sustainability

MDPI

Article

City Green Economy Evaluation: Empirical Evidence from 15 Sub-Provincial Cities in China

Baofeng Shi *, Hufeng Yang, Jing Wang and Jingxu Zhao

College of Economics & Management, Northwest A & F University, Yangling, Shaanxi 712100, China; yanghufeng@126.com (H.Y.); jing.wang@nwsuaf.edu.cn (J.W.); zhaojingxu1103@163.com (J.Z.)
* Correspondence: fengbei_wuyu@163.com or shibaofeng@nwsuaf.edu.cn; Tel.: +86-029-8708-1209

Academic Editor: Vincenzo Torretta
Received: 9 March 2016; Accepted: 3 June 2016; Published: 15 June 2016

Abstract: City green economy plays an important role in the development of low-carbon economy and the achievement of sustainable development of economy, society and ecological environment. From the perspective of economy, society, environment and resources, the evaluation of the green economy in urban areas tends to offer us a new insight into the green economy of cities. This paper is about the creation of a novel urban green economy evaluation model and its application. First of all, we established a city green economy evaluation index system based on *R* cluster analysis and coefficient of variation. Secondly, based on the nonlinear weighted utilizing entropy weight method, a city green economy evaluation model is established based on inferior constraints. Thirdly, by comparing the differences between evaluation rankings under inferior constraints and non-inferior constraints, the advantageous factors and the disadvantageous ones in urban green economy development are obtained. The proposed model has been verified with the data on 15 sub-provincial cities in China. Empirical analysis results show that: (1) The proposed approach can accurately find out the advantageous and disadvantageous factors for each sub-provincial city; (2) In the evaluation of green economy development, the order of importance of the three criterion layers is X_1 *Economy development* > X_2 *Social livelihood of the people* > X_3 *Resources and environment*; (3) Local governments should implement differential, reasonable policies in order to improve their green economy development. Moreover, our research is not only significant for developing green economy in China's sub-provincial cities, but also serves as a reference for the development of green economy in other cities in the world.

Keywords: Sustainability assessment; city green economy evaluation; green economy; environment and resources; sustainable development

1. Introduction

The development of green economy is an inevitable choice for the sustainable development of economy, society and ecological environment [1,2]. Green economy development is needed to alleviate the conflict among economic development and energy consumption, resource utilization and the environmental protection [3,4]. In order to promote green economy development worldwide, many international authority organizations have developed a variety of green economy development policies [5–9]. At the same time, the Chinese government also puts forward a proposal that everyone should firmly establish and implement the green economy development concepts of innovation, coordination, green, open, shared during the thirteenth five-year period [10]. Under this background, the city green economy evaluation is urgent need of extracting the advantageous factors and the bottleneck factors in green economy development, which can help the authorities to make or adjust corresponding green economy development policies.

The main proposed references to evaluate green economy development can be divided into two categories. The first category focuses on the green economy evaluation index systems, and the second category of studies concentrate on the comprehensive evaluation methods of green economy. Pearce *et al.* firstly proposed the concept of the green economy, and then lots of researchers began to explore the development of the green economy [11]. To date, there has been no unified definition of the green economy. The related definitions mostly emphasize that "a green economy can be thought of as one which is low-carbon, resource efficient, socially inclusive and sustainable development" [12,13]. As an important part of the green economy, the city green economy development has gradually attracted more and more scholars' attention.

Up to now, little research on city green economy evaluation index systems has been presented in existing studies. Nevertheless, the overwhelming majority of studies have sought to establish evaluation index systems for sustainable development and green industry development. The UK Office for National Statistics proposed the British sustainable development index system, which mainly covered aspects of economic growth, energy consumption and environmental impacts [5]. The Global Reporting Initiative (GRI) proposed the global sustainable development index system, which evaluated the sustainable development level from economic, social and environmental aspects [14]. The World Bank economists released an green economic development framework for countries. The framework consisted of economic growth, social welfare, natural resources, human capital and green innovation [15]. The Organization for Economic Co-operation and Development (OECD) developed a green growth index system, including four aspects of the economy, natural resources, environment and human well-being [16]. The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) created a green growth roadmap for Asia and the Pacific countries, which involved economic development, social development, environment development and sustainable development [17]. Ministry of Environmental Protection of the People's Republic of China developed the "twelfth five-year" period urban environmental comprehensive improvement quantitative assessment indices, which included 16 indicators, such as coverage rate of green area in completed construction area, comprehensive utilization rate of industrial solid waste and urban air quality [18]. Beijing Municipal Commission of Development and Reform set up the "Green Beijing" index system, which had three criterion layers: green production, green consumption and green environment [19]. Satterthwaite proposed that the definition of green cities is environmentally friendly. He used eleven indicators to measure green cities performance, such as levels of pollution and carbon emission, energy and water consumption, primary forests and agricultural land loss [20]. Azapagic presented an index system to evaluate sustainable development of mining industry in terms of economy, environment and society [21]. Shi *et al.* applied *R* cluster analysis with coefficient of variation methods to develop a green industry evaluation index system. The index system included the three guidelines of green production, green consumption and green environment. Using the data on Dalian green industry, empirical results suggested that the final index system reflects 98.44% of original information by 27.7% of initial indicators [22]. Meng and Chi established an evaluation index system of green industry based on Gini coefficient and partial correlation analysis. The proposed index system includes 24 indices, which has three criterion layers: green production, green consumption and green environment [23]. Although these studies could provide valuable references for assessing sustainable development or green industry development, they did not establish an evaluation system for city green economic development.

Research on how to improve the level of city green economy development requires comprehensive evaluation of green economy. For the past few years, more and more scholars began to monitor and evaluate the green economy development, which deepens the associated theoretical research and practical processes of green development [4,24]. Zhao *et al.* presented a comprehensive evaluation model for city eco-industrial system by utilizing system dynamics and grey cluster approaches. The authors proposed that society, economy and environment should be considered in eco-industrial evaluation. At last, four different development strategies of city eco-industrial system were simulated

during 2005–2020 by using standard system dynamic models [25]. In order to assess agricultural sustainability development level, Wang *et al.* established an evaluation system including agricultural economic profitability and environmental sustainability [26]. Chen *et al.* calculated the indices' weights by using the AHP method, and then established an industrial green development evaluation model. Empirical results by using the data on China's 30 provinces concluded that China's industrial green development level has the characteristic of typical regional differentiation with a ladder-like distribution from the east and middle to the west [27]. Wang *et al.* measured Dalian's level of green industry development from three aspects of green production, green consumption and green environment and constructed a green industry evaluation model by using the fuzzy control method to assess the level of Dalian's green industry development [28]. Nalan *et al.* assessed the green economy development conditions in Turkey. The study showed that Turkey also had a large potential for renewable energies, and most policy-makers, potential consumers and energy firm managers lacked the knowledge about renewable energy technologies [29]. Liang *et al.* created an index system to evaluate the performance of the low-carbon industry by using an expert scoring method [30]. Chi *et al.* proposed a path selection model for green city by utilizing scenarios analysis method. By taking Dalian as an example, empirical results showed that weak intervention scenario was the optimal industrial development path of the twelfth five-year plan for Dalian [31]. Mundaca *et al.* used an indicator-based method to evaluate the progress with respect to social-economic, energy and environmental issues derived from RE stimulus programs linked to the American Reinvestment and Recovery Act. The evaluation results showed that stimulus programs had a positive effect on the RE sector [32].

The above studies have made great progress in illustrating the depth and breadth of research on associated green development issues. However, research on city green economy development issues is still insufficient. Current research must be improved in at least two aspects. First of all, most of the current index systems focus on evaluating sustainable development or green industry development. There is still no authoritative evaluation index system of city green economy development. Secondly, during the comprehensive evaluation of green economy, most evaluation models are designed to solve the assessment ranking problems, but they cannot be used to find out the advantageous factors and the disadvantageous factors influencing city green economy development.

To fill in the above gaps, our study advances in three aspects. First, this paper creates a novel city green economy evaluation model by introducing the inferior constraint fuzzy comprehensive evaluation method into city green economy evaluation. The proposed model not only can calculate the evaluation ranking of city green economy development, but also can find out the advantageous and disadvantageous factors of city green economy development. Second, we propose that economy, society, environment and resources should be taken into account in city green economy development assessment. Then we establish an evaluation index system of city green economy development by combining *R* cluster analysis with coefficient of variation quantitative reduction approaches. The index system includes 23 indicators, which involves three criterion layers: X_1 *Economic development*, X_2 *Social livelihood of the people* and X_3 *Resources and environment*. Third, using the green economy development data on 15 sub-provincial cities in China, empirical results present the corresponding advantageous and disadvantageous factors for each sub-provincial city. The study can help the authorities to make or adjust corresponding green economy policies.

The rest of the paper is organized as follows. Section 2 introduces the design and methodology of this study. Section 3 presents the data and empirical analysis of our green economy evaluation model for 15 sub-provincial cities in China. Section 4 is the conclusions and future work.

2. Design and Methodology of the Study

2.1. Index Explainations of the Evaluation System

Evaluation index system of city green economy development should be based on fundamental principles, such as low-carbon, resource efficient, socially inclusive, comprehensive, coordinated,

sustainable development and data accessibility. Through investigating the literature and combining these high frequency indicators of international authoritative organizations [5–10,12–19], the established first criteria layer is comprised of X_1 *Economic development*, X_2 *Social livelihood of the people* and X_3 *Resources and environment*. On this basis, a mass-election evaluation index system composed of six secondary criteria layers and 82 tertiary indices are created, as shown in Table 1. The detailed index set and its explanation are presented in Appendix Table A1.

Table 1. Index reduction process of green economy evaluation.

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Unit	(6) Index Type	(7) Reduction Result
1	X_1 Economic development	X'_1 Economic growth	$X_{1,1}$ Gross domestic product (GDP)	Hundred million Yuan	Positive	Deleted by coefficient of variation
2			$X_{1,2}$ GDP Per capita	Yuan	Positive	Deleted by coefficient of variation
...			...	...	...	...
24			$X_{1,24}$ Added value of the logistics industry	Hundred million Yuan	Positive	Retained
25		X''_1 Economic structure	$X_{1,25}$ The ratio of the added value of the primary sector to GDP	%	Moderate (4%)	Deleted by coefficient of variation
...			...	...	...	...
34			$X_{1,34}$ The ratio of logistics industry added value to GDP	%	Moderate (12%)	Deleted by coefficient of variation
35	X_2 Social livelihood of the people	X'_2 People's livelihood improvement	$X_{2,1}$ Census register population	Ten thousand persons	Positive	Retained
...			...	...	...	...
49			$X_{2,15}$ Number of beds in hospitals (10000 units)	——	Positive	Deleted by coefficient of variation
50		X''_2 Social undertakings	$X_{2,16}$ The ratio of government expenditure on education to general budget expenditure	%	Positive	Retained
...			...	...	...	...
59			$X_{2,25}$ Completed construction area	Square kilometers	Positive	Deleted by coefficient of variation
60	X_3 Resources and environment	X'_3 Resource carrying	$X_{3,1}$ Protection area of cultivated land	Hectare	Positive	Retained
...			...	...	...	...
68			$X_{3,9}$ Oil consumption of industrial enterprises above designated size	Ton	Negative	Deleted by coefficient of variation
69		X''_3 Environmental quality	$X_{3,10}$ Nitrogen dioxide content in air	Milligram/cubic meters	Negative	Deleted by coefficient of variation
...			...	...	...	...
82			$X_{3,23}$ Reduction of ammonia and nitrogen emissions of main pollutants	Ton	Positive	Deleted by coefficient of variation

X_1 *Economic development* criteria: The assessment of city green economy development should give full consideration to the unification of economic development speed, benefits and structure. Especially in the process of current Chinese economic development, economic growth and green transformation are equally important [33]. Out of the above considerations, two aspects of the indices X'_1 *Economic growth* and X''_1 *Economy structure* are designed under the first criteria layer X_1 *Economic development*. (1) In order to evaluate the contribution degree of the primary industry, secondary industry, and tertiary industry to city's economic development, nine indices are established, such as $X_{1,2}$ Per capita GDP, $X_{1,7}$ Value added of the tertiary sector and $X_{1,9}$ Value added of the construction industry. The three indices of $X_{1,4}$ Government revenue, $X_{1,10}$ Budgetary revenue of local government and $X_{1,12}$ Total investment in fixed assets are used to assess the city's fiscal revenue and

investment situation. To evaluate the city's financial industry development, three indices are developed, they are $X_{1,18}$ Balance of loans and deposit in RMB and foreign currencies in financial institutions, $X_{1,19}$ Balance of loans in RMB and foreign currencies in financial institutions and $X_{1,23}$ Value added of the financial industry. Statistics from the National Development and Reform Commission show that logistics industrial has become one of the pillar industries in economic development [34]. To assess the contribution degree of logistics industry on Chinese sub-provincial city economic development, four indices are presented, *i.e.*, $X_{1,20}$ Freight volume, $X_{1,21}$ Airport passenger throughput, $X_{1,22}$ Freight turnover and $X_{1,24}$ Added value of the logistics industry. Under the second criterion layer of X'_1 Economic growth, there are five other indices are designed to describe the impact of merchandise trade on economic growth, such as $X_{1,15}$ Total retail sales of consumer goods; (2) Since the reform and opening, China's rapid economic development has made remarkable achievements. At the meantime, China's ecological environment and consumption of energy and resources have paid a heavy price. The economic green transformation and upgrading is the inevitable choice for the sustainable development of China's economy. Based on the above considerations, five parts of the indices are designed under the criterion layer of X''_1 Economic structure. The proportions of the primary industry, secondary industry, and tertiary industry to GDP are used to evaluate the economic restructuring development level, such as $X_{1,25}$ The ratio of the added value of the primary sector to GDP, $X_{1,27}$ The ratio of industrial added value to GDP and $X_{1,28}$ The ratio of the added value of the tertiary industry to GDP. $X_{1,31}$ The ratio of private economic value added to GDP reveals the contribution degree of private economy to the regional economy development. $X_{1,32}$ The ratio of county economic aggregate to GDP reflects the development of the county economic sector. $X_{1,33}$ The ratio of value added of financial industry to GDP indicates the contribution degree of financial industry to the regional economy development. $X_{1,34}$ The ratio of logistics industry added value to GDP reflects the impact of the logistics industry on Chinese sub-provincial city economic development.

X_2 *Social livelihood of the people* criteria: The ultimate purpose of economic development is to achieve a better quality of life and improve people's welfare. In the criterion layer of X_2 Social livelihood of the people, two areas are considered: X'_2 People's livelihood improvement and X''_2 Social undertakings. (1) In the evaluation of people's livelihood improvement, income distribution, health care, employment and population situation should be considered. The income distribution is measured by five indices, such as $X_{2,5}$ Per capita disposable annual income of urban households and $X_{2,8}$ The average annual growth rate of per capita disposable income of urban households. The health care is evaluated utilizing six indices, for instance $X_{2,10}$ Number of basic endowment insurance urban contributors and $X_{2,15}$ Number of beds in hospitals (10,000 units). $X_{2,3}$ Registered unemployment rate in cities and towns and $X_{2,4}$ Annual new employment in cities and towns are used to assess the city's employment level. The two indices of $X_{2,1}$ Census register population and $X_{2,2}$ Natural population growth rate are developed to assess the population situation; (2) Regarding the social undertakings, three parts of indices are designed: basic education, food safety and social security. The five indices are used to evaluate the basic education level of the sub-provincial cities, such as $X_{2,16}$ The ratio of government expenditure on education to general budget expenditure and $X_{2,20}$ High school education gross enrollment ratio. $X_{2,21}$ Acceptance rate of foodstuffs sample survey is developed to assess the food safety status. The other four indices are presented to assess the city's social security level, such as $X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District) and $X_{2,23}$ Daily supply of tap water.

X_3 *Resources and environment* criteria: To consider low-carbon, resource efficient and environmentally friendly, a resource and environment index is designed from two parts: X'_3 *Resource carrying* and X''_3 *Environmental quality*. (1) In order to reflect impacts of the bearing capacity of land resources, the ecological carrying capacity and the population bearing capacity on the city green economy and sustainable development, four indices are used: $X_{3,1}$ Protection area of cultivated land, $X_{3,5}$ Forest coverage rate, $X_{3,6}$ Coverage rate of green area in completed construction area and $X_{3,7}$ Public green space per capita. At the same time, regarding the influence of energy consumption on urban green economic development, five indices, such as $X_{3,4}$ Energy consumption elasticity coefficient,

are developed to specify the energy consumption; (2) X''_3 *Environmental quality* is the basic index to indicate the impact of city development on the environment, and *environmental quality* is mainly reflected from four aspects: atmospheric emissions, wastewater discharge, urban solid waste emissions and urban air quality status. On this basis, seven indices, such as $X_{3,10}$ Nitrogen dioxide content in air, are presented to assess the influence of waste gas emissions on the city environment; $X_{3,14}$ Treatment rate of living waste water and $X_{3,16}$ Urban wastewater discharge are the main indices to describe city water consumption and sewage recycling utilization status; the three indices: $X_{3,12}$ Industrial soot emissions, $X_{3,17}$ Decontamination rate of urban refuse and $X_{3,19}$ Comprehensive use of industrial solid wastes are developed to measure urban solid waste emissions and recycling efficiency; $X_{3,18}$ Fairly good air quality day is used to evaluate the urban air quality status.

The above 82 indices are used to establish the mass-election index system, which reflects the principles of comprehensive, coordinated, sustainable development and data accessibility. In the following section, we will carry out index reduction based on the mentioned indices.

2.2. Index Reduction of City Green Economy Development Evaluation

(1) Standardization of index data

In order to eliminate the influence of the differences between indices dimensions and units on index reduction, the original green economy evaluation data must be converted into numbers within the interval [0, 1]. According to the features of indices, the evaluation index can be divided into four types: positive index, negative index, interval index and medium index. The positive indices are indices showing that the greater their green economy evaluation values are, the better the city green economy development is, such as "$X_{1,2}$ *GDP Per capita*". The negative indices are indices showing that the less their values are, the better the city green economy development is, such as "$X_{2,3}$ *Registered unemployment rate in cities and towns*". The interval indices are indices which are reasonable only when the original index data are within certain range, such as "$X_{1,26}$ *Consumer price index* (*CPI*)". The ideal range of "$X_{1,26}$ *Consumer price index* (*CPI*)" [35] is [101, 105]. It indicates that neither deflation nor inflation exists, when the *CPI* is within range [101, 105]. The moderate indices are indices showing that the closer their values to a certain ideal value are, the better city green economy development is. For example, the ideal value of the moderate index "$X_{1,29}$ *Urbanization rate*" is 75% [36]. Index types are shown in Table 1.

