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Sustainability Investigation of Resource-Based Cities in Northeastern China

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Abstract: Improving the sustainability of traditional resource-based cities in China has been a core issue and policy-priority for Chinese government to establish long-term ecological civilization, particularly for northeastern China which is recognized as a typical agglomeration area of resources cities. In this study, we establish a three-layer index system consisting of a comprehensive layer, systemic layer, and variable layer, and including 22 indicators which are grouped into economic, social and environmental subsystems. After that, the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was applied to measure and rank the sustainability of the selected 15 typical resource-based cities in northeast China, and then a GIS (Geographical Information System) technique based on the software of *SuperMap* was applied to map the sustainability in terms of the spatial effects among these cities. The results reveal that a unilateral improvement of a subsystem did not mean an improvement or contribution to whole system. In detail, during the past 15 years from 2000 to 2015, the comprehensive sustainability of resource-based cities in Northeastern China shows a declining trend in the mass, and the sustainability of the economic subsystem shows increase; the sustainability of the social system remains stable, while the environmental subsystem shows decrease. These situations might result from policy interventions during the past 15 years, therefore, promoting the sustainability of resource-based cities needs a historical approach, which should focus on the coordinated development of its economic, social, and environmental subsystems.

Keywords: human-natural relationship; sustainability governance; sustainability assessment

1. Introduction

Improving the sustainability of traditional resource-based cities in China has been a core issue and policy-priority for Chinese government to meet the long-term ecological civilization, particularly for the northeastern China which is recognized as a typical agglomeration area of resources cities. In China, resource-based cities refer to those cities (including municipal-level cities and counties) where the local economy and leading industries of which mostly depend on the exploitation and primary processing of local natural resources, for instance, coal mining, oil, and forestry [1,2]. Since 1949, the resource-based cities cumulative produced more than 52.9 billion tons of raw coal, 5.5 billion tons of crude oil, 5.8 billion tons of iron ore, and 2 billion cubic meters of timber, made a historic contribution for China to establish a complete industrial system and promote economic development [3]. Aiming to improve the overall sustainability of resource-based cities, the State Council decided to conduct an economic transition pilot program in Fuxin city of Liaoning province in 2001, after that, a total of 43 cities were defined as resource-based cities in 2008/2009, then in 2013, a total of 262 cities (including 126 prefecture-level cities, 62 county-level cities, 58 counties, and 16 economic development zones) were defined as resources based cities in the *Sustainable Development Plan for Resource-based Cities* (2013–2020). Among these 262 resource-based cities, 37 of them (14.1%) are located in Northeast China (including Heilongjiang, Jilin, and Liaoning Province), which has been recognized as a typical agglomeration area of resource-based cities. In April 2016, the Communist Party of China (CPC) Central Committee and State Council joint launched an important policy document entitled "*Certain Opinions Regarding the Comprehensive Revival of Old Industrial Bases Including the Northeast*" [4], which underlined the importance and urgency of improving sustainability of resource-based cities in northeast China. Therefore, measuring the sustainability of resource-based cities in northeast China is an important and practical issue for decision makers.

Approaches and indicators for measuring sustainability are varies in different cases, with a wide range of spatial and temporal scales. For example, *Emergy Accounting* has been applied widely for measuring the ecological-economic sustainability of the human-natural system at the scales from global level to a project level [5–7], herein, emergy is defined as a single unit of energy that was previously used directly or indirectly to produce a product or service, with aiming to bridge the economic system and ecological system [8,9]; in comparison, another method used as one of the mainstream approaches in sustainability measurement is ecological footprint, representing the productive area required to provide the renewable resources by measuring in hectare-equivalent units, namely global hectares [10]. Comparing emergy accounting with ecological footprint, it is worth noting that both of them are using a unified transformed unit as indicator to measure the objective's sustainability, however, regarding the practical level in most real cases, such unit-unified indicators cannot meet the realistic policy-making demand, for example, there are about 230 indicators are approved to monitor the 17 goals and 169 targets of the United Nations Sustainable Development Goals (UN SDGs), even though roughly half of them lack acceptable country coverage, agreed-upon methodologies or both [11]. Therefore, given the fact that any individual force could cause either positive or negative impacts on sustainability directly or indirectly [12], more smart approaches with metric indicators are encouraged to be applied or developed for measuring sustainability.

Regarding sustainability measurement at a city scale, various models and frameworks have been developed and applied by involving a number of sustainability criteria [13]. For instance, Zhang et al. developed a new objective weighting approach in the context of multi-criteria decision making, and applied this approach to evaluate the sustainability performance of 13 cities in China [13], Egilmez et al. developed a four-step hierarchical fuzzy multi-criteria decision-making approach to assess the environmental sustainability performance of 27 U.S. and Canada metropoles, by defining the sustainability score's scale between 0 and 1 [14]; Li et al., based on the results of material flow analysis, employed structural decomposition and decoupling analysis to evaluate the sustainability potential by taking Jinchang City in Gansu province of China as a case [15]; and Zeng et al. employed a data-mining method named Association Rule Mining to evaluate the sustainability of 110 prefecture-level mining cities in China, and they found some novel, implicit, and previously unknown characteristics and patterns with regarding the mining city's sustainability [16].

Therefore, this paper, by focusing on the 15 resource-based cities in northeast China, aims innovatively to apply TOPSIS (*Technique for Order Preference by Similarity to Ideal Solution*) to measure and rank the sustainability of resource-based cities, based on a new indicator system which is further categorized as economic, social, and ecological subsystems. The paper is organized as follows: a brief introduction to the case study is presented in Section 2, the methods applied in this research are illustrated in Section 3, followed by presentation of the results and a discussion in Section 4, and the conclusions are presented in Section 5.

2. Studied Cases

According to the *Sustainable Development Plan for Resource-based Cities* (2013–2020), there are 37 cities locate in Northeast China are defined as resource-based cities. In addition, among these 37 cities, 21 of them are prefecture-level cities, 9 of them are county-level cities, 3 of them are counties, and 4 of them are districts or economic development zones. However, considering the integrity, accessibility, and transparency of the research data which are required in applying TOPSIS method, 15 of the prefecture-level cities are finally selected as studied cases. Their locations are shown in Figure 1 and the brief profiles of these 15 cities are shown in Table 1, respectively. Among these 15 cities, 6 of them are located in Heilongjiang and Liaoning province, respectively, and 3 of them are located in Jilin province. The main resources in these cities consist of oil, coal, natural gas, iron ore, magnetite, graphite, and molybdenum. For example, the Daqing city of the Heilongjiang province, which oilfield is among of the largest oilfields in the world and is China's largest, accounts for nearly 25% of China's oil production; however, the future oil production would decline from 41.6 million tons in 2007 to 8.0 million tons in 2060 [17], and the Anshan city of the Liaoning province is one of the richest iron deposit areas in China, in which the iron ores discovered have been estimated to be more than 7 billion tons at <500 m [18].

Table 1. Brief profiles of studied cities.

