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How to Make Cities Get across "The Valley of Death"? Exploring the Ecological Index System and Index Correlation of Green Cities

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Abstract: Disasters caused by climate change are continuing around the world. Densely populated urban areas have been pushed to the forefront of global climate change, and ecological security has gradually become the focus of global attention. Whether it is predictable natural disasters, or it is long-term global warming, or any unexpected events, exploring green development that coexists with them, green urban environmental strategies will play an important role in urban development. We analyzed data from 31 sample cities in China, accurately quantified indicators through qualitative and quantitative analysis, and then explored the development status and related indicator systems of green cities in China by "Driving Force–State–Response" model. The results reveal that (1) economic factors are the fundamental and decisive factors for the development of green cities. The higher the level of economic development, the stronger the ability of urban development; we also revealed the indicators that are significantly correlated with the level of green city construction and clarified the important factors of green cities; (2) technological factors are crucial for the construction of green cities. Only with continuous improvement at the technological level do green industries have the driving force for sustainable development, and traditional high-energy consuming and high-pollution industries can be continuously eliminated so as to promote the construction of green cities. (3) Based on the correlation analysis between each indicator and comprehensive scores, this study also pointed out that there is a significant gap in the level of green city construction among different regions in China.

Keywords: green city; DSR model; ecological indicators; index system; green sustainable development; urban design

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1. Introduction

In the context of climate change and the rapid urbanization process, the high energy consumption and high pollution problems cannot be underestimated. The urban area in the world accounts for only 1% of the global land area, but it absorbs more than half of the global population, consumes more than 70% of global energy, and generates 60% of global carbon emissions. Air pollution, water resource shortage, noise pollution and other problems have become increasingly prominent contradictions with natural resources and the ecological environment while the world is suffering from climate change [1,2]. In 1991, UN-Habitat (United Nations Human Settlements Programme) and UNEP (United Nations Environment Programme) proposed the "Urban Sustainable Development Plan", which mentioned the concept of "green cities". "Green" will become the main theme and basic requirement of future development. In this context, as the main body that absorbs the majority of the global population consumes most of the global energy and generates most of the carbon emissions [3,4], cities should be at the forefront of implementing the concept of green development and green growth [5–7]. Therefore, for the future of the Earth and humanity, it is imperative to build green cities and harmonize the development of cities with the natural environment [8].

As of the end of 2022, the urbanization rate of China reached 65.22%, an increase of 0.5 percentage points compared to the end of 2021. At present, the population in China is still rapidly converging towards mega-cities, causing many "urban diseases" [9,10]. In addition, significant regional development differences make the development stages of each city different, some of which have accomplished industrialization, some cities are still in the late stages of industrialization or have already achieved equal emphasis on economic development and low-carbon construction [11], while others still rely on high energy consumption and high pollution industries [12]. In this context, the urgency of building green cities in China is particularly prominent. However, building a green city needs a suitable index system, which is not enough in the depth and breadth of analysis on green cities in China. To date, scholars have carried out much research on green cities, but there is still a lack of studies on this topic that address the following research questions: First, the selection of indicators and index system is mainly influenced by subjective factors, lacking the support of theoretical models; second, some studies proposed the framework for index system without providing specific index weighting methods; and third, some index systems are too complex with too many specific indicators, which are not conducive to practical application.

Hence, in order to thoroughly understand green development and green cities, the purpose of this study is to construct an index system for green cities and determine the weights in order to accurately quantify the level of urban green construction and expose the existing problems. This study focuses on green cities in the context of addressing climate change, and thus the primary research questions are proposed as follows:

(1) What is the effective theoretical model for supporting the selection of indicators and index systems?
(2) What are the specific index weighting methods for the index system?
(3) Which indicators can consider ecology and environment as well as economic and social development?

Based on the above research questions, this paper is organized as follows: Sections 1 and 2 review the literature and theories, define the concept and connotation of green cities, and highlight the problems and aims of this study. In Section 3, research methods of green cities and the index system are proposed, while Section 4 presents the empirical analysis of a selection of indicators and the weight determination of the green cities, evaluates the index system of green cities, calculates the comprehensive score and ranking of sample cities, and points out the indicators that are significantly correlated with the level of green city. Findings, theoretical contributions, recommendations and future directions are provided in Section 5. Conclusions are summarized in Section 6.

2. Theory and Research Trend

2.1. Interpretation of the Green City

Green cities reflect the harmonious coexistence of humans and nature, which has already been reflected in the ancient concept of "Unity of Heaven and Man" in China. Britain took the lead in completing the Industrial Revolution, experiencing rapid urbanization and environmental pollution. Therefore, in the late 19th century, the famous British urban scientist Ebenezer published the book Tomorrow: A Road to True Reform, advocating for the construction of pastoral cities that can perfectly combine the convenience of urban life with the beautiful environment of rural life, reflecting the concept of green development. During the 20th century, more and more countries began to industrialize, and environmental pollution problems became increasingly serious [13]. In 1990, Indian economist David Gordon first proposed the concept of "green city" in his book and analyzed eight qualitative conditions for green cities. Afterward, countries around the world, especially developed countries that have entered the post-industrial era, began actively exploring the construction path of green cities.

For a considerable period of time in the past, the world's economic development has adopted an extensive growth strategy, resulting in serious environmental pollution and other issues [14]; hence, our living environment is increasingly emphasizing green development. Raffaele [15] pointed out that the main purpose of green city construction was to restore nature and achieve harmonious coexistence between humans and nature; from the perspective of energy replacement, Wang and Jiang [16] and Li et al. [17] revealed the evolution rules of green urban design during the period of carbon enlightenment, carbon dependence and carbon decoupling. Calderón-Argelich et al. [18] thought that urban planning needed to consider issues related to the natural ecological environment with sustainable development of the city, namely the "new-type green city planning". Cheng et al. [19] believed that low-carbon and green city construction could be achieved by actively utilizing index systems and technological means so as to reduce carbon emissions in declining urban areas.

Therefore, it can be concluded that green cities have the following characteristics: (1) Green cities are different from traditional extensive urban development models, balancing economic and social development with ecological environment protection, and emphasizing the sustainability of urban development. (2) Green city construction covers many aspects, i.e., industry, life, environment, etc. In the process of building a green city, a large number of new technologies are needed, which can drive the innovative development of related industries, create job opportunities, and ultimately achieve the harmonious unity of economy, society and environment, so as to improve the life quality of residents and achieve high-quality development.

This study defines the concept of green cities as follows: green cities refer to cities that achieve ecological friendliness in terms of residents' lives and urban environment through technological innovation, industrial transformation, energy conservation, emission reduction and public opinion promotion, promoting harmonious coexistence between humans and nature, and achieving sustainable and high-quality development.

2.2. Research on Index and Index System of Green Cities

Steps have been taken to construct index systems of green cities in different countries, which have successively constructed distinctive index systems based on their countries' actual situation. The overall goals of the sustainable development index system constructed by the UK include social progress, environmental protection, resource classification and rapid economic development, which are divided into 13 special projects and over 100 indicators. The sustainable development of the United States includes 10 goals, including economic, social, environmental and educational goals, each with supporting indicators for quantitative evaluation. In the early 21st century, Germany formulated a national sustainable development strategy and constructed a sustainable development evaluation of the index system. The 21 key indicators were repeatedly screened to evaluate the status of national key development areas. The Sustainable Development Indicators Report published by Denmark in 2002 is mainly divided into a general index system and a specific index system, and the data is updated annually. The general index system consists of 14 indicators which are updated annually to summarize the data of sustainable development strategy achievements over the past year and are reflected in the specific index system.

With the deepening of sustainable development and low-carbon concepts, scholars are paying attention to the research on indicators of green cities. Alfaro-Navarro et al. [20] developed a new sustainable city index based on the intellectual capital approach by using the triple bottom line approach and considered the economic, social and environmental dimensions. Huang et al. [21] integrated comprehensive index analysis, coordination analysis, difference analysis, and correlation analysis into an analytical toolbox, and investigated the green development of 36 major cities in China. Yang et al. [22] proposed evaluation indicators of ecological transformation of mineral resource-based cities from the perspective of stage division.

Many scholars also have their own opinions on the construction of index systems of green cities which mainly focus on the elements and comprehensive levels of green economy, ecological environment, human settlement, etc. First, from the perspective of a green economy, Hicks established an indicator for measuring green GDP, which means that GDP should eliminate the consumption costs caused by natural resources and environmental pollution in 1975 [23]. Daly and Cobb created a new method of urban green economy: the sustainable economic welfare index in 1989 [24]. Compared with Hicks, they increased the quality of life and proposed that residents' living conditions, i.e., social crime rate, education and medical expenses, and unemployment rate should be included in the cost range. Second, from the perspective of the ecological environment, Liu established a development plan indicator system and a model using system dynamics with ecological low carbon as the core, to analyze whether the city has achieved the established goals [25]. The third category is from the perspective of human settlement, with a focus on factors such as residents' well-being and urban livability. Mc Mahon SK focused on analyzing Bristol, UK, and further expanded the evaluation indicators to the field of quality of life by using simple and intuitive mapping methods for descriptive analysis [26].