Index data standardization process for the four types of indices is as follows. Let p_{ij} denote the standardized score of the j^{th} city on the i^{th} index. Let v_{ij} denote the index original data of the j^{th} city on the i^{th} index. Let n denote the number of cities. The standardization equations of positive indices and negative indices are represented by Equations (1) and (2) respectively.

$$p_{ij} = \frac{v_{ij} - \min\limits_{1 \leqslant j \leqslant n}(v_{ij})}{\max\limits_{1 \leqslant j \leqslant n}(v_{ij}) - \min\limits_{1 \leqslant j \leqslant n}(v_{ij})} \tag{1}$$

$$p_{ij} = \frac{\max\limits_{1 \leqslant j \leqslant n}(v_{ij}) - v_{ij}}{\max\limits_{1 \leqslant j \leqslant n}(v_{ij}) - \min\limits_{1 \leqslant j \leqslant n}(v_{ij})} \tag{2}$$

Let q_1 denote the left boundary of the ideal interval and let q_2 denote the right boundary of the ideal interval. Then the standardized score equation of the interval indices is expressed in Equation (3).

$$p_{ij} = \begin{cases} 1 - \frac{q_1 - v_{ij}}{\max(q_1 - \min\limits_{1 \leqslant j \leqslant n}(v_{ij}), \max\limits_{1 \leqslant j \leqslant n}(v_{ij}) - q_2)}, & v_{ij} < q_1 \quad (a) \\ 1 - \frac{v_{ij} - q_2}{\max(q_1 - \min\limits_{1 \leqslant j \leqslant n}(v_{ij}), \max\limits_{1 \leqslant j \leqslant n}(v_{ij}) - q_2)}, & v_{ij} > q_2 \quad (b) \\ 1, & q_1 \leqslant v_{ij} \leqslant q_2 \quad (c) \end{cases} \tag{3}$$

Let v_{i0} denote the ideal value of the i^{th} index. The standardized equation of the moderate indices is shown as Equation (4).

$$p_{ij} = \begin{cases} 1 - \frac{v_{i0} - v_{ij}}{\max(v_{i0} - \min\limits_{1 \leqslant j \leqslant n}(v_{ij}), \max\limits_{1 \leqslant j \leqslant n}(v_{ij}) - v_{i0})}, & v_{ij} < v_{i0} \quad (a) \\ 1 - \frac{v_{ij} - v_{i0}}{\max(v_{i0} - \min\limits_{1 \leqslant j \leqslant n}(v_{ij}), \max\limits_{1 \leqslant j \leqslant n}(v_{ij}) - v_{i0})}, & v_{ij} > v_{i0} \quad (b) \\ 1, & v_{ij} = v_{i0} \quad (c) \end{cases} \tag{4}$$

(2) Indices cluster analysis

In this subsection, R cluster analysis is utilized to cluster the indices, which reflect the same information in one class. It ensures that the different categories of indices reflect different data characteristics, and eliminate the information chaos of index system [22]. The steps of R cluster analysis are as follows.

Step 1: Treat m indices as n categories.

Step 2: Combine any pair of evaluation indices in those m indices into one class, with no change in indices left. There are $m(m-1)/2$ kinds of combination. Calculate the sum of square deviation S_i of each class of indices according to formula (5). If cluster m evaluation indices into l categories, let S_i denote the i^{th} class's sum of square deviation, let m_i be the number of the i^{th} class's indices, let $X_i^{(j)}$ be the standardized sample value vector ($j = 1, 2, \ldots, m_i$) of the j^{th} evaluation index in the i^{th} class's indices, let $\overline{X}_i$ be the average vector of the i^{th} class of indices. The sum of square deviation S_i of the i^{th} class's indices is shown as Equation (5) [22].

$$S_i = \sum_{j=1}^{m_i} (X_i^{(j)} - \overline{X}_i)^T (X_i^{(j)} - \overline{X}_i) \tag{5}$$

Step 3: Calculate total sum of squares of deviations by formula (6), re-classify the indices in the way of indices' combination that would minimize the total sum of squares of deviation. Then

$$S = \sum_{i=1}^{k} \sum_{j=1}^{m_i} (X_i^{(j)} - \overline{X}_i)^T (X_i^{(j)} - \overline{X}_i) \tag{6}$$

Step 4: Repeat *Step* 3 until the final classification number equals l. It should be pointed out that the initial clustering number l is determined by subjective for the indices in the same second criterion layer.

Step 5: Test whether clustering number l is reasonable or not by using the nonparametric *K-W* test method. If the significance level of each class is greater than 0.05 [22], it means that the similar indices in the same class have no significant differences in values. The clustering number l is reasonable. Otherwise, the clustering number l is not reasonable, and we need to return to *Step* 4 to adjust the clustering number l.

(3) Calculation of the index information content

In this subsection, coefficient variation method is used to screen the index with the highest information content loading in each class, which ensures that the selected index has the greatest influence on the city green economy evaluation. The coefficient variation of index reflects the identification ability in the city green economy evaluation. The greater the coefficient of variation is, the greater the distribution of variation and the information content are in the city green economy evaluation, and the stronger the index information distinguishing ability is.

Let b_i denote the coefficient of variation the i^{th} index, let n denote the number of sub-provincial cities, let p_{ij} denote the standardized data of the i^{th} index in the j^{th} city, then we get

$$b_i = \frac{\sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(p_{ij}-\overline{p}_i\right)^2}}{\overline{p}_i} \tag{7}$$

(4) The judgment of reasonability of the established index system

As we know, index data variance reflects index information content [22,37]. This paper uses the ratio of the selected index system original data variance and the mass-election index system original data variance to judge the reasonability of the established index system. An index system is considered reasonably if the established index system is able to contribute more than 90% of original information by using less than 30% of indices in the mass-election index set.

Let S denote the covariance matrix of the indices' data, let trS denote the trace of the covariance matrix, let s denote the number of indices in the established index system, and let h denote the number of mass-election index set. The contribution rate In of the selected index system to the mass-election index set is given by [22]

$$In = trS_s/trS_h \tag{8}$$

2.3. A City Green Economy Evaluation Model Based on Inferior Constraint

In this section, we introduce a novel city green economy evaluation model by combining the entropy weight method with the inferior constraint fuzzy comprehensive evaluation technology. Firstly, the weightings of the selected indices in Section 2.2 can be calculated by using the entropy weight method. Secondly, a green economy evaluation model is established based on inferior constraint. Thirdly, the evaluation rankings of 15 sub-provincial cities under inferior constraints and non-inferior constraint are obtained. By comparing the differences between evaluation rankings under inferior constraints and non-inferior constraint, the advantageous factors and the disadvantageous factors impacting the sub-provincial cities green economy development can be worked out. A step-by-step instruction is as follows.

2.3.1. Weightings Determination Based on Entropy Weight Method

Let f_{ij} denote the subordinate degree weight of the i^{th} index in the j^{th} city, let p_{ij} denote the standardized score of the i^{th} index in the j^{th} city, let n denote the number of cities and m denote the number of evaluation indices. The subordinate degree function f_{ij} of the index p_{ij} is

$$f_{ij} = p_{ij} \Big/ \sum_{j=1}^{n} p_{ij} \tag{9}$$

Then, the entropy H_i of the i^{th} evaluation index can be calculated by Equation (10).

$$H_i = -\frac{1}{\ln n}\sum_{j=1}^{n} f_{ij}\ln f_{ij} \tag{10}$$

Subsequently, the entropy weight w_i of the i^{th} evaluation index is [38]:

$$w_i = (1-H_i) \Big/ (m - \sum_{i=1}^{m} H_i) \tag{11}$$

where $\sum_{i=1}^{m} w_i = 1$.

2.3.2. A City Green Economy Evaluation Model

Now we outline the steps to build the city green economy evaluation model. Step 1 is to calculate the superior vector and the inferior vector. Let $\boldsymbol{V^{\alpha}}$ and $\boldsymbol{V^{\beta}}$ denote the superior vector and the inferior vector of evaluation index sample values respectively. We have [39]

$$\boldsymbol{V^{\alpha}} = ({v_1}^{\alpha}, {v_2}^{\alpha}, \ldots, {v_m}^{\alpha})^T \tag{12}$$

$$\boldsymbol{V^{\beta}} = ({v_1}^{\beta}, {v_2}^{\beta}, \ldots, {v_m}^{\beta})^T \tag{13}$$

where ${v_i}^{\alpha}$ denotes the best sample value of the i^{th} evaluation index in all cities, and ${v_i}^{\beta}$ denotes the worst sample value (i = 1, 2, ..., m).

Step 2 is to calculate the superior subordinate degree and the inferior subordinate degree. Corresponding to the superior vector $\boldsymbol{V^{\alpha}}$ and the inferior vector $\boldsymbol{V^{\beta}}$, the superior subordinate degree $\boldsymbol{x^{\alpha}}$ and the inferior subordinate degree $\boldsymbol{x^{\beta}}$ can be got.

$$\boldsymbol{x^{\alpha}} = ({x_1}^{\alpha}, {x_2}^{\alpha}, \ldots, {x_m}^{\alpha})^T = (1, 1, \ldots, 1)^T \tag{14}$$

$$\boldsymbol{x^{\beta}} = ({x_1}^{\beta}, {x_2}^{\beta}, \ldots, {x_m}^{\beta})^T = (0, 0, \ldots, 0)^T \tag{15}$$

where ${x_i}^{\alpha}$ denotes the best subordinate degree of the i^{th} evaluation index in all cities, *i.e.*, ${x_i}^{\alpha}$ = 1, and ${x_i}^{\beta}$ denote the worst subordinate degree, *i.e.*, ${x_i}^{\beta}$ = 0.

Step 3 is to establish the inferior constraint. If we select t evaluation indices from m evaluation indices ($1 \leqslant t \leqslant m$), the worst evaluation value vector of the t evaluation indices in all n cities is called an inferior constraint. The inferior constraint vector $\boldsymbol{x_{Sk}}$ that is comprised of t evaluation indices is given by:

$$x_{S_k} = \{(x_{S_{k1}}, x_{S_{k2}}, ..., x_{S_{kt}})^T\} = \{(0, 0, \ldots, 0)^T\} \tag{16}$$

Step 4 is to calculate the superiority of weight. Let $\boldsymbol{x_j}$ denote the subordinate degree vector of the j^{th} city, then

$$\boldsymbol{x_j} = (x_{j1}, x_{j2}, \ldots, x_{jm})^T \tag{17}$$

The Euclidean distance $d(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}})$ between the subordinate degree vector $\boldsymbol{x_j}$ of the j^{th} city and the superior subordinate degree $\boldsymbol{x^{\alpha}}$ can be calculated by Equation (18).

$$d(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}}) = \left[\sum_{i=1}^{m} w_i (x_{ij} - x_i^{\alpha})^2\right]^{1/2} \tag{18}$$

Let ${y_j}^{\alpha}$ denote the subordinate degree of the j^{th} city belonging to the superior vector $\boldsymbol{V^{\alpha}}$, and then, the superiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}})$ belonging to the superior vector $\boldsymbol{V^{\alpha}}$ is given by:

$$D(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}}) = {y_j}^{\alpha} d(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}}) \tag{19}$$

In Equation (19), the superiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}})$ describes the distance between the subordinate degree vector $\boldsymbol{x_j}$ of the j^{th} city and the superior subordinate degree $\boldsymbol{x^{\alpha}}$.

Step 5 is to calculate the inferiority of weight. In the same way, the Euclidean distance $d(\boldsymbol{x_j}, \boldsymbol{x^{\beta}})$ between the subordinate degree vector $\boldsymbol{x_j}$ and the inferior subordinate degree $\boldsymbol{x^{\beta}}$ can be got.

$$d(\boldsymbol{x_j}, \boldsymbol{x^{\beta}}) = \left[\sum_{i=1}^{m} w_i (x_{ij} - x_i^{\beta})^2\right]^{1/2} \tag{20}$$

Let ${y_i}^{\beta}$ denote the subordinate degree of the j^{th} city belonging to the inferior vector $\boldsymbol{V^{\beta}}$. Then, the inferiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x^{\beta}})$ belonging to the inferior vector $\boldsymbol{V^{\beta}}$ can be obtained by Equation (21).

$$D(x_j, x^{\beta}) = {y_i}^{\beta} d(x_j, x^{\beta}) \tag{21}$$

And then, the Euclidean distance $d(\boldsymbol{x_j}, \boldsymbol{x_{Sk}})$ between the subordinate degree vector $\boldsymbol{x_j}$ and the inferior constraint vector $\boldsymbol{x_{Sk}}$ is given by Equation (22).

$$d(\boldsymbol{x_j}, \boldsymbol{x_{sk}}) = \left[\sum_{i \in S_k} \left(\frac{w_i}{\sum\limits_{i \in S_k} w_i} (x_{ij} - x_{S_{ki}})^2 \right) \right]^{1/2} \tag{22}$$

Let $y^{\beta}_{jS_k}$ denote the subordinate degree of the j^{th} city belonging to the inferior constraint vector $\boldsymbol{x_{Sk}}$. Thus, the inferiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x_{Sk}})$ of the j^{th} city belonging to the inferior constraint $\boldsymbol{x_{Sk}}$ is

$$D(\boldsymbol{x_j}, \boldsymbol{x_{sk}}) = y^{\beta}_{jS_k} d(\boldsymbol{x_j}, \boldsymbol{x_{sk}}) \tag{23}$$

Equation (23) describes the distance between the subordinate degree vector $\boldsymbol{x_j}$ and the inferior constraint vector $\boldsymbol{x_{Sk}}$.

Step 6 is to establish the inferior constraints evaluation model. We set the objective function to be the minimal weighted sum of squares of the superiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}})$, the inferiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x^{\beta}})$ and the inferiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x_{Sk}})$ [39]. Then

$$Obj: \min\{F = \sum_{j=1}^{m} [\frac{1}{L}(D(x_j, x^{\alpha}))^2 + (D(x_j, x^{\beta}))^2 + \sum_{k=1}^{L-1} (D(x_j, x_{S_k}))^2]\} \tag{24}$$

where L = the number of inferior constraints + 1.

Equation (24) is applied to evaluate the city green economy development. On the right side of the equal sign, $(D(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}}))^2$ denotes the square of the superiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x^{\alpha}})$ of the j^{th} city, $(D(\boldsymbol{x_j}, \boldsymbol{x^{\beta}}))^2$ denotes the square of the inferiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x^{\beta}})$ of the j^{th} city, and $(D(\boldsymbol{x_j}, \boldsymbol{x_{Sk}}))^2$ denotes the square of the inferiority of weight $D(\boldsymbol{x_j}, \boldsymbol{x_{Sk}})$ of the j^{th} city. Equation (24) indicates that the smaller the distance between the j^{th} evaluation city and the ideal city is, the better the green economy development of the j^{th} city would be.

Step 7 is to present a method of how to obtain a global optimal solution. Substitute Equation (18) to Equation (23) into Equation (24), and we can solve the derivatives of Equation (24) with respect to variables ${y_j}^{\alpha}$, ${y_j}^{\beta}$ and $y^{\beta}_{jS_k}$ respectively. The three derivative equations constitute a system of equations. Solve the system of equations, and the optimal solution y^{α}_{jS} containing the inferior constraint $\boldsymbol{x_{Sk}}$ can be obtained. That is

$$y^{\alpha}_{jS} = \frac{\frac{L}{d^2(x_j, x^{\alpha})}}{\frac{L}{d^2(x_j, x^{\alpha})} + \frac{1}{d^2(x_j, x^{\beta})} + \sum\limits_{k=1}^{L-1} \frac{1}{d^2(x_j, x_{S_k})}} \tag{25}$$

Equation (25) is the ratio of $\frac{L}{d^2(x_j, x^{\alpha})}$ to $\frac{L}{d^2(x_j, x^{\alpha})} + \frac{1}{d^2(x_j, x^{\beta})} + \sum\limits_{k=1}^{L-1} \frac{1}{d^2(x_j, x_{S_k})}$. The third item of denominator in Equation (25) reflects the influence of the inferior constraint vector $\boldsymbol{x_{Sk}}$ on the city green economy evaluation results. Equation (25) illustrates that the smaller the distance $d^2(\boldsymbol{x_j}, \boldsymbol{x_{Sk}})$ between the subordinate degree vector $\boldsymbol{x_j}$ and the inferior constraint vector $\boldsymbol{x_{Sk}}$ is, the bigger the denominator would be, and the smaller the optimal solution value y^{α}_{jS} would be, and this means that the inferior constraint $\boldsymbol{x_{Sk}}$ is the bottleneck factor of the j^{th} city green economy development. On the contrary, the bigger the distance $d^2(\boldsymbol{x_j}, \boldsymbol{x_{Sk}})$ between the subordinate degree vector $\boldsymbol{x_j}$ and the inferior constraint vector $\boldsymbol{x_{Sk}}$ is, the smaller the denominator would be, the bigger the optimal solution value y^{α}_{jS} would be. It indicates that the inferior constraint $\boldsymbol{x_{Sk}}$ is the advantageous factor of the j^{th} city green economy development.

If $\sum\limits_{k=1}^{L-1} \frac{1}{d^2(x_j, x_{S_k})}$ equals 0 in Equation (25), the optimal solution y^{α}_{jS} without containing the inferior constraint $\boldsymbol{x_{Sk}}$ is shown in Equation (26).

$$y_j^{\alpha} = \frac{\frac{1}{d^2(x_j,x^{\alpha})}}{\frac{1}{d^2(x_j,x^{\alpha})} + \frac{1}{d^2(x_j,x^{\beta})}} \quad (26)$$

Equation (26) indicates that the smaller the distance $d^2(\boldsymbol{x_j},\boldsymbol{x^{\alpha}})$ between the subordinate degree vector $\boldsymbol{x_j}$ and the superior subordinate degree vector $\boldsymbol{x^{\alpha}}$ is, the better the green economy development of the j^{th} city would be. Conversely, the bigger the distance $d^2(\boldsymbol{x_j},\boldsymbol{x^{\beta}})$ between the subordinate degree vector $\boldsymbol{x_j}$ and the inferior subordinate degree vector $\boldsymbol{x^{\beta}}$ is, the better the green economy development of the j^{th} city would be.

2.3.3. Key Factor Extraction of the City Green Economy Evaluation Model

This part is about the extraction of the common key factors influencing the sub-provincial cities' green economy development. Through comparing the differences d^* between 15 sub-provincial cities' evaluation rankings under inferior constraints and non-inferior constraints, the differences d^* can be divided into five categories by using Wald cluster analysis. These indices corresponding to the first classification are the common key factors, because they have the greatest influence on the sub-provincial cities' green economy development.

When selecting the advantageous factors and the disadvantageous factors influencing a sub-provincial city's green economy development after comparing the differences between a sub-provincial city's evaluation raking under the inferior constraint x^* and non-inferior constraint, we can determine whether index x^* is the advantageous factor of the sub-provincial city green economy development, or disadvantageous factor. If the evaluation rank $rank_{\text{inferior}}$ under the inferior constraint x^* is less than the evaluation rank $rank_{\text{non-inferior}}$ under the non-inferior constraint (*i.e.*, $rank_{\text{inferior}} - rank_{\text{non-inferior}} < 0$), index x^* is called an advantageous factor of green economy development. Conversely, if the evaluation rank $rank_{\text{inferior}}$ under the inferior constraint x^* is greater than the evaluation rank $rank_{\text{non-inferior}}$ under the non-inferior constraint (*i.e.*, $rank_{\text{inferior}} - rank_{\text{non-inferior}} > 0$), index x^* is called an disadvantageous factor of green economy development. For instance, in the following empirical analysis of Section 3.3.4, we select the index "$X_{1,10}$ *Budgetary revenue of local government*" as an inferior constraint. As mentioned below, the Dalian's evaluation rank $rank_{\text{non-inferior}}$ under the non-inferior constraint equals 11, while its evaluation rank $rank_{\text{inferior}}$ under the inferior constraint "$X_{1,10}$ *Budgetary revenue of local government*" equals 9. When $rank_{\text{inferior}} - rank_{\text{non-inferior}} = 9 - 11 = -2 < 0$, it indicates that index "$X_{1,10}$ *Budgetary revenue of local government*" is an disadvantageous factor of green economy development for Dalian.