Province	Case Cities	Main Resources (Reserves, Unit) [a]	Population (10^4)	Area (km^2)	Per-Capita GDP (US Dollar) [b]
Heilongjiang	Hegang	Coal (3 bt); Graphite (600 mt)	110	14,784	3941
	Yichun	Gold (120 t); Iron ore (3.16 mt)	121	39,017	3288
	Shuangyashan	Coal (11.7 bt); Magnetite (120 mt)	147	22,483	4719
	Qitaihe	Marble (140 mt); Ineral resources (2.2 bt)	93	6221	3810
	Jixi	Coal (6.4 bt); Graphite (490 mt)	181	23,040	4561
	Daqing	Oil (8–10 bt); Natural gas (858–4290 bm^3)	293	22,161	16,329
Jilin	Songyuan	Oil shale (77.5 bt)	278	22,000	9095
	Liaoyuan	Coal (0.17 bt); Limestone (35 mt)	121	5125	9928
	Baishan	Coal (38 mt); Diatomite (42 mt); Dolomite (30 mt)	125	17,485	8807
Liaoning	Fuxin	Coal (1 bt)	189	10,445	4884
	Fushun	Coal (1.42 bt); Iron ore (234 mt)	216	11,271	9401
	Benxi	Iron ore (2.7 bt); Limestone (210 mt); Solvent (130 mt)	151	8413	10,862
	Panjin	Oil (2.1 bt); Natural gas (178 bm^3)	129	4084	14,152
	Anshan	Iron ore (7.54 bt); Magnetite (3.37 bt);	346	9252	10,866
	Huludao	Coal (380 mt); Molybdenum (310 mt)	280	10,302	4524

Notes: [a] Unit of the reserves: bt—billion tons; mt—million tons; t—tons; bm^3—billion cubic meters; [b] Exchange rate: 1 US dollar = 6.2284 RMB.

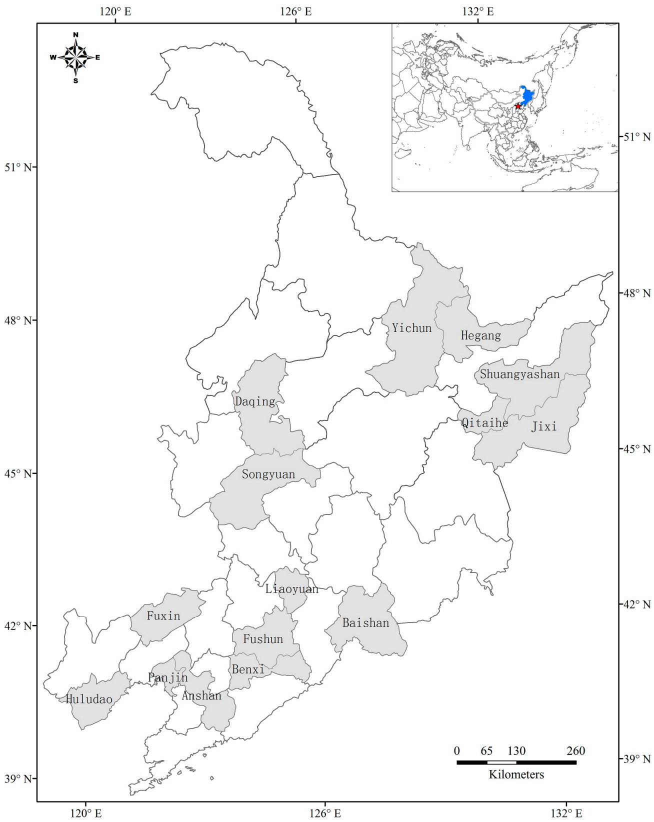

Figure 1. Location of the studied cities.

3. Methods

3.1. Methodology: TOPSIS

TOPSIS, is one of the most known classical multiple criteria decision making methods and was first developed by Hwang and Yoon [19]. It is based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution and on the other side the farthest distance of the negative ideal solution [20]. In the field of multiple criteria decision making (MCDM) analysis which is concerned with structuring and solving decision and planning problems involving multiple criteria, besides TOPSIS, various available methods have been applied and developed for solving such problems, such as Analytic Hierarchy Process (AHP), Data Envelopment Analysis (DEA), Analytic Network Process (ANP), and Value Analysis (VA), and many of them are implemented by specialized decision-making software. For example, Wu et al. investigated and demonstrated the quantitative indicator from combination of ANP and Porter's five forces [21], Quadros and Nassi employed the AHP method to present the criteria priorities on the decisions of transportation infrastructure investments in Brazil [22], Javid et al. applied AHP to rank various on-road emissions mitigation strategies in the United States [23], Park et al. applied AHP, ELECTRE III, PROMETHEE II, and Compromise Programming as MCDM techniques for investigating how the priority rankings for dam construction sites, and they found that selecting an appropriate MCDM technique is more important than the data generation method [24]. However, typically, there does not exist a unique optimal solution for such problems and it is necessary to use decision-maker's preferences to differentiate between solutions. Therefore, considering typical features such as clear and easily understandable geometric meaning, while simultaneously considering both best and worst points of view, and convenient calculation and implementation [25–27], TOPSIS is a popular method for solving problems in decision making [28], for example, in 2012, Behzadian et al. reviewed 266 scholarly papers from 103 journals since the year 2000, and they found that TOPSIS methodology has been successfully applied globally to a wide range of application areas and industrial sectors with varying terms and subjects, mainly including supply chain management and logistics, design, engineering and manufacturing systems, business and marketing management, health, safety and environment management, human resources management, energy management, chemical engineering, water resources management, and other topics [29]. Recently, TOPSIS method has been applied in more subjects, for example, Çetinkaya et al. applied a GIS-combined TOPSIS method to identify and rank the potential refugee camp sites for southeastern Turkey [30]; Morteza et al. employed the TOPSIS obtain final priorities for the investors in tourism industries to select the optimal tourism site in a fuzzy environment in the Integrated Coastal Zone Management in Iran [31]; Dace and Blumberga applied TOPSIS as one of the three main approaches to compare the 28 European Union Member States with respect to the emission intensity of the agricultural sector [32]. However, the use of TOPSIS as a tool for the city comparison with respect to sustainability has not been reported in the literature reviewed by the authors.

The basic principle of TOPSIS is based on the concept that the chosen alternative should be as close as possible to the ideal solution and as far as possible from the negative-ideal solution. Generally speaking, firstly, the normalized matrix would be obtained when the impact of various indexes with different units is eliminated through related standardization processing method; and then both the optimal solution and the worst solution in each scheme will be found, based on the calculation of the distance of each alternative solution to the best as well as the worst solution. The basic steps of the TOPSIS method are as follows:

Build an evaluation matrix. Herein, m is the number of evaluation objects, n denotes index number, and x_{ij} is the j index values of the i scheme. The formula for calculation is as follows:

$$\mathrm{X} = (x_{ij})_{m\times n} \tag{1}$$

In this study, different types of indicators are classified, divided into "efficiency index" and "cost index", and then the weight of each type of indicators is objective calculated by using the variation coefficient method. For efficiency index, a bigger value indicates more positive, while for cost index, a bigger value means more negative. The calculation formulas of normalization for efficiency index (Formula (2)) and cost index (Formula (3)) are as follows:

$$y_{ij} = \frac{x_{ij} - x_{\min(j)}}{x_{\max(j)} - x_{\min(j)}} \tag{2}$$

$$y_{ij} = \frac{x_{\max(j)} - x_{ij}}{x_{\max(j)} - x_{\min(j)}} \tag{3}$$

Herein, $x_{max(j)}$ denotes the maximum value of index j column, and $x_{min(j)}$ denotes the minimum value of index j column, while y_{ij} indicates the evaluation value after the range of standardization, therefore the matrix Y is obtained after the standard treatment of the original data (Formula (4)).