In terms of the research method selection of the index system of green cities, Zhu used the AHP evaluation method and green comprehensive index method to study the green development status of Xiangyang City by taking society, production, and resources to establish an indicator system [27]. Zhu, Wu (2016) and Yang et al. (2020) established indicator systems based on the interpretation of green cities and used the entropy weight method for evaluation [28,29]. Chen et al. established an indicator evaluation system of green smart cities with five dimensions of urban development and economic status, social resources, environmental quality, infrastructure, and technological innovation as subsystems, and used principal component analysis and grey correlation analysis to explain the level of urban development [30]. Ane Pan constructed a model using entropy and urban coordinated development index to measure the green coordinated development performance of four central municipalities and 15 sub-provincial cities from 2007 to 2016, reflecting interaction and coordination relationships [31]. Jiang and Zhu [32] focused on the construction of an indicator system of low-carbon cities and discussed the development of low-carbon cities under the "dual carbon" goal.

Currently, there is a lack of consistent standards for judging and measuring the development level of green cities. Scholars have created different evaluation index systems for the development level of green cities based on their existing experience and understanding of the concept of green cities, reflecting the development level and problems of green cities. However, there is currently a lack of a systematic framework for building green cities. Green cities are comprehensive and sustainable cities that include economic, social, environmental, and human settlements. Therefore, constructing a comprehensive evaluation index system to consider green cities can objectively evaluate the degree of urban green development. Based on the above literature review, we introduced the Driving Force–State–Response model (DSR model), which is widely used in the field of ecological environment, to construct the systematic index system of green cities. Then, data on sample cities were collected, and the Criteria Importance Through Intercriteria Correlation method (CRITIC method) was used to determine the index weight based on the characteristics of indicators. After that, this study calculated the comprehensive scores of each sample city, and the correlation coefficient between the indicator and comprehensive score, then summarized indicators with significant positive and negative correlations so that we could draw the level of green city, and, finally, proposed recommendations.

3. Methods

3.1. Data Collection

This study takes 31 major cities in China as samples, which include 4 municipalities directly under the central government, the provincial capitals or capitals of provinces and autonomous regions. The economic and social development level of these cities is at a relatively high level, and they are the main net inflow cities with a total population of over 320 million, nearly a quarter of the national level, which can basically represent the overall level of green city construction in China (Figure 1). Based on data from the China Statistical Yearbook 2021, China Urban Statistical Yearbook 2021, China Energy Statistical Yearbook 2021, China Environmental Statistical Yearbook 2021, China Urban Construction Statistical Yearbook 2021, National Science and Technology Investment Statistical Bulletin 2021, China Education Expenditure Statistical Yearbook 2021, as well as cities' 2021 National Economic and Social Development Statistical Bulletin and Ecological Environment Quality Bulletin, etc., we summarized and analyzed the data of 31 samples.

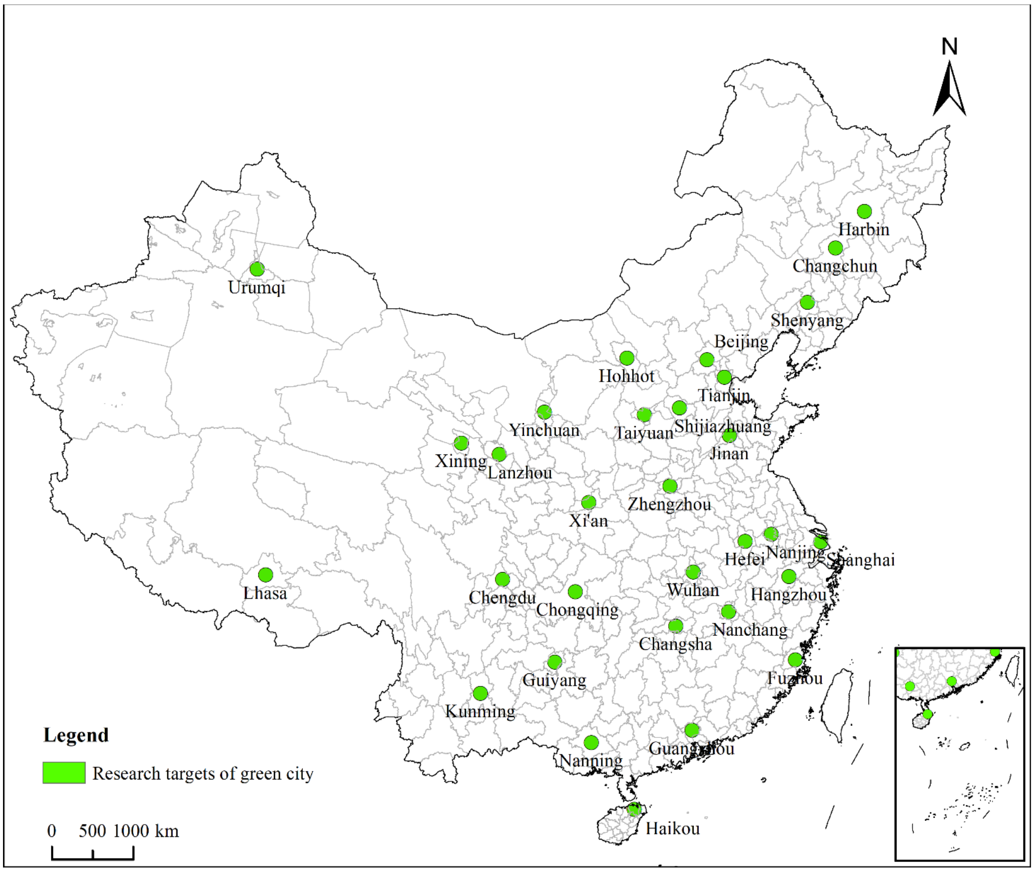

Figure 1. Spatial distribution of 31 samples of green cities in China. Source: author self-painting. The base map is the map of the People's Republic of China (vertical) by the Ministry of Natural Resources, People's Republic of China.

3.2. DSR Model

The DSR model has a wide range of applications in the ecological environment. The prototype of the DSR model is the PSR model (Pressure–State–Response model), known as the "Driving Force–State–Response" model, which is a supplement and extension of the PSR model. The DSR model changes the "pressure" to "driving force", and the driving force can be positive or negative. The state indicator represents the characteristics and changes of the ecological environment at a certain point in time, while the response indicator refers to a series of reactions and measures made by humans to changes in the ecological environment. The DSR model, which includes both positive and negative aspects, is more comprehensive. In this study, the DSR model theory is used to conceptualize the index system of green cities based on the close relationship between green city construction and the ecological environment. Due to the emphasis on harmonious coexistence between humans and nature in green cities, it is necessary to analyze the interaction between humans and the environment; hence, based on the systematic and complex nature of green cities, this study selects the DSR model to construct the index system for green cities.

3.3. CRITIC Method

After using the DSR model to achieve the construction of the index system and the selection of indicators, it is necessary to determine the weights of each indicator. The CRITIC method (Criteria Importance Through Intercriteria Correlation method) is a commonly used method for determining weights, which comprehensively considers the variability of indicator data and the correlation between indicators. Moreover, the core of the CRITIC method is more in line with the principles of index system construction; therefore, this article uses the CRITIC method to determine the weight of each indicator. We collected data from 31 representative large and medium-sized cities in China as samples to use the CRITIC method to determine the weight of the index system of green cities.

The CRITIC method is an objective weighting method proposed by Diakoulaki, Mavrotas, and Papayannakis in 1995 [33], which is a better objective weighting method than the entropy weight method and standard deviation method. The objective weight of indicators is comprehensively measured by the comparative strength of indicators and the degree of conflict between indicators. The weight is determined by the standard deviation and correlation coefficient of indicators, which is a scientific evaluation method that fully utilizes the objective attributes of the data. Due to the different orders of magnitude of each indicator, they need to be compared within the same range, and the indicators also need to be normalized. In addition, the weight calculation of indicators using the critical method mainly revolves around contrast and contradiction. By calculating the information-carrying capacity, the weight can be inferred. Generally, the larger the information-carrying capacity, the greater the weight can be considered. Based on the principle of data selection, this study found the larger the standard deviation of the indicator, the greater the degree of data dispersion among different cities, indicating that this indicator is a relatively easy one to widen the gap between cities and evaluate the level of green city construction. Furthermore, indicators with strong correlation indicate a strong overlap with the content reflected by other indicators, which has a certain degree of substitutability, so the weight should be declined. Hence, the calculation principle of the CRITIC weight method is in line with the data selection principle in this study. The specific practical steps are shown in Section 4.2. CRITIC analysis on index system of green cities.