3. Empirical Study Based on Chinese 15 Sub-Provincial Cities

3.1. Sample Selection and Data Collection

In order to judge the city green economy development level, and find out the insufficiency and difference existing in the development of green economy, in July 2011, the WWF launched "2050 Shanghai Low-carbon Development Road Map Report", and began the low carbon development research in Shanghai [40]. In September 2011, the Beijing Committee of Communist Party and the Beijing Municipal People's Government issued "Green Beijing Development Construction Planning in Twelfth Five-year Period" [19]. On the basis of Green Beijing and Low-Carbon Shanghai, this paper selects all of 15 sub-provincial cities in China as empirical samples. The 15 sub-provincial cities includes Dalian, Haerbin, Changchun, Shenyang, Jinan, Qingdao, Nanjing, Hangzhou, Ningbo, Xiamen, Guangzhou, Shenzhen, Wuhan, Chengdu and Xi'an, as shown in Table 2.

The original data of green economy evaluation index of the 15 sub-provincial cities are derived from the corresponding sub-provincial cities' statistics in Yearbook 2013 [41,42], as shown from Column 5 to Column 19 in Table 2.

Table 2. Original data and standardized data of green economy evaluation indices.

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Indices	Original Data v_{ij}			STANDARDIZED Data p_{ij}		
				(5) Dalian	…	(19) Xi'an	(20) Dalian	…	(34) Xi'an
1	X_1 Economic development	X'_1 Economic growth	$X_{1,1}$ Gross domestic product (GDP)	7002.80	…	4369.37	0.390	…	0.145
…			…	…	…	…	…	…	…
24			$X_{1,24}$ Added value of the logistics industry	283.43	…	283.43	0.011	…	0.011
25		X''_1 Economy structure	$X_{1,25}$ The ratio of the added value of the primary sector to GDP	6.40	…	4.50	0.662	…	0.930
…			…	…	…	…	…	…	…
34			$X_{1,34}$ The ratio of logistics industry added value to GDP	6.23	…	6.23	0.264	…	0.264
35	X_2 Social livelihood of the people	X'_2 People's livelihood improvement	$X_{2,1}$ Census register population	590.30	…	795.98	0.407	…	0.616
…			…	…	…	…	…	…	…
49			$X_{2,15}$ Number of beds in hospitals (10000 units)	58.70	…	44.85	0.624	…	0.368
50		X''_2 Social undertakings	$X_{2,16}$ The ratio of government expenditure on education to general budget expenditure	15.37	…	18.08	0.073	…	0.828
…			…	…	…	…	…	…	…
59			$X_{2,25}$ Completed construction area	395	…	375	0.176	…	0.149
60	X_3 Resources and environment	X'_3 Resource carrying	$X_{3,1}$ Protection area of cultivated land	328004	…	246610	0.087	…	0.065
…			…	…	…	…	…	…	…
68			$X_{3,9}$Oil consumption of industrial enterprises above designated size	24,497,894	…	2,174,699	0.023	…	0.917
69		X''_3 Environmental quality	$X_{3,10}$ Nitrogen dioxide content in air	0.038	…	0.042	0.889	…	0.667
…			…	…	…	…	…	…	…
82			$X_{3,23}$ Main pollutants ammonia and nitrogen emissions reduction	68.58	…	486.00	0.475	…	0.491

3.2. Application of Index Reduction Model

(1) The index data standardization

According to the index type in Column 6 in Table 1, take the original data of positive indices v_{ij} from Column 5 to 19 in Table 2 into Equation (1), the original data of negative indices v_{ij} into Equation (2), the original data of interval indices v_{ij} into Equation (3), and the original data of moderate indices v_{ij} into Equation (4), the standardized data p_{ij} of indices are obtained. The results are shown in Column 20 to 34 in Table 2.

(2) R cluster analysis

In order to explain the process of R cluster analysis, the 24 indices of the first secondary criterion layer "X'_1 *Economic growth*" gathering are divided into six categories as an example. Substitute the corresponding indices' data into Equation (5) and Equation (6), and the cluster results are obtained. From Column 4 in Table 3, the eight indices of $X_{1,1}$, $X_{1,7}$, $X_{1,11}$, $X_{1,15}$, $X_{1,18}$, $X_{1,19}$, $X_{1,21}$ and $X_{1,24}$ are the similar R cluster indices. Take the eight indices' data into SPSS17.0 software, the significance level *Sig* of *K-W* test that equals 0.563 can be got. Obviously, the significance level 0.563 is greater than 0.05, which means that the eight indices in the same class have no significant differences in values.

Similarly, we can obtain the significance levels of the rest of five classes indices which are greater than 0.05. It indicates that the clustering number six is reasonable for the first criterion layer. In the same way, we can get the corresponding cluster results for the rest of the five secondary criterion layers, as shown in Table 3.

Table 3. Index reduction based on R cluster analysis and coefficient of variation.

(1) No.	(2) The Second CRITERION Layer	(3) Indices	(4) Clustering Categories	(5) Significance Level *Sig*	(6) Coefficient of Variation	(7) Reserve or not
1	X'_1 Economic growth	$X_{1,1}$	1	0.563	0.673	Deleted
2		$X_{1,7}$	1		0.852	Deleted
3		$X_{1,11}$	1		0.877	Deleted
4		$X_{1,15}$	1		0.639	Deleted
5		$X_{1,18}$	1		0.819	Deleted
6		$X_{1,19}$	1		0.803	Deleted
7		$X_{1,21}$	1		0.984	Deleted
8		$X_{1,24}$	1		**1.266**	Retained
...		...	...	...	...	...
23		$X_{1,16}$	6	0.899	0.789	Deleted
24		$X_{1,22}$	6		**1.068**	Retained
...	...	...	...	...	...	...
69	X''_3 Environmental quality	$X_{3,1}$	1	0.912	0.642	Deleted
70		$X_{3,2}$	1		0.631	Deleted
71		$X_{3,6}$	1		0.472	Deleted
72		$X_{3,12}$	1		**0.691**	Retained
73		$X_{3,14}$	1		0.371	Deleted
...		...	...	...	...	...
82		$X_{3,3}$	4	-	**0.751**	Retained

(3) Index reduction by coefficient of variation

Substitute the standardized data in Table 2 into Equation (7), and the coefficients of variation of 82 indices can be obtained, as shown in Column 6 in Table 3. In the same clustering category in Table 3, we retain the index which has the biggest coefficient of variation, and delete the rest indices. The results are shown in Column 7 in Table 3. At last, we select 23 indices of city green economy evaluation, as shown in Table 4.

(4) The reasonability judgment of the established index system

Take the corresponding original data of the 23 selected indices and the original data of the 82 mass-election indices into Equation (8), and the contribution rate *In* of the selected index system to the mass-election index set is $In = trS_s/trS_h = 1.066 \times 10^{14}/1.122 \times 10^{14} = 95.01\%$. It means that the reduction index system indicates 95.01% original information with 28.05% indices (28.05% = 23/82).

It should be pointed out that there are some locally oriented indices in the established green economy evaluation index system, such as $X_{1,24}$ Added value of the logistics industry. Statistical data from the National Development and Reform Commission show that logistics industrial has become one of the pillar industries in economic development [34], so we use $X_{1,24}$ to reflect the contribution degree of the logistics industry to Chinese sub-provincial city economic development. Combining the above empirical analysis, the eight indices are the similar R cluster indices, *i.e.*, $X_{1,1}$, $X_{1,7}$, $X_{1,11}$, $X_{1,15}$, $X_{1,18}$, $X_{1,19}$, $X_{1,21}$ and $X_{1,24}$, and the index of $X_{1,24}$ has the biggest coefficient of variation, so it should be retained.

3.3. Application of the Green Economy Evaluation Model

3.3.1. The Determination of Index Weight

In Table 2, take the standard score data of the retained 23 indices into Equation (9) to Equation (11), the entropy weights of the 23 indices and the corresponding weights of the criterion layers can be obtained, as shown in Table 4.

Known from Table 4, the ranking results of weights in descending order is $X_1 = 0.506 > X_2 = 0.256 > X_3 = 0.238$. It means that the order of importance of the three criterion layers is X_1 *Economy development* > X_2 *Social livelihood of the people* > X_3 *Resources and environment*. In other words, in the evaluation of green economy for sub-provincial city, economy development is at the core position, which means achieving a minimum negative impact on the environment and resources consumption while improving the economic growth and increasing social welfare.

Table 4. Green economy evaluation index system for sub-provincial cities.

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Weight	(6) Dalian	...	(20) Xi'an
1	X_1 Economy development ($W_{X1} = 0.506$)	X'_1 Economy growth ($W'_{X1} = 0.451$)	$X_{1,10}$ Budgetary revenue of local government	0.027	0.335	...	0.036
2			$X_{1,12}$ Total investment in fixed assets	0.016	0.942	...	0.639
3			$X_{1,13}$ Total foreign trade value	0.072	0.124	...	0.017
4			$X_{1,20}$ Freight volume	0.212	0.009	...	0.011
5			$X_{1,22}$ Freight turnover	0.051	1.000	...	0.019
6			$X_{1,24}$ Added value of the logistics industry	0.073	0.011	...	0.011
7		X''_1 Economic structure ($W''_{X1} = 0.055$)	$X_{1,28}$ The ratio of the added value of the tertiary industry to GDP	0.028	0.008	...	0.486
8			$X_{1,31}$ The ratio of private economic value added to GDP	0.010	0.488	...	0.732
9			$X_{1,32}$ The ratio of county economic aggregate to GDP	0.017	0.649	...	0.163
10	X_2 Social livelihood of the people ($W_{X2} = 0.256$)	X'_2 People's livelihood improvement ($W'_{X2} = 0.115$)	$X_{2,1}$ Census register population	0.014	0.407	...	0.616
11			$X_{2,7}$ Urban households per capita consumption expenditure	0.033	0.218	...	0.297
12			$X_{2,9}$ The average annual growth rate of rural residents capita net income	0.045	0.119	...	0.505
13			$X_{2,14}$ Number of doctors (10000 persons)	0.023	0.353	...	0.177
14		X''_2 Social undertakings ($W''_{X2} = 0.141$)	$X_{2,16}$ The ratio of government expenditure on education to general budget expenditure	0.030	0.073	...	0.828
15			$X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District)	0.098	0.070	...	0.036
16			$X_{2,24}$ Urban per capita housing area	0.013	0.412	...	0.896
17	X_3 Resources and Environment ($W_{X3} = 0.238$)	X'_3 Resource carrying ($W'_{X3} = 0.116$)	$X_{3,1}$ Protection area of cultivated land	0.064	0.087	...	0.065
18			$X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size	0.018	0.866	...	0.945
19			$X_{3,7}$ Public green space per capita	0.034	0.317	...	0.030
20		X''_3 Environmental quality ($W''_{X3} = 0.122$)	$X_{3,12}$ Industrial soot emissions	0.034	0.022	...	0.705
21			$X_{3,18}$ Fairly good air quality day	0.015	0.383	...	0.871
22			$X_{3,21}$ Ammonia and nitrogen emissions of major pollutants	0.029	1.000	...	0.471
23			$X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants	0.044	0.064	...	0.132

3.3.2. Calculate the Optimal Subordinate Degree

(1) Calculate Euclidean distance between the evaluation cities and the superior subordinate degree

Substitute the data from Column 5 to Column 6 in Table 4 into Equation (18), the Euclidean distance $d^2(\boldsymbol{x_1}, \boldsymbol{x^\alpha})$ between the subordinate degree vector $\boldsymbol{x_1}$ of Dalian and the superior subordinate degree $\boldsymbol{x^\alpha}$ can be obtained: $d^2(\boldsymbol{x_1}, \boldsymbol{x^\alpha}) = \sum_{i=1}^{23} w_i(x_{i1} - x_i^\alpha)^2 = 0.027 \times (0.335 - 1)^2 + ... + 0.044 \times (0.064 - 1)^2 = 0.710$. In the same way, we can calculate the Euclidean distances $d^2(\boldsymbol{x_j}, \boldsymbol{x^\alpha})$ between the rest of 14 sub-provincial cities subordinate degree vectors and the superior subordinate degree $\boldsymbol{x^\alpha}$, as shown in the first Row in Table 5.

Table 5. Quadratic sum of Euclidean distance.

(1) No.	(2) Euclidean Distance	(3) Dalian	(4) Haerbin	(5) Changchun	(6) Shenyang	(7) Jinan	(8) Qiangdao	(9) Nanjing	(10) Hangzhou	(11) Ningbo	(12) Xiamen	(13) Guangzhou	(14) Shenzhen	(15) Wuhan	(16) Chengdu	(17) Xi'an
1	$d^2(x_j, x^{\alpha})$	0.710	0.744	0.525	0.765	0.755	0.597	0.676	0.628	0.646	0.686	0.530	0.523	0.656	0.662	0.714
2	$d^2(x_j, x^{\beta})$	0.138	0.152	0.308	0.078	0.078	0.146	0.080	0.175	0.129	0.179	0.299	0.305	0.136	0.131	0.123
3	$d^2(x_j, X_{1,10})$	0.112	0.000	0.165	0.165	0.000	0.071	0.102	0.183	1.000	0.165	0.400	0.910	0.161	0.165	0.001
4	$d^2(x_j, X_{1,12})$	0.887	0.330	0.163	0.887	0.035	0.383	0.541	0.275	0.118	0.000	0.469	0.046	1.000	1.000	0.408
5	$d^2(x_j, X_{1,13})$	0.015	0.000	0.001	0.000	0.000	0.022	0.012	0.015	0.039	0.022	0.061	1.000	0.001	0.008	0.000
6	$d^2(x_j, X_{1,20})$	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	$d^2(x_j, X_{1,22})$	1.000	0.000	0.039	0.000	0.015	0.048	0.323	0.000	0.048	0.004	0.365	0.043	0.112	0.039	0.000
8	$d^2(x_j, X_{1,24})$	0.000	0.000	0.000	0.000	0.008	0.244	0.080	0.026	0.215	0.000	1.000	0.000	0.525	0.058	0.000
9	$d^2(x_j, X_{1,28})$	0.000	0.255	0.000	0.013	0.329	0.111	0.281	0.177	0.002	0.155	0.964	0.396	0.081	0.126	0.237
10	$d^2(x_j, X_{1,31})$	0.238	0.942	0.302	0.323	0.441	0.893	0.261	0.719	0.537	0.000	0.255	0.211	0.237	0.786	0.537
11	$d^2(x_j, X_{1,32})$	0.421	0.923	0.641	0.159	0.366	0.269	0.006	0.208	0.665	0.393	0.000	0.393	0.407	0.579	0.026
12	$d^2(x_j, X_{2,1})$	0.165	0.667	0.332	0.295	0.181	0.347	0.208	0.269	0.155	0.000	0.413	0.010	0.412	1.000	0.379
13	$d^2(x_j, X_{2,7})$	0.047	0.000	0.000	0.034	0.035	0.046	0.141	0.162	0.194	0.322	1.000	0.501	0.009	0.009	0.088
14	$d^2(x_j, X_{2,9})$	0.014	1.000	0.004	0.021	0.045	0.039	0.025	0.000	0.001	0.025	0.050	0.050	0.101	0.000	0.255
15	$d^2(x_j, X_{2,14})$	0.124	0.000	0.039	0.042	0.230	0.112	0.163	0.048	0.267	0.955	1.000	0.021	0.267	0.394	0.031
16	$d^2(x_j, X_{2,16})$	0.005	0.853	0.895	0.017	0.484	1.000	0.099	0.996	0.310	0.004	0.180	0.029	0.000	0.149	0.685
17	$d^2(x_j, X_{2,22})$	0.005	0.000	0.001	0.000	0.001	0.003	0.000	0.005	0.007	0.012	0.007	1.000	0.002	0.007	0.001
18	$d^2(x_j, X_{2,24})$	0.170	0.030	1.000	0.377	0.377	0.212	0.371	0.377	0.739	0.878	0.000	0.216	0.884	0.377	0.803
19	$d^2(x_j, X_{3,1})$	0.008	0.282	0.122	0.043	0.009	0.038	0.004	1.000	0.007	0.000	0.001	0.000	0.003	0.013	0.004
20	$d^2(x_j, X_{3,3})$	0.750	0.729	0.362	0.806	0.524	0.746	0.000	0.060	0.006	1.000	0.101	0.144	0.322	0.904	0.894
21	$d^2(x_j, X_{3,7})$	0.100	0.000	0.115	0.062	0.014	0.202	0.150	0.289	0.010	1.000	0.289	0.415	0.000	0.115	0.001
22	$d^2(x_j, X_{3,12})$	0.000	0.000	0.060	0.000	0.001	0.281	0.061	0.158	0.173	1.000	0.848	0.688	0.416	0.315	0.497
23	$d^2(x_j, X_{3,18})$	0.147	0.063	0.043	0.434	1.000	1.000	0.277	1.000	1.000	0.901	0.000	0.563	0.555	1.000	0.759
24	$d^2(x_j, X_{3,21})$	1.000	0.003	0.216	0.444	0.004	0.279	0.089	0.222	0.209	0.534	0.000	0.509	0.061	0.002	0.222
25	$d^2(x_j, X_{3,22})$	0.004	0.063	0.000	0.036	0.011	0.024	0.012	0.013	0.007	0.008	1.000	0.038	0.015	0.033	0.017

(2) Calculate Euclidean distance between the evaluation cities and the inferior subordinate degree

Substitute the data from Column 5 to Column 6 in Table 4 into Equation (20), and the Euclidean distance $d^2(\boldsymbol{x_1}, \boldsymbol{x^\beta})$ between the subordinate degree vector $\boldsymbol{x_1}$ of Dalian and the inferior subordinate degree $\boldsymbol{x^\beta}$ can be obtained: $d^2(\boldsymbol{x_1}, \boldsymbol{x^\beta}) = \sum_{i=1}^{23} w_i(x_{i1} - x_i^\beta)^2 = 0.027 \times (0.335 - 0)^2 + ... + 0.044 \times (0.064 - 0)^2 = 0.138$. In the same way, we can calculate the Euclidean distances $d^2(\boldsymbol{x_j}, \boldsymbol{x^\beta})$ (j = 2, ..., 15), as shown in the second Row in Table 5.

(3) Calculate Euclidean distance between the evaluation cities and the inferior constraint vector

For example, we select the index "$X_{1,10}$ *Budgetary revenue of local government*" as an inferior constraint. Then we can obtain the inferior constraint vector $x_{S_1} = \{x_{S_{1,1}}\} = \{0\}$. Substitute the data in Table 4 into Equation (22), and the Euclidean distance $d^2(\boldsymbol{x_1}, \boldsymbol{x_{S1}})$ between the subordinate degree vector $\boldsymbol{x_1}$ of Dalian and the inferior constraint vector $\boldsymbol{x_{S1}}$ can be obtained: $d^2(\boldsymbol{x_1}, \boldsymbol{x_{S1}}) = \sum_{i \in S_k} \left(\frac{w_i}{\sum_{i \in S_k} w_i}(x_{i1} - x_{S_{ki}})^2\right) = 1 \times (0.335 - 0)^2 = 0.112$. Likewise, we can calculate the Euclidean distances $d^2(\boldsymbol{x_j}, \boldsymbol{x_{Sk}})$ between the rest of 14 sub-provincial cities subordinate degree vectors and the inferior constraint vector $\boldsymbol{x_{Sk}}$, as shown in Row 3 to Row 25 in Table 5.

