sustainable city growth; (2) This promotion effect is mainly achieved through the positive interaction between green space and the ecosystem and the overall industrial structure; (3) Variations in the influence of urban green areas on sustainable progress across diverse locations. The effect of green space is even more significant in economically underdeveloped regions, China's central and western regions, and resource-based cities.

Findings suggest these policy implications:

(1)To enhance the role of urban green spaces in promoting urban sustainability, should scientifically plan and rationally use urban green space to enhance the USG's role in promoting sustainable urban development. According to the density and needs of residents, priority will be given to increasing green Spaces in old urban areas and industrial areas, creating convenient green Spaces "within a 15-minute walk", combining parks with facilities such as fitness areas and cultural squares, and saving land through rooftop greening and three-dimensional planting. At the same time, indicators such as green area and carbon reduction effect will be included in urban construction approval standards, and enterprises will be encouraged to participate in green projects. In addition, it is necessary to use satellite monitoring and other technologies to dynamically track the effectiveness of green space construction, link green planning with carbon emission control and ecological compensation policies, and attract social capital to invest in green infrastructure through the "ecological development" model. Finally, through scientific layout, the green space can take into account the multiple functions of ecological protection, residents' life and low-carbon economic transformation, and help the sustainable development of the city.

(2) For USG, the sustainable development is mainly promoted by optimizing the ecosystem and promoting the overall upgrading of the industry, and ecological and industrial optimization can be jointly promoted through ecological and industrial structural dimensions. Enhancing USG' s ecological impact through scientific layout of urban green space network and ecological investment, systematic restoration of degraded ecosystems, while introducing low-carbon industries such as ecological cultural tourism and green science and innovation around ecological green Spaces, transforming ecological resources into carriers of industrial upgrading; Additionally, multi-tiered public spaces (e.g., pocket parks and waterfront trails) enhance land-use efficiency while embedding nature within 500-meter living circles, fostering residents' environmental stewardship through daily interactions.

(3)Boosting USG' s industrial upgrading impact. Facilitating a greening of the whole industrial chain with green space as a link, encourage enterprises to integrate green technologies such as vertical greening and photovoltaic roofs in the construction of the park, and rely on the ecological park to

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build a green financial platform, develop carbon sink pledge, ecological credit loans and other products, and guide capital flow to clean energy and circular economy. Crucially, eco-industrial zones serve as innovation incubators, accelerating technologies like hydrogen energy storage and smart irrigation. In this process, the government needs to establish an incentive mechanism simultaneously, and give tax incentives to enterprises that adopt ecological engineering methods and participate in carbon sink trading. Through the establishment of a two-way collaborative mechanism, green space can simultaneously become a provider of ecological services and a catalyst for industrial transformation, and comprehensively enhance sustainable urban development.

The government should adopt differentiated policies according to the regional characteristics of the resource type and economic development level of the city. Due to long-term dependence on resource-intensive industries or ecological degradation, USG plays a more significant role in promoting sustainable development in economically underdeveloped areas, Midwest cities and resource-based cities. Therefore, it is suggested to adopt the following differentiated strategies: in less developed areas, priority should be given to the construction of ecological corridors and community green space networks to alleviate the pressure of environmental degradation; Central and western cities need to integrate green space with industrial parks, supporting photovoltaic, intelligent irrigation and other facilities to drive low-carbon transformation; Resource-based cities need to customize fiscal and tax incentives (such as tax breaks for green technology enterprises) and carbon sink trading mechanisms to guide social capital to participate in green space development. At the same time, a digital monitoring platform based on GIS is established to dynamically evaluate the ecological and economic output of green space to ensure flexible policy adjustment.

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