3.4. Coordination between the DSR Model and CRITIC Method

In view of the understanding of the systematicity and complexity of green cities, the "Theme–Hierarchy" construction method is suitable for green cities. That is, around the "green city", different levels are divided into different perspectives, and different indicators are selected to form an indicator set. The index system is composed of a multi-layer structure of a target layer, criterion layer and index layer. Among them, the target layer reflects the overall goal and domain of the index system, the criterion layer reflects which criteria the index system should be composed of, and the index layer is a set of indicators determined around each element of the criteria layer, which can be one or multiple. The indicators form a certain logical relationship, which can reflect the main characteristics of different criteria and the internal connections between them. This method has a clear organization and smooth structure, which can demonstrate the logical and systematic nature of the index system and is conducive to analyzing and integrating various tasks that affect green development. Therefore, it is suitable for use in this study.

Based on the literature review, we compared different research methods and found that the principal component analysis will reduce the dimensionality of evaluation due to the information concentration. The entropy method is based on the theory of information entropy and constructs the entropy value method, which is more suitable for the small mutual influence between attributes. Based on the different contributions of each attribute, the CRITIC method is suitable for situations where the mutual influence and correlation between attributes are relatively strong and can reduce bias. In this study, due to the strong correlation and influence between indicators, the CRITIC method is better than other methods that mainly determine weights through indicator variability. Considering the comparative strength and conflict among indicators, the CRITIC method is not suitable for standardization. The DSR model is used to construct the index system for green cities, based on this model, the target layer of green city development evaluation can be decomposed into three criteria layers: driving force, state and response. The internal connection and mutual influence among the three are considered, and specific indicators under each criterion are proposed; thus, we can construct a scientific evaluation indicator system. The combination of the DSR model and the CRITIC method to determine index weights is the base of empirical analysis in this study.

3.5. Construction Principles

The level of green development in a city is influenced by multiple factors, and multiple indicators need to be selected from multiple aspects to reflect it. In order to measure the level of green city, this article follows the following principles to construct an index system:

(1) Systematicness: Green cities are a complex organic whole that involves a wide range of aspects and distinct levels. It is necessary to construct an evaluation index system from a global perspective, systematically control the correlation of indicators, and reveal the actual development situation.
(2) Comprehensiveness: The index system can fully reflect the connotation of green cities, meet the requirements of green cities and grasp the essence of green cities from a scientific perspective.
(3) Comparability: The indicators within the index system have relative stability, and a city itself can be compared vertically at different times or horizontally between different cities.
(4) Operability: While selecting indicators, we fully consider the difficulty of quantifying the indicators, obtaining data, and trying to choose indicators that are widely used and can obtain data from authoritative statistical departments, especially representative key indicators. Each indicator should have a specific meaning, and the calculation method of the indicator should not be too complex.

4. Empirical Analysis and Results

4.1. Construction Process

Green cities are complex systems with multiple dimensions, so the construction of index systems must also be carried out from different dimensions. This study summarizes national environmental policies, existing environmental indicator systems, and previous research on green city-related index systems. Based on the CRITIC method and DSR model, the index system framework of green cities can be developed. According to the CRITIC method, this study divides the framework of the index system into three levels: target layer, criteria layer and index layer. The theme of the index system of green cities is used as the target layer, the criteria layer is divided into various criteria based on the DSR model, and the indicators of the index layer are determined based on analysis of the criteria layer and reference to previous research results. Thus, the analysis of the criteria layer of the index system of green cities is as follows.

The "D" in the DSR model refers to the driving force, originally referring to the impact of human economic and social activities on the ecological environment. In the index system of green cities, due to changes in the subject, it can be understood as the impact of human economic and social activities on the construction of green cities, shown as both positive and negative sides; "S" refers to the state, which originally represents the characteristics and changes of the ecological environment at a certain point in time. In the index system of green cities, it can be considered as the green construction situation and characteristics under the influence of various driving forces; "R" refers to response, which originally refers to a series of reactions and measures made by humans to changes in the ecological environment. The index system of green cities can be considered as people's reactions and measures to the current state and changes in green city construction. This study takes the driving force, state and response as the criteria layer with multiple sub-criteria layers and specific indicators. The sub-criteria layers and specific indicators are determined with reference to previous research results. Hence, the meaning and application of the DSR model in the index system of green cities are drawn in Figure 2.

Based on the three criteria layers of driving force, state and response, each sub-criteria layer can be determined and specific indicators are selected in detail.

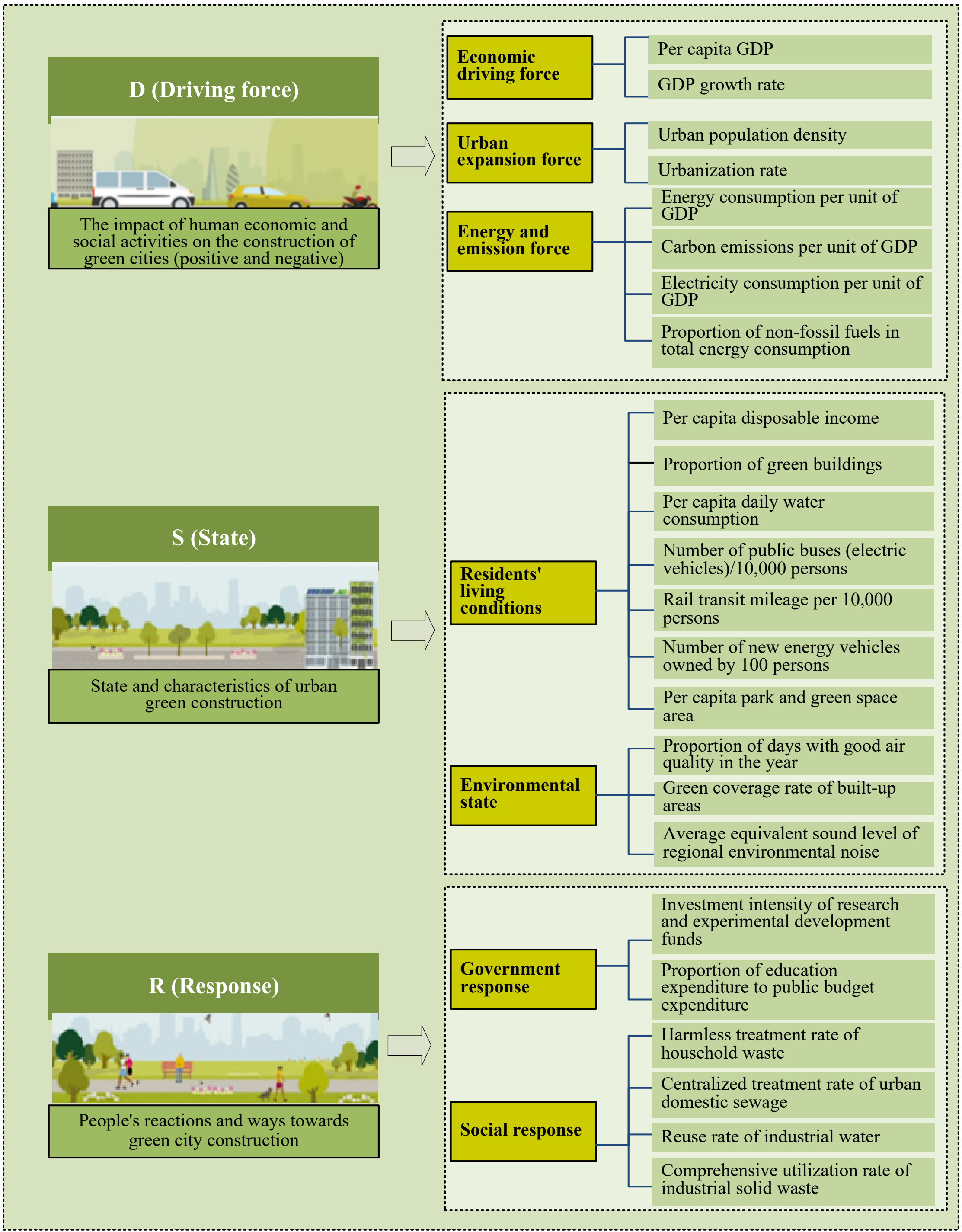

Figure 2. Structure diagram of DSR model application in the index system of green cities. Source: author self-painting. (Source of figures: London Environmental Strategy.)

4.1.1. D (Driving Force)

The driving force refers to the impact of economic and social activities of human beings on the construction of green cities, which includes positive and negative driving forces, corresponding to positive and negative impacts. The impact of economic activities on the construction of green cities is mainly reflected in the economic development of cities, so economic development is a driving force. The driving force of economic development is the most fundamental positive one for the construction of green cities. The level of economic development is a fundamental factor determining the level of green city construction, as economic strength is the indicator that best reflects the development status and capacity of a city. The economic development status of a city can be considered in two perspectives: the current level of economic development, and the potential for subsequent economic development. This article uses per capita GDP (Gross Domestic Product) to characterize the current level of present economic development and uses the GDP growth rate to analyze the potential of subsequent economic development. Scholars such as Ju et al. [34] also emphasized the importance of urban economic strength when establishing an evaluation index system for green cities, and included per capita GDP as an indicator.