(4) Calculate the subordinate degree of green economy evaluation

First, we calculate the subordinate degree and the evaluation rankings without inferior constraint. Take the data $d^2(\boldsymbol{x_1}, \boldsymbol{x^\alpha})$ = 0.710 and $d^2(\boldsymbol{x_1}, \boldsymbol{x^\beta})$ = 0.138 into Equation (26), and the Dalian optimal subordinate degree y_1^α without containing the inferior constraint can be obtained: $y_1^\alpha = \frac{\frac{1}{d^2(x_1, x^\alpha)}}{\frac{1}{d^2(x_1, x^\alpha)} + \frac{1}{d^2(x_1, x^\beta)}} = \frac{\frac{1}{0.710}}{\frac{1}{0.710} + \frac{1}{0.138}} = 0.162$. Smilarly, we can calculate the optimal subordinate degree y_j^α without containing the inferior constraint for the rest of the 14 sub-provincial cities. According to the data of Row 1 in Table 6, we can obtain the corresponding evaluation rankings of 15 sub-provincial cities in a descending order, as shown in Row 2 in Table 6.

Table 6. The subordinate degree and the evaluation rankings of 15 Sub-provincial cities.

(1) No.	(2) Subordinate Degree/Rankings	(3) Dalian	(4) Haerbin	...	(17) Xi'an
1	y_j^α	0.162	0.170	...	0.147
2	Rankings without inferior constraint	11	8	...	12
3	$y_{j\,X_{1,10}}^\alpha$	0.080	0.000	...	0.002
4	Rankings ($y_{j\,X_{1,10}}^\alpha$)	9	15	...	13
...	...	...	...	...	...
47	$y_{j\,X_{3,22}}^\alpha$	0.006	0.056	...	0.021
48	Rankings ($y_{j\,X_{3,22}}^\alpha$)	14	3	...	7

Second, we calculate the subordinate degree and the evaluation rankings containing inferior constraint. Take the data of Row 1 to Row 3 and Column 3 in Table 5 into Equation (25), and the Dalian optimal subordinate degree y_{1S}^α containing the inferior constraint can be obtained: $y_{1S}^\alpha = \frac{\frac{2}{d^2(x_1, x^\alpha)}}{\frac{2}{d^2(x_1, x^\alpha)} + \frac{1}{d^2(x_1, x^\beta)} + \frac{1}{d^2(x_1, x_{S_k})}} = \frac{\frac{2}{0.710}}{\frac{2}{0.710} + \frac{1}{0.138} + \frac{1}{0.112}} = 0.080$. In the same way, we can calculate the optimal subordinate degree y_{jS}^α containing the inferior constraint for the rest of the 14 sub-provincial cities under 23 different inferior constraints, as shown in Row 3, Row 5, ..., and Row 45 in Table 6. According to the data in Table 6, we can obtain the corresponding evaluation rankings of 15 sub-provincial cities under 23 different inferior constraints in a descending order, as shown in Row 4, Row 6, ..., and Row 48 in Table 6.

3.3.3. Extract the Common Key Factors of Sub-Provincial Cities' Green Economy Development

On the basis of the evaluation rankings' data from Row 2 and Row 4 in Table 6, the rankings' differences d^* of 15 sub-provincial cities' evaluation rankings under inferior constraint $X_{1,10}$ can be calculated: $d^*(X_{1,10}) = |9 - 11| + |15 - 8| + \ldots + |13 - 12| = 32$. Similarly, we can calculate the rankings' differences d^* of 15 sub-provincial cities containing the rest of 22 inferior constraints, as shown in Column 3 and Column 6 in Table 7.

Table 7. The rankings' differences of green economy development with and without inferior constraint.

(1) No.	(2) Inferior Constraint	(3) Ranking Difference d^*	(4) No.	(5) Inferior Constraint	(6) Ranking Difference d^*
1	$X_{1,10}$	32	13	$X_{2,14}$	70
2	$X_{1,12}$	52	14	$X_{2,16}$	58
3	$X_{1,13}$	44	15	$X_{2,22}$	46
4	$X_{1,20}$	62	16	$X_{2,24}$	42
5	$X_{1,22}$	64	17	$X_{3,1}$	76
6	$X_{1,24}$	66	18	$X_{3,3}$	54
7	$X_{1,28}$	52	19	$X_{3,7}$	44
8	$X_{1,31}$	28	20	$X_{3,12}$	42
9	$X_{1,32}$	42	21	$X_{3,18}$	60
10	$X_{2,1}$	48	22	$X_{3,21}$	54
11	$X_{2,7}$	60	23	$X_{3,22}$	68
12	$X_{2,9}$	74	—	—	—

Known from Column 3 and Column 6 in Table 7, the 23 indices have different effects on green economy evaluation of sub-provincial cities. The maximal rankings' differences d^* equals 76, and the minimal rankings' differences d^* equals 28. Divide the 23 rankings' differences d^* into five categories. The classification results are illustrated in Table 8. From Table 8, the six indices corresponding to the first classification are the most important factors, *i.e.*, the common key factors. They have the greatest influence on the sub-provincial cities' green economy development.

Table 8. Common key factors of sub-provincial cities' green economy development.

(1) No.	(2) Categories	(3) Factors/Indices
1	The first classification	$X_{1,22}$ Freight turnover, $X_{1,24}$ Added value of the logistics industry, $X_{2,9}$ The average annual growth rate of rural residents per capita net income, $X_{2,14}$ Number of doctors (10,000 persons), $X_{3,1}$ Protection area of cultivated land, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants
2	The second classification	$X_{1,20}$ Freight volume, $X_{2,7}$ Urban households per capita consumption expenditure, $X_{2,16}$ The ratio of government expenditure on education to general budget expenditure, $X_{3,18}$ Fairly good air quality day
3	The third classification	$X_{1,12}$ Total investment in fixed assets, $X_{1,28}$ The ratio of the added value of the tertiary industry to GDP, $X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size, $X_{3,21}$ Ammonia and nitrogen emissions of major pollutants
4	The fourth classification	$X_{1,13}$ Total foreign trade value, $X_{1,32}$ The ratio of county economic aggregate to GDP, $X_{2,1}$ Census register population, $X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District), $X_{2,24}$ Urban per capita housing area, $X_{3,7}$ Public green space per capita, $X_{3,12}$ Industrial soot emissions
5	The fifth classification	$X_{1,10}$ Budgetary revenue of local government, $X_{1,31}$ The ratio of private economic value added to GDP

3.3.4. Select Advantageous and Disadvantageous Factors of Sub-Provincial Cities' Green Economy Development

According to the evaluation rankings' data from Row 2 and Row 4 in Table 6, the ranking difference $d_{\text{Dalian}}(X_{1,10})$ under inferior constraint $X_{1,10}$ can be obtained: $d_{\text{Dalian}}(X_{1,10}) = 9 - 11 = -2$. Similarly, we can calculate the rankings' differences $d_j(X_i)$ of 15 sub-provincial cities containing the 23 inferior constraints, as shown in Table 9.

Table 9. Ranking difference $rank_{\text{inferior}}$-$rank_{\text{non-inferior}}$ for 15 sub-provincial cities' green economy development.

(1) No.	(2) Index	(3) Dalian	(4) Haerbin	(5) Changchun	(6) Shenyang	(7) Jinan	(8) Qiangdao	(9) Nanjing	(10) Hangzhou	(11) Ningbo	(12) Xiamen	(13) Guangzhou	(14) Shenzhen	(15) Wuhan	(16) Chengdu	(17) Xi'an
1	$X_{1,10}$	−2	7	2	−4	0	4	−1	1	−5	1	−1	−1	0	−2	1
2	$X_{1,12}$	−4	0	1	−3	0	−2	−3	2	2	10	−2	11	−4	−5	−3
3	$X_{1,13}$	−4	6	9	−2	1	−2	−5	2	−6	0	−1	−1	4	−1	0
4	$X_{1,20}$	−3	−2	0	−1	−1	6	−8	7	0	10	−1	8	−4	−3	−8
5	$X_{1,22}$	**−9**	7	5	−2	−4	1	−10	10	−1	6	−2	3	−3	−1	0
6	$X_{1,24}$	1	6	9	0	−6	−3	−7	3	−5	6	−2	7	−5	−5	1
7	$X_{1,28}$	**4**	−4	13	−3	−4	1	−4	−1	4	0	−2	0	4	−2	−6
8	$X_{1,31}$	0	−2	0	−1	−1	−1	−1	0	−1	10	−1	1	3	−3	−3
9	$X_{1,32}$	−1	−4	0	−3	−3	1	1	5	−4	−2	12	0	1	−4	1
10	$X_{2,1}$	−1	−2	1	−3	−1	−2	−2	1	0	10	−2	12	0	−7	−4
11	$X_{2,7}$	−2	7	13	−4	−4	2	−7	0	−4	−2	−2	0	5	3	−5
12	$X_{2,9}$	0	−7	11	−5	−7	0	−4	11	4	3	2	2	−4	4	−10
13	$X_{2,14}$	−4	7	9	−2	−5	0	−5	7	−4	−3	−2	10	−3	−7	2
14	$X_{2,16}$	2	−3	0	−3	−5	−3	−3	−2	−2	9	1	9	8	−2	−6
15	$X_{2,22}$	−4	5	11	0	−3	2	1	2	−5	−3	0	−1	2	−5	−2
16	$X_{2,24}$	−1	6	0	−2	−2	3	−2	0	−3	−2	12	0	−2	−2	−5
17	$X_{3,1}$	−3	−5	1	−10	−7	−2	−2	−3	0	10	10	12	5	−4	−2
18	$X_{3,3}$	−4	−2	0	−4	−2	−3	2	9	5	−3	7	2	2	−5	−4
19	$X_{3,7}$	−3	7	4	−5	−3	0	−4	0	3	−2	−1	−1	7	−3	1
20	$X_{3,12}$	2	6	9	0	−2	−2	−2	4	0	−2	−2	0	−2	−4	−5
21	$X_{3,18}$	−2	6	12	−3	−4	−2	−2	−2	−4	−2	12	−1	0	−4	−4
22	$X_{3,21}$	**−7**	5	1	−6	−2	−1	−2	2	−2	−2	12	−1	3	4	−4
23	$X_{3,22}$	**3**	−5	14	−9	−3	−1	−3	5	4	7	−2	0	1	−6	−5

We put the numbers in a descending order for each sub-provincial city by combining the data from Table 9. The indices corresponding to the maximal value and the second largest value are the most important advantageous factors of green economy development, labeled as "++". The indices corresponding to the minimal value and the second smallest value are the most important disadvantageous factors of green economy development, labeled as "--". Take Dalian as an example. Known from the third Column in Table 9, the maximal value of ranking difference $rank_{\text{inferior}} - rank_{\text{non-inferior}}$ equals 4, and the second largest value of ranking difference $rank_{\text{inferior}} - rank_{\text{non-inferior}}$ equals 3. The two corresponding indices $X_{1,28}$ and $X_{3,22}$ are the most important advantageous factors for Dalian green economy development, labeled as "++". Similarly, we can obtain two indices $X_{1,22}$ and $X_{3,21,}$ the most important disadvantageous factors for Dalian green economy development, labeled as "--", as shown in Table 10. It means that Dalian municipal government can improve its green economy development by raising "$X_{1,22}$ *Freight turnover*" and lowering "$X_{3,21}$ *Ammonia and nitrogen emissions of major pollutants*". In the same way, we can obtain the most important advantageous factors and the most important disadvantageous factors for the 15 sub-provincial cities, as shown in Table 11.

Table 10. The key labels for sub-provincial cities' green economy development.

(1) No.	(2) Index	(3) Dalian	(4) Haerbin	(5) Changchun	(6) Shenyang	(7) Jinan	(8) Qiangdao	(9) Nanjing	(10) Hangzhou	(11) Ningbo	(12) Xiamen	(13) Guangzhou	(14) Shenzhen	(15) Wuhan	(16) Chengdu	(17) Xi'an
1	$X_{1,10}$		++				++			--			--			
2	$X_{1,12}$										++	--		--		
3	$X_{1,13}$					++				--			--			
4	$X_{1,20}$						++	--			++			--		--
5	$X_{1,22}$	--	++					--	++			–				
6	$X_{1,24}$					--	--	--		--		--		--		
7	$X_{1,28}$	**++**		++						++		--				
8	$X_{1,31}$										++					
9	$X_{1,32}$							++				++				
10	$X_{2,1}$										++		++		--	
11	$X_{2,7}$		++	++				--				--				
12	$X_{2,9}$		--		--	--			++	++				--	++	--
13	$X_{2,14}$		++								--	--			--	++
14	$X_{2,16}$						--							++		
15	$X_{2,22}$							++		--	--		--			
16	$X_{2,24}$											++				
17	$X_{3,1}$		--		--	--			--		++		++			
18	$X_{3,3}$						--	++	++	++	--					
19	$X_{3,7}$		++		--								--	++		
20	$X_{3,12}$											--				
21	$X_{3,18}$											++	--			
22	$X_{3,21}$	--			--							++	--		++	
23	$X_{3,22}$	**++**	--	++	--					++		--				

Table 11. The advantage and disadvantage of 15 sub-provincial cities' green economy development.

(1) No.	(2) City	(3) The Advantage Factors	(4) The Disadvantage Factors
1	Dalian	$X_{1,28}$ The ratio of the added value of the tertiary industry to GDP, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants	$X_{1,22}$ Freight turnover, $X_{3,21}$ Ammonia and nitrogen emissions of major pollutants
2	Haerbin	$X_{1,10}$ Budgetary revenue of local government, $X_{1,22}$ Freight turnover, $X_{2,7}$ Urban households per capita consumption expenditure, $X_{2,14}$ Number of doctors (10,000 persons), $X_{3,7}$ Public green space per capita	$X_{2,9}$ The average annual growth rate of rural residents capita net income, $X_{3,1}$ Protection area of cultivated land, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants
...	...	...	...
15	Xi'an	$X_{2,14}$ Number of doctors (10,000 persons)	$X_{1,20}$ Freight volume, $X_{2,9}$ The average annual growth rate of rural residents capita net income

4. Conclusions and Policy Implications

In order to help the authorities to make or adjust corresponding green economic development policies, we conduct the city green economy evaluation. First of all, this paper creates an index reduction model by using R cluster analysis to delete the repeated information indices and utilizing coefficient of variation to screen indices which have the greatest influence on city green economy evaluation. Secondly, on the basis of the nonlinear weighted by utilizing entropy weight method, a city green economy evaluation model based on inferior constraint is established. Thirdly, the cities' green economy evaluation rankings under inferior constraints and non-inferior constraints are obtained. By comparing the differences between evaluation rankings under inferior constraints and non-inferior constraints, we extract the advantageous factors and the disadvantageous factors of cities green economy development. The proposed model is verified by the data from 15 sub-provincial cities in China. Empirical analysis results are provided below. (1) The proposed approach can accurately find out the advantageous factors and the disadvantageous factors for each sub-provincial city; (2) The established green economy evaluation index system reflects 95.01% of original information by 28.05% of initial indicators, which includes 23 indices, such as "$X_{1,28}$ *The ratio of the added value of the tertiary industry to GDP*", "$X_{2,24}$ *Urban per capita housing area*" and "$X_{3,7}$ *Public green space per capita*"; (3) In the evaluation of green economy development, the order of importance of the three criterion layers is X_1 *Economy development* > X_2 *Social livelihood of the people* > X_3 *Resources and environment*; (4) The six indices of $X_{1,22}$ *Freight turnover*, $X_{1,24}$ *Added value of the logistics industry*, $X_{2,9}$ *The average annual growth rate of rural residents per capita net income*, $X_{2,14}$ *Number of doctors (10,000 persons)*, $X_{3,1}$ *Protection area of cultivated land* and $X_{3,22}$ *Reduction of chemical oxygen demand emissions of main pollutants* have the greatest influence on the green economy development of sub-provincial city.

The contributions of this paper lie in three aspects. First, the evaluation of the green economy of cities from the economy, society, environment, and resource perspective, instead of a more traditional economy development perspective, seems to offer a new insight into the green economy of the cities. Second, this paper builds an index system, which is suitable for city green economy development. Third, our research not only has practical significance for developing green economy in the 15 sub-provincial cities in China, but also provides a reference for development of green economy in other cities in the world.

Policy implications derived from the empirical findings are provided as follows. (1) The central government should establish the performance evaluation system for sub-provincial cities' green economic development. In this evaluation system, economy, society, environment, resources and some other relevant factors must be involved; (2) Due to the fact that different sub-provincial cities have different advantage and disadvantage factors in green economy development, local governments should implement differential, reasonable policies based on the bottleneck factors and advantage factors; (3) In order to locate the bottleneck factors and adjust the corresponding green economic development policies timely, local governments should conduct the dynamic performance evaluation of green economy development.

Although some results and insights have been gathered from this exploratory study, there are some limitations and room for further investigation. For our case, only empirical related data of the 15 sub-provincial cities of China are utilized. Policy and implications are derived from the analysis results, which may not be generalized enough for all cities in China. When investigating sustainability issues, there are also concerns about more relevant data. In addition, some new variables such as green innovation, green policy, global resource limits, climate change can be taken into consideration. Generalizing this technique to incorporate additional characteristic indicators is not too difficult and researchers can easily extract the impacts of these additional characteristic indicators through cases and empirical studies.

Acknowledgments: The research was supported by National Natural Science Foundation of China (No. 71503199, 71471027, 71403215 and 71373207), National Social Science Foundation of China (No. 15BJY153), Project Funded by China Postdoctoral Science Foundation (the Special Fund Project and the Project of No. 2015M572608), Basic Business Project of Humanities Social Sciences for Central University (No. 2015RWYB09), the Natural Science Basic Research Project in Shaanxi Province (No. 2016JQ7005), Shaanxi Province Postdoctoral Science Foundation Funded Project. We thank the organizations mentioned above. In addition, we thank the three anonymous reviewers for their valuable suggestions.

Author Contributions: Baofeng Shi and Hufeng Yang conceived and designed the experiments; Baofeng Shi and Jingxu Zhao performed the experiments; Baofeng Shi performed the experiments; Baofeng Shi and Jing Wang contributed analysis tools; Baofeng Shi and Jingxu Zhao wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix

Table A1. The characteristic of indices for city green economy evaluation.

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Explanation
1	X_1 Economic development	X'_1 Economic growth	$X_{1,1}$ Gross domestic product (GDP)	Gross domestic product is the sum of added values of all industries in a specific area. It is used to estimate the economic performance of a region.
2			$X_{1,2}$ Per capita GDP	Per capita GDP is the ratio of GDP to the total population, and it measures the standard of living in local areas and reveals the economic development level during a year.
3			$X_{1,3}$ Average growth rate of GDP per annum	The index is the average growth rate of GDP beyond one-year period in the whole city, it is a dynamic indicator that reveals the change in the level of economic development in a given period.
4			$X_{1,4}$ Government revenue	The government revenue is the money income made by the government, including the central government, in a given period. It is one of the main ways that the government can achieve its aim of economic policies and provide public products and services.
5			$X_{1,5}$ Value added of the primary sector	The value added of the primary sector is the added value of products that are made by agriculture, forestry, animal husbandry and fishery industry. It is the foundation of the national economy.
6			$X_{1,6}$ Value added of the second sector	The value added of the second sector is the added value of building industry, mining industry, manufacturing and electricity industry. It plays an important role in economic growth.
7			$X_{1,7}$ Value added of the tertiary sector	The value added of the tertiary sector is the added value of service industry. It is the foundation of the national economy. It is an important part of economic growth during Chinese economic green transformation period.
8			$X_{1,8}$ Industrial value added	The industrial value added is the achievement of industrial production in monetary terms in the reporting period. It reflects the development status of the second industry.
9			$X_{1,9}$ Value added of the construction industry	The value added of the construction industry is the achievement of construction production and business activities in monetary terms in the reporting period. It indicates the development of the second industry.
10			$X_{1,10}$ Budgetary revenue of local government	The budgetary revenue of local government is a kind of budget management funds that is dominated by the government. It can help to organize and coordinate economic activities, and complete set economic goals effectively.
11			$X_{1,11}$ Sales value in wholesale and retail sale trade	The sales value in wholesale and retail sale trade is the total amount of goods that are sold to outside enterprises and individuals. It reflects the development of the tertiary sector.
12			$X_{1,12}$ Total investment in fixed assets	The total investment in fixed assets is the construction and purchase workload of fixed assets in currencies. It is a comprehensive index that can reflect the scale, speed and other factors of investment in fixed assets.
13			$X_{1,13}$ Total foreign trade value	The total foreign trade value is the sum of the value of foreign merchandise trade and the value of trade commercial services. It is an important economic indicator that can measure the foreign trade situation of a country or a region.

