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Research on the Sustainable Development of Green-Space in Beijing Using the Dynamic Systems Model

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Abstract: Greater contradiction and conflict among urban green space, the development of social economy and the environment have occurred in Beijing. However, few studies have been conducted that consider the three subsystems as a whole. In this study, we defined sustainable development of green space (SDGS) as the coordinated development of the urban green system, social economy, and environment. Based on the datasets from 2000 to 2015, we forecast the SDGS in Beijing under multiple scenarios based on real-world policies using a system dynamics model. We found that the historical SDGS value increased to its highest level in 2012, but declined slightly by 2015. Second, the forecasted SDGS values declined over time in all scenarios, but the decline was greater in scenarios placing a high priority on economic development. In these scenarios, the performance of the indices only improved in certain subsystems. The simulation shows the implementation of the four policies proposed by the government failed to improve the overall level of SDGS in Beijing. This study could provide support for decision-making designed to improve the overall condition of urban green space in Beijing through integrated forecast and scenario simulation.

Keywords: Beijing; forecast; policy formulation; scenario simulation; sustainable development of green space; system dynamics model

1. Introduction

Urban green space is an important component of a city that is closely related to the health and well-being of city dwellers [1]. Green space also helps to shape the landscape of a city and improve city life [2] by providing opportunities for aesthetic enjoyment [3] and recreational [4] as well as several other benefits. Meanwhile, the development of urban green space has a positive relationship with the environment and the social economy referring to the financial economy and human activities related to urbanization. Urban green spaces generate ecosystem services, foster resilience in cities [5] and improve the quality of the environment, thus providing comfortable living conditions with clean air and a beautiful, ecologically sound environment. However, rapid urbanization and population growth has caused a great loss of urban green space [6]. High density development and limited land resources make it impossible to exploit large areas of new green space. Therefore, urban development and increased economic activity have caused many changes to the existing urban green space in well-developed city regions worldwide [7].

Similar problems have occurred in Beijing as have happened elsewhere. In 2014, Beijing's population reached 21.52 million with the GDP of Beijing having increased rapidly featuring a growth rate of more than 7% for 10 years since 2000 [8,9]. However, this rapid economic expansion has led to great pressure on the environment and natural resources of Beijing, causing serious environmental problems and seriously affecting urban green space negatively. The development of urban green space in the well-urbanized region of Beijing has been very dynamic [7]. People put extra effort into developing new green space. However, some effect of new green space area is offset by the occupation of green space, which has been converted into other land use types in support of economic development, e.g., residential, commercial, or even industrial land. According to interpreted thematic mapper satellite data, green space occupied 120 km^2 in 2007 and 43.41 km^2 in 2009. The rapid urbanization of Beijing is expected to continue in the coming 20 years, creating an enormous strain on existing green space. Knowing how to attain sustainable development while balancing the needs for urban green space, the environment and the social economy has become a major concern for Beijing. This article defined sustainable development of green space (SDGS) as a state that in a particular time and space, an urban green system can achieve self-stability; in addition, SDGS provides the ecosystem service functions needed to protect the environment as well as meeting the needs for sustainable development of society and the economy. The government of Beijing has implemented many policies that are designed to develop green space, such as the "Afforestation Project for the Plains of Beijing" and "Urban Green System Planning of Beijing (2004–2020)". Although the total urban space area and urban green space ratio has been increasing, the development of green space in Beijing still fails to meet the needs of the city in light of high speed urbanization and the explosion of the population. Therefore, establishing a simulation model is essential to study changes of the SDGS and to understand the mechanism of SDGS for Beijing. Providing simulations on the basis of the complexity of the SDGS can provide a significant guide for testing the effectiveness of policies, selecting the most reasonable policy decisions for Beijing, and thus achieving the SDGS of Beijing during "The 13th Five-year Plan". Currently, some studies have made considerable effort in this area of forecasting and simulating through modeling, including a land transformation model [10], cellular automata [11] and GEOMOD model [12]. However, these models are spatially complex systems for forecasting. Other simulation methods, such as principal component analysis [13], system cluster analysis [14] and fuzzy comprehensive evaluation [15], have the ability to simulate static changes, but are not suitable for simulating a dynamic system including a complex index. The relationship between green space, the social economy, and environment is a dynamic and complex process. Therefore, a method that couples the analysis of changeable factors related to the SDGS is needed.

Forrester of the Massachusetts Institute of Technology initially proposed a system dynamics (SD) model in the early 1960s [16] that has been widely used in strategic policy analysis [17]. A SD method involves theory combining system theory, cybernetics, information theory, decision theory and computer simulations [16]; this method is widely used in the fields of food security [18], urban air pollution [19] and market competition [20]. A SD model simulates the effects among factors in a non-linear fashion when complex feedback occurred within a system [17]; this makes the SD model suitable for simulating the complex relationships within the development of green space, the social economy, and changes to the environment. Additionally, the SD model could better simulate and analyze the post treatment effects under various control schemes, seeking the best way to improve the functioning of a system [21]. After the model is constructed, it will be tested by the existing data to ensure the simulation is reliable and effective.

In this study, we constructed an integrated evaluation and scenario simulation model based on a system dynamics modeling method to forecast the SDGS for Beijing. We evaluate and simulate the different performances of the SDGS for Beijing under the influence of recent policies related to urban green space, the society economy and environmental management in Beijing. Then, the SD model verifies the complementary role of these policies and selects a more reliable control method. This paper has the following three aims:

(1) Establish and calculate the SDGS index system for Beijing.

(2) Establish a forecast and scenario simulation model of the SDGS for Beijing based on the complex feedback relationship within three subsystems involved in the SDGS, which includes the green space resource, social economy and environment subsystems.