In addition, human social activities can also become a major driving force for the development of green cities. The driving force of human social activities on green city construction includes two aspects: the expansion of the city caused by human social activities, and the consumption of energy and emissions of various substances in social activities and urban expansion processes. Therefore, this study views urban expansion as a driving force for green cities, while urban expansion is mainly reflected in the influx of non-urban population into cities, leading to a continuous increase in population density and an increase in urbanization rate. Therefore, this article uses population density and urbanization rate as specific indicators to measure the driving force of urban expansion; human survival and development in social activities are inseparable from energy consumption and carbon emissions, which will have a direct and undeniable impact on the construction of green cities. This study also considers energy and emissions as a driving force for green cities. Both energy and emissions can be reflected in intensity and energy should not only focus on consumption intensity, but also on another aspect, namely, the consumption structure. For the intensity of energy consumption and carbon emissions, this article uses energy consumption per unit of GDP, carbon emissions per unit of GDP, and electricity consumption per unit of GDP to measure. However, since most cities do not disclose specific values of energy consumption and carbon emissions per unit of GDP and only disclose their decrease, we use the decrease as an indicator for energy consumption and carbon emissions per unit of GDP. Scholars such as Stowell et al. [35] used these indicators to reflect a city's green construction and low-carbon development level when studying similar index systems such as green cities and low-carbon economic development.

For the consumption structure of energy, energy can be divided into fossil energy and non-fossil energy. Compared to fossil energy, non-fossil energy refers to renewable clean energy, i.e., wind energy, hydropower, solar energy, etc., which generally has the characteristics of being clean, environmentally friendly and renewable. Therefore, developing non-fossil energy and increasing the proportion of total energy consumption can effectively reduce greenhouse gas emissions, protect the ecological environment and promote sustainable energy development, which is of great significance for the construction of green cities. This study selects the proportion of non-fossil energy in the total energy consumption to reflect the structure of urban energy consumption. Scholars such as Sánchez et al. [36] also explored the importance of non-fossil energy in energy conservation, emission reduction and low-carbon development, and included them in the indicator system of low-carbon cities. Hence, for the driving force of the index system of green cities as the criterion layer, this study presents a detailed structure as shown in Figure 2 and Table 1.

Table 1. Framework diagram of index system of green cities.

Target Layer	Criteria Layer	Sub-Criteria Layer	Index Layer	Unit	Attribute
Index System of Green Cities	D (Driving force)	Economic driving force	Per capita GDP	10,000 CNY	Positive
			GDP growth rate	%	Positive
		Urban expansion force	Population density	person/square kilometer	Positive
			Urbanization rate	%	Positive
		Energy and emission force	Reduction in energy consumption per unit of GDP	%	Positive
			Reduction in carbon emissions per unit of GDP	%	Positive
			Electricity consumption per unit of GDP	KWh/10,000 CNY	Negative
			The proportion of non-fossil fuels in total energy consumption	%	Positive
	S (State layer)	Residents living conditions	Per capita disposable income	10,000 CNY	Positive
			Proportion of green buildings in newly built buildings	%	Positive
			Per capita daily water consumption	Liter	Negative
			Public bus (electric) vehicle ownership per 10,000 persons	Vehicle	Positive
			Number of rail transit kilometers per 10,000 persons	Meter	Positive
			Number of new energy vehicles owned by 100 persons	Vehicle	Positive
		Environmental state	Per capita park and green area	Square meter	Positive
			The proportion of days with good air quality in the whole year	%	Positive
			Green coverage rate in built-up areas	%	Positive
			Average equivalent sound level of regional environment noise	Decibel	Negative
	R (Response)	Government response	Investment intensity of research and experimental development funds	%	Positive
			Proportion of education expenditure to public budget expenditure	%	Positive
		Social response	Harmless treatment rate of household waste	%	Positive
			Centralized treatment rate of urban domestic sewage	%	Positive
			Reuse rate of industrial water	%	Positive
			Comprehensive utilization rate of industrial solid waste	%	Positive

4.1.2. S (State)

In the index system of green cities, the state refers to the green construction situation and characteristics of a city under the influence of driving forces. The state can be separated into two categories according to the subject, one is the state of "people" and the other is the state of "things". The state of "people" can be considered as the living state of residents, while the state of "things" can be considered as the environmental state. Therefore, for the criteria layer of state, two sub-criteria layers are adopted: residents' living state and environmental state. This study uses the most widely used and recognized indicator to measure residents' income level—per capita disposable income—to measure residents' income level. Per capita disposable income: the ratio of total disposable income to population size. Total disposable income refers to the total income of households minus respective taxes and social security measures. Per capita disposable income is also an important indicator to measure the level of economic development. Ruan and Yan [37] also used the indicator "per capita disposable income" to measure the overall living standards of urban residents when constructing an index system of green cities.

For the construction of green cities, the impact of residents' food and clothing is negligible with a focus on "living" and "transportation". The most closely related part of "living" in a green city is green buildings. Green buildings refer to high-quality buildings that can provide users with a healthy and comfortable living environment, as well as achieve environmental protection, pollution reduction and ecological friendliness, which is of great significance for green city construction. Therefore, this study includes the proportion of green buildings in new buildings as one of the sub-indicators of residents' living conditions. The proportion of green buildings to new buildings is the ratio of the area of new green buildings to the total area of new buildings. Green buildings are high-quality buildings that can achieve living comfort, energy conservation and environmental protection, which is of great significance for the construction of green cities. Scholars such as Liu et al. [38] also emphasized the role of green buildings in building an index system.

In addition, residents inevitably need water, electricity and types of energy, the consumption of electricity and energy has been discussed in the driving force criteria layer, so only water is discussed here. Currently, the most commonly used indicator to measure the intensity of residents' domestic water consumption is the per capita daily water consumption, which is included in the sub-indicators of their living conditions in this article. Per capita daily water consumption, which is used to measure the intensity of daily water consumption by residents in different cities, can reflect the green and healthy level of their living and consumption. Kato-Huerta and Geneletti [39] also classified green cities into the "Resource Conservation" and "Lifestyle Health" sections when evaluating them.

In terms of residents' travel, the impact of travel on the construction of green cities is mainly reflected in the development of green transportation. Green and environmentally friendly travel ways include walking, cycling, public transportation and subway, etc. The first two are undoubtedly the most environmentally friendly modes of transportation, but due to the difficulty in obtaining accurate data, this study mainly focuses on public transportation and the subway. The promotion of buses can help reduce the proportion of individual transportation modes, alleviate traffic congestion, promote energy conservation, emission reduction, environmental protection and green city construction.

Therefore, to measure the degree of promotion and popularization of buses, this study includes "the number of public buses per 10,000 population" in the index system. The number of public buses (electric vehicles) owned by ten thousand persons, which is the ratio of the number of public buses (electric vehicles) in a city to the population of ten thousand persons, is an important indicator to measure the popularization of public buses. The promotion and popularization of buses can alleviate traffic congestion and promote energy conservation and emission reduction, which is of great significance for the construction of green cities. Scholars such as Garg and Kashav [40] also pointed out that a larger value of this indicator in the evaluation of green transportation indicates a more complete infrastructure, a higher level of green transportation development, a more perfect green city construction, and a higher quality of life.

Urban rail transit generally includes subways, light rail, etc., which are usually powered by electricity. Its operation causes much less environmental pollution than motor vehicles, and can effectively alleviate ground traffic congestion. Therefore, the implementation of rail transit has a direct impact on the construction of green cities. To measure the popularity of rail transit, this article includes the indicator of "rail transit mileage per 10,000 persons" in the index system. The ratio of the total mileage of urban rail transit to the population in 10,000 is used to measure the popularity of rail transit, including subways and light rail. Compared to motor vehicles, subway and light rail transit have lower energy consumption and pollution, can alleviate traffic congestion, and facilitate and benefit people, which are of great significance for the construction of green cities. Ma et al. [41] also emphasized the importance of subway and other rail transit for green and low-carbon development when evaluating sustainable low-carbon cities, and listed this indicator as one of the evaluation indicators.

For private cars, China is developing new energy vehicles. A new energy vehicle (NEV), also known as a new energy automobile, refers to a vehicle that uses unconventional vehicle fuels as its power source (or uses conventional vehicle fuels and new on-board power devices), integrates advanced technology in vehicle power control and driving, and forms an advanced technical principle with new technologies and structures. New energy vehicles mainly include pure electric vehicles and hybrid electric vehicles. The use of new energy vehicles can break people's dependence on non-renewable energy such as oil, reduce urban noise and emission pollution, and make a significant contribution to improving urban air quality. Based on the above analysis, this study incorporates the number of new energy vehicles owned by 100 individuals in the state and characteristics of urban green construction of DSR model application in the index system of green cities in order to show the role of new energy in green city construction and improve the indicator system. Compared to traditional fuel vehicles, their greenhouse gas emissions are significantly reduced. Since the implementation of new energy vehicles, the average annual reduction in carbon emissions in China has reached 7%. Therefore, the large-scale promotion and use of new energy vehicles is an important way to promote energy conservation and emission reduction in transportation and build green cities. To measure the promotion and popularization of new energy vehicles, this article includes "the number of new energy vehicles owned by 100 persons" into an indicator system. The number of new energy vehicles owned by 100 persons refers to the total number of new energy vehicles owned by the city and the population in units of 100 persons, which is an important indicator to measure the popularity of new energy vehicles. Compared to traditional fuel vehicles, new energy vehicles consume less energy and cause less pollution, which plays an important role in green development. Scholars such as Rahman and Thill [42] also emphasized the importance of new energy vehicles and included them in the evaluation index system when evaluating green urban transportation.