$$Y = (y_{ij})_{m\times n} \tag{4}$$

Applying the coefficient-variation method (Formulas (5)–(8)) to determine the weight:

$$s_j = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}(y_{ij} - \overline{y_j})^2}, (j = 1, 2, \cdots, n) \tag{5}$$

$$\overline{y_j} = \frac{1}{m}\sum_{i=1}^{m} y_{ij}, (j = 1, 2, \cdots, n) \tag{6}$$

$$v_j = \frac{s_j}{\left|\overline{y}_j\right|}, (j = 1, 2, \cdots, n) \tag{7}$$

$$w_j = \frac{v_j}{\sum\limits_{j=1}^{n} v_j}, (j = 1, 2, \cdots, n) \tag{8}$$

wherein, w_j denotes the weight of each index, v_j denotes the coefficient of variation of each index evaluation value, s_j denotes the standard deviation, and $\overline{y_j}$ denotes the mean value of the j index. Then, the main diagonal elements of the diagonal matrix are constructed by respectively, and then the weighted normalized matrix is obtained (Formula (9)), followed by the Euclidean distance calculation (Formulas (10) and (11)).

$$A = (a_{ij})_{m\times n} = (y_{ij})_{m\times n} \times w \tag{9}$$

$$d_i{}^{+} = \sqrt{\sum_{j=1}^{n} (a_{ij} - a_j{}^{+})^2}, (i = 1, 2, \cdots, m) \tag{10}$$

$$d_i{}^{-} = \sqrt{\sum_{j=1}^{n} (a_{ij} - a_j{}^{-})^2}, (i = 1, 2, \cdots, m) \tag{11}$$

Herein, $a_j{}^{+}$ represents the maximum value of the column j of a weighted normalized matrix, and $a_j{}^{-}$ represents the minimum value of the column j of a weighted normalized matrix.

Finally, calculate the relative closeness to the ideal solution (Formula (12)), wherein C_i is the relative closeness degree of each evaluation object, in other words, it represents the comprehensive evaluation value of the urban sustainable development ability of the i evaluation object. Obviously, $C_i \in [0, 1]$, therefore, when the TOPSIS value tends to 1, it indicates that the city's sustainability is stronger, and vice versa.

$$C_i = \frac{d_i{}^{-}}{d_i{}^{+} + d_i{}^{-}}, (i = 1, 2, \cdots, m) \tag{12}$$

3.2. Index and Data Processing

The role of index system is to communicate the highlighted information regarding the key issues relevant for sustainability [33], which make indicators have become the most commonly accepted approach in assessing sustainable development as they bring different meaning to different levels [34], however, at present there is no single common recognized index system for measuring the sustainability at a city scale, because in most cases it links to the framework and model which was applied in the study [35], therefore, just as Rametsteiner et al. argued, "the development of sustainability indicators is a process of both scientific 'knowledge production' and of political 'norm creation', and both components need to be properly acknowledged" [36].

In this study, the index system was developed by combining the literature reviews regarding indicators investigation for measuring city sustainability (for example, Michael et al. [37]; Wong [38]; Ding et al. [39], and UNEP SDGs [40]) with their local conditions in northeastern China, such as the accessibility and transparency of the data, finally, a total of 22 indicators which are grouped into economic, social, and environmental subsystems were selected for TOPSIS analysis (Table 2).

Data applied in this study were extracted from the *Liaoning Provincial Statistical Yearbook* (2001–2015) [41], *Jilin Provincial Statistical Yearbook* (2001–2015) [42], and *Heilongjiang Provincial Statistical Yearbook* (2001–2015) [43]. Data for the year 2015 are extracted from the Provincial Statistics Bulletin of Liaoning, Jilin, and Heilongjiang Province, respectively. Based on the Formulas (1)–(12), the indicator's weight of studied years—2000, 2005, 2010, and 2015—are calculated and shown in Table 3.

Table 2. Index system for TOPSIS analysis.

Comprehensive Layer	System Layer	Indicator Layer (Indicator, [Code])	Unit	Index Properties
Sustainability	Economic subsystem	GDP growth rate [C_1]	%	Positive
		Per capita GDP [C_2]	Yuan/per capita	Positive
		Per capita revenues [C_3]	Yuan/per capita	Positive
		Total retail sales of consumer goods [C_4]	Billion	Positive
		Gross fixed asset formation [C_5]	Billion	Positive
		Output value of farming, forestry, husbandry, and fishery [C_6]	Million	Positive
		Secondary industry production per GDP [C_7]	%	Positive
		Tertiary industry production per GDP [C_8]	%	Positive
		Total export-import volume [C_9]	USD	Positive
	Social subsystem	Registered urban unemployment rate [C_{10}]	%	Negative
		Natural population growth rate [C_{11}]	‰	Positive
		Urban per capita disposable income [C_{12}]	Yuan	Positive
		Investment in environmental protection as a proportion of GDP [C_{13}]	%	Positive
		Personnel in population health institutions [C_{14}]	Person/10^4 people	Positive
		Average number of beds per million people [C_{15}]	Piece	Positive
		Education spending [C_{16}]	Million	Positive
		Technology spending [C_{17}]	Million	Positive
	Environmental subsystem	Ratio green coverage of built up areas [C_{18}]	ha	Positive
		Per capita green area [C_{19}]	m^2	Positive
		Industrial wastewater effluent [C_{20}]	%	Negative
		Industrial SO_2 emissions [C_{21}]	T	Negative
		Industrial smoke and dust emissions [C_{22}]	T	Negative

Table 3. Weight of indicators for year 2000, 2005, 2010, and 2015.

Indicator's Code	Weight Value			
	2000	2005	2010	2015
C_1	0.0141	0.0312	0.0342	0.0180
C_2	0.0567	0.0607	0.0483	0.0514
C_3	0.0960	0.0448	0.0462	0.0544
C_4	0.0798	0.0800	0.0759	0.0767
C_5	0.0656	0.0896	0.0738	0.0747
C_6	0.0516	0.0503	0.0460	0.0516
C_7	0.0336	0.0283	0.0209	0.0246
C_8	0.0149	0.0176	0.0193	0.0179
C_9	0.1639	0.1485	0.1392	0.1346
C_{10}	0.0123	0.0230	0.1945	0.0196
C_{11}	0.0264	0.0219	0.0290	0.0254
C_{12}	0.0177	0.028	0.0286	0.0470
C_{13}	0.0540	0.0365	0.0403	0.0350
C_{14}	0.0180	0.0223	0.0250	0.0250
C_{15}	0.0259	0.0249	0.0240	0.0219
C_{16}	0.0670	0.0623	0.0510	0.0581
C_{17}	0.0795	0.0810	0.1187	0.1195
C_{18}	0.0458	0.0526	0.0612	0.0603
C_{19}	0.0297	0.0419	0.0421	0.0340
C_{20}	0.0120	0.0110	0.0116	0.0105
C_{21}	0.0162	0.0203	0.0278	0.0194
C_{22}	0.0193	0.0222	0.0180	0.0198

4. Results

4.1. Calculation Results and Grouping

Based on the steps, fulmars and the indicator's weight we presented in Section 3, the comprehensive sustainability based on TOPSIS method of those 15 resource-based cities are calculated and then listed in Table 4, and the results for the three subsystems are listed in Table 5 (economic subsystem), Table 6 (social subsystem), and Table 7 (environmental subsystem), respectively. In order to rank the sustainability of each city, the city's set is categorized as five levels—including extremely low, low, medium, upper medium, and high—by referring the uniform distribution function, as well as their maximum and minimum value from the TOPSIS results, in detail, the threshold value and its numerical interval are shown in Table 8, the TOPSIS value should belongs to the interval (0, 1], and when the value tends to 1, it indicates that the city's sustainability is stronger, and vice versa.