Table A1. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Explanation
14	X_1 Economic development	X'_1 Economic growth	$X_{1,14}$ Value of export	The value of export is the total amount of shipping in the goods and services out of the jurisdiction of a country. It is an important economic indicator that can measure the foreign trade situation of a country or a region.
15			$X_{1,15}$ Total retail sales of consumer goods	The total retail sales of consumer goods is the amount of retail sales of wholesale, retail trade, accommodation and catering industry and other industries directly sold to urban and rural residents and social group. It reflects the improvement of people's living standards in a certain period.
16			$X_{1,16}$ Foreign investment in actual use	The foreign investment in actual use is the actual arrival of foreign funds after signing the contract between China and a foreign country. It reflects the level of utilization of foreign investment in China.
17			$X_{1,17}$ Gross industrial output value of enterprises above designated size	The gross industrial output value of enterprises above designated size is the gross value of industrial corporate enterprises whose main business income reached 2000 million Yuan. It reflects the structure of industrial output value.
18			$X_{1,18}$ Balance of loans and deposit in RMB and foreign currencies in financial institutions	The index is the sum of the balance of deposits and loans in local and foreign currencies in financial institutions. It is the sum of a bank's assets and liabilities. It reflects the money supply in the green economic development.
19			$X_{1,19}$ Balance of loans in RMB and foreign currencies in financial institutions	The balance of loans in RMB and foreign currencies in financial institutions is the loan in local and foreign currencies that the borrower has not yet returned to the lender. It reflects banks' asset condition under the background of current economic development.
20			$X_{1,20}$ Freight volume	The freight volume is the actual shipping quantities of goods in transportation enterprises in a certain period. It reflects the contribution degree of transportation enterprises to the city economic development.
21			$X_{1,21}$ Airport passenger throughput	The airport passenger throughput is the number of passengers who buy tickets into and out of a certain region within one year. It indicates the development of the tertiary industry indirectly.
22			$X_{1,22}$ Freight turnover	The freight turnover is the total freight traffic that is calculated by the combination of actually completed freight and traffic distance and achieved by different kinds of transport tools. It reflects the transportation and production achievements comprehensively.
23			$X_{1,23}$ Value added of the financial industry	The value added of the financial industry is the final achievement that is calculated in market prices and made by a city's resident units who engage in financial production activities in a certain period. It indicates the development status of financial industry in the economic activity.
24			$X_{1,24}$ Added value of the logistics industry	Added value of the logistics industry is the final achievement of logistics activities made by logistics industry in monetary measures. Statistics from the National Development and Reform Commission show that logistics industrial has become one of the pillar industries in economic development [34]. This index reflects the contribution degree of the logistics industry to Chinese sub-provincial city economic development.
25		X''_1 Economic structure	$X_{1,25}$ The ratio of the added value of the primary sector to GDP	The ratio of the added value of the primary sector to GDP is the ratio of the added value of products that are made by the nature to GDP. It reflects the economic structure changes in a region in economic transformation and upgrading period.

Table A1. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Explanation
26	X_1 Economic development	X''_1 Economic structure	$X_{1,26}$ Consumer price index (CPI)	A consumer price index (CPI) measures the changes in the price level of a market basket of consumer goods and services purchased by households. It is an important index to observe regional inflation in the transformation of economic structure.
27			$X_{1,27}$ The ratio of industrial added value to GDP	The index is the ratio of the achievement of industrial production in monetary terms in the reporting period to GDP. It also reflects the economic structure changes in a region in economic transformation and upgrading period.
28			$X_{1,28}$ The ratio of the added value of the tertiary industry to GDP	The ratio of the added value of the tertiary industry to GDP is the ratio of the added value of service industry to GDP. It indicates the economic structure changes in a region in economic transformation and upgrading period.
29			$X_{1,29}$ Urbanization rate	The urbanization rate is the ratio of people in cities and towns to the total population. It not only reflects the process of aggregation of people shifting from rural to urban areas, but also indicates the intensive degree of economic development in economic structure transformation and upgrading period [43].
30			$X_{1,30}$ The ratio of the third industry practitioners to the proportion of all employees	The ratio of the third industry practitioners to the proportion of all employees is the ratio of people who engage in the service industry to the total employees. It reflects the employment structure in regional economic development.
31			$X_{1,31}$ The ratio of private economic value added to GDP	The ratio of private economic value added to GDP is the ratio of the price of the product and service minus the cost of producing in the private sector to GDP. It indicates the contribution degree of private economy to the regional economy development.
32			$X_{1,32}$ The ratio of county economic aggregate to GDP	The ratio of county economic aggregate to GDP is the ratio of the price of the product and service in the county economic sector to GDP. It reflects the development of the county economic sector.
33			$X_{1,33}$ The ratio of value added of financial industry to GDP	The index is the ratio of the final achievement that is calculated in market prices and made by a country's resident units who engage in financial production activities in a certain period to GDP. It indicates the contribution degree of financial industry to the regional economy development.
34			$X_{1,34}$ The ratio of logistics industry added value to GDP	The ratio of logistics industry added value to GDP is the ratio of the final achievement of logistics activities made by logistics industry in currencies to GDP. It reflects the contribution degree of the logistics industry to Chinese sub-provincial city economic development.
35	X_2 Social livelihood of the people	X'_2 People's livelihood improvement	$X_{2,1}$ Census register population	The census register population is the total amount of citizens who have registered in the public household management authority in their habitual residence. The index reflects the population bearing capacity in the region during the sustainable development.
36			$X_{2,2}$ Natural population growth rate	The natural population growth rate is the ratio of the natural population increase to the average number of population in a given period. It shows the degree and the trend of the population growth.
37			$X_{2,3}$ Registered unemployment rate in cities and towns	The registered unemployment rate in cities and towns is the ratio of the amount of registered urban unemployment population to the labor force in the end of the reporting period. It is the main index to evaluate the employment status of a city.

Table A1. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Explanation
38	X_2 Social livelihood of the people	X'_2 People's livelihood improvement	$X_{2,4}$ Annual new employment in cities and towns	The annual new employment in cities and towns is the newly employed people in a year in cities and towns. It reflects the employment improvement situation of a region.
39			$X_{2,5}$ Per capita disposable annual income of urban households	The per capita disposable annual income of urban households is the average of a person's total personal income minus personal current taxes in towns and cities. It reflects the urban residents' income level.
40			$X_{2,6}$ Per capita annual net income of rural households	The per capita annual net income of rural households is the average of a person's income minus the cost of earning money in all kinds of sources in rural areas. It reflects the income level in rural areas.
41			$X_{2,7}$ Urban households per capita consumption expenditure	The urban households per capita consumption expenditure is the cost of living in cities and towns, including the cost of buying products and services. It is used to evaluate the urban residents' living standards.
42			$X_{2,8}$ The average annual growth rate of per capita disposable income of urban households	The index is the average growth rate of people's total personal income minus personal current taxes in cities. It reflects the urban residents' income growth level in a certain period.
43			$X_{2,9}$ The average annual growth rate of per capita net income of rural households	The average annual growth rate of per capita net income of rural households is the average annual growth rate of a person's income minus the cost of earning money in all kinds of sources in rural areas. It reflects the income growth level in rural areas.
44			$X_{2,10}$ Number of basic endowment insurance urban contributors	The index indicates the government's financial support in improving residents' health care situation and basic medical conditions.
45			$X_{2,11}$ Number of basic medical insurance urban contributors	The five indices reflect the government's financial support in improving residents' health care situation and basic medical conditions.
46			$X_{2,12}$ Number of basic medical insurance urban residents contributors	
47			$X_{2,13}$ Number of basic medical insurance urban staff contributors	
48			$X_{2,14}$ Number of doctors (10000 persons)	
49			$X_{2,15}$ Number of beds in hospitals (10000 units)	
50		X''_2 Social undertakings	$X_{2,16}$ The ratio of government expenditure on education to general budget expenditure	The ratio of government expenditure on education to general budget expenditure is the ratio of the actual cost spent on education in the budget management made by the government on the general budget expenditure. It reflects the government's financial support for education.

Table A1. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Explanation
51	X_2 Social livelihood of the people	X''_2 Social undertakings	$X_{2,17}$ Number of books in public libraries per capita	The index is the average amount of books owned by every individual from the libraries supported by the government. It shows a regional emphasis on education.
52			$X_{2,18}$ The number of movie theaters (municipal districts)	The number of movie theaters is the total number of cinemas and theatres in municipal districts. It reflects the richness of people's material and cultural life and reveals the improvement of social undertakings.
53			$X_{2,19}$ Gross enrollment rate of high school	The gross enrollment rate of high school is the ratio of children who have enrolled in schools on the total number of the school-age children. It reveals the popularity of primary education.
54			$X_{2,20}$ Gross enrollment rate of high school	The gross enrollment rate of high school is the ratio of high school students who have enrolled in schools on the total number of the high school age students. It is the essential index to measure the educational development level.
55			$X_{2,21}$ Acceptance rate of foodstuffs sample survey	The acceptance rate of foodstuffs sample survey is the ratio of food selected and examined by the government on the total amount of food in the production. It shows that the government lays emphasis on food safety.
56			$X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District)	Number of public transportation vehicles per 10,000 persons (District), it reveals the public transportation development.
57			$X_{2,23}$ Daily supply of tap water	The daily supply of tap water is the capacity of daily water supply by the government. It reflects the basic infrastructure's operation ability and the guarantee capability.
58			$X_{2,24}$ Urban per capita housing area	The urban per capita housing area is the ratio of residential building areas on the resident population. It reflects people's daily living conditions.
59			$X_{2,25}$ Completed construction area	The completed construction area is the urban area where there are infrastructures, or is being developed. The index indirectly reflects the convenience degree of the city town facilities.
60	X_3 Resources and environment	X'_3 Resource carrying	$X_{3,1}$ Protection area of cultivated land	The index is the total amount of arable land in certain areas. It reflects the bearing capacity of land resources in economic development.
61			$X_{3,2}$ Coal consumption	The coal consumption is the consumption of coal for the use of production and life in a region in a given period. It indirectly reveals the impact of energy consumption on urban green economic development.
62			$X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size	The comprehensive energy consumption of industrial enterprises above designated size is the total amount of energy consumption of industrial enterprises whose main business income reached 2000 million Yuan. It reflects the resource carrying capacity in city's economic development.
63			$X_{3,4}$ Energy consumption elasticity coefficient	The energy consumption elasticity coefficient is the ratio of the growth of energy consumption on the growth of GDP. The index is used to evaluate city energy consumption and energy savings status.
64			$X_{3,5}$ Forest coverage rate	The index refers to a city forest area accounts for the percentage of land area. It reflects the bearing capacity of forest resources in green economic development.
65			$X_{3,6}$ Coverage rate of green area in completed construction area	This index is the percentage of green coverage area in completed construction area. It reveals the ecological carrying capacity in green economy development.

Table A1. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Explanation
66	X_3 Resources and environment	X'_3 Resource carrying	$X_{3,7}$ Public green space per capita	The index is the average of public green areas owned by urban non-agricultural population. It is used to assess the population bearing capacity in terms of city sustainable development.
67			$X_{3,8}$ The ratio of water consumption to industrial added value	The index is the ratio of water consumption on the achievement of industrial production in monetary measures in the reporting period. It is used to assess the resource usage efficiency according to efficiency and water-savings.
68			$X_{3,9}$ Oil consumption of industrial enterprises above designated size	The index is the total amount of oil consumption of industrial corporate enterprises whose main business income reached 2000 million Yuan. It reveals the city energy consumption and energy savings status indirectly.
69		X''_3 Environmental quality	$X_{3,10}$ Nitrogen dioxide content in air	The two indices are used to assess the influence of waste gas emissions on the city environment.
70			$X_{3,11}$ Reduction of NO_2 emission for per unit of GDP	
71			$X_{3,12}$ Industrial soot emissions	The index is developed to measure urban solid waste emissions in economic development.
72			$X_{3,13}$ Emission reduction of main pollutants SO_2	The index reflects the impact of industrial pollution treatment efficiency on city environment.
73			$X_{3,14}$ Treatment rate of living waste water	The two indices are used to describe city water consumption and sewage recycling utilization status.
74			$X_{3,15}$ Main water pollutants discharge reduction	
75			$X_{3,16}$ Urban wastewater discharge	The index is used to evaluate city water consumption and sewage recycling utilization status.
76			$X_{3,17}$ Decontamination rate of urban refuse	The index is designed to evaluate urban solid waste recycling efficiency.
77			$X_{3,18}$ Fairly good air quality day	The index is used to evaluate the city air quality.
78			$X_{3,19}$ Comprehensive use of industrial solid wastes	The index is used to evaluate urban industrial solid wastes usage efficiency.
79			$X_{3,20}$ Chemical oxygen demand emissions of major pollutants	The four indices are used to evaluate the impact of waste gas emissions on the city environment.
80			$X_{3,21}$ Ammonia and nitrogen emissions of major pollutants	
81			$X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants	
82			$X_{3,23}$ Reduction of ammonia and nitrogen emissions of main pollutants	

Table A2. Indices reduction process of green economy evaluation.

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Indices	(5) Unit	(6) Index type	(7) Reduction Result
1	X_1 Economic development	X'_1 Economic growth	$X_{1,1}$ Gross domestic product (GDP)	Hundred million yuan	Positive	Deleted by coefficient of variation
2			$X_{1,2}$ Per capita GDP	Yuan	Positive	Deleted by coefficient of variation
3			$X_{1,3}$ Average growth rate of GDP per annum	%	Positive	Deleted by coefficient of variation
4			$X_{1,4}$ Government revenue	Hundred million yuan	Positive	Deleted by coefficient of variation
5			$X_{1,5}$ Value added of the primary sector	Hundred million yuan	Positive	Deleted by coefficient of variation
6			$X_{1,6}$ Value added of the second sector	Hundred million yuan	Positive	Deleted by coefficient of variation
7			$X_{1,7}$ Value added of the tertiary sector	Hundred million yuan	Positive	Deleted by coefficient of variation
8			$X_{1,8}$ Industrial value added	Hundred million yuan	Positive	Deleted by coefficient of variation
9			$X_{1,9}$ Value added of the construction industry	Hundred million yuan	Positive	Deleted by coefficient of variation
10			$X_{1,10}$ Budgetary revenue of local government	Hundred million yuan	Positive	Retained
11			$X_{1,11}$ Sales value in wholesale and retail sale trade	Ten thousand yuan	Positive	Deleted by coefficient of variation
12			$X_{1,12}$ Total investment in fixed assets	Hundred million yuan	Positive	Retained
13			$X_{1,13}$ Total foreign trade value	Hundred million dollar	Positive	Retained
14			$X_{1,14}$ Value of export	Hundred million dollar	Positive	Deleted by coefficient of variation
15			$X_{1,15}$ Total retail sales of consumer goods	Hundred million yuan	Positive	Deleted by coefficient of variation
16			$X_{1,16}$ Foreign investment in actual use	Ten thousand dollar	Positive	Deleted by coefficient of variation
17			$X_{1,17}$ Gross industrial output value of enterprises above designated size	Ten thousand yuan	Positive	Deleted by coefficient of variation
18			$X_{1,18}$ Balance of loans and deposit in RMB and foreign currencies in financial institutions	Ten thousand yuan	Positive	Deleted by coefficient of variation
19			$X_{1,19}$ Balance of loans in RMB and foreign currencies in financial institutions	Ten thousand yuan	Positive	Deleted by coefficient of variation
20			$X_{1,20}$ Freight volume	Ten thousand tons	Positive	Retained
21			$X_{1,21}$ Airport passenger throughput	Ten thousand person-times	Positive	Deleted by coefficient of variation
22			$X_{1,22}$ Freight turnover	Hundred million ton-km	Positive	Retained
23			$X_{1,23}$ Value added of the financial industry	Hundred million yuan	Positive	Deleted by coefficient of variation
24			$X_{1,24}$ Added value of the logistics industry	Hundred million yuan	Positive	Retained
25		X''_1 Economic structure	$X_{1,25}$ The ratio of the added value of the primary sector to GDP	%	Moderate (4%)	Deleted by coefficient of variation
26			$X_{1,26}$ Consumer price index (CPI)	%	Interval [101, 105]	Deleted by coefficient of variation
27			$X_{1,27}$ The ratio of industrial added value to GDP	%	Moderate (21%)	Deleted by coefficient of variation
28			$X_{1,28}$ The ratio of the added value of the tertiary industry to GDP	%	Moderate (64%)	Retained
29			$X_{1,29}$ Urbanization rate	%	Moderate (75%)	Deleted by coefficient of variation

Table A2. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Indices	(5) Unit	(6) Index type	(7) Reduction Result
30	X_1 Economic development	X''_1 Economic structure	$X_{1,30}$ The ratio of the third industry practitioners to the proportion of all employees	%	Moderate (80%)	Deleted by coefficient of variation
31			$X_{1,31}$ The ratio of private economic value added to GDP	%	Moderate (55%)	Retained
32			$X_{1,32}$ The ratio of county economic aggregate to GDP	%	Moderate (35%)	Retained
33			$X_{1,33}$ The ratio of value added of financial industry to GDP	%	Moderate (5%)	Deleted by coefficient of variation
34			$X_{1,34}$ The ratio of logistics industry added value to GDP	%	Moderate (12%)	Deleted by coefficient of variation
35	X_2 Social livelihood of the people	X'_2 People's livelihood improvement	$X_{2,1}$ Census register population	Ten thousand persons	Positive	Retained
36			$X_{2,2}$ Natural population growth rate	‰	Moderate (7.2%)	Deleted by coefficient of variation
37			$X_{2,3}$ Registered unemployment rate in cities and towns	%	Negative	Deleted by coefficient of variation
38			$X_{2,4}$ Annual new employment in cities and towns	Ten thousand persons	Positive	Deleted by coefficient of variation
39			$X_{2,5}$ Per capita disposable annual income of urban households	Yuan	Positive	Deleted by coefficient of variation
40			$X_{2,6}$ Per capita annual net income of rural households	Yuan	Positive	Deleted by coefficient of variation
41			$X_{2,7}$ Urban households per capita consumption expenditure	Yuan	Positive	Retained
42			$X_{2,8}$ The average annual growth rate of per capita disposable income of urban households	%	Positive	Deleted by coefficient of variation
43			$X_{2,9}$ The average annual growth rate of rural residents capita net income	%	Positive	Retained
44			$X_{2,10}$ Number of basic endowment insurance urban contributors	Ten thousand persons	Positive	Deleted by coefficient of variation
45			$X_{2,11}$ Number of basic medical insurance urban contributors	Ten thousand persons	Positive	Deleted by coefficient of variation
46			$X_{2,12}$ Number of basic medical insurance urban residents contributors	Ten thousand persons	Positive	Deleted by coefficient of variation
47			$X_{2,13}$ Number of basic medical insurance urban staff contributors	Ten thousand persons	Positive	Deleted by coefficient of variation
48			$X_{2,14}$ Number of doctors (10000 persons)	Person	Positive	Retained
49			$X_{2,15}$ Number of beds in hospitals (10000 units)	——	Positive	Deleted by coefficient of variation
50		X''_2 Social undertakings	$X_{2,16}$ The ratio of government expenditure on education to general budget expenditure	%	Positive	Retained
51			$X_{2,17}$ Number of books in public libraries per capita	Volume/person	Positive	Deleted by coefficient of variation
52			$X_{2,18}$ The number of movie theaters	——	Positive	Deleted by coefficient of variation
53			$X_{2,19}$ Gross enrollment rate of high school	%	Positive	Deleted by coefficient of variation
54			$X_{2,20}$ High school education gross enrollment ratio	%	Positive	Deleted by coefficient of variation
55			$X_{2,21}$ Acceptance rate of foodstuffs sample survey	%	Positive	Deleted by coefficient of variation
56			$X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District)	——	Positive	Retained