(3) Propose five dynamic control scenarios that are based on the policies applied by the government to develop the urban green space, social economy and to manage the environment of Beijing. Then, we simulate each optimal control scheme to determine the different results of the SDGS for Beijing.

2. Study Area

Beijing stands on the northwestern edge of North China Plain between 39°28′ and 41°05′N and 115°25′ and 117°30′E, covering an area of 16,410.54 km^2 (Figure 1). Until 2015, there were 21.7 million permanent residents living in Beijing [22]. Meanwhile, the total urban green area in Beijing reached 8.13 × 10^2 km^2, with an urban green coverage of 48.4% and greening rate of 45.7% [23]. After the successful Olympic bid in 2001, Beijing has devoted major efforts to developing urban green space to improve the local environment and arrangement of urban green space. For example, the state council issued "The Decision of the State Council on Strengthening the Construction of Urban Greening" in 2001, which requested that urban greening be considered as an important part of the city's infrastructure and is important in the content of urban modernization. In 2015, the "13th Five-Year" national economy and social development plan proposed by the Beijing Municipal Party Committee put forward the aim of strengthening the development of urban green space.

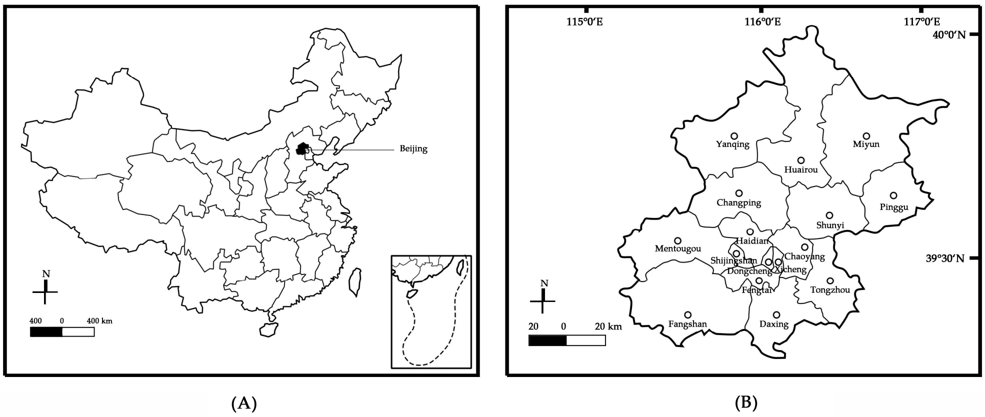

Figure 1. Map of the study area: (**A**) vicinity map of the area within China; and (**B**) map of all administrative areas of Beijing City, comprising the present study area.

3. Methods

3.1. SDGS Index System and Weight

To judge the quality or failings of the SDGS in Beijing, we evaluate the sustainable rate of green space management by analytical hierarchy process, which has multiple criteria and weight values that can be used to solve complex evaluation problems [24]. A reasonable and scientific index system would contribute to an accurate evaluation of the sustainable development of green space [25].

A variety of studies have focused on the evaluation of the green space. Some studies [26,27] have primarily conducted evaluations of green space from a green space resource perspective (e.g., park area ratio, the size of green space). Other studies [28–30] have expanded the evaluation of green space by considering the social economy (e.g., the relationship between green space and other factors such as population density and/or the cost of living). Recent studies [31] also view the environmental conditions as indicators used to evaluate the quality of green space. Although these researchers acknowledge that the evaluation of the green space is associated with the social economy and environmental factors, their major limitation, however, rests on evaluating from a solitary perspective.

In this study, we define several comprehensive assessment indices to evaluate the level of sustainable development of urban green space in the city. Based on our definition of the sustainable development of green space, relevant literature [32–42] and the Evaluation Standard for Urban Landscape and the National Ecology Garden City Standard in China [32], while considering the accessibility of the data for indices, we establish our evaluation index system for the SDGS (Table 1). The index was classified into three categories, including green space resources, the social economy and environment, using 13 detailed indices in total.

In the system, various indices have different effects on the evaluation; therefore, the weight of each evaluation index needed to be determined. The relative weight of each evaluation index was calculated by Equation (1) [43]:

$$C_i = A_j \times C_{j,i} \quad (1)$$

where C_i is the weight of the index relative to the first level indicator; A_j is the weight of the second-level indicators relative to the first-level indicator; and $C_{j,i}$ is the weight of the index relative to the second level indicators.

Table 1. Index system table related to the sustainable development of green space.

First Level Indicator	Second Level Indicators	Index Name (Unit)	Explanation	Formula	Direction	Weight
The SDGS assessment in Beijing (A1)	Urban green space (B1)	C1 Urban green coverage rate (%)	Urban green coverage rate is an important index in the evaluation of urban landscaping and ecological environment [32].	Vertical projection area of planting/construction land area × 100%	+	0.0851
		C2 Urban green space ratio (%)	Urban green space ratio is a crucial evaluation standard for urban landscape planning [32].	Green space area/construction land area × 100%	+	0.0657
		C3 Public green area per capita (/Ha)	Per capita public green area is a crucial index in the evaluation for the harmony of urban development and landscape construction [32].	Total population/public green space area	+	0.0896
		C4 Investment of green space construction (ten thousands yuan)	The investment in Green space has a positive effect on the development of green spaces.	Obtained directly	+	0.1187
	Social economy (B2)	C5 Occupied area of green space (/Ha)	The decreasing areas of green spaces lead to a negatively impact on the services of ecosystems [33].	Interpret Thematic Mapper satellite images	−	0.0816
		C6 Population density (/Ha)	The growing proportion of human populations living in urban areas could affect the availability of urban green spaces [34], which may become a more important negative predictor of extent of green space and tree-cover.	Population at the end of each area/land survey area	−	0.0667
		C7 GDP per unit area (ten thousands yuan/Ha)	Per capita GDP has the significant relationships with green space coverage [35].	GDP/land survey area	−	0.0396
		C8 Industrial structure index (%)	Industrial structure is an important factor affecting landscape diversity and landscape patterns [36].	(secondary industry GDP/GDP) × 100%	−	0.0408