Table 4. Comprehensive results for year 2000, 2005, 2010, and 2015.

Cities	2000	2005	2010	2015
Hegang	0.1830	0.1671	0.1935	0.1587
Yichun	0.1951	0.1890	0.1898	0.1651
Shuangyashan	0.1988	0.1801	0.1553	0.1366
Qitaihe	0.2515	0.1934	0.2270	0.1544
Jixi	0.1620	0.1679	0.1865	0.1779
Daqing	0.5211	0.3457	0.3141	0.3232
Songyuan	0.1607	0.1909	0.2111	0.1790
Liaoyuan	0.1448	0.1804	0.1975	0.1708
Baishan	0.1581	0.1974	0.2181	0.1786
Fuxin	0.1817	0.1474	0.1813	0.1832
Fushun	0.2806	0.2112	0.2205	0.2113
Benxi	0.2512	0.2460	0.2330	0.2354
Panjin	0.2775	0.2593	0.2993	0.2798
Anshan	0.4375	0.2770	0.2702	0.2517
Huludao	0.2257	0.1710	0.1676	0.1740

Table 5. TOPSIS results of economic subsystem for year 2000, 2005, 2010, and 2015.

Cities	2000	2005	2010	2015
Hegang	0.0665	0.1074	0.0980	0.0492
Yichun	0.0758	0.0832	0.0666	0.0887
Shuangyashan	0.0607	0.0894	0.1042	0.0548
Qitaihe	0.0813	0.1512	0.2035	0.0808
Jixi	0.0725	0.0998	0.1027	0.0673
Daqing	0.4076	0.3210	0.2844	0.2947
Songyuan	0.0897	0.1501	0.1709	0.1501
Liaoyuan	0.0633	0.1360	0.1272	0.1349
Baishan	0.0795	0.1219	0.1143	0.1379
Fuxin	0.0765	0.0997	0.1378	0.1171
Fushun	0.1274	0.1514	0.1909	0.1816
Benxi	0.1160	0.1782	0.2099	0.2142
Panjin	0.1964	0.2257	0.3025	0.2657
Anshan	0.1911	0.2366	0.2686	0.2333
Huludao	0.1086	0.1200	0.1147	0.1194

Table 6. TOPSIS results of social subsystem for year 2000, 2005, 2010, and 2015.

Cities	2000	2005	2010	2015
Hegang	0.2182	0.2180	0.2598	0.1999
Yichun	0.1887	0.2703	0.2365	0.1906
Shuangyashan	0.2421	0.2685	0.1958	0.1555
Qitaihe	0.3532	0.2540	0.2220	0.1740
Jixi	0.1556	0.2256	0.2336	0.2354
Daqing	0.3476	0.3219	0.2738	0.2831
Songyuan	0.1498	0.2339	0.2211	0.1826
Liaoyuan	0.1371	0.2277	0.2281	0.1744
Baishan	0.1591	0.3080	0.2996	0.1957
Fuxin	0.2196	0.1879	0.2078	0.2353
Fushun	0.3654	0.3014	0.2250	0.2264
Benxi	0.2838	0.3580	0.2454	0.2512
Panjin	0.2429	0.3066	0.2778	0.2954
Anshan	0.6529	0.3598	0.2545	0.2682
Huludao	0.2967	0.2382	0.1973	0.2098

Table 7. TOPSIS results of environmental subsystem for year 2000, 2005, 2010, and 2015.

Cities	2000	2005	2010	2015
Hegang	0.8151	0.3113	0.3052	0.3231
Yichun	0.8673	0.4241	0.3994	0.3426
Shuangyashan	0.8356	0.3319	0.2409	0.3087
Qitaihe	0.7888	0.2737	0.3516	0.3315
Jixi	0.8147	0.3240	0.3325	0.3135
Daqing	0.8829	0.6450	0.5769	0.4129
Songyuan	0.7823	0.3030	0.2910	0.2540
Liaoyuan	0.7943	0.2874	0.3444	0.3066
Baishan	0.7803	0.2591	0.3013	0.2915
Fuxin	0.8052	0.2809	0.2917	0.2680
Fushun	0.8039	0.3259	0.3536	0.3256
Benxi	0.8295	0.3350	0.2277	0.3069
Panjin	0.8149	0.3549	0.3452	0.3090
Anshan	0.7656	0.3187	0.3330	0.2989
Huludao	0.7603	0.2709	0.2821	0.2850

Table 8. Numerical interval for five levels in sustainability.

Layers	Extremely Low	Low	Medium	Upper Medium	High
Comprehensive	(0, 0.1]	(0.1, 0.2]	(0.2, 0.3]	(0.3, 0.4]	(0.4, 1]
economic subsystem	(0, 0.1]	(0.1, 0.2]	(0.2, 0.3]	(0.3, 0.4]	(0.4, 1]
Social subsystem	(0, 0.1]	(0.1, 0.2]	(0.2, 0.3]	(0.3, 0.4]	(0.4, 1]
Environmental subsystem	(0, 0.2]	(0.2, 0.4]	(0.4, 0.6]	(0.6, 0.8]	(0.8, 1]

4.2. Comprehensive Sustainability and Ranking

Observed from the ranking perspective, the orders of the sustainability in these cities almost has no change, for example, the top four cities with high sustainability in 2000 are Daqing, Anshan, Fushun, and Panjin, and those in 2015 are Daqing, Panjin, Anshan, and Benxi. However, by comparing in details, 9 of them show a decline trend in sustainability, while six of them show an extreme slow increase (Figure 2), for example, compared 2015 to 2000, the TOPSIS-based sustainability of Anshan reduced about 42.5%, followed by Qitaihe (38.6%), and Daqing (38.0%), in contrast, the biggest jump, in Liaoyuan, only up 18.0%, followed by Baishan (12.9%) and Songyuan (11.4%). According to the grouping results (Figure 3), in 2000, there are two cities (Daqing and Anshan) belonging to the high group, eight cities belonging to the low group, and five cities belonging to medium group; in 2005, Daqing city degrades to the upper medium group and another two cities (Qitaihe and Huludao) from the medium group to the low group, and then in 2015, the situation is the same as in 2005, even though three cities (Qitaihe, Songyuan, and Baishan) upgrade to the medium group in 2010, but return to the low group again in 2015.