Table A2. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Indices	(5) Unit	(6) Index type	(7) Reduction Result
57	X_2 Social livelihood of the people	X''_2 Social undertakings	$X_{2,23}$ Daily supply of tap water	Ten thousand cubic meters	Positive	Deleted by coefficient of variation
58			$X_{2,24}$ Urban per capita housing area	Square meters	Positive	Retained
59			$X_{2,25}$ Completed construction area	Square kilometers	Positive	Deleted by coefficient of variation
60	X_3 Resources and environment	X'_3 Resource carrying	$X_{3,1}$ Protection area of cultivated land	Hectare	Positive	Retained
61			$X_{3,2}$ Coal consumption	Ton	Negative	Deleted by coefficient of variation
62			$X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size	Ton standard coal (Mtce)	Negative	Retained
63			$X_{3,4}$ Energy consumption elasticity coefficient	——	Negative	Deleted by coefficient of variation
64			$X_{3,5}$ Forest coverage rate	%	Positive	Deleted by coefficient of variation
65			$X_{3,6}$ Coverage rate of green area in completed construction area	%	Positive	Deleted by coefficient of variation
66			$X_{3,7}$ Public green space per capita	Square meters	Positive	Retained
67			$X_{3,8}$ The ratio of water consumption to industrial added value	Cubic meters/ten thousand yuan	Negative	Deleted by coefficient of variation
68			$X_{3,9}$Oil consumption of industrial enterprises above designated size	Ton	Negative	Deleted by coefficient of variation
69	X_3 Resources and environment	X''_3 Environmental quality	$X_{3,10}$ Nitrogen dioxide content in air	Milligram/cubic meters	Negative	Deleted by coefficient of variation
70			$X_{3,11}$ Reduction of NO_2 emission for per unit of GDP	%	Positive	Deleted by coefficient of variation
71			$X_{3,12}$ Industrial soot emissions	Ten thousand tons	Negative	Retained
72			$X_{3,13}$ Emission reduction of main pollutants SO_2	%	Positive	Deleted by coefficient of variation
73			$X_{3,14}$ Treatment rate of living waste water	%	Positive	Deleted by coefficient of variation
74			$X_{3,15}$ Main water pollutants discharge reduction	%	Positive	Deleted by coefficient of variation
75			$X_{3,16}$ Urban wastewater discharge	Ten thousand tons	Negative	Deleted by coefficient of variation
76			$X_{3,17}$ Decontamination rate of urban refuse	%	Positive	Retained
77			$X_{3,18}$ Fairly good air quality day	——	Positive	Deleted by coefficient of variation
78			$X_{3,19}$ Comprehensive use of industrial solid wastes	Ten thousand tons	Positive	Deleted by coefficient of variation
79			$X_{3,20}$ Chemical oxygen demand emissions of major pollutants	Ten thousand tons	Negative	Deleted by coefficient of variation
80			$X_{3,21}$ Ammonia and nitrogen emissions of major pollutants	Ton	Negative	Retained
81			$X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants	Ton	Positive	Retained
82			$X_{3,23}$ Reduction of ammonia and nitrogen emissions of main pollutants	Ton	Positive	Deleted by coefficient of variation

Table A3. Original data of green economy evaluation for 15 sub-provincial cities in China.

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Dalian	(6) Haerbin	(7) Changchun	(8) Shenyang	(9) Jinan	(10) Qiangdao	(11) Nanjing	(12) Hangzhou	(13) Ningbo	(14) Xiamen	(15) Guangzhou	(16) Shenzhen	(17) Wuhan	(18) Chengdu	(19) Xi'an
1	X_1 Economic development	X'_1 Economic growth	$X_{1,1}$	7002.80	4550.10	4456.60	6606.80	4812.68	7302.11	7201.57	7803.98	6582.21	2815.17	13,551.21	12,950.08	8003.82	8138.90	4369.37
2			$X_{1,2}$	102,922	45,810	58691	80532	69,574	82,680	88525	88985	114,065	77340	105,909	123,247	79482	57624	51,166
3			$X_{1,3}$	10.30	10.00	12.00	9.96	9.50	10.60	11.70	9.00	7.80	12.10	10.50	10.00	11.40	13.00	11.80
4			$X_{1,4}$	750.11	1175.82	340.80	1175.82	793.68	670.18	1427.25	1627.89	2206.04	739.46	1579.68	1792.99	1397.74	781.00	753.07
5			$X_{1,5}$	451.40	506.80	317.10	315.20	252.92	324.41	184.64	255.93	268.52	25.30	213.76	5.56	301.21	348.10	195.59
6			$X_{1,6}$	3634.80	1638.90	2291.90	3389.10	1938.14	3402.23	3170.78	3626.88	3516.84	1363.85	4720.65	5737.64	3869.56	3790.60	1893.79
7			$X_{1,7}$	2916.70	2404.40	1847.60	2902.50	2621.62	3575.47	3846.15	3921.17	2796.85	1426.02	8616.79	7206.88	3833.05	4000.30	2279.99
8			$X_{1,8}$	3207.40	677.40	1822.30	3304.70	1357.40	3200.00	2748.45	3190.32	3170.07	1100.35	4264.16	5091.42	3064.57	3149.60	1340.75
9			$X_{1,9}$	427.38	510.90	369.40	336.20	335.10	360.92	422.33	436.56	436.90	210.08	456.49	381.79	665.90	641.00	553.04
10			$X_{1,10}$	750.10	354.70	834.52	834.52	380.82	670.18	733.02	859.99	1536.51	834.52	1102.40	1482.08	828.58	834.52	396.96
11			$X_{1,11}$	27,834,492	19,901,121	14,521,662	81,509,462	33,939,510	46,190,644	98,359,119	132,405,716	80,876,623	54,575,084	222,511,826	146,577,769	90,317,488	62,856,720	36,740,584
12			$X_{1,12}$	5624.40	3950.00	3172.90	5625.40	2186.10	4153.90	4683.45	3722.75	2901.43	1332.64	4454.55	2314.43	5890.10	5890.10	4243.43
13			$X_{1,13}$	625.60	53.30	196.80	127.50	91.33	732.08	552.35	616.83	965.70	744.91	1188.88	4667.85	203.54	475.40	130.14
14			$X_{1,14}$	336.90	18.60	29.00	59.70	34.18	408.20	319.01	412.62	614.40	454.00	628.06	2713.70	107.48	303.60	72.99
15			$X_{1,15}$	2224.05	2394.60	1739.64	2802.20	2420.25	2635.62	3103.82	2944.63	2329.26	881.91	6882.85	4008.78	3432.43	3317.67	2263.86
16			$X_{1,16}$	1,235,033	190,000	368,000	580435	122,016	460,027	413,000	496,100	285,000	177,400	457,500	522,900	444,400	859,000	360,300
17			$X_{1,17}$	103,508,193	27,750,000	82,635,000	128,584,000	44,784,067	140,402,764	114,378,000	129,622,800	119,621,000	44,307,900	148,570,900	213,630,500	90,188,800	90,578,200	40,663,100
18			$X_{1,18}$	198,795,000	129,183,000	124,716,000	185,123,000	185,265,600	184,511,700	296,197,500	382,396,700	239,415,000	105,793,500	501,230,900	514,707,400	247,074,300	359,840,000	210,940,000
19			$X_{1,19}$	91,117,000	55,580,000	58,283,000	80,707,000	86,327,600	86,328,400	130,793,200	180,909,000	119,610,000	51,073,500	199,365,200	218,083,400	115,758,400	156,300,000	88,080,400
20			$X_{1,20}$	40,176	11764	3,125,000	21720	26030	29238	41,999	30,200	32600	13,600	76,100	30,335	43,892	39,569	44,900
21			$X_{1,21}$	1334	914	582	1101	766	1260	662	1912	527	1735	4831	2957	1398	3160	2342
22			$X_{1,22}$	7791.70	470.28	1912.20	584.36	1367.50	2064.88	4624.72	456.36	2071.10	941.80	4889.43	1969.89	2910.22	1912.20	595.87
23			$X_{1,23}$	445.40	226.70	153.41	347.60	411.30	226.70	226.70	820.04	502.40	237.03	971.00	1819.19	530.00	741.00	311.61
24			$X_{1,24}$	283.43	283.43	283.43	274.90	341.70	643.00	485.20	394.75	620.00	283.43	1020.00	283.43	815.00	455.00	283.43
25		X''_1 Economic structure	$X_{1,25}$	6.40	11.10	7.10	4.77	5.30	4.40	2.60	3.30	4.10	0.90	1.60	0.04	3.70	4.30	4.50
26			$X_{1,26}$	103.40	103.20	102.30	102.96	102.40	102.70	102.70	102.50	101.70	102.10	103.00	102.80	102.80	103.00	102.80
27			$X_{1,27}$	45.80	24.79	43.14	46.15	33.37	41.65	38.16	40.61	48.16	40.96	31.47	41.36	38.36	38.43	30.43
28			$X_{1,28}$	41.65	52.85	41.46	43.99	54.39	48.97	53.40	50.94	42.49	50.33	63.59	55.65	47.89	49.46	52.42
29			$X_{1,29}$	50.68	47.44	41.18	63.45	57.81	36.33	19.61	50.61	39.14	42.10	0.00	41.18	18.87	47.23	71.51
30			$X_{1,30}$	53.66	47.96	47.96	51.96	47.96	40.21	55.69	44.07	39.19	54.40	53.78	51.58	47.56	43.05	46.12
31			$X_{1,31}$	70.82	54.09	41.09	68.35	44.63	53.30	39.90	59.70	46.73	24.10	39.70	38.30	39.13	58.51	46.73
32			$X_{1,32}$	25.55	33.95	29.64	18.81	24.37	47.96	10.20	20.36	39.97	24.97	8.09	24.97	25.26	28.56	12.47
33			$X_{1,33}$	6.36	4.98	3.44	5.26	8.55	3.10	3.15	10.51	7.63	8.42	7.17	14.05	6.62	9.10	7.13
34			$X_{1,34}$	6.23	6.23	6.23	4.16	7.10	8.81	6.74	5.06	9.50	6.23	7.53	9.88	10.18	5.59	6.23
35	X_2 Social livelihood of the people	X'_2 People's livelihood improvement	$X_{2,1}$	590.30	993.50	756.90	724.80	609.20	769.56	638.48	700.52	577.70	190.90	822.30	287.60	821.70	1173.30	795.98
36			$X_{2,2}$	3.14	−0.50	−2.20	−0.06	3.67	1.57	3.40	3.95	2.10	8.20	6.20	19.80	5.10	0.10	4.56
37			$X_{2,3}$	2.60	3.39	3.78	3.00	3.08	2.93	2.70	1.63	2.55	3.49	2.41	2.40	3.81	2.89	3.49
38			$X_{2,4}$	20.50	12.58	11.30	20.90	22.30	23.10	20.20	24.36	15.20	20.30	33.00	8.40	15.93	21.90	12.42
39			$X_{2,5}$	27,539	22,499	22,970	26,431	32,570	32,145	36,322	37,511	37,902	37,576	38,054	40,742	27,061	27,194	29,982
40			$X_{2,6}$	15,990	11,443	9064	13,045	11,786	13,990	14,786	17,017	18,475	13,455	16,788	13,399	11,190	11,501	11,442
41			$X_{2,7}$	20,417	17,615	17,863	20,002	20,032	20,391	22,446	22,800	23,288	24,922	30,490	26,728	18,813	18,814	21,434
42			$X_{2,8}$	13.40	12.31	12.70	13.34	12.73	12.52	12.80	4.81	11.70	11.95	10.50	11.61	14.00	13.63	15.40
43			$X_{2,9}$	12.51	19.10	12.10	12.70	13.20	13.10	12.80	11.62	11.85	12.80	13.30	13.30	14.00	11.70	15.40
44			$X_{2,10}$	176.30	119.60	177.78	320.73	175.02	303.07	268.88	492.62	474.30	210.46	583.42	792.44	350.59	485.39	241.63
45			$X_{2,11}$	453.10	364.10	403.24	351.22	283.77	359.05	420.36	804.80	430.48	280.66	768.22	556.07	575.47	552.57	413.15
46			$X_{2,12}$	103.27	181.68	245.20	110.82	110.20	181.68	85.99	378.99	181.68	98.34	260.36	181.68	186.15	159.07	181.68
47			$X_{2,13}$	349.83	182.42	158.04	240.40	173.57	177.37	334.37	425.81	248.80	182.32	507.86	374.39	389.32	393.50	231.47
48			$X_{2,14}$	28.60	19.12	24.40	24.64	32.00	28.10	29.97	25.00	33.00	45.39	46.00	23.00	33.00	36.00	23.89
49			$X_{2,15}$	58.70	56.37	55.89	56.65	64.00	61.40	59.26	42.47	49.00	59.25	75.00	25.00	70.00	79.00	44.85
50		X''_2 Social undertakings	$X_{2,16}$	15.37	18.43	18.51	15.58	17.61	18.70	16.24	18.69	17.11	15.34	16.63	15.73	15.11	16.50	18.08
51			$X_{2,17}$	4.04	1.62	2.44	2.42	2.97	1.15	2.74	3.52	2.44	3.22	2.61	9.37	21.87	1.65	0.72
52			$X_{2,18}$	6	59	16	45	17	28	43	43	26	5	34	88	58	13	24
53			$X_{2,19}$	95.70	96.41	99.98	86.40	100.00	100.00	96.41	98.60	99.70	96.41	96.41	100.00	82.93	97.20	99.97
54			$X_{2,20}$	98.00	89.48	76.00	106.40	85.27	70.50	85.27	57.80	99.10	85.27	85.27	75.70	92.77	85.27	99.67

Table A3. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Dalian	(6) Haerbin	(7) Changchun	(8) Shenyang	(9) Jinan	(10) Qiangdao	(11) Nanjing	(12) Hangzhou	(13) Ningbo	(14) Xiamen	(15) Guangzhou	(16) Shenzhen	(17) Wuhan	(18) Chengdu	(19) Xi'an
55			$X_{2,21}$	96.80	94.77	95.50	94.77	87.53	91.50	94.00	97.70	91.10	97.60	95.30	94.20	97.00	99.00	94.77
56	X_2 Social livelihood of the people	X''_2 Social undertakings	$X_{2,22}$	16.62	11.53	12.60	10.02	13.37	14.83	11.28	16.73	17.89	20.39	18.01	103.77	14.38	17.85	13.43
57			$X_{2,23}$	163.00	221.10	118.90	84.04	153.40	106.70	241.80	159.00	608.49	97.90	702.70	692.00	332.11	208.21	190.17
58			$X_{2,24}$	27.30	24.50	34.20	29.67	29.67	27.86	29.61	29.67	32.55	33.46	22.46	27.91	33.50	29.67	32.98
59			$X_{2,25}$	395	383	434	455	363	375	653	453	290	264	1010	863	520	516	375
60			$X_{3,1}$	328,004	1,967,611	1,297,155	771,886	361,077	723,031	238,570	3,701,200	309,450	20,411	99,086	5820.73	203,820	424,102	246,610
61			$X_{3,2}$	19,005,923	18,582,950	1,689,359	28,025,000	1,689,359	16,017,632	28,613,217	13,383,049	40,014,267	4,172,950	1,689,359	4,284,267	9,769,800	6,583,941	7,512,882
62			$X_{3,3}$	16,725,203	17,767,062	39,375,306	14,006,000	28,909,398	16,891,000	90,995,991	69,982,272	84,333,093	5,218,523	63,705,300	58,404,771	42,306,600	9,445,854	9,913,115
63		X'_3 Resource carrying	$X_{3,4}$	0.17	−0.68	−0.68	−0.68	−1.51	0.21	0.24	−0.47	−7.24	−4.35	0.36	0.60	−0.25	−2.08	7.05
64			$X_{3,5}$	41.50	45.40	34.96	25.00	32.30	38.60	26.61	34.96	34.96	42.80	34.96	39.20	27.11	37.64	34.96
65			$X_{3,6}$	44.68	37.03	41.50	42.22	38.21	44.78	44.02	40.03	38.21	41.80	40.49	45.08	38.19	39.34	39.53
66			$X_{3,7}$	13.2	10	13.43	12.50	11.16	14.58	13.94	15.5	10.97	20.3	15.5	16.6	9.91	13.43	10.22
67			$X_{3,8}$	15	67.28	12.79	13.39	18.56	5.69	63.66	0.50	30.81	33.04	30.58	33.04	47.74	50.27	55.21
68			$X_{3,9}$	24,497,894	3,521,457	9056475.9	9,056,475.9	9,056,475.9	14,112,814	21,184,944	9,056,475.9	25,061,182	9,056,475.9	90,56,475.9	105,031.57	6,190,700	100,979.31	2,174,699
69	X_3 Resources and environment		$X_{3,10}$	0.038	0.047	0.044	0.049	0.036	0.041	0.051	0.053	0.044	0.046	0.049	0.04	0.054	0.051	0.042
70			$X_{3,11}$	0.4216505	0.0472211	0.0808928	0.2608816	0.153596	0.1924797	0.4431612	0.1789658	−0.013311	0.1373299	0.0920965	0.2596203	0.2003272	0.1578019	0.0940928
71			$X_{3,12}$	5.21	5.23	4.08	5.32	5.16	2.63	4.07	3.30	3.21	0.25	0.65	1.12	2.05	2.47	1.75
72			$X_{3,13}$	10.27	4.92	0.10	4.92	5.07	3.13	4.03	6.05	5.23	2.74	15.00	4.92	2.94	4.92	4.92
73			$X_{3,14}$	95.10	91.60	83.78	89.83	87.11	91.34	62.70	93.37	75.36	90.70	82.70	96.00	92.30	91.00	93.40
74			$X_{3,15}$	0.33	11.28	−3.36	−8.89	4.02	−3.83	−9.06	−8.89	1.26	−14.24	−8.89	−8.89	−8.89	−8.29	−22.24
75		X''_3 Environmental quality	$X_{3,16}$	34,881	35,257	48,001.19	48,001.19	28,263	36,372	89,638	47,330	36,223.11	48,001.19	48,001.19	48,001.19	66,420	62,684	29,823.64
76			$X_{3,17}$	87.90	85.30	84.47	93.30	100.00	100.00	90.70	100.00	100.00	99.00	80.38	95.10	95.00	100.00	97.47
77			$X_{3,18}$	352	319	339	208	329	340	317	336	342	366	360	360	321	293	306
78			$X_{3,19}$	675.28	573.7	388.5484	671.12	2232.83	841.02	2232.83	655.81	1147	109.87	2232.83	120.51	1365.33	577	248.58
79			$X_{3,20}$	18.42	31.47	18.33	26.05	11.58	14.94	10.89	10.48	6.84	4.40	11.91	14.96	15.91	19.84	11.83
80			$X_{3,21}$	2460.22	22,802.4	13,942.513	9613	22,500	12,573.29	17,500	13,800	14,100	8226	23,900	8600	18,600	23,000	13,800
81			$X_{3,22}$	0.18	1.67	−0.33	1.19	0.50	0.89	0.53	0.59	0.35	0.40	7.65	1.23	0.65	1.13	0.72
82			$X_{3,23}$	68.58	937.6	107.4871	13705	−12289	626.71	436	384	400	437.42	890	4988	628	1467	486

Table A4. The standardized data of green economy evaluation for 15 sub-provincial cities in China.