Table 1. *Cont.*

First Level Indicator	Second Level Indicators	Index Name (Unit)	Explanation	Formula	Direction	Weight
	Environment (B3)	C9 Carbon dioxide emissions index (t/Ha)	Carbon dioxide emissions, the main component of the greenhouse gas, attribute to green space maintenance directly [37].	Fossil fuel consumption × carbon dioxide emission coefficient/land survey area	−	0.1298
		C10 Annual average daily particulate matter (mg/m^3)	Particulate matter was the major pollutant affecting the urban air quality [38], thus making many cities suffer from various environmental problems.	Obtained directly	−	0.0732
		C11 Days of air quality above grade II rate (%)	Days of air quality above grade II rate represent the quality of the air, which will lead the trees morbidity, reduce trees growth and make impact on ecosystem [39].	Obtained directly	+	0.0640
		C12 Annual rainfall (hundred mm)	The annual rainfall influenced trees density [40] and their growth speed directly [41], which is an important factor influencing the planting.	Obtained directly	+	0.0597
		C13 Environmental protection investment index (%)	An increasing investment in environmental protection is one of the most important ways to enhance ecosystem services (e.g., the ecosystem services of green space) [42].	Obtained directly	+	0.0852

Note: Variables in the system have different effects on SDGS. When the index has positive or negative effect on SDGS, we use "+" or "−" to indicate the direction. The green space resource data are from The Beijing Parks and Forestry Yearbook and The Beijing Parks Yearbook; the social economy data are from The Beijing Statistical Yearbook and the occupied area of green space is based on an interpretation of Thematic Mapper satellite image data.

3.2. Measurement

The metrics of the index may be composed of different measurement units and magnitudes. Therefore, a uniform measurement is required to assess the level of the SDGS. Accordingly, the positive and negative indices are normalized, respectively, by Equations (2) and (3):

$$S_{ij} = (g_{ij} - min_i)/(max_i - min_i) \tag{2}$$

$$S_{ij} = (max_i - g_{ij})/(max_i - min_i) \tag{3}$$

where S_{ij} is the normalized score of ith index in year j, g_{ij} is the actual value of ith index in year j, max_i is the maximum of the ith index, and min_i is the minimum of ith index.

To reflect the overall performance of the SDGS in Beijing, the normalized scores of all indices are summed up. This can be expressed as Equation (4):

$$P_j = \sum_{i=1}^{m} S_{ij} \times S_{ij} \tag{4}$$

where P_j is the overall score of the SDGS in year j, S_{ij} is the normalized score of ith index in year j and W_{ij} is the weight value of ith index.

3.3. Establishment of the SDGS Model

The foundation of an SD model is the feedback loop structure, which can reflect the dynamics of a non-linear system and estimate the trends and interaction among important factors to represent the behavior of the system [44]. The structure includes the components and relationships among those components [17]. Therefore, the basic structure of the system and the proper variables must be identified first. First, endogenous variables are determined by the SDGS index system in Table 1, which impacts the dynamics of the system through the interactions of the variables. Second, exogenous variables that could impact the values of the endogenous variables form the boundary of the model [45]. For instance, urban green space ratio is the endogenous variable, whereas green space area and construction land area that could impact the value of urban green space ratio become the exogenous variables. Variables insensitive to the model for the output would be excluded out of the model.

The feedback interactions among these variables within the system will be depicted by flowcharts with clear, visual symbols [17]. To represent the interactions among the SDGS system more clearly, we divided the SDGS system into three subsystems based on the concept and description of the SDGS. These include: (1) the urban green space; (2) the social economy; and (3) the environment subsystems. The factors of these subsystems all belong to the overall system and they work together to affect the behavior and the changing trends of the SDGS system by their mutual interactions [46].

The green space resource subsystem is the core component of SDGS. Its health condition or potential for exploitation explicitly represents the level of sustainable development of green space. In the green space resource subsystem, we select year-end green space area as the most important variable. This variable represents the total green space resource, characterizing the security situation related to the sustainable development of the green space system. Interrelationships between year-end green coverage area, year-end green space area, occupied area of green space, investment of green space development and net urban green space area are considered during the simulation. Among this, year-end green space area is measured by public, production, protected, attached and occupied green spaces area. Two categories are identified as the factors that influence the year-end green coverage area. First, the fluctuation (e.g., growth or decline) of green plants itself contributes to the change (e.g., increase or decrease) of green coverage area. In addition, the production green space provides seedlings for green coverage area. Second, occupying green space area has become an important way to increase the spatial extent of construction land area (e.g., both residential and commercial land), which decreases the year-end green space area. Eventually, the year-end green coverage area tends to decline. The attached green space area, however, reversely increases because of the growing construction land area. Furthermore, harvesting for economic interests (e.g., the secondary industry) will occupy some green space resources. However, as year-end green space area is decreasing continuously, the increase of the incremental particulate matter and carbon dioxide emissions would draw the attention of people to the condition of the environment (green space), which in turn stimulates investment and protection/development of the environment and additional green space.

The social economy subsystem is a critical factor that influences the socioeconomic development of Beijing, and contributes to the major effects of urbanization on the SDGS and controls the nature of conditions of green space resource to some extent. In the social economy subsystem, the interaction between the total population and economic amount is primarily simulated. People engage in various constructive and productive activities (e.g., occupied green space often the first to be developed, then primary industries second) to facilitate economic growth, which results in a higher GDP. Therefore, the increase in the total population results in economic growth. Meanwhile, a higher GDP transforms into higher requirements for green space. Once the development of the social economy exceeds the environmental carrying capacity, the environment is inevitably heavily degraded. Subsequently, the year-end green coverage area tends to decline as a result of the damage to habitats in the green space. Other environmental indices (e.g., annual average daily particulate matter, days of air quality above a Grade II rating, energy consumption, carbon dioxide emissions) will be involved. Conversely, to compensate, rapid economic development draws public attention to environmental issues, encouraging additional investment in environmental protection; also, there is an increment of attached green space stemming from incremental development of construction land.