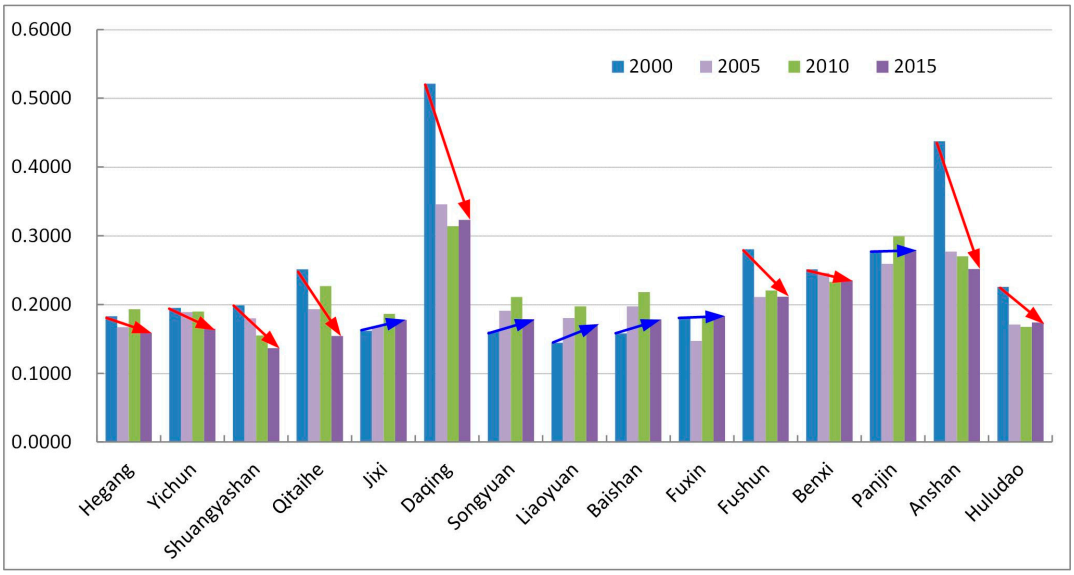

Figure 2. Illustration of the comprehensive results for year 2000, 2005, 2010, and 2015.

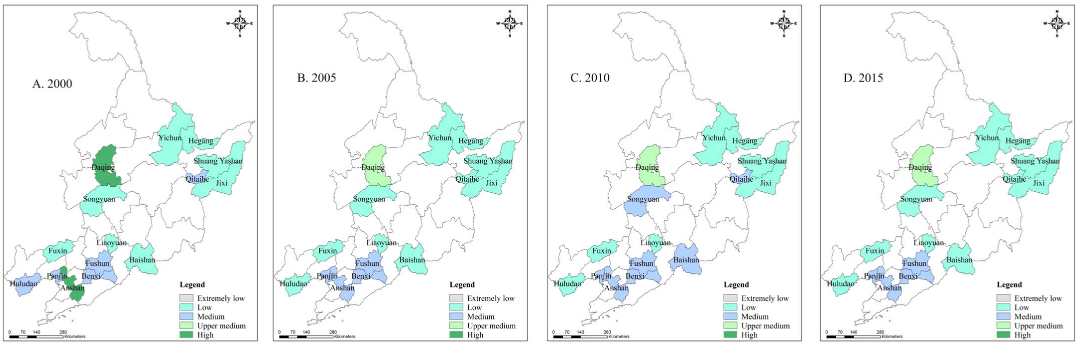

Figure 3. Mapping the TOPSIS-based sustainability for year 2000, 2005, 2010, and 2015.

4.3. Economic Subsystem

The order of the TOPSIS-based sustainability regarding economic subsystem in these 15 cities almost has no change in year 2000, 2005, 2010 and 2015, for example, the top three cities with higher sustainability in 2000 are Daqing, Panjin, and Anshan, and this is exactly the same order as in 2015 (Figure 4). In comparison for each city from the temporal perspective, 10 of them show various degree of increase, from 113.03% (Liaoyuan) to 9.95% (Huludao), and only Daqing city shows a decrease about 27.70%, and for the other four cities—Hegang, Shuangyashan, Qitaihe, and Jixi—they show an increase in 2005 and 2010 but decrease to almost the same level in 2015. From the spatial perspective (Figure 5), in 2000, a total of nine cities (accounts 60%) belong to the extremely low group, five cities belong to the low group, and only one city (Daqing) belongs to the high group, while in 2015, Daqing city degraded to the medium group and three more cities including Panjin, Anshan, and Benxi upgrade to the medium group, and four cities—Songyuan, Fuxin, Liaoyuan, and Baishan—upgraded to the low group. Provincially speaking, except Daqing, all cities located in Heilong province remain at the same level of extremely low both in 2000 and 2015, and cities located in Jilin province upgrade one level from extremely low to low.

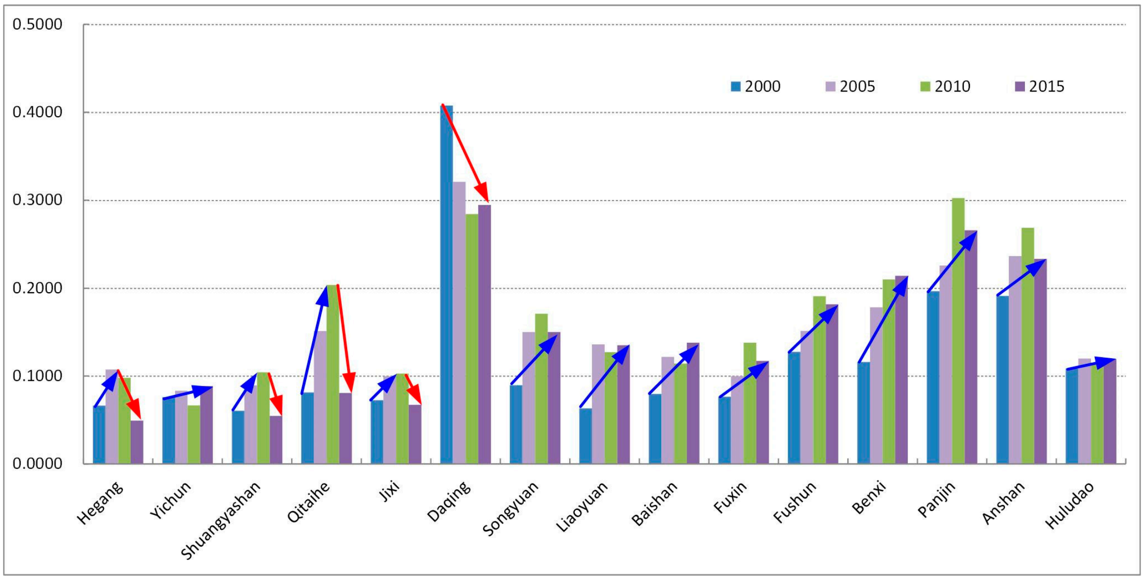

Figure 4. Illustration of the economic subsystem for year 2000, 2005, 2010, and 2015.

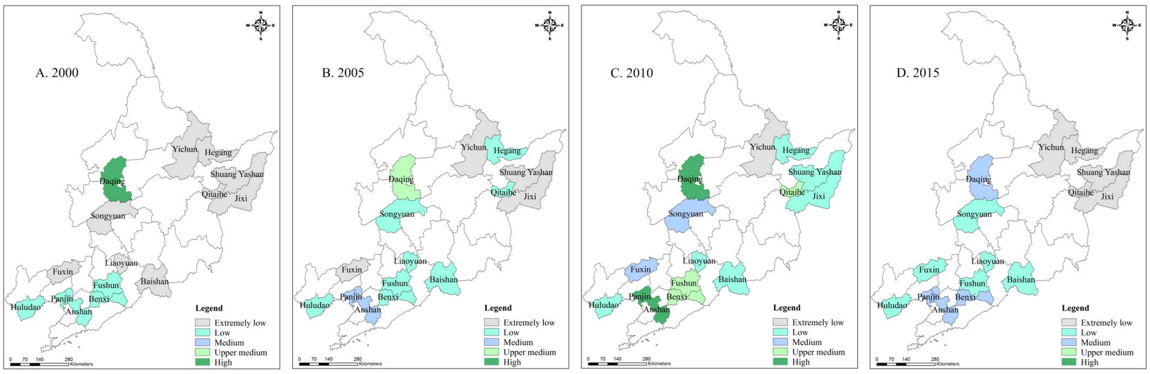

Figure 5. Mapping economic subsystem for year 2000, 2005, 2010, and 2015.