For citizens' travel, it is also necessary to consider where to go. The existence of various types of green spaces is not only a good place for relaxing and traveling, but also can increase greening, sequester carbon and release oxygen, purify air and water sources and promote green city construction. Therefore, green spaces should also be included in the factors that measure residents' living conditions. This study uses the most commonly used "per capita park and green space area" indicator to measure the degree of park and green space construction in a city. Per capita park and green space area refers to the ratio of the city's public green space to the total urban population, which measures the overall level of public green space in the city and can well reflect the green construction situation of the city.

Scholars such as Ignatieva et al. [43] used the per capita park and green space to evaluate green cities and green development strategies when studying the evaluation index system and development strategy index system of green cities. The green coverage rate of built-up areas refers to the ratio of the green coverage area of built-up areas to the total area of built-up areas. Green coverage area refers to the vertical projection area of green space, which includes not only a green space area, but also a roof green area and vertical green area. The green coverage rate of built-up areas is the most important indicator to measure the level of urban greening. Zeng et al. [44] also believed that green coverage was crucial for a city's green development when conducting comprehensive evaluation research on green city development, and has included it in the comprehensive evaluation index system of green city development. For greening, various types of urban greening can be considered terrestrial carbon sinks in green and low-carbon development. Carbon sinks refer to the process, activity or mechanism of absorbing carbon dioxide from the atmosphere through measures such as afforestation and vegetation restoration, biomass accumulation and soil carbon sequestration, etc., thereby reducing the concentration of greenhouse gases in the atmosphere. Data show that terrestrial carbon sinks absorb over 30% of global carbon emissions, indicating their significance for green cities. Therefore, in order to examine the degree and level of urban greening, this article incorporates the widely used "green coverage rate of built-up areas" indicator into the index system.

The state of "things", which is the environmental state, is closely related to residents' lives and a green city is considered from the perspectives of air, water, greenery and noise. Due to the difficulty in obtaining specific values of water quality indicators in each city, this study mainly focuses on air, greenery and noise. For the construction of green cities, the air quality is especially important. There is an "Air Quality Index (AQI)" to measure air quality. When its value is less than or equal to 100, it is judged as excellent. If it is greater than 100, it is considered that there exists air pollution. The better the green development status of a city, the higher the overall air quality, and the more days it takes for air quality to reach an excellent level. Therefore, this article incorporates the proportion of days with good air quality in the year into the index system to measure urban air quality; the proportion of days with good air quality throughout the year measures the overall situation of a city's air quality and can also indicate the level of pollution, which is an important indicator for judging the level of green city construction. Wang et al. [45] also considered it as an important factor in the ecological environment status of green cities.

Urban environmental noise includes industrial noise, traffic noise, construction noise, life noise, etc. Various noises can affect people's health and cause harm to animals and plants. Therefore, the average equivalent sound level of regional environmental noise is also included in the environmental state as a negative indicator for assessment. The average equivalent sound level of regional environmental noise is an important indicator to measure the level of urban environmental noise, which is also known as sound pollution, and is an unfavorable factor for the development of green cities. The commonly used and important indicator for measuring noise levels in cities is the "average equivalent sound level of regional environmental noise". When evaluating the construction of green cities, noise pollution is incorporated into the index system as a negative indicator to measure urban noise [46]. Based on the above analysis, the structure diagram of the state criterion layer is drawn in Figure 2 and Table 1.

4.1.3. R (Response)

Response indicators refer to people's reactions to the current state and changes in green cities, as well as ways taken to promote green city construction. There are two categories based on its subject: government response and social response. The government's response is mainly by means of fiscal expenditure. In the process of green city construction, technology is an essential support for improving the level of technology, replacing the high-energy consuming and high-pollution industries and promoting green city construction while completing industrial upgrading. In addition, education is equally important for promoting green cities.

On one hand, education can cultivate the necessary talents for the construction of green cities. On the other hand, the government can also establish green, low-carbon and sustainable development awareness through education, allowing them to practice green living and actively cooperate with the construction of green cities. Therefore, technology and education play a significant and even fundamental role. The government can promote the construction of green cities by increasing investment in technology and education.

Hence, this study incorporates an examination of the government's investment in technology and education into the index system. The investment in technology is measured by the most commonly used "R&D funding intensity" indicator (research and development funding intensity), the development and investment in technology play an important role in promoting the construction of green cities. Xin and Qian [47] included this indicator in their established indicator system. The investment in education is measured by the proportion of education funds to public budget expenditures. Yang [22] emphasized the importance of education and included this indicator when evaluating green development.

Social response refers to the practice of green production and living concepts in society, actively cooperating with green city construction and promoting environmental protection. Representative examples include the harmless treatment and resource recycling of daily household waste through sanitary landfilling, incineration and composting. The harmless treatment rate of garbage is the ratio of the harmless treatment amount of household waste to the total amount of household waste, which is one of the most important indicators for green living. Scholars such as Schmidt and Laner [48] thought that the higher the value of this indicator, the lower the negative impact of waste on the environment. This indicator is indispensable for measuring the improvement of the level of green cities. In addition, the index system of the National Ecological Civilization Demonstration City has also included this indicator in the "Improvement of Human Settlements".

Urban domestic sewage is sent to sewage treatment plants for centralized treatment through biochemical treatment and biological filters to avoid environmental pollution. In addition, industrial water reuse is commonly achieved through the use of cooling towers, water quality stabilization techniques, countercurrent rinsing techniques, and the extraction of valuable components, recovery of useful substances, production of building materials and substitution of production raw materials to achieve utilization of industrial solid waste. The centralized treatment rate of urban domestic sewage refers to the ratio of the centralized treatment amount of urban domestic sewage to the total amount of urban domestic sewage, which can explain the water and water quality situation of green cities. Scholars such as Mao et al. [49] found that the larger the value of this indicator, the more effective and harmless treatment of domestic sewage in the city, which can improve the ecological situation of water sources and the water environment. These actually reflect the idea of a circular economy, which emphasizes resource conservation, efficiency and circular utilization from the perspective of sustainable development. Hence, this study uses the "harmless treatment rate of domestic waste", "centralized treatment rate of urban domestic sewage", "reuse rate of industrial water" and "reuse rate of general industrial solid waste" to measure the level of social response.

Industrial water reuse rate refers to the ratio of the amount of industrial water reused and the total amount of industrial water used. Industrial water reuse can save water resources, improve water utilization efficiency and reflect the concept of circular economy. Scholars such as Wu et al. [50] also mentioned the importance of industrial water reuse when constructing an indicator system of an ecological city. The comprehensive utilization rate of industrial solid waste is the ratio of the comprehensive utilization amount of general industrial solid waste to the total amount of general industrial solid waste. Wang et al. [51] also use this indicator as one of the indispensable indicators to measure the effectiveness of energy conservation and emission reduction.

The subdivision structure of the R (response) criteria layer and the final indicator system framework are also shown in Figure 2 and Table 1.

4.2. CRITIC Analysis on Index System of Green Cities

Assuming there are n samples to be evaluated, forming a p-term evaluation index for the original index data matrix.

$$X = \begin{pmatrix} X_{11} & \cdots & X_{1p} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{np} \end{pmatrix} \tag{1}$$

Among them, X_{ij} represents the value of the evaluation indicator j in the sample j, and the required steps are as follows:

Step 1: Dimensionless processing. To eliminate the impact of different dimensions on the evaluation results of indicators, it is necessary to perform dimensionless treatment on each indicator. The most commonly used methods for dimensionless processing are forward and reverse.

The normalization index refers to the index that requires positive processing, and the formula for normalization is as follows:

$$X'_{ij} = \frac{X_j - X_{\min}}{X_{\max} - X_{\min}} \tag{2}$$

Reverse indicators refer to indicators with smaller values and require reverse processing. The reverse processing formula is as follows:

$$X'_{ij} = \frac{X_{\max} - X_j}{X_{\max} - X_{\min}} \tag{3}$$

Step 2: Variability of indicators calculation. The variability of indicators is used to represent the magnitude of the difference in values among different evaluation schemes in the form of standard deviation:

$$\overline{X_j} = \frac{1}{n}\sum_{i=1}^{n} X_{ij} \tag{4}$$

$$S_j = \sqrt{\frac{\sum_{i=1}^{n}\left(X_{ij} - \overline{X_j}\right)^2}{n-1}} \tag{5}$$

where S_j represents the standard deviation of the indicator j. In the CRITIC method, the larger the standard deviation, the larger the degree of data dispersion, the larger the variability of the indicators, the more information the indicators can reflect, and the larger the weight.