An urban environment provides habitats for plants, which affect the "quality" and "quantity" of the urban green space resource. The urban environment also has a close relationship with the social economy. The environment subsystem becomes a connection between the urban green space and social economy subsystems. In this article, we select days of air quality above a Grade II rating as the state variable of the environment subsystem to simulate the interactions among the development of the society economy, urban green space and the environment. The amount of green space (year-end green coverage area) will influence the environmental indices (e.g., amount of plants can affect the CO_2 emission index related to the carbon sequestration function). Therefore, people could improve the environment by increasing the amount and quality of green space and by planting more trees, which could translate to an increase in year-end green space area. Meanwhile, the development of the economy results in an increase in the investment of environmental protection projects that have been completed. In summary, the environment subsystem interacts with environmental indices (e.g., days of air quality above Grade II, carbon dioxide emissions, annual rainfall and annual average daily particulate matter), the development of the social economy and the status of the urban green space resource. Based on the feedback interactions among these variables within the three subsystems, the flowchart of the SDGS model could be formed (Figure 2).

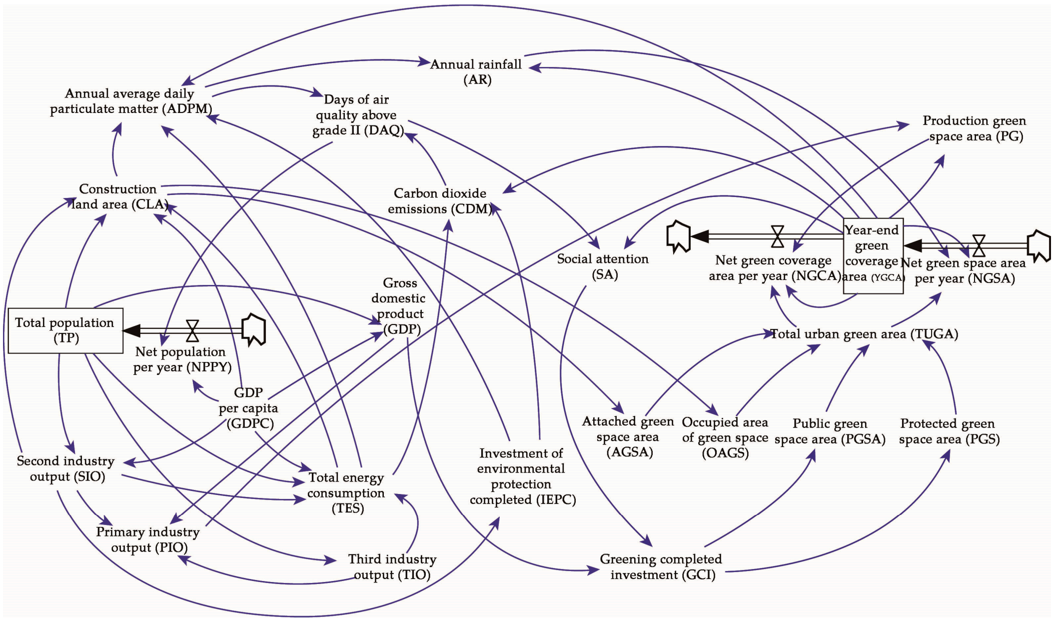

Figure 2. System dynamics flowchart of the sustainable development of green space model for Beijing.

Based on the flowchart, the SD equations will be constructed to describe the recursive relationship among variables quantitatively by mathematical formulae. These differential equations are created by Vensim PLE software and reflect the variables changing from a known initial state to the next state [21]. The initial values of the main variables in the model were based on data collected from 2000 to 2015 [8,47,48]. A regression analysis is conducted to calculate whether the variables are highly correlated. Then the SD model is run via the simulation platform to debug the model using the historical data forming the equations and to simulate the each dynamic control scenario to forecast the changing trends of the system over time. Equations expressing the SDGS model are available as Table 2.

Table 2. Main variables and expressions used in the model.

Name of Variables	Expression	Unit
Annual average daily particulate matter	$= (-0.001) \times CLA - (-0.006) \times YGCA - 0.125 \times IEPC + (-0.011) \times TES + 0.834$	mg/m^3
Annual rainfall	$= (-65.098) \times ADPM + (-0.377) \times YGCA + 15.545$	100 mm
Days of air quality above grade II	$= (-83.988) \times CDM - (-11.56) \times ADPM + 3.316$	100 days
Production green space area	$= 0.018 \times PIO + 0.023 \times YGCA - 0.035$	$100\ km^2$
Construction land area	$= (-6.77) \times (TP \times GDPC - TIO - SIO) + 0.177 \times TIO + (-0.275) \times SIO + 0.944$	$1000\ km^2$
Carbon dioxide emissions	$= (-0.00008358) \times YGCA + 0.001 \times TES + (-0.001) \times IEPC + 0.004$	$million\ ton/km^2$
Social attention	$= 0.186 \times DAQ + 0.042 \times YGCA - 0.304$	-
Net population per year	$= 0.025 \times DAQ + (-0.002) \times GDPC + 0.014$	Ten million people
Second industry output	$= 0.2 \times (TP \times GDPC) + 0.488$	One hundred billion yuan
Total energy consumption	$= 0.149 \times TP + 1.017 \times GDPC + (-0.301) \times TIO + 0.047 \times SIO + 1.985$	Ten million tons
Primary industry output	$= GDP - TIO - SIO$	One hundred billion yuan
Third industry output	$= 0.8 \times (TP \times GDPC) - 0.588$	One hundred billion yuan
Investment of environmental protection	$= 0.009 \times SIO + 0.02$	One hundred billion yuan
Net green coverage area per year	$= PG + (YGCA/TUGA) \times PG$	$100\ km^2$
Year-end green coverage area	$= INTEG\ (NGSA - NGCA, 2.679)$	$100\ km^2$
Total urban green area	$= PGSA + OAGS + PGS + AGSA$	$100\ km^2$
Attached green space area	$= 1.8192 \times CLA$	$100\ km^2$
Occupied area of green space	$= (-0.9957) \times CLA + 1.6684$	$100\ km^2$
Public green space area	$= (-0.849) \times SA + 0.1 \times GCI + 0.782$	$100\ km^2$
Protected green space area	$= 0.691 \times GCI$	$100\ km^2$
Greening completed investment	$= 26.456 \times SA + 0.157 \times GDP + (-3.215) \times IEPC + 0.953$	One hundred million yuan
Industrial pollution control investment	$= (-0.055) \times SIO + 1.102$	One hundred million yuan