4.4. Social Subsystem

Concerning the social subsystem from TOPSIS analysis, taking into account these 15 cities social sustainability in four years, that means, among the 60 sample-points (15 cities times 4 years), only 10 (accounting for 16.67%) sample-points' value are over 0.30, and 35 (accounting for 58.33%) sample-points' value belonging to the interval of (0.20, 0.30] (medium group), and 15 (accounting for 25%) sample-points' value belong to the interval of (0.10, 0.20] (low group). Comparing the value of each city in year 2000 to that in year 2015, eight of them show various degree of decrease, from 58.92% (Anshan) to 8.37% (Hegang), and seven of them show increases to various degrees, from 51.31% (Jixi) to 0.96% (Yichun), even though some of these cities during the whole studied years show the phenomenon of first rose then descended (Figure 6). From the spatial perspective, the social sustainability of the cities (except Daqing) in Heilongjiang province have been improved at least one level from extremely low to low or medium, and that for all the cities in Jilin province improved from extremely low in 2000 to medium in 2010, but then decreased to low in 2015; for Liaoning province, generally, that for cities jumped two levels from low in 2000 to upper medium in 2005, but then remain at medium in 2010 and 2015 (Figure 7).

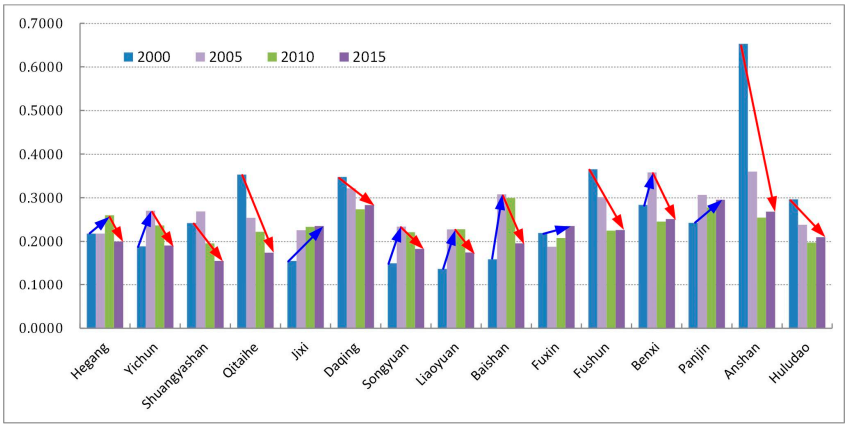

Figure 6. Illustration of the social subsystem for year 2000, 2005, 2010, and 2015.

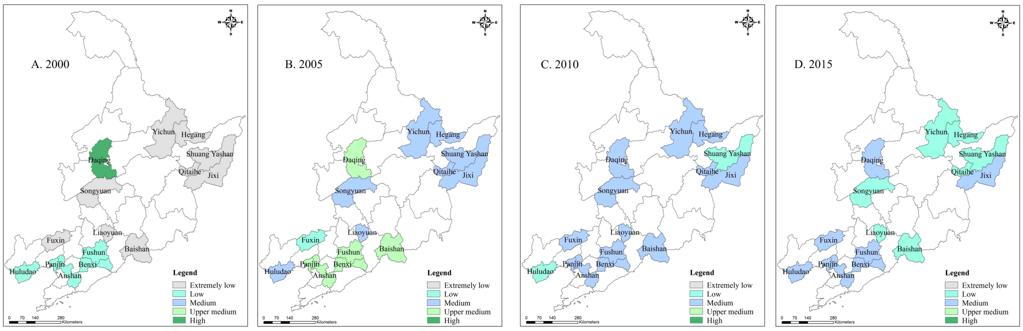

Figure 7. Mapping social subsystem for year 2000, 2005, 2010, and 2015.

4.5. Environmental Subsystem

Environmental subsystem in northeastern China has degraded seriously from 2000 to 2015 (Figures 8 and 9). The TOPSIS-based analysis shows that, in 2000, there are nine cities (accounting for 60%) belong to the high group and the other six cities (accounting for 40%) belong to the upper medium group, but 15 years later, in 2015, only one city (Daqing) belongs to group medium and the other 14 cites (accounting for 93.33%) belongs to the low group. In details, Daqing city reduced two levels from high to medium, eight cities (Yichun, Hegang, Shuangyashan, Jixi, Fuxin, Fushun, Benxi, and Panjin) decreased three levels from high in 2005 to low in 2015, and the other six cities (Qitaihe, Songyuan, Liaoyuan, Baishan, Anshan, and Huludao) decreased two levels from upper medium to low.

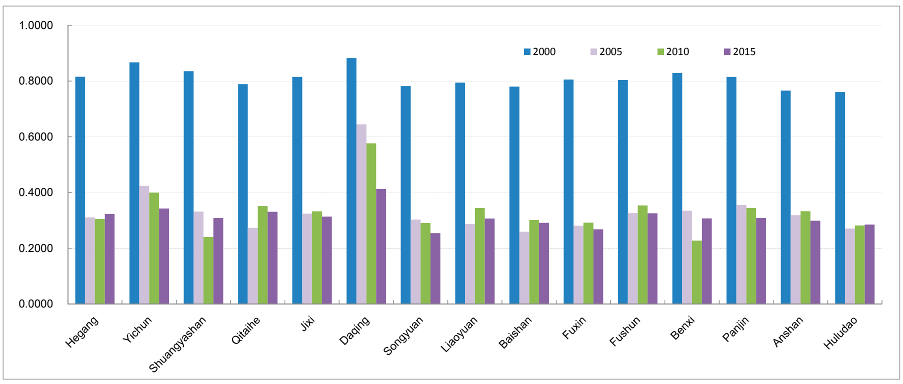

Figure 8. Illustration of the environmental subsystem for year 2000, 2005, 2010, and 2015.

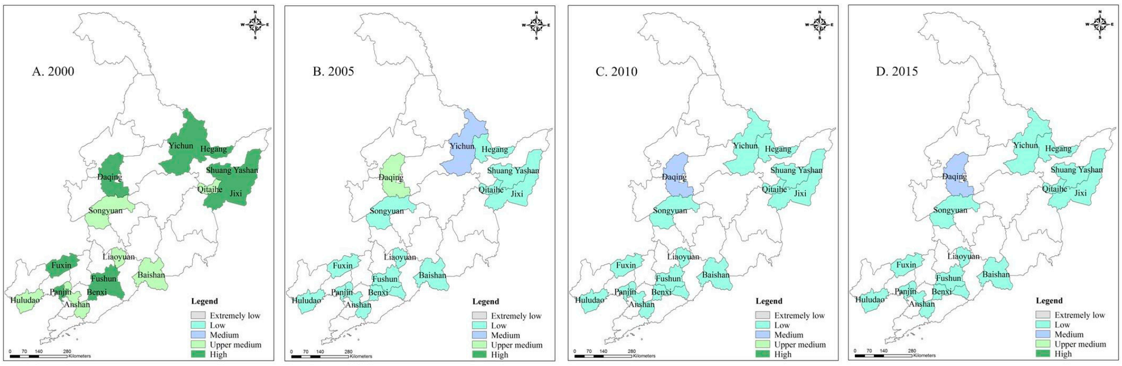

Figure 9. Mapping environmental subsystem for year 2000, 2005, 2010, and 2015.