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Dalian	(6) Haerbin	(7) Changchun	(8) Shenyang	(9) Jinan	(10) Qiangdao	(11) Nanjing	(12) Hangzhou	(13) Ningbo	(14) Xiamen	(15) Guangzhou	(16) Shenzhen	(17) Wuhan	(18) Chengdu	(19) Xi'an
1			$X_{1,1}$	0.390	0.162	0.153	0.353	0.186	0.418	0.409	0.465	0.351	0.000	1.000	0.944	0.483	0.496	0.145
2			$X_{1,2}$	0.738	0.000	0.166	0.448	0.307	0.476	0.552	0.558	0.881	0.407	0.776	1.000	0.435	0.153	0.069
3			$X_{1,3}$	0.481	0.423	0.808	0.415	0.327	0.538	0.750	0.231	0.000	0.827	0.519	0.423	0.692	1.000	0.769
4			$X_{1,4}$	0.219	0.448	0.000	0.448	0.243	0.177	0.582	0.690	1.000	0.214	0.664	0.779	0.567	0.236	0.221
5			$X_{1,5}$	0.889	1.000	0.622	0.618	0.493	0.636	0.357	0.500	0.525	0.039	0.415	0.000	0.590	0.683	0.379
6			$X_{1,6}$	0.519	0.063	0.212	0.463	0.131	0.466	0.413	0.517	0.492	0.000	0.767	1.000	0.573	0.555	0.121
7	X_1 Economic development	X'_1 Economic growth	$X_{1,7}$	0.207	0.136	0.059	0.205	0.166	0.299	0.337	0.347	0.191	0.000	1.000	0.804	0.335	0.358	0.119
8			$X_{1,8}$	0.573	0.000	0.259	0.595	0.154	0.571	0.469	0.569	0.565	0.096	0.813	1.000	0.541	0.560	0.150
9			$X_{1,9}$	0.477	0.660	0.350	0.277	0.274	0.331	0.466	0.497	0.498	0.000	0.541	0.377	1.000	0.945	0.752
10			$X_{1,10}$	0.335	0.000	0.406	0.406	0.022	0.267	0.320	0.428	1.000	0.406	0.633	0.954	0.401	0.406	0.036
11			$X_{1,11}$	0.064	0.026	0.000	0.322	0.093	0.152	0.403	0.567	0.319	0.193	1.000	0.635	0.364	0.232	0.107
12			$X_{1,12}$	0.942	0.574	0.404	0.942	0.187	0.619	0.735	0.524	0.344	0.000	0.685	0.215	1.000	1.000	0.639
13			$X_{1,13}$	0.124	0.000	0.031	0.016	0.008	0.147	0.108	0.122	0.198	0.150	0.246	1.000	0.033	0.091	0.017
14			$X_{1,14}$	0.118	0.000	0.004	0.015	0.006	0.145	0.111	0.146	0.221	0.162	0.226	1.000	0.033	0.106	0.020
15			$X_{1,15}$	0.224	0.252	0.143	0.320	0.256	0.292	0.370	0.344	0.241	0.000	1.000	0.521	0.425	0.406	0.230

Table A4. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Dalian	(6) Haerbin	(7) Changchun	(8) Shenyang	(9) Jinan	(10) Qiangdao	(11) Nanjing	(12) Hangzhou	(13) Ningbo	(14) Xiamen	(15) Guangzhou	(16) Shenzhen	(17) Wuhan	(18) Chengdu	(19) Xi'an
16	X_1 Economic development	X'_1 Economic growth	$X_{1,16}$	1.000	0.061	0.221	0.412	0.000	0.304	0.261	0.336	0.146	0.050	0.301	0.360	0.290	0.662	0.214
17			$X_{1,17}$	0.408	0.000	0.295	0.542	0.092	0.606	0.466	0.548	0.494	0.089	0.650	1.000	0.336	0.338	0.069
18			$X_{1,18}$	0.227	0.057	0.046	0.194	0.194	0.193	0.466	0.676	0.327	0.000	0.967	1.000	0.346	0.621	0.257
19			$X_{1,19}$	0.240	0.027	0.043	0.177	0.211	0.211	0.477	0.777	0.410	0.000	0.888	1.000	0.387	0.630	0.222
20			$X_{1,20}$	0.009	0.000	1.000	0.003	0.005	0.006	0.010	0.006	0.007	0.001	0.021	0.006	0.010	0.009	0.011
21			$X_{1,21}$	0.187	0.090	0.013	0.133	0.056	0.170	0.032	0.322	0.000	0.281	1.000	0.565	0.202	0.612	0.422
22			$X_{1,22}$	1.000	0.002	0.198	0.017	0.124	0.219	0.568	0.000	0.220	0.066	0.604	0.206	0.335	0.198	0.019
23			$X_{1,23}$	0.175	0.044	0.000	0.117	0.155	0.044	0.044	0.400	0.210	0.050	0.491	1.000	0.226	0.353	0.095
24			$X_{1,24}$	0.011	0.011	0.011	0.000	0.090	0.494	0.282	0.161	0.463	0.011	1.000	0.011	0.725	0.242	0.011
25		X''_1 Economic structure	$X_{1,25}$	0.662	0.000	0.563	0.891	0.817	0.944	0.803	0.901	0.986	0.563	0.662	0.442	0.958	0.958	0.930
26			$X_{1,26}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
27			$X_{1,27}$	0.087	0.861	0.185	0.074	0.545	0.240	0.368	0.278	0.000	0.265	0.615	0.250	0.361	0.358	0.653
28			$X_{1,28}$	0.008	0.505	0.000	0.112	0.574	0.333	0.530	0.421	0.046	0.394	0.982	0.629	0.285	0.355	0.486
29			$X_{1,29}$	0.634	0.593	0.515	0.793	0.723	0.454	0.245	0.633	0.489	0.526	0.000	0.515	0.236	0.590	0.894
30			$X_{1,30}$	0.354	0.215	0.215	0.313	0.215	0.025	0.404	0.120	0.000	0.373	0.358	0.304	0.205	0.095	0.170
31			$X_{1,31}$	0.488	0.971	0.550	0.568	0.664	0.945	0.511	0.848	0.732	0.000	0.505	0.460	0.486	0.886	0.732
32			$X_{1,32}$	0.649	0.961	0.801	0.398	0.605	0.518	0.078	0.456	0.815	0.627	0.000	0.627	0.638	0.761	0.163
33			$X_{1,33}$	0.850	0.998	0.828	0.971	0.608	0.791	0.795	0.391	0.709	0.622	0.761	0.000	0.821	0.546	0.764
34			$X_{1,34}$	0.264	0.264	0.264	0.000	0.375	0.593	0.329	0.114	0.681	0.264	0.429	0.730	0.768	0.182	0.264
35	X_2 Social livelihood of the people	X'_2 People's livelihood improvement	$X_{2,1}$	0.407	0.817	0.576	0.543	0.426	0.589	0.456	0.519	0.394	0.000	0.643	0.098	0.642	1.000	0.616
36			$X_{2,2}$	0.678	0.389	0.254	0.424	0.720	0.553	0.698	0.742	0.595	0.921	0.921	0.000	0.833	0.437	0.790
37			$X_{2,3}$	0.555	0.193	0.014	0.372	0.335	0.404	0.511	1.000	0.578	0.147	0.642	0.647	0.000	0.422	0.147
38			$X_{2,4}$	0.492	0.170	0.118	0.508	0.565	0.598	0.480	0.649	0.276	0.484	1.000	0.000	0.306	0.549	0.163
39			$X_{2,5}$	0.276	0.000	0.026	0.216	0.552	0.529	0.758	0.823	0.844	0.826	0.853	1.000	0.250	0.257	0.410
40			$X_{2,6}$	0.736	0.253	0.000	0.423	0.289	0.523	0.608	0.845	1.000	0.467	0.821	0.461	0.226	0.259	0.253
41			$X_{2,7}$	0.218	0.000	0.019	0.185	0.188	0.216	0.375	0.403	0.441	0.568	1.000	0.708	0.093	0.093	0.297
42	X_2 Social livelihood of the people	X'_2 People's livelihood improvement	$X_{2,8}$	0.811	0.708	0.745	0.806	0.748	0.728	0.755	0.000	0.651	0.674	0.537	0.642	0.868	0.833	1.000
43			$X_{2,9}$	0.119	1.000	0.064	0.144	0.211	0.198	0.158	0.000	0.031	0.158	0.225	0.225	0.318	0.011	0.505
44			$X_{2,10}$	0.084	0.000	0.086	0.299	0.082	0.273	0.222	0.554	0.527	0.135	0.689	1.000	0.343	0.544	0.181
45			$X_{2,11}$	0.329	0.159	0.234	0.135	0.006	0.150	0.267	1.000	0.286	0.000	0.930	0.525	0.562	0.519	0.253
46			$X_{2,12}$	0.059	0.327	0.543	0.085	0.083	0.327	0.000	1.000	0.327	0.042	0.595	0.327	0.342	0.249	0.327
47			$X_{2,13}$	0.548	0.070	0.000	0.235	0.044	0.055	0.504	0.765	0.259	0.069	1.000	0.618	0.661	0.673	0.210
48			$X_{2,14}$	0.353	0.000	0.196	0.205	0.479	0.334	0.404	0.219	0.516	0.977	1.000	0.144	0.516	0.628	0.177
49			$X_{2,15}$	0.624	0.581	0.572	0.586	0.722	0.674	0.634	0.324	0.444	0.634	0.926	0.000	0.833	1.000	0.368
50		X''_2 Social undertakings	$X_{2,16}$	0.073	0.924	0.946	0.131	0.696	1.000	0.315	0.998	0.557	0.064	0.424	0.171	0.000	0.386	0.828
51			$X_{2,17}$	0.157	0.043	0.081	0.080	0.106	0.020	0.096	0.132	0.081	0.118	0.089	0.409	1.000	0.044	0.000
52			$X_{2,18}$	0.012	0.651	0.133	0.482	0.145	0.277	0.458	0.458	0.253	0.000	0.349	1.000	0.639	0.096	0.229
53			$X_{2,19}$	0.748	0.790	0.999	0.203	1.000	1.000	0.790	0.918	0.982	0.790	0.790	1.000	0.000	0.836	0.998
54			$X_{2,20}$	0.827	0.652	0.374	1.000	0.565	0.261	0.565	0.000	0.850	0.565	0.565	0.368	0.720	0.565	0.862
55			$X_{2,21}$	0.808	0.631	0.695	0.631	0.000	0.346	0.564	0.887	0.311	0.878	0.677	0.582	0.826	1.000	0.631
56			$X_{2,22}$	0.070	0.016	0.028	0.000	0.036	0.051	0.013	0.072	0.084	0.111	0.085	1.000	0.047	0.084	0.036
57			$X_{2,23}$	0.128	0.222	0.056	0.000	0.112	0.037	0.255	0.121	0.848	0.022	1.000	0.983	0.401	0.201	0.172
58			$X_{2,24}$	0.412	0.174	1.000	0.614	0.614	0.460	0.609	0.614	0.859	0.937	0.000	0.464	0.940	0.614	0.896
59			$X_{2,25}$	0.176	0.160	0.228	0.256	0.133	0.149	0.521	0.253	0.035	0.000	1.000	0.803	0.343	0.338	0.149
60	X_3 Resources and environment	X'_3 Resource carrying	$X_{3,1}$	0.087	0.531	0.349	0.207	0.096	0.194	0.063	1.000	0.082	0.004	0.025	0.000	0.054	0.113	0.065
61			$X_{3,2}$	0.548	0.559	1.000	0.313	1.000	0.626	0.297	0.695	0.000	0.935	1.000	0.932	0.789	0.872	0.848
62			$X_{3,3}$	0.866	0.854	0.602	0.898	0.724	0.864	0.000	0.245	0.078	1.000	0.318	0.380	0.568	0.951	0.945
63			$X_{3,4}$	0.481	0.541	0.541	0.541	0.599	0.479	0.477	0.526	1.000	0.798	0.468	0.451	0.511	0.639	0.000
64			$X_{3,5}$	0.809	1.000	0.488	0.000	0.358	0.667	0.079	0.488	0.488	0.873	0.488	0.696	0.103	0.620	0.488
65			$X_{3,6}$	0.950	0.000	0.555	0.645	0.147	0.963	0.868	0.373	0.147	0.593	0.430	1.000	0.144	0.287	0.311
66			$X_{3,7}$	0.317	0.009	0.339	0.249	0.120	0.449	0.388	0.538	0.102	1.000	0.538	0.644	0.000	0.339	0.030
67			$X_{3,8}$	0.783	0.000	0.816	0.807	0.730	0.922	0.054	1.000	0.546	0.513	0.550	0.513	0.293	0.255	0.181
68			$X_{3,9}$	0.023	0.863	0.641	0.641	0.641	0.439	0.155	0.641	0.000	0.641	0.641	1.000	0.756	1.000	0.917

Table A4. *Cont.*

(1) No.	(2) The First Criterion Layer	(3) The Second Criterion Layer	(4) Index	(5) Dalian	(6) Haerbin	(7) Changchun	(8) Shenyang	(9) Jinan	(10) Qiangdao	(11) Nanjing	(12) Hangzhou	(13) Ningbo	(14) Xiamen	(15) Guangzhou	(16) Shenzhen	(17) Wuhan	(18) Chengdu	(19) Xi'an
69			$X_{3,10}$	0.889	0.389	0.556	0.278	1.000	0.722	0.167	0.056	0.556	0.444	0.278	0.778	0.000	0.167	0.667
70			$X_{3,11}$	0.953	0.133	0.206	0.601	0.366	0.451	1.000	0.421	0.000	0.330	0.231	0.598	0.468	0.375	0.235
71			$X_{3,12}$	0.022	0.018	0.244	0.000	0.031	0.530	0.247	0.398	0.415	1.000	0.921	0.829	0.645	0.562	0.705
72			$X_{3,13}$	0.683	0.323	0.000	0.323	0.334	0.203	0.264	0.399	0.344	0.177	1.000	0.323	0.191	0.323	0.323
73			$X_{3,14}$	0.973	0.868	0.633	0.815	0.733	0.860	0.000	0.921	0.380	0.841	0.601	1.000	0.889	0.850	0.922
74			$X_{3,15}$	0.673	1.000	0.563	0.398	0.783	0.549	0.393	0.398	0.701	0.239	0.398	0.398	0.398	0.416	0.000
75	X_3 Resources and environment	X''_3 Environmental quality	$X_{3,16}$	0.892	0.886	0.678	0.678	1.000	0.868	0.000	0.689	0.870	0.678	0.678	0.678	0.378	0.439	0.975
76			$X_{3,17}$	0.383	0.251	0.208	0.659	1.000	1.000	0.526	1.000	1.000	0.949	0.000	0.750	0.745	1.000	0.871
77			$X_{3,18}$	0.911	0.703	0.829	0.000	0.766	0.835	0.690	0.810	0.848	1.000	0.962	0.962	0.715	0.538	0.620
78			$X_{3,19}$	0.266	0.218	0.131	0.264	1.000	0.344	1.000	0.257	0.489	0.000	1.000	0.005	0.591	0.220	0.065
79			$X_{3,20}$	0.482	0.000	0.485	0.200	0.735	0.611	0.760	0.775	0.910	1.000	0.723	0.610	0.575	0.430	0.726
80			$X_{3,21}$	1.000	0.051	0.464	0.666	0.065	0.528	0.299	0.471	0.457	0.731	0.000	0.714	0.247	0.042	0.471
81			$X_{3,22}$	0.064	0.251	0.000	0.190	0.104	0.153	0.108	0.115	0.085	0.091	1.000	0.195	0.123	0.183	0.132
82			$X_{3,23}$	0.475	0.509	0.477	1.000	0.000	0.497	0.490	0.488	0.488	0.490	0.507	0.665	0.497	0.529	0.491

Table A5. The subordinate degree and the evaluation rankings of 15 Sub-provincial cities.

(1) No.	(2) Subordinate Degree /Rankings	(3) Dalian	(4) Haerbin	(5) Changchun	(6) Shenyang	(7) Jinan	(8) Qiangdao	(9) Nanjing	(10) Hangzhou	(11) Ningbo	(12) Xiamen	(13) Guangzhou	(14) Shenzhen	(15) Wuhan	(16) Chengdu	(17) Xi'an
1	y_j^{α}	0.162	0.170	0.370	0.093	0.094	0.197	0.106	0.218	0.167	0.207	0.361	0.369	0.172	0.165	0.147
2	Rankings without inferior constraint	11	8	1	15	14	6	13	4	9	5	3	2	7	10	12
3	$y_j^{\alpha}{}_{X_{1,10}}$	0.080	0.000	0.170	0.065	0.001	0.074	0.062	0.125	0.151	0.111	0.244	0.304	0.101	0.099	0.002
4	Rankings ($y_j^{\alpha}{}_{X_{1,10}}$)	9	15	3	11	14	10	12	5	4	6	2	1	7	8	13
5	$y_j^{\alpha}{}_{X_{1,12}}$	0.144	0.123	0.169	0.086	0.031	0.151	0.094	0.146	0.087	0.000	0.256	0.072	0.154	0.149	0.117
6	Rankings ($y_j^{\alpha}{}_{X_{1,12}}$)	7	8	2	12	14	4	10	6	11	15	1	13	3	5	9
7	$y_j^{\alpha}{}_{X_{1,13}}$	0.019	0.000	0.002	0.000	0.000	0.031	0.015	0.021	0.044	0.028	0.087	0.309	0.002	0.012	0.000
8	Rankings ($y_j^{\alpha}{}_{X_{1,13}}$)	7	14	10	13	15	4	8	6	3	5	2	1	11	9	12
9	$y_j^{\alpha}{}_{X_{1,20}}$	0.000	0.000	0.310	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
10	Rankings ($y_j^{\alpha}{}_{X_{1,20}}$)	8	6	1	14	13	12	5	11	9	15	2	10	3	7	4
11	$y_j^{\alpha}{}_{X_{1,22}}$	0.146	0.000	0.062	0.000	0.017	0.057	0.087	0.000	0.052	0.006	0.237	0.067	0.086	0.044	0.001
12	Rankings ($y_j^{\alpha}{}_{X_{1,22}}$)	2	15	6	13	10	7	3	14	8	11	1	5	4	9	12
13	$y_j^{\alpha}{}_{X_{1,24}}$	0.000	0.000	0.000	0.000	0.010	0.133	0.056	0.035	0.111	0.000	0.303	0.000	0.142	0.057	0.000
14	Rankings ($y_j^{\alpha}{}_{X_{1,24}}$)	12	14	10	15	8	3	6	7	4	11	1	9	2	5	13
15	$y_j^{\alpha}{}_{X_{1,28}}$	0.000	0.114	0.000	0.014	0.077	0.096	0.085	0.123	0.003	0.108	0.301	0.248	0.072	0.088	0.102
16	Rankings ($y_j^{\alpha}{}_{X_{1,28}}$)	15	4	14	12	10	7	9	3	13	5	1	2	11	8	6
17	$y_j^{\alpha}{}_{X_{1,31}}$	0.109	0.150	0.225	0.076	0.081	0.174	0.083	0.183	0.139	0.000	0.206	0.193	0.116	0.145	0.123
18	Rankings ($y_j^{\alpha}{}_{X_{1,31}}$)	11	6	1	14	13	5	12	4	8	15	2	3	10	7	9
19	$y_j^{\alpha}{}_{X_{1,32}}$	0.127	0.150	0.284	0.064	0.079	0.137	0.008	0.132	0.144	0.152	0.000	0.247	0.135	0.139	0.030
20	Rankings ($y_j^{\alpha}{}_{X_{1,32}}$)	10	4	1	12	11	7	14	9	5	3	15	2	8	6	13
21	$y_j^{\alpha}{}_{X_{2,1}}$	0.096	0.143	0.233	0.075	0.068	0.147	0.079	0.145	0.098	0.000	0.247	0.018	0.135	0.149	0.115
22	Rankings ($y_j^{\alpha}{}_{X_{2,1}}$)	10	6	2	12	13	4	11	5	9	15	1	14	7	3	8