Note: The variables in the expressions are the abbreviations of names in Table 2.

3.4. Verification Test

The SDGS model for the output is only sensitive to some parameters [49]. Therefore, the Monte Carlo method was used to select sensitive parameters [46]. In the present study, the total urban green space area and GDP were selected for calibration. The error degree between the simulated and actual values of data from 2000 to 2015 was calculated to verify the model [46]. The results showed the average error was 5.8% and 7.8% (Figure 3a,b, respectively), which was within the allowable range of 10%. Thus, the SDGS model can simulate the actual system.

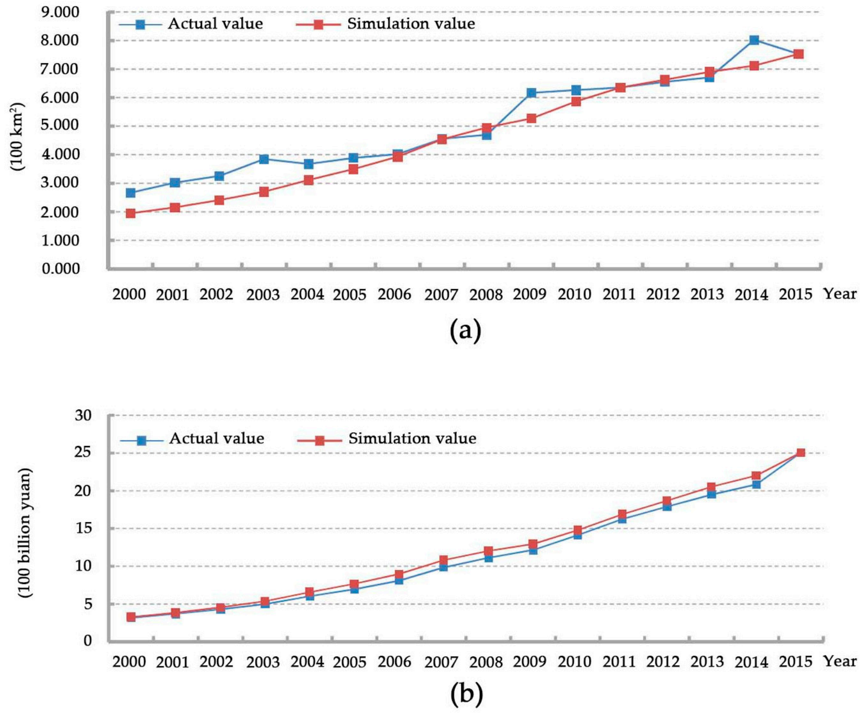

Figure 3. Error testing based on: (**a**) the total urban green space area; and (**b**) the GDP in Beijing for 2000–2015.

3.5. Scenario Design

The government of Beijing has proposed and applied several policies to Beijing's green space problem. However, we confine ourselves to policy scenarios that are suitable to Beijing's current SDGS situation. Thus, five policy scenarios are tested for the experiment to select the most reasonable policy that can facilitate the sustainable development of urban green space while improving the social economy and environment in Beijing. These scenarios are described in Table 3.

First, the SDGS-as-usual (SAU) scenario describes the continuation of the current situation as a base reference scenario.

Second, the Urban Green space Work Plan (UGWP) scenario reflects a situation of promoting the use of the urban green space resource. In this scenario, Beijing attempts to increase urban green space area through the implementation of the 2016 Urban Greening Work Plan issued by the Beijing Municipal Bureau of Landscape and Forestry. It is assumed that the government endorsement of the implementation of the UGWP will stably increase the quality and amount of the available urban green space resource starting from the base year. The urban green space area is simulated to increase by 432 ha annually, which is the target of the UGWP plan [23]. This plan includes an increase of public green space area of 208 ha and attached green space of 261 ha annually [23]. To simulate this, the net urban green space area value per year is set to 432 ha, increasing the public green space area of 208 ha and attached green space of 261 ha starting from 2016, while the other parameters are set at their original value.

Third, another scenario reflects a situation in which the urban green space subsystem is comprehensive increased under Beijing "13th Five-Year" Landscape and Greening Plan (LGP). To simulate this situation, the urban green coverage rate and public green area per capita are set to increase to 48.5% and 16.5 m^2 per capita by the end of 2020, respectively [50]. The net urban green space area per year value is set to 450 ha by 2020 [50]. Other parameters outside these scenarios follow the historical data trajectory.