Step 3: Conflict between indicators. Based on the correlation between indicators, we use the correlation coefficient to measure the conflict degree between indicators:

$$R_j = \sum_{i=1}^{p}\left(1 - r_{ij}\right) \tag{6}$$

where r_{ij} represents the correlation coefficient between evaluation indicators i and j.

Step 4: Information calculation. The information refers to the product of variability and conflictiveness of an index, namely,

$$C_j = S_j \times R_j \tag{7}$$

The larger the C_j value, the larger the role that j-term evaluation indicators play in the evaluation index system, and the larger the weight that this indicator occupies.

Step 5: Objective weights calculation. The objective weight is calculated by normalizing the information, i.e., the objective weight of the indicator j is

$$W_j = \frac{C_j}{\sum_{i=1}^{p} C_j} \tag{8}$$

The weight of each indicator was determined by using the CRITIC weighting method on SPSSAU (Statistical Product and Service Software Automatically) based on data from 31 sample cities. First, we performed dimensionless processing on each indicator; that is, we performed forward or reverse processing on the data based on the positive and negative directionality of the indicator. As an abbreviation for positive measurement standards, "MMS" stands for "Positive Measurement Standards". As an abbreviation for reverse measurement metrics, "NMMS" stands for "Negative Measurement Standards". Therefore, in Tables 2 and 3, indicators starting with "MMS" are positive indicators, while indicators starting with "NMMS" are negative indicators. As shown in Table 2, indicators starting with "MMS" are forward-oriented indicators, and indicators starting with "NMMS" are reverse-oriented indicators. After processing, descriptive statistics were performed to calculate the standard deviation of each indicator. Then, we calculated the variability and conflict of the indicators to obtain the final weights as shown in Table 3.

Table 2. Descriptive statistics of average value and standard deviation for 31 cities sampled.

Item	Sample	Average Value	Standard Deviation
MMS_Education expenditure as a percentage of public budget expenditure	31	0.523	0.297
MMS_Investment intensity of R&D and experimental development funds	31	0.277	0.201
MMS_Population density	31	0.230	0.203
NMMS_Average equivalent sound level of regional environmental noise	31	0.635	0.260
MMS_Centralized treatment rate of urban domestic sewage	31	0.816	0.224
MMS_Days with good air quality	31	0.613	0.285
MMS_Harmless treatment rate of household waste	31	0.966	0.179
MMS_Green coverage rate in built-up areas	31	0.554	0.207
MMS_Comprehensive utilization rate of industrial solid waste	31	0.755	0.281
MMS_GDP Per capita GDP	31	0.388	0.274
MMS_Reduction in energy consumption per unit of GDP	31	0.384	0.248
MMS_Per capita Park and green area	31	0.332	0.204
NMMS_Per capita daily water consumption	31	0.543	0.287
MMS_Reuse rate of industrial water	31	0.635	0.317
MMS_Reduction in carbon emissions per unit of GDP	31	0.381	0.228
MMS_GDP growth rate	31	0.219	0.174
MMS_Urbanization rate	31	0.462	0.236
NMMS_Electricity consumption per unit of GDP	31	0.860	0.222
MMS_Proportion of non-fossil fuels in energy consumption	31	0.397	0.230
MMS_Per capita disposable income	31	0.311	0.284
MMS_New energy vehicle ownership per 100 persons	31	0.321	0.273
MMS_Proportion of green buildings in newly built buildings	31	0.637	0.311
MMS_Rail transit mileage per 10,000 persons	31	0.352	0.264
MMS_Number of public buses/electric vehicles per 10,000 persons	31	0.489	0.234

Table 3. CRITIC weight calculation results.

Item	Indicator Variability	Indicator Conflict	Value	Weight (%)
MMS_Proportion of education expenditure to public budget expenditure	0.297	19.645	5.826	4.98
MMS_Investment intensity of R&D and experimental development funds	0.201	16.344	3.285	2.81
MMS_Population density	0.203	17.135	3.476	2.97
NMMS_Average equivalent sound level of regional environmental noise	0.260	23.010	5.977	5.11
MMS_Centralized treatment rate of urban domestic sewage	0.224	22.777	5.096	4.35
MMS_Days with good air quality	0.285	24.992	7.113	6.08
MMS_Harmless treatment rate of household waste	0.179	22.253	3.994	3.41
MMS_Green coverage rate in built-up areas	0.207	19.178	3.973	3.39
MMS_Comprehensive utilization rate of general industrial solid waste	0.281	20.470	5.755	4.92
MMS_Per capita GDP	0.274	15.611	4.277	3.65
MMS_Reduction in energy consumption per unit of GDP	0.248	20.145	5.005	4.28
MMS_Per capita Park and green area	0.204	20.608	4.202	3.59
NMMS_Per capita daily water consumption	0.287	27.121	7.776	6.64
MMS_Reuse rate of industrial water	0.317	21.625	6.845	5.85
MMS_Reduction in carbon emissions per unit of GDP	0.228	19.423	4.438	3.79
MMS_GDP growth rate	0.174	20.611	3.596	3.07
MMS_Urbanization rate	0.236	18.640	4.401	3.76
NMMS_Electricity consumption per unit of GDP	0.222	20.242	4.484	3.83

Table 3. *Cont.*

Item	Indicator Variability	Indicator Conflict	Value	Weight (%)
MMS_Proportion of non-fossil fuels in energy consumption per unit of GDP	0.230	17.868	4.115	3.50
MMS_Per capita disposable income	0.284	15.382	4.371	3.73
MMS_New energy vehicle ownership per 100 persons	0.273	17.452	4.772	4.08
MMS_Proportion of green buildings in newly built buildings	0.311	17.653	5.497	4.69
MMS_Rail transit mileage per 10,000 persons	0.264	16.325	4.306	3.68
MMS_Number of public buses/electric vehicles per 10,000 persons	0.234	19.239	4.496	3.84

The CRITIC method is based on the comparative strength of evaluation indicators and the conflict between indicators to comprehensively measure the objective weight of indicators. Considering the variability of indicators and also the correlation, its scientific evaluation is based on the objective attributes of the data. The conflict between indicators is represented by a correlation coefficient. If there is a strong positive correlation between the two indicators, it indicates that the smaller the conflict, the lower the weight. For the CRITIC method, while the standard deviation is constant, generally the smaller the conflict between indicators and the smaller the weight, the greater the conflict, the greater the weight (Table 3). For instance, the indicator conflict of average equivalent sound level of regional environmental noise is 23.010, while the weight result is up to 5.11%, and the weight of population density is 2.97, while the indicator conflict comes to 17.135. Therefore, based on CRITIC calculation results, we could determine the correlation between the indicator conflict and the weight.

After determining the weights of each indicator in the index layer, the corresponding weights for each criteria layer can be calculated based on the corresponding criteria layer of each indicator. Based on the results of Tables 1 and 3, the weight of the driving force layer consists of the per capita GDP (3.65%), the GDP growth rate (3.07%), population density (2.97%), urbanization rate (3.76%), the reduction in energy consumption per unit of GDP (4.28%), the reduction in carbon emissions per unit of GDP (3.79%), electricity consumption per unit of GDP (3.83%), and the proportion of non-fossil fuels in total energy consumption (3.50%), totalling 28.85%; the weight of the state layer consists of per capita disposable income (3.73%), the proportion of green buildings in newly built buildings (4.69%), per capita daily water consumption (6.64%), public bus/electric vehicle ownership per 10,000 persons (3.84%), the number of rail transit kilometers per 10,000 persons (3.68%), the number of new energy vehicles (4.08%), the per capita park and green area (3.59%), days with good air quality (6.08%), green coverage rate in built-up areas (3.39%), and the average equivalent sound level of regional environmental noise (5.11%), totalling 44.83%; the weight of the response layer consists of investment intensity of research and experimental development funds (2.81%), the proportion of education expenditure to public budget expenditure (4.98%), the harmless treatment rate of household waste (3.41%), the centralized treatment rate of urban domestic sewage (4.35%), the reuse rate of industrial water (5.85%), and the comprehensive utilization rate of industrial solid waste (4.92%), totalling 26.32%.

Next, the summary score of each city can be calculated based on the values of each indicator after forward or reverse transformation, and the corresponding weights of each indicator. The summary score is the value of each indicator after the forward and reverse transformation of each city, multiplied by its corresponding weights, and added together. The final result and ranking from high to low are shown in Figure 3. According to the division of index layers, the scores and rankings of each city at different index layers are shown, respectively.