5. Discussions and Conclusions

Sustainability of cities is one of the most critical issues faced by humans, given that more than half of the world's population live in urban and rapidly urbanizing areas [44]. Human activities happening in cities have significant impacts on its sustainability, due to the high intensity of population mobility, energy consumption, waste emission, and resources exploitation [35]—particularly for resource-based cities [45]. Currently, resource-based cities in China are faced with multiple economic, social, and environmental problems—such as resource depletion, unsatisfactory social welfare, and environmental pollution [46]—furthermore, after decades or even centuries of exploitation, natural resources such as minerals and coal are becoming exhausted, and their environmental pollution and ecological conditions are becoming worse [47], therefore, to investigate the sustainability of resource-based cities is an important step for policy makers as well as other relevant stakeholders—such as the public, scientific community, and investors—to have a better understanding on this issue.

With regarding the sustainability in the 15 resource-based cities of Northeastern China, the TOPSIS-based analysis show that, during the past 15 years from 2000 to 2015, the comprehensive sustainability of resource-based cities in Northeastern China shows a decline trend in the mass, and this could be due to the "lock in" effects of resource-based cities [47,48]. Specially, concerning on the three subsystems, it could be concluded that sustainability in the economic subsystem shows increase, remains stable in the social subsystem, and shows decrease in the environmental subsystem; furthermore, these situation might be resulted from the policy interventions during the past 15 years.

From 2000, the Chinese government started taking measures to improve resource-based cities. In 2001, Fuxin city was selected as the first pilot city under the program of economic transition for resource-exhausted cities in China, then in 2008, the State Council launched a document entitled with "*Opinions on Promoting the Sustainable Development of Resource-Based Cities*", with the objectives of establishing two main mechanisms: compensation mechanisms for resource exploitations and aid mechanisms for shrinking industries [49], then the State Council announced the first list of the resource-based cities name including 12 cities, followed in 2009, the second list including 32 cities was announced, for those selected cities, they will receive special financial transfer payments from the central government for improving their public service capacity. Based on the lessons and experiences learned from the pilot projects in 2013, the State Council launched a consolidated plan of the *Sustainable Development Plan for Resource-Based Cities* (2013–2020), aims to improve the overall capacity of sustainable transition and development [3].

Specially for northeastern China—one of the most famous industrial bases and a typical agglomeration area of resource-based cities—in October 2003, a remarkable document entitled with "*Opinions on the Strategy of Revitalizing Northeast China and Other Old Industrial Bases*" was promulgated by the Central Committee of the Communist Party of China and the State Council, and some resource-based-cities-related objectives were set up such as developing measures of compensation for resources exploitation and aid for shrinking industries, arranging special funds to support the transition and improving infrastructure [50]; then the National Development and Reform Commission launched the *Plan of Revitalizing Northeast China* in August 2007, in which promoting sustainable development of resource-based cities is taken as a key part. However, again, the main actions focused on the compensation for resources exploitation and industrial restructure [51]. From those policies, we found that the policy intervention these resource-based cities during the past years more focus on industrial re-structure with a bias towards to economic redevelopment, and lack of special policies regarding environmental protection and ecosystem conservation, and this would be the driving force behind why sustainability of the economic subsystem shows an increase while the environmental subsystem shows a decrease. For example, as the pilot resource-based city, Fuxin received 152 projects from the central and provincial governments, for developing new industries, changing the coal-based industrial structure and improving living standards of the local people [1].

Promoting the sustainability of resource-based cities needs a historical approach, which should focus on the coordinated development of its economic, social, and environmental subsystem. TOPSIS results on the sustainability investigation on the 15 resource-based cities in northeastern China suggest that a unilateral improvement of a subsystem—for example, increased industrial investment or subsidies for the economic subsystem—did not mean an improvement or contribution to whole system, however, green investment should be considered for creating co-benefits [52,53]. Moreover, in order to activate a sustainability policy that starts from a territorial observatory, the usefulness of assessment methods such as TOPSIS need to be further developed and applied to monitor the change over time of the indicators at the individual city level.

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References

1. Li, H.; Long, R.; Chen, H. Economic transition policies in Chinese resource-based cities: An overview of government efforts. *Energy Policy* **2013**, *55*, 251–260. [CrossRef]
2. Yu, C.; de Jong, M.; Cheng, B. Getting depleted resource-based cities back on their feet again—The example of Yichun in China. *J. Clean. Prod.* **2016**, *134*, 42–50. [CrossRef]
3. The State Council of China. Sustainable Development Plan for Resources-Based Cities in China (2013–2020). [File Number: State Council, 2013/43]. Available online: http://www.gov.cn/zwgk/2013-12/03/content_2540070.htm (accessed on 10 July 2016).
4. CPC Central Committee and State Council. Certain Opinions Regarding the Comprehensive Revival of Old Industrial Bases Including the Northeast. 2016. Available online: http://www.gov.cn/zhengce/2016-04/26/content_5068242.htm (accessed on 10 August 2016).
5. Brown, M.T.; Ulgiati, S. Emergy assessment of global renewable sources. *Ecol. Model.* **2016**, *339*, 148–156. [CrossRef]
6. Xue, B.; Chen, X.; Geng, Y.; Yang, M.; Yang, F.; Hu, X. Emergy-based study on eco-economic system of arid and semi-arid region: A case of Gansu province, China. *J. Arid Land* **2010**, *2*, 207–213.
7. Pan, Y.; Li, H. Sustainability evaluation of end-of-life vehicle recycling based on emergy analysis: A case study of an end-of-life vehicle recycling enterprise in China. *J. Clean. Prod.* **2016**, *131*, 219–227. [CrossRef]
8. Odum, H.T. *Environmental Accounting: Emergy and Environmental Decision Making*; John Wiley & Sons: New York, NY, USA, 1995.
9. Amaral, L.P.; Martins, N.; Gouveia, J.B. A review of emergy theory, its application and latest developments. *Renew. Sustain. Energy Rev.* **2016**, *54*, 882–888. [CrossRef]