Fourth, the next scenario reflects a situation of macroeconomic regulation under Beijing "13th Five-Year" National Economy and Social Development Plan (NESP) issued by the Beijing Municipal Party Committee. To simulate this situation of medium-speed socioeconomic development, the total population is limited to 23 million by the end of 2020 [51]. The net GDP growth rate is set to 6.5%. Meanwhile, the net tertiary industry output growth rate increases by 5.5% annually starting from 2016 and remains at that level until the end of the simulation.

Fifth, the next scenario reflects a comprehensive development of the SDGS system under the plan on the Work Report of the Beijing Municipal People's Government (WRBG) in 2016. The urban green space, social economy and environment subsystems are aggressively addressed until the end of 2025. To simulate this situation, the net GDP rate is limited to 6.5% from 2016 [52]. The implementation of environmental control measures that may result in a decrease in total energy consumption, carbon dioxide emissions and annual average daily particulate matter is considered in this scenario. These parameter settings lead to a decrease in total energy consumption, carbon dioxide emissions and annual average daily particulate matter of 3.5%, 4% and 5% annually, respectively [52]. Meanwhile, the urban green space area is expected to increase by 400 ha annually starting from 2016.

Table 3. Scenarios for experimentation.

Scenario	Design Basis	Detailed Procedure
Scenario 1	The SDGS-as-usual (SAU)	Maintain the current situation as a base reference scenario
Scenario 2	The Urban Green space Work Plan (UGWP)	Increase the urban green space area, public green space area and attached green space area by 432 ha, 208 ha and 261 ha annually from 2016.
Scenario 3	Beijing "13th Five-Year" Landscape and Greening Plan (LGP)	Increase the urban green coverage rate and public green area per capita to 48.5% and 16.5 m^2 per capita by 2020; Increase the urban green space area by 450 ha annually from 2016 to 2020.
Scenario 4	Beijing "13th Five-Year" National Economy and Social Development Plan (NESP)	Limit the total population to 23 million by 2020; Set the net GDP growth rate and the net tertiary industry output growth rate to 6.5% and 5.5% annually from 2016.
Scenario 5	The Work Report of the Beijing Municipal People's Government (WRBG)	Set the net GDP growth rate to 6.5% annually from 2016; Decrease the total energy consumption, carbon dioxide emissions and annual average daily particulate matter by 3.5%, 4% and 5% annually from 2016; Increase the urban green space area by 400 ha annually from 2016.

4. Results

4.1. Performance for the Subsystems

To reflect the SDGS performance in the individual subsystem, the performance score of indices belonging to the subsystem are summed up [53]. In the following section, the performance of each subsystem is compared to analyze the impact that is either beneficial or detrimental to each subsystem under five different scenarios. Figures 4–6 present the scenario simulation results.

According to the simulation, the performance of the urban green space subsystem would increase before 2012, but decline in every scenario after 2020 (Figure 4). Only the LGP scenario would have some positive effects on the performance of the urban green space subsystem. The LGP scenario would only yield a significantly higher performance than the SAU after 2020. The highest score of 0.29 in 2020 is 43.6% higher than the SAU scenario and 55.0% higher than the base year in 2000. However, the performance then declines rapidly until 2025, where it is 0.21, only 10.21% higher than the base year in 2000.

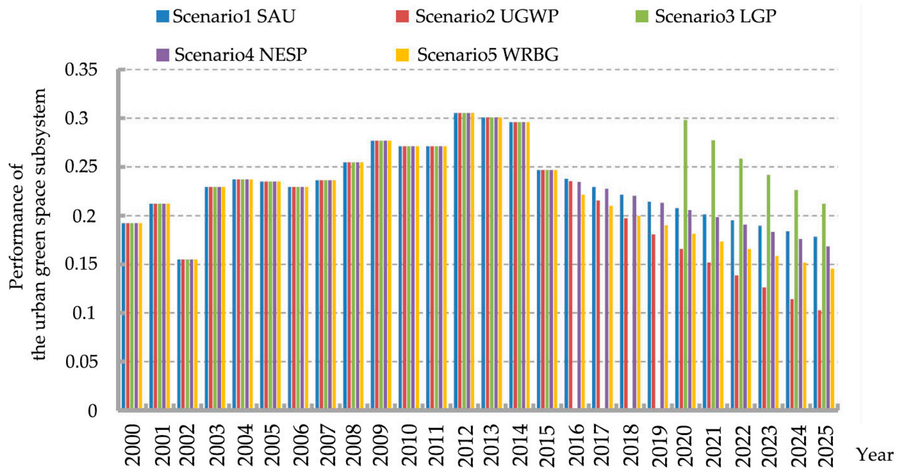

Figure 4. Development trend for the urban green space subsystem with different scenarios for the historical period 2000–2015 and forecasted period 2016–2025.

All scenarios suggest that Beijing's social economy subsystem in 2025 will be worse than it was in 2000 (Figure 5). Although the GDP and construction land area increase significantly, they are negative indices for the SDGS. The NESP scenario creates a better score than the other scenarios. The WRBG scenario represents the sharpest decline, which is 76.0% lower than in the base year.