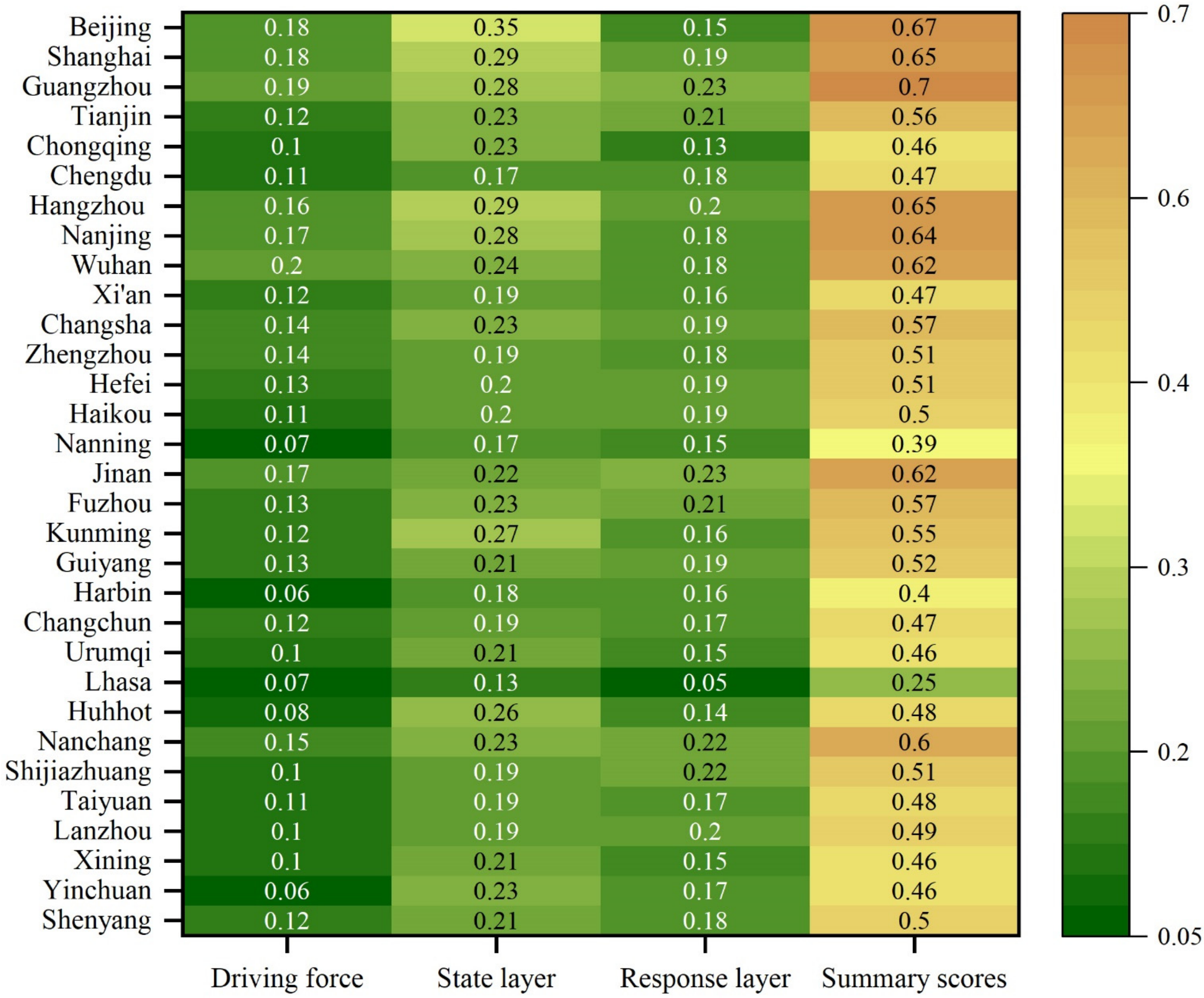

Figure 3. Result and ranking of the object cities. Source: author self-painting.

Figure 3 shows that the three cities with the highest summary scores are Guangzhou, Beijing and Shanghai, with scores of 0.704, 0.671 and 0.653, respectively. The three cities with the lowest comprehensive scores are Harbin, Nanning and Lhasa, with scores of 0.397, 0.386 and 0.253, respectively. In the scores of each criteria layer, except for Shanghai and Beijing, which have slightly lagged behind in the response layer, three major super first-tier cities are in a relatively leading position in the other criteria layers. In terms of the driving force, Wuhan ranks first mainly because it has a high score in the "Energy and Emissions" sub-criteria level, especially in the three indicators that represent energy and emission intensity, "Energy Consumption Reduction per unit GDP", "Carbon Emission Reduction per unit GDP" and "Electricity Consumption per unit GDP". In the state layer, the top five cities with the highest scores are Beijing, Shanghai, Hangzhou, Guangzhou and Nanjing, respectively, which happens to be the top five cities with the highest per capita GDP. It indicates that the indicators in the state layer, including indicators of residents' living conditions and environmental conditions, are closely related to the sub-criteria layer of economic development in the driving force criteria layer such as per capita GDP. Cities with high per capita GDP and high GDP growth rates usually have stronger capabilities to improve residents' life quality and environment, which also confirms that the driving force of economic development is the fundamental driving force of green city construction.

Per capita GDP and GDP growth rate in Chengdu are not low, while its score ranking at the state level is relatively lower, which is mainly because Chengdu's performance in the indicators of "average equivalent sound level of regional environmental noise", "per capita daily water consumption”, “green coverage rate in built-up areas” and “proportion of days with good air quality in the whole year” is slightly behind in the sub-criteria level of environmental status. The Chengdu government still needs to spend more effort to manage the environment and establish awareness of water conservation. The main reasons that the per capita GDP of Kunming and Yinchuan is not high but the status level score is higher are the good performance of indicators such as “proportion of days with good air quality in the whole year”, “per capita daily water consumption”, “proportion of green buildings in new buildings” and “average equivalent sound level of regional environmental noise”. At the response level, the rankings of Shanghai and Beijing are relatively lower. The weak indicator for Shanghai is “education expenditure accounting for public budget expenditure”, while the weak indicator for Beijing is “industrial water reuse rate” and “comprehensive utilization rate of general industrial solid waste”, which can reflect green production. The low proportion of education expenditure in Shanghai to public budget expenditure may be mainly affected by the large base of public budget expenditure. Lhasa’s score in the response layer is significantly lower than that of other cities because Lhasa performs poorly in all indicators except for the “harmless treatment rate of biochemical waste” in the response layer.

Overall, at the regional level, the summary scores of green city construction in economically developed and populous cities such as super first-tier cities, first-tier cities and eastern cities are generally higher, and their scores in criteria levels are also not low. Central cities such as Changsha, Hefei, Wuhan, Chengdu, Guiyang, and other cities generally rank in the upper or lower middle reaches of the summary score and each criterion layer. Cities with relatively small populations and underdeveloped economies in the western region generally rank at the lower end of the comprehensive score and criterion layer score. South China cities such as Haikou and Nanning, Haikou have relatively lower scores, while Nanning performs poorly. Northeast cities such as Harbin, Changchun and Shenyang have encountered bottlenecks in economic development and population reduction in recent years, in which summary scores and scores at various criteria levels are generally ranked in the middle and bottom, with Shenyang, Changchun and Harbin performing in descending order from high to low. It is basically consistent with their per capita GDP ranking, indicating that economic factors do play a fundamental and decisive role in the construction of green cities.

4.3. Correlation Analysis on Index System of Green Cities

Next, this study used the 31 large and medium-sized cities mentioned above as samples to analyze the correlation between various indicators and comprehensive scores. Due to the fact that different dimensions have no impact on the correlation analysis, the indicator values that have undergone positive and negative transformations cannot well reflect the positive and negative correlation with comprehensive scores. Therefore, when analyzing the correlation between indicators and comprehensive scores, this study adopted the original values of the indicator data instead of the indicator values after forward and backward processing. The correlation between the indicators of each criteria layer and the comprehensive score is shown in Tables 4–6.

Table 4. Correlation analysis between indicators of driving force layer and comprehensive scores.

Indicators of Driving Force Layer	Score
Per capita GDP	0.785
Electricity consumption per unit of GDP	−0.299
Reduction in energy consumption per unit of GDP	0.427
GDP growth rate	0.313
Population density	0.632
Reduction in carbon emissions per unit of GDP	0.495
The proportion of non-fossil fuels in energy consumption	0.563
Urbanization rate	0.497

Table 5. Correlation analysis between indicators of state layer and comprehensive scores.

Indicators of State Layer	Score
The proportion of days with good air quality in the whole year	−0.092
Per capita park and green area	0.316
Average equivalent sound level of regional environmental noise	−0.191
Number of rail transit kilometers per 10,000 persons	0.697
Green coverage rate in built-up areas	0.407
Number of new energy vehicles owned by 100 persons	0.599
Per capita disposable income	0.805
Proportion of green buildings in newly built buildings	0.661
Per capita daily water consumption	0.243
Number of public buses/electric vehicles per 10,000 persons	0.437

Table 6. Correlation analysis between indicators of response layer and comprehensive scores.

Indicators of Response Layer	Score
Harmless treatment rate of household waste	0.134
Centralized treatment rate of urban domestic sewage	0.181
Comprehensive utilization rate of industrial solid waste	0.384
Reuse rate of industrial water	0.321
Investment intensity of R&D and experimental development funds	0.718
The proportion of education funds in public budget expenditures	0.429

As shown in Table 4, among the 8 indicators in the driving force layer, the indicators show a significant positive correlation with the comprehensive score (correlation coefficient greater than 0.5) including per capita GDP, population density and the proportion of non-fossil fuels to energy consumption, with correlation coefficients of 0.785, 0.632 and 0.563, respectively. Those correlation coefficients are located in the driving forces of economic development, urban expansion, energy and emissions, proving that three driving forces under the driving force layer can have a significant impact on the final comprehensive score. The per capita GDP is the indicator with the highest correlation coefficient, proving that the development of a city's economic strength is the most important factor in promoting the construction of green cities. As the only negative indicator, the electricity consumption per unit GDP which had a negative correlation coefficient with the comprehensive score is −0.299.