Table A5. *Cont.*

(1) No.	(2) Subordinate Degree /Rankings	(3) Dalian	(4) Haerbin	(5) Changchun	(6) Shenyang	(7) Jinan	(8) Qiangdao	(9) Nanjing	(10) Hangzhou	(11) Ningbo	(12) Xiamen	(13) Guangzhou	(14) Shenzhen	(15) Wuhan	(16) Chengdu	(17) Xi'an
23	$y_j^{\alpha}{}_{X_{2,7}}$	0.047	0.000	0.001	0.030	0.031	0.056	0.070	0.118	0.107	0.144	0.303	0.266	0.012	0.012	0.067
24	Rankings ($y_j^{\alpha}{}_{X_{2,7}}$)	9	15	14	11	10	8	6	4	5	3	1	2	12	13	7
25	$y_j^{\alpha}{}_{X_{2,9}}$	0.018	0.151	0.008	0.021	0.036	0.049	0.027	0.000	0.001	0.031	0.075	0.076	0.081	0.000	0.104
26	Rankings ($y_j^{\alpha}{}_{X_{2,9}}$)	11	1	12	10	7	6	9	15	13	8	5	4	3	14	2
27	$y_j^{\alpha}{}_{X_{2,14}}$	0.084	0.000	0.061	0.035	0.072	0.096	0.074	0.057	0.119	0.180	0.303	0.036	0.121	0.129	0.034
28	Rankings ($y_j^{\alpha}{}_{X_{2,14}}$)	7	15	10	13	9	6	8	11	5	2	1	12	4	3	14
29	$y_j^{\alpha}{}_{X_{2,16}}$	0.007	0.148	0.304	0.018	0.082	0.176	0.062	0.192	0.124	0.006	0.175	0.049	0.000	0.095	0.127
30	Rankings ($y_j^{\alpha}{}_{X_{2,16}}$)	13	5	1	12	9	3	10	2	7	14	4	11	15	8	6
31	$y_j^{\alpha}{}_{X_{2,22}}$	0.007	0.000	0.001	0.000	0.002	0.004	0.000	0.008	0.010	0.016	0.013	0.309	0.003	0.010	0.002
32	Rankings ($y_j^{\alpha}{}_{X_{2,22}}$)	7	13	12	15	11	8	14	6	4	2	3	1	9	5	10
33	$y_j^{\alpha}{}_{X_{2,24}}$	0.097	0.033	0.310	0.078	0.079	0.127	0.089	0.160	0.146	0.178	0.000	0.195	0.152	0.128	0.130
34	Rankings ($y_j^{\alpha}{}_{X_{2,24}}$)	10	14	1	13	12	9	11	4	6	3	15	2	5	8	7
35	$y_j^{\alpha}{}_{X_{3,1}}$	0.010	0.117	0.143	0.035	0.011	0.048	0.006	0.192	0.010	0.000	0.001	0.000	0.004	0.017	0.006
36	Rankings ($y_j^{\alpha}{}_{X_{3,1}}$)	8	3	2	5	7	4	11	1	9	15	13	14	12	6	10
37	$y_j^{\alpha}{}_{X_{3,3}}$	0.141	0.145	0.241	0.085	0.083	0.170	0.000	0.067	0.009	0.181	0.125	0.158	0.127	0.147	0.131
38	Rankings ($y_j^{\alpha}{}_{X_{3,3}}$)	7	6	1	11	12	3	15	13	14	2	10	4	9	5	8
39	$y_j^{\alpha}{}_{X_{3,7}}$	0.076	0.000	0.137	0.043	0.016	0.125	0.072	0.148	0.015	0.181	0.217	0.252	0.000	0.085	0.001
40	Rankings ($y_j^{\alpha}{}_{X_{3,3}}$)	8	15	5	10	11	6	9	4	12	3	2	1	14	7	13
41	$y_j^{\alpha}{}_{X_{3,12}}$	0.001	0.000	0.087	0.000	0.001	0.139	0.049	0.117	0.103	0.181	0.294	0.288	0.135	0.122	0.121
42	Rankings ($y_j^{\alpha}{}_{X_{3,12}}$)	13	14	10	15	12	4	11	8	9	3	1	2	5	6	7
43	$y_j^{\alpha}{}_{X_{3,18}}$	0.091	0.056	0.068	0.080	0.088	0.176	0.084	0.192	0.151	0.179	0.000	0.275	0.143	0.149	0.129
44	Rankings ($y_j^{\alpha}{}_{X_{3,18}}$)	9	14	13	12	10	4	11	2	5	3	15	1	7	6	8
45	$y_j^{\alpha}{}_{X_{3,21}}$	0.146	0.003	0.195	0.080	0.005	0.139	0.059	0.135	0.110	0.164	0.000	0.267	0.060	0.003	0.100
46	Rankings ($y_j^{\alpha}{}_{X_{3,21}}$)	4	13	2	9	12	5	11	6	7	3	15	1	10	14	8
47	$y_j^{\alpha}{}_{X_{3,22}}$	0.006	0.056	0.000	0.031	0.012	0.033	0.015	0.019	0.011	0.012	0.303	0.061	0.020	0.039	0.021
48	Rankings ($y_j^{\alpha}{}_{X_{3,22}}$)	14	3	15	6	11	5	10	9	13	12	1	2	8	4	7

Table A6. The advantageous and disadvantageous factors of 15 sub-provincial cities' green economy development.

(1) No.	(2) City	(3) The Advantageous Factors	(4) The Disadvantageous Factors
1	Dalian	$X_{1,28}$ The ratio of the added value of the tertiary industry to GDP, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants	$X_{1,22}$ Freight turnover, $X_{3,21}$ Ammonia and nitrogen emissions of major pollutants
2	Haerbin	$X_{1,10}$ Budgetary revenue of local government, $X_{1,22}$ Freight turnover, $X_{2,7}$ Urban households per capita consumption expenditure, $X_{2,14}$ Number of doctors (10,000 persons), $X_{3,7}$ Public green space per capita	$X_{2,9}$ The average annual growth rate of rural residents capita net income, $X_{3,1}$ Protection area of cultivated land, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants
3	Changchun	$X_{1,28}$ The ratio of the added value of the tertiary industry to GDP, $X_{2,7}$ Urban households per capita consumption expenditure, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants	——

Table A6. *Cont.*

(1) No.	(2) City	(3) The Advantageous Factors	(4) The Disadvantageous Factors
4	Shenyang	——	$X_{2,9}$ The average annual growth rate of rural residents capita net income, $X_{3,1}$ Protection area of cultivated land, $X_{3,7}$ Public green space per capita, $X_{3,21}$ Ammonia and nitrogen emissions of major pollutants, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants
5	Jinan	$X_{1,13}$ Total foreign trade value	$X_{1,24}$ Added value of the logistics industry, $X_{2,9}$ The average annual growth rate of rural residents capita net income, $X_{3,1}$ Protection area of cultivated land
6	Qiangdao	$X_{1,10}$ Budgetary revenue of local government, $X_{1,20}$ Freight volume	$X_{1,24}$ Added value of the logistics industry, $X_{2,16}$ The ratio of government expenditure on education to general budget expenditure, $X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size
7	Nanjing	$X_{1,32}$ The ratio of county economic aggregate to GDP, $X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District), $X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size	$X_{1,20}$ Freight volume, $X_{1,22}$ Freight turnover, $X_{1,24}$ Added value of the logistics industry, $X_{2,7}$ Urban households per capita consumption expenditure
8	Hangzhou	$X_{1,22}$ Freight turnover, $X_{2,9}$ The average annual growth rate of rural residents capita net income, $X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size	$X_{3,1}$ Protection area of cultivated land,
9	Ningbo	$X_{1,28}$ The ratio of the added value of the tertiary industry to GDP, $X_{2,9}$ The average annual growth rate of rural residents capita net income, $X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants	$X_{1,10}$ Budgetary revenue of local government, $X_{1,13}$ Total foreign trade value, $X_{1,24}$ Added value of the logistics industry, $X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District)
10	Xiamen	$X_{1,12}$ Total investment in fixed assets, $X_{1,20}$ Freight volume, $X_{1,31}$ The ratio of private economic value added to GDP, $X_{2,1}$ Census register population, $X_{3,1}$ Protection area of cultivated land	$X_{2,14}$ Number of doctors (10,000 persons), $X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District), $X_{3,3}$ Comprehensive energy consumption of industrial enterprises above designated size
11	Guangzhou	$X_{1,32}$ The ratio of county economic aggregate to GDP, $X_{2,24}$ Urban per capita housing area, $X_{3,18}$ Fairly good air quality day, $X_{3,21}$ Ammonia and nitrogen emissions of major pollutants	$X_{1,12}$ Total investment in fixed assets, $X_{1,22}$ Freight turnover, $X_{1,24}$ Added value of the logistics industry, $X_{1,28}$ The ratio of the added value of the tertiary industry to GDP, $X_{2,7}$ Urban households per capita consumption expenditure, $X_{2,14}$ Number of doctors (10,000 persons), $X_{3,12}$ Industrial soot emissions, $X_{3,22}$ Reduction of chemical oxygen demand emissions of main pollutants
12	Shenzhen	$X_{2,1}$ Census register population, $X_{3,1}$ Protection area of cultivated land	$X_{1,10}$ Budgetary revenue of local government, $X_{1,13}$ Total foreign trade value, $X_{2,22}$ Number of public transportation vehicles per 10,000 persons (District), $X_{3,7}$ Public green space per capita, $X_{3,18}$ Fairly good air quality day, $X_{3,21}$ Ammonia and nitrogen emissions of major pollutants
13	Wuhan	$X_{2,16}$ The ratio of government expenditure on education to general budget expenditure, $X_{3,7}$ Public green space per capita	$X_{1,12}$ Total investment in fixed assets, $X_{1,20}$ Freight volume, $X_{1,24}$ Added value of the logistics industry, $X_{2,9}$ The average annual growth rate of rural residents capita net income
14	Chengdu	$X_{2,9}$ The average annual growth rate of rural residents capita net income, $X_{3,21}$ Ammonia and nitrogen emissions of major pollutants	$X_{2,1}$ Census register population, $X_{2,14}$ Number of doctors (10000 persons)
15	Xi'an	$X_{2,14}$ Number of doctors (10,000 persons)	$X_{1,20}$ Freight volume, $X_{2,9}$ The average annual growth rate of rural residents capita net income

References

1. Forsyth, T.; Levidow, L. An ontological politics of comparative environmental analysis: The green economy and local diversity. *Glob. Environ. Politics* **2015**, *15*, 140–151. [CrossRef]
2. Newton, P.; Newman, P. Critical connections: The role of the built environment sector in delivering green cities and a green economy. *Sustainability* **2015**, *7*, 9417–9443. [CrossRef]
3. Schmitz, H.; Lema, R. The global green economy: Competition or cooperation between Europe and China? *Triple Chall. Eur. Econ. Dev. Clim. Chang. Gov.* **2015**, *5*, 118–141.
4. Hu, A. Introduction: Entering the Green Industrial Revolution. In *China: Innovative Green Development*; Springer: Berlin, Germany, 2014.
5. Department for Environment, Food and Rural Affairs. A selection of UK Government's indicators of sustainable development (UKCSD). In *Sustainable Development Indicators in Your Pocket 2004*; National Statistics: London, UK, 2004.
6. Energy Conservation Service Industry Committee of China Energy Conservation Association (EMCA). *Energy Conservation Service Industry Development Report of China 2009*; Energy Conservation Service Industry Committee of China Energy Conservation Association: Beijing, China, 2009.
7. International Energy Conservation Environmental Protection Association (IECEPA). *Ecological Safety Strategic Key Points of International Urban Ecological Construction*; International Energy Conservation Environmental Protection Association: Beijing, China, 2010.
8. United Nations Environment Program (UNEP). *Green Economy: Cities Investing in Energy and Resource Efficiency*; United Nations Environment Program: Nairobi, Kenya, 2011.
9. United Nations Industrial Development Organization (UNIDO). The International Conference on Green Industries in Asia Bulletin: Managing the Transition to Resource-Efficient and Low-Carbon Industries. Available online: http://www.unido.org/greenindustryconference.html (accessed on 20 February 2016).
10. The State Council Information Office of the People's Republic of China (SCIOPRC). The Communique of the Eighteen Session of the Fifth Plenary Session. Available online: http://www.scio.gov.cn/zxbd/tt/jd/Document/1453365/1453365.htm (accessed on 20 February 2016).
11. Pearce, D.W.; Markandya, A.; Barbier, E. *Blueprint for a Green Economy*; Earthscan: London, UK, 1989.
12. Lynn, R.K.; Eda Gurel-Atay, E. *Communicating Sustainability for the Green Economy*; M.E. Sharpe: New York, NY, USA, 2014.
13. United Nations Environment Programme (UNEP). *What is the "Green Economy"?* Available online: http://www.unep.org/greeneconomy/AboutGEI/WhatisGEI/tabid/29784/Default.aspx (accessed on 26 April 2016).
14. GRI—Global Reporting Initiative. *Sustainability Reporting Guidelines Version 3.0*; GRI: Amsterdam, The Netherlands, 2006.
15. The World Bank. *Inclusive Green Growth: The Pathway to Sustainable Development*; The World Bank Publishing: Washington, DC, USA, 2012.
16. The Organization for Economic Co-operation and Development (OECD) Green Growth Studies. *Green Growth Indicators 2014*; OECD Publishing: Paris, France, 2014.
17. The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). *Low Carbon Green Growth Roadmap for Asia and the Pacific*; UNESCAP Publishing: Bangkok, Thailand, 2012.
18. Ministry of Environmental Protection of the People's Republic of China (MEPC). The Urban Environment Quantitative Evaluation Index during the Twelfth Five-Year Plan and Its Implementing Regulations, 7 November. Available online: http://www.mep.gov.cn/gkml/hbb/bgth/201111/t20111116_220023.htm (accessed on 20 February 2016).
19. Beijing Municipal Commission Development and Reform (BMCDR). *Green Beijing Construction Planning during the Twelve Five-Year Plan*; Beijing Municipal Commission Development and Reform: Beijing, China, 2011.
20. Satterthwaite, D. Sustainable cities or cities that contribute to sustainable development? *Urban Stud.* **1997**, *34*, 1667–1691. [CrossRef]
21. Azapagic, A. Developing a framework for sustainable development indicators for the mining and minerals industry. *J. Clean. Prod.* **2004**, *12*, 639–662. [CrossRef]

22. Shi, B.F.; Chi, G.T. Green industry evaluation indicators screening model based on the maximum information content and its application. *Syst. Eng. Theory Pract.* **2014**, *34*, 1799–1810.
23. Meng, B.; Chi, G.T. Evaluation index system of green industry based on maximum information content. *Singap. Econ. Rev.* **2016**. in press.
24. Smulders, S.; Toman, M.; Withagen, C. Growth theory and green growth. *Oxf. Rev. Econ. Policy* **2014**, *30*, 423–446. [CrossRef]
25. Zhao, Y.; Shang, J.C.; Chen, C.; Wu, H.N. Simulation and evaluation on the eco-industrial system of Changchun Economic and Technological Development Zone, China. *Environ. Monit. Assess.* **2008**, *139*, 339–349. [CrossRef] [PubMed]
26. Wang, X.H.; Shen, J.X.; Zhang, W. Emergy evaluation of agricultural sustainability of Northwest China before and after the grain-for-green policy. *Energy Policy* **2014**, *67*, 508–516. [CrossRef]
27. Chen, C.F.; Han, J.; Fan, P.L. Measuring the Level of Industrial Green Development and Exploring Its Influencing Factors: Empirical Evidence from China's 30 Provinces. *Sustainability* **2016**, *8*, 1–20. [CrossRef]
28. Wang, H.; Wang, J.; Shi, B.F. Model and application of green industry evaluation based on fuzzy control. *J. Intell. Fuzzy Syst.* **2015**, *29*, 2489–2494. [CrossRef]
29. Nalan, C.B.; Murat, O.; Nuri, O. Renewable energy market conditions and barriers in Turkey. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1428–1436. [CrossRef]
30. Liang, Z.; Zhou, X. Low carbon industry innovation system operation performance evaluation index system. *Stat. Decis.* **2012**, *3*, 31–34.
31. Chi, G.T.; Du, Y.Q.; Shi, B.F. Path selection of industrial dust emissions of green city. *J. Syst. Eng.* **2014**, *29*, 309–314.
32. Mundaca, L.; Richter, J.L. Assessing 'green energy economy' stimulus packages: Evidence from the U.S. programs targeting renewable energy. *Renew. Sustain. Energy Rev.* **2015**, *42*, 1174–1186. [CrossRef]
33. China Economic Information Network (CEINET). The Realization of Green Development and Economic Growth Utilizing the Green Transformation. Available online: http://finance.ce.cn/rolling/201208/07/t20120807_16920702.shtml (accessed on 29 April 2016).
34. Xinhua. Logistics Industrial has become one of the Pillars of China's Economic Development. Available online: http://news.xinhuanet.com/fortune/2014--04/27/c_1110432337.htm (accessed on 30 April 2016).
35. Shi, B.F.; Wang, J.; Qi, J.Y.; Cheng, Y.Q. A novel imbalanced data classification approach based on logistic regression and Fisher discriminant. *Math. Probl. Eng.* **2015**, *2015*, 1–12. [CrossRef]
36. Chi, G.T.; Yan, D.W. The ecosystem evaluation model based on improved group-G1 and the empirical study on provinces. *Syst. Eng. Theory Pract.* **2012**, *32*, 1464–1475.
37. Yu, S.; Huang, T.Z.; Liu, X.; Chen, W. Information measures based on fractional calculus. *Inf. Process. Lett.* **2012**, *112*, 916–921. [CrossRef]
38. Zou, Z.H.; Yun, Y.; Sun, J.N. Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment. *J. Environ. Sci. China* **2006**, *18*, 1020–1023. [CrossRef]
39. Zhou, Z.; Chi, G.T.; Zhang, S. Evaluation of scientific development for county and districts based on key factor judgment. *J. Syst. Eng.* **2014**, *29*, 257–268.
40. WWF Shanghai Low Carbon Development Roadmap Research Team. *2050 Shanghai Low Carbon Development Roadmap Report*; Science Press: Beijing, China, 2011; pp. 146–178.
41. China Statistics Press. *China Statistical Yearbook*; China Statistics Press: Beijing, China, 2013.
42. China Statistics Press. *China 15 Sub-Provincial Cities' Statistical Yearbook*; China Statistics Press: Beijing, China, 2013.
43. Cohen, B. Urbanization, City growth, and the New United Nations development agenda. *Cornerstone* **2015**, *3*, 4–7.