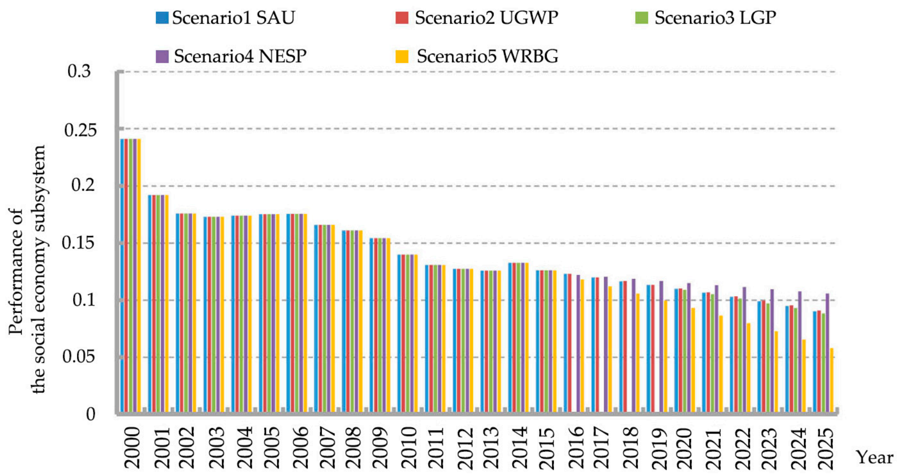

Figure 5. Development trend for the social economy subsystem with different scenarios for the historical period 2000–2015 and forecasted period 2016–2025.

All the scenarios would have positive effects on the performance of the environment subsystem. Before 2022, the LGP scenario provides a better score, increasing to its highest level at 0.24, which is 51.8% higher when compared with the base year, but then falls slightly in 2023, 2024 and 2025 (Figure 6). In 2025, the WRBG scenario represents the greatest improvement with the value of 0.26, which is 54.0% higher than the base year.

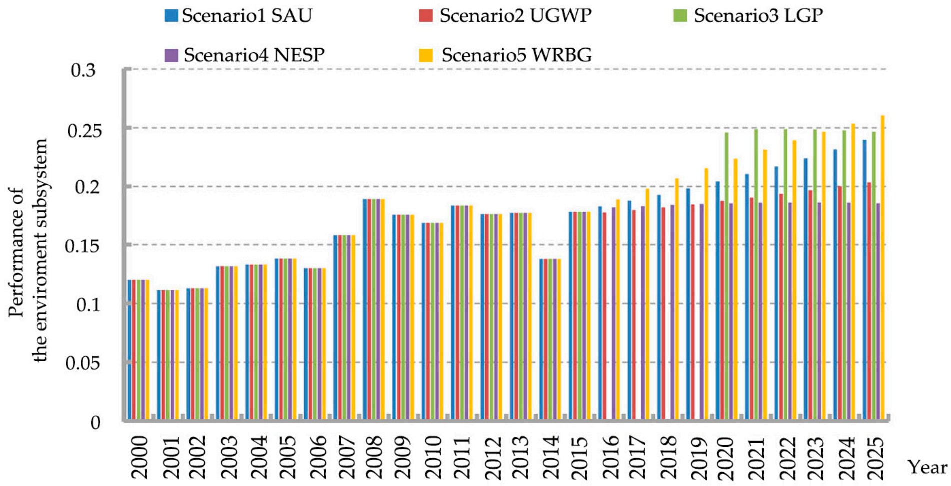

Figure 6. Development trend for the environment subsystem with different scenarios for the historical period 2000–2015 and forecasted period 2016–2025.

4.2. Performance for the SDGS Value

To analyze the results of the SDGS value under simulated scenarios, an analysis can be performed by summing all of the indices and then identifying the impact of different scenarios on the SDGS value improvement (or deterioration) [53].

The historical trends of the SDGS index value exhibited an increasing trend from 2000 to 2012, reaching to its highest level of 0.61 in 2012, but declined slightly to 0.55 by 2015. All scenarios (Scenarios 1–5) would decline to 0.50, 0.39, 0.54, 0.45 and 0.46, respectively, which were all poorer scores than that of the base year in 2000 (Figure 7). The forecast results show the LGP scenario provides a better score than the others. The LGP scenario reached its highest point of 0.65 in 2020. It improves the performance of the SDGS by 18.0% over the base year, but then declines sharply. This situation would result in a slight decrease in the SDGS index value in 2025 by keeping it close to the 2000 level. The SDGS index values of the SAU, NESP and WRBG scenarios fall significantly after 2016, but, if compared with the base year, the decline is less than 8.1%. However, the UGWP scenario encountered the sharpest decline. At its lowest point of 0.40 in 2025, the SDGS performance is 28.2% lower than it was in 2000.

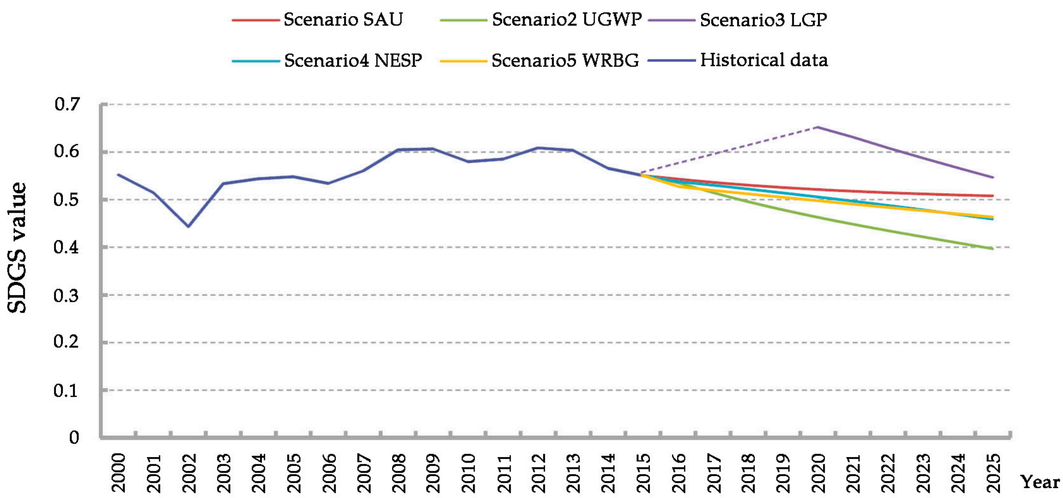

Figure 7. Development trend for the sustainable development of green space value with different scenarios for the historical period 2000–2015 and the forecasted period 2016–2025.