As shown in Table 5, among the 10 indicators of the state layer, indicators show a significant positive correlation with the comprehensive score (correlation coefficient greater than 0.5) including the mileage of rail transit owned by 10,000 persons, the number of new energy vehicles owned by 100 persons, per capita disposable income, and the proportion of green buildings to new buildings, all of which belong to positive indicators and two sub-criteria layers under the state layer: residents' living status and environmental status. The correlation coefficient of per capita disposable income is the highest, reaching 0.805, indicating that the improvement of residents' income level will have a significant promoting effect on the construction of green cities. Local governments should attach importance to income distribution, strive to improve residents' income levels and narrow the wealth gap. In addition, the government should also give full attention to green transportation such as new energy vehicles, rail transit and green buildings, and accelerate their development. The correlation coefficient of "proportion of days with good air quality in the whole year" as a positive indicator is negative, and the correlation coefficient of "per capita daily water consumption" as a negative indicator may be negative. The reason is that air quality is not only affected by factors such as industrial structure, but also by local geography, climate, resources and other comprehensive factors. The per capita daily water consumption is not only influenced by the industrial structure and residents' awareness of water conservation, but also by factors such as geography, climate and culture. These factors mainly affect water demand, such as the abundance of freshwater resources in the south and the hotter climate compared to the north. Therefore, there is relatively more water demand, which will increase the "per capita daily water consumption" indicator to some extent.

As shown in Table 6, among the six positive indicators in the response layer, the only one showing a significant positive correlation with the comprehensive score and the highest correlation coefficient is the "R&D and experimental development funding intensity" indicator from the sub-criteria layer of "government response". The correlation coefficient reaches 0.718, and this result indicates that cities that value technological development and R&D investment often achieve greater results in green city construction. The technology can fundamentally promote the green transformation of industries and eliminate outdated industries with high energy consumption and high pollution to promote the construction of green cities.

Hence, the three indicators with the most significant positive correlation and the comprehensive score of green cities are "per capita disposable income", "per capita GDP" and "R&D and experimental development investment intensity", all of which are greater than 0.7. The first two indicators are closely related to the economy, while the latter is closely related to technology. This indicates that the economy and technology have a fundamental and decisive role in the development of green cities, which can not only improve people's well-being, but also help to enhance the city's strength.

Based on the principles of systematicity, scientificity, comparability and operability, this study focused on the connotation and requirements of green cities, the CRITIC method and DSR model were used to analyze and establish the target layer, criteria layer, sub-criteria layer and indicator layer from different perspectives. The framework of the index system of green cities was constructed, and the connotation and significance of each indicator were elaborated in detail. After that, by using 31 large and medium-sized cities as sample cities, data on indicators of each city was collected from national and local statistical yearbooks. Then, the weights of each secondary indicator were calculated based on the variability and conflict characteristics of each indicator by using the CRITIC method. The weights of each primary indicator were calculated by adding different indicator weights, achieving precise quantification and scientific determination of weights for each indicator. Based on this, the comprehensive scores and rankings of 31 major cities were calculated, and different cities were evaluated according to the criteria layer. Finally, based on the criteria layer, the correlation between various indicators and comprehensive scores could be explored and conclusions were drawn.

5. Discussion

5.1. Theoretical Contributions

On a theoretical level, our study contributes to the green city in the following ways: first, it summarizes the relevant research results and defines the connotation and concept of green cities; second, it analyzes the development status and related indicator systems of green cities, introduced the DSR model and layers to determine which criteria layer, sub-criteria layer and specific indicators should be included in the index system of green cities. Third, combining the principles of indicator construction and characteristics of indicators, the CRITIC method was used to assign reasonable weights to determined indicators and define the weight of every index layer, calculating the comprehensive score and ranking of sample cities in order to summarize the strengths and weaknesses of different regions. Finally, an index system of green cities is constructed, which concretizes the meaning of green cities and analyzes the development paths of green cities, which can provide a reference for reasonably evaluating the index system.

5.2. Practical Implications

On a practical level, our findings have several implications for green cities. First, this study constructs an index system of green cities, analyzes the logical relationship and internal correlation between various criteria and indicators, determines the weights and provides a reliable evaluation model for green city construction. Second, the hierarchical logical analysis of "Driving Force–State–Response" based on the DSR model helps the government to find the development and construction path of green cities. Based on the correlation analysis between each indicator and the comprehensive score, this study also pointed out the indicators that are significantly correlated with the level of green city construction and clarified the important factors of green cities. Moreover, the correlation between each indicator and the comprehensive score can be explored by calculating the scores of indicators for cities with different development levels in different regions, so different regions can identify their shortcomings and take targeted measures to improve, which is conducive to clarifying the heterogeneity of urban development and find a long-term mechanism for building green cities.

5.3. Policy Recommendations

Green cities refer to cities that focus on ecological environment protection, resource conservation and utilization, low-carbon emission reduction and comfortable living in urban planning, construction and management. The construction of green cities is an important measure for the sustainable development of human society and an inevitable choice in the process of urbanization. The development of green cities needs to be carried out from multiple aspects, including urban planning, architectural design, transportation, energy utilization, waste treatment, etc. It requires the joint participation of the government, enterprises and residents, and is of great significance for promoting sustainable development and prosperity of cities. Based on the construction and weight determination of the green city indicator system, as well as the analysis of data collected from 31 major large and medium-sized cities in China, this study proposes the following policy recommendations:

First, from the perspective of the government, local governments should attach importance to the development of the green economy, which can not only improve people's well-being, but also promote the construction of green cities in the post-pandemic era. The government should pay more attention to technology and education and increase budget expenditures, develop a circular economy and comprehensive utilization in order to improve resource utilization efficiency and reduce its invisible carbon emissions, which is crucial for the construction of green cities.

Second, in the planning and design of green cities, traffic issues should be fully considered and sustainable transportation solutions should be sought. Residents can be encouraged to use public transportation or bicycles for travel so as to promote new energy vehicles, reduce pollutant emissions, and effectively alleviate urban traffic congestion and air pollution problems. Moreover, accelerating the implementation of traffic energy and transformation can promote environmental protection and create more employment opportunities.

Third, in the construction of green cities, the first thing to pay attention to is the greening of the city. Greening not only beautifies the urban environment, but also purifies the air quality. Attention should also be paid to urban energy conservation and environmental protection. The high energy consumption and emissions of urban energy have become a global problem. Reasonable energy-saving and environmental protection measures can not only save energy, but also reduce energy pollution, consumption and emissions. For instance, adopting energy-saving lighting poles and underground lighting systems, etc., in urban lighting systems can reduce the consumption of natural resources while also protecting the visual environment.

Finally, in the development of green cities, we should also pay attention to the development of urban–rural integration. The development of cities must be planned, step by step, and focused, and the construction of urban–rural integration is essential. The construction of urban–rural integration can promote the interaction between cities and rural districts, form a buffer zone between them, disperse the development pressure of cities and create a more balanced and harmonious green environment.

5.4. Limitations and Future Directions

This study is mainly focused on the index system and index correlation on green cities, ignoring the impact degree of green development of cities. The core of urban construction is always how to achieve green sustainable development. Hence, a future study will further expand the impact degree of different indicators on green cities.

6. Conclusions

On the basis of theoretical development and empirical tests, several revealing conclusions can be drawn from this study. First, economic factors are the fundamental and decisive factors for the development of green cities. The higher the level of economic development, the stronger the ability of urban development. Second, technological factors are crucial for the construction of green cities. Only with the continuous improvement of the technological level, green industries have the driving force for sustainable development, traditional high-energy consuming and high pollution industries can be continuously eliminated so as to promote the construction of green cities. Third, there is a significant gap in the level of green city construction among different regions in China. According to the results of scores and correlation analysis, the first-tier and eastern cities, i.e., Shanghai, Hangzhou, Guangzhou, etc., are relatively excellent; the central region is average, i.e., Xi'an, Hefei, etc.; the southern and northeastern regions are relatively poor, i.e., Nanning, Harbin, Changchun, etc.; and the western region is the worst, i.e., Xining, Yinchuan Lhasa, etc. Therefore, it is urgent to find ways to narrow regional development differences and improve the overall level of green city construction. Moreover, the green city can be seen as a multi-dimensional and complex system, and green city construction should focus on all these aspects.

Promoting green development in cities can effectively address climate change and environmental pollution, reduce damage to the ecological environment and ecosystems, improve people's well-being index and make cities like a park [52]. Green city is the direction of urban sustainable development that we can look forward to. It is green, ecological, low carbon, the buildings are readable, the streets are walkable, the spaces are restful, and the city always has warmth.

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