5. Discussion

5.1. Analysis of the Subsystem Performance

The simulation results show that all the currently adopted policies failed to effectively improve the urban green space and social economy subsystems in the long term. This contributes to the current SDGS policy debate in Beijing by showing that these subsystems are in conflict with each other. By taking the urban green space subsystem as an example, the option of increasing the urban green space resource in the UGWP scenario is even less effective towards improving the overall level of the urban green space subsystem than the macroeconomic regulation on the economic and social development in the NESP scenario. The main reason lies in that the governing body neglects to understand the compound mechanisms that act among the urban green space, social economy and environment subsystems for Beijing. While net urban green space area maintains an increasing trend in the UGWP scenario, this scenario maintains the social economy development rate as before, which translates as a higher occupied area for green space. The effect of net urban green space area is dampened by the increase in the occupied area of green space, which made the total green area at a low level. Meanwhile, the increasing trend of total population and construction land discourage an increase in the urban green coverage rate, urban green space ratio and public green area per capita. Therefore, the performance of the urban green space subsystem in the UGWP scenario represents a worsening score over time.

5.2. Analysis of the SDGS Performance

The overall performance of Beijing's SDGS under all the scenarios in 2025 exhibited a degraded condition when compared with conditions in 2000. Therefore, the policies that have currently been adopted are inappropriate towards improving the overall SDGS level. The UGWP, LGP and NESP scenarios only improve performance of indices of a certain subsystem. The simulation results show that these scenarios are not appropriate for improving the overall and compound level of the SDGS. The WRBG scenario proposed by the People's Congress of Beijing considers a set of detailed measures involving the urban green space, social economy and environment subsystems comprehensively. However, the social economy subsystem is given the highest priority based on how much of the other indices are expected to improve. Most indices in the social economy subsystem have negative effects on the SDGS. Therefore, the improvements in the urban green space and environment subsystems are offset by a sharp decline in the performance of the social economy subsystem. Index-oriented policies aimed at achieving some vanity projects are usually performed in some cities of China, which is not conducive to the sustainable development of the city. When formulating the development policies, the UGWP scenario proposed by Beijing Municipal Bureau of Landscape and Forestry mainly focused on increasing the urban green space area [23]. However, the "13th Five-Year" national economy and social development plan (NESP) issued by Beijing municipal party committee prioritizes the development of indices related to the social economy [51]. This leads to development in a different direction than that which would benefit the SDGS. Meanwhile, the governing body failed to clarify the future trends of the subsystems or the entire system in relation to the proposed aim. Therefore, a lack of forecasting prior to policy formulation becomes the main reason that Beijing's SDGS fails to be improved effectively.

5.3. Implications for Urban Green Space Development Policy Formulation

In the future, more policy options suitable to the case of Beijing's SDGS should be proposed by different governing bodies. The SDGS features several important aspects that should be considered when formulating policy related to the SDGS: (1) The SDGS model takes the interrelationships between the urban green space, the social economy and environment subsystems into account as proposed in our research; this could be considered when making decisions in the policy formulating process. Moreover, the model should combine the stakeholders' viewpoints toward the SDGS model in future studies; (2) The Integrated Forecast and Scenario Simulation Model based on the complexity of the change in SDGS that was established in our research could become an effective way to significantly guide reasonable decision-making and to help policy makers understand the post-effects of their policy as they formulate the policy [10,54]. The SDGS model includes spatial simulation (e.g., cellular automaton model), which is able to capture the spatial features of green space; this aspect should be considered in future simulation studies; (3) Our research shows that the social economy subsystem could experience a decreasing trend because of the constant increase of GDP in Beijing. Increasing GDP will cause the performance of the social economy subsystem to remain at a low level. The environment subsystem is sensitive to these policies, and could be improved in a similar way. However, the urban green space subsystem is difficult to regulate and control, especially the index of occupied area of green space. Therefore, the urban green space subsystem should be given greater priority.

Based on our findings, we made the following recommendations to improve the urban green space subsystem through the development of integrated regulations. In Beijing, urban green spaces are managed by the municipal government. The government needs to set up standards for maintaining green spaces. First, "Green Line Management System" should be implemented to control the conversion of green space into other land types. "The first green isolation belt" in the Fourth Ring area and "the second green isolation belt" between the Fifth and Sixth Ring area were planned to restrict the expansion of the construction land. The two belts should be given greater priority by the government to protect existing green spaces and prevent construction interests from occupying and degrading them. Second, due to the fact that there are few possibilities to add new green spaces in the most crowded city in Beijing [55], the emphasis should be on increasing green spaces by restoring the abandoned land (e.g., the brownfield). Furthermore, multi-spatial green space can be planned. Roof greening, vertical plants and Greenways should be the priority of future urban greening program which are low-impact methods for creating more green space.

6. Conclusions

The combination of forecast and scenario simulation based on a SD model approach enabled the timely and accurate measurement of SDGS of Beijing. Based on these datasets from 2000 to 2025, the historical trends of the SDGS value exhibited an increasing trend from 2000 to 2012, which reached 0.60, but declined in 2013, 2014 and 2015. However, the urban green space, social economy subsystem and the entire SDGS system would decrease in 2025 when compared with the base year in varying degrees in almost every scenario designed based on the policies proposed by different governing bodies of Beijing. Only the score of the LGP scenario reached 0.21, slightly higher than 0.19 in the base year. The environment subsystem would exhibit an increasing trend in every scenario. Generally, the policies proposed by the governing bodies of Beijing are inappropriate for improving the overall SDGS level. Therefore, during the future formulation of policies and planning for the SDGS, the government of Beijing should pay particular attention to the integrated forecasting and scenario simulation presented here to ensure effective improvement of the SDGS of Beijing.

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