10. Gallia, A.; Giampietro, M.; Goldfinger, S.; Lazarusd, E.; Lind, D.; Saltellie, A.; Wackernageld, M.; Müller, F. Questioning the Ecological Footprint. *Ecol. Indic.* **2016**, *69*, 224–232. [CrossRef]
11. Dunning, C. 230 Indicators Approved for SDG Agenda. Available online: http://www.cgdev.org/blog/230-indicators-approved-sdg-agenda (accessed on 10 August 2016).
12. Liu, J. China's road to sustainability. *Science* **2010**, *328*, 50. [CrossRef] [PubMed]
13. Zhang, L.; Xu, Y.; Yeh, C.-H.; Liu, Y.; Zhou, D. City sustainability evaluation using multi-criteria decision making with objective weights of interdependent criteria. *J. Clean. Prod.* **2016**, *131*, 491–499. [CrossRef]
14. Egilmez, G.; Gumus, S.; Kucukvar, M. Environmental sustainability benchmarking of the U.S. and Canada metropoles: An expert judgment-based multi-criteria decision making approach. *Cities* **2015**, *42*, 31–41. [CrossRef]
15. Li, Y.; Beeton, R.J.S.; Halog, A.; Sigler, T. Evaluating urban sustainability potential based on material flow analysis of inputs and outputs: A case study in Jinchang City, China. *Resour. Conserv. Recycl.* **2016**, *110*, 87–98. [CrossRef]
16. Zeng, L.; Wang, B.; Fan, L.; Wu, J. Analyzing sustainability of Chinese mining cities using an association rule mining approach. *Resour. Policy* **2016**, *49*, 394–404. [CrossRef]
17. Tang, X.; Zhang, B.; Höök, M.; Feng, L. Forecast of oil reserves and production in Daqing oilfield of China. *Energy* **2010**, *35*, 3097–3102. [CrossRef]
18. Fan, Z.; Huang, X.; Tan, L.; Yang, X.; Zhang, H.; Zhou, D.; Liu, Q.; Cao, B. A study of iron deposits in the Anshan area, China based on interactive inversion technique of gravity and magnetic anomalies. *Ore Geol. Rev.* **2014**, *57*, 618–627. [CrossRef]
19. Hwang, C.-L.; Yoon, K. *Multiple Attribute Decision Making—Methods and Applications a State-of-the-Art Survey*; Springer: Berlin/Heidelberg, Germany, 1981.
20. Jahanshahloo, G.R.; Lotfi, F.H.; Izadikhah, M. Extension of the TOPSIS method for decision-making problems with fuzzy data. *Appl. Math. Comput.* **2006**, *181*, 1544–1551. [CrossRef]
21. Wu, K.J.; Tseng, M.L.; Chiu, A.S.F. Using the Analytical Network Process in Porter's Five Forces Analysis–Case Study in Philippines. *Procedia Soc. Behav. Sci.* **2012**, *57*, 1–9. [CrossRef]
22. Quadros, S.G.R.; Nassi, C.D. An evaluation on the criteria to prioritize transportation infrastructure investments in Brazil. *Transp. Policy* **2015**, *40*, 8–16. [CrossRef]
23. Javid, J.R.; Nejat, A.; Hayhoe, K. Selection of CO_2 mitigation strategies for road transportation in the United States using a multi-criteria approach. *Renew. Sustain. Energy Rev.* **2014**, *38*, 960–972. [CrossRef]
24. Park, D.; Kim, Y.; Um, M.-J.; Choi, S.-U. Robust Priority for Strategic Environmental Assessment with Incomplete Information Using Multi-Criteria Decision Making Analysis. *Sustainability* **2015**, *7*, 10233–10249. [CrossRef]
25. Chen, Y.; Li, K.W.; Liu, S.F. An OWA-TOPSIS method for multiple criteria decision analysis. *Expert Syst. Appl.* **2011**, *38*, 5205–5211. [CrossRef]
26. Kim, G.; Park, C.S.; Yoon, K.P. Identifying investment opportunities for advanced manufacturing systems with comparative integrated performance measurement. *Int. J. Prod. Econ.* **1997**, *50*, 23–33. [CrossRef]
27. Shih, H.S.; Shyur, H.H.; Lee, E.S. An extension of TOPSIS for group decision making. *Math. Comput. Model.* **2007**, *45*, 801–813. [CrossRef]
28. Nădăban, S.; Dzitac, S.; IDzitac, I. Fuzzy TOPSIS: A General View. *Procedia Comput. Sci.* **2016**, *91*, 823–831. [CrossRef]
29. Behzadian, M.; Otaghsara, S.K.; Yazdani, M.; Ignatius, J. A state-of the-art survey of TOPSIS applications. *Expert Syst. Appl.* **2012**, *39*, 13051–13069. [CrossRef]
30. Çetinkaya, C.; Özceylan, E.; Erbas, M.; Kabak, M. GIS-based fuzzy MCDA approach for siting refugee camp: A case study for southeastern Turkey. *Int. J. Disaster Risk Reduct.* **2016**, *18*, 218–231. [CrossRef]
31. Morteza, Z.; Reza, F.M.; Seddiq, M.M.; Sharareh, P.; Jamal, G. Selection of the optimal tourism site using the ANP and fuzzy TOPSIS in the framework of Integrated Coastal Zone Management: A case of Qeshm Island. *Ocean Coast. Manag.* **2016**, *130*, 179–187. [CrossRef]
32. Dace, E.; Blumberga, D. How do 28 European Union Member States perform in agricultural greenhouse gas emissions? It depends on what we look at: Application of the multi-criteria analysis. *Ecol. Indic.* **2016**, *71*, 352–358. [CrossRef]
33. Zhang, L.; Xue, B.; Geng, Y.; Ren, W.; Lu, C. Emergy-based city's sustainability assessment: Indicators, features and findings. *Sustainability* **2014**, *6*, 952–966. [CrossRef]

34. Lynch, A.J.; Andreason, S.; Eisenmen, T.; Robinson, J.; Stelf, K.; Birch, E.L. Sustainable Urban Development Indicators for the United States. Available online: http://penniur.upenn.edu/uploads/media/sustainable-urban-development-indicators-for-the-united-states.pdf (accessed on 1 August 2016).
35. Tobias, M.; Xue, B. Sustainability in China: Bridging Global Knowledge with Local Action. *Sustainability* **2015**, *7*, 3714–3720.
36. Rametsteiner, E.; Pülzl, H.; Alkan-Olsson, J.; Frederiksen, P. Sustainability indicator development—Science or political negotiation? *Ecol. Indic.* **2011**, *11*, 61–70. [CrossRef]
37. Michael, F.L.; Noor, Z.Z.; Figueroa, M.J. Review of urban sustainability indicators assessment—Case study between Asian countries. *Habitat Int.* **2014**, *44*, 491–500. [CrossRef]
38. Wong, C. A framework for 'City Prosperity Index': Linking indicators, analysis and policy. *Habitat Int.* **2015**, *45*, 3–9. [CrossRef]
39. Ding, X.; Zhong, W.; Shearmur, R.G.; Zhang, X.; Huisingh, D. An inclusive model for assessing the sustainability of cities in developing countries—Trinity of Cities' Sustainability from Spatial, Logical and Time Dimensions (TCS-SLTD). *J. Clean. Prod.* **2015**, *109*, 62–75. [CrossRef]
40. UNEP. Sustainable Development Goals. Available online: https://sustainabledevelopment.un.org/sdgs (accessed on 5 August 2016).
41. Liaoning Bureau of Statistics. *Liaoning Provincial Statistical Yearbook (2001–2015)*; China Statistics Press: Beijing, China, 2001–2015.
42. Jilin Bureau of Statistics. *Jilin Provincial Statistical Yearbook (2001–2015)*; China Statistics Press: Beijing, China, 2001–2015.
43. Heilongjiang Bureau of Statistics. *Heilongjiang Provincial Statistical Yearbook (2001–2015)*; China Statistics Press: Beijing, China, 2001–2015.
44. Grimm, N.B.; Faeth, S.H.; Golubiewski, N.E.; Redman, C.L.; Wu, J.; Bai, X.; Briggs, J.M. Global change and the ecology of cities. *Science* **2008**, *319*, 756–760. [CrossRef] [PubMed]
45. Pani, N. Resource cities across phases of globalization: Evidence from Bangalore. *Habitat Int.* **2009**, *33*, 114–119. [CrossRef]
46. He, S.Y.; Lee, J.; Zhou, T.; Wu, D. Shrinking cities and resource-based economy: The economic restructuring in China's mining cities. *Cities* **2017**, *60*, 75–83. [CrossRef]
47. Dong, S.; Li, Z.; Li, B.; Xue, M. Problems and strategies of industrial transformation of China's resource-based cities. China Population. *Resour. Environ.* **2007**, *17*, 12–17.
48. Grabher, G. The weakness of strong ties: The lock-in of regional development in the Ruhr area. In *The Embedded Firm: On the Socioeconomics of Industrial Networks*; Grabher, G., Ed.; Routledge: London, UK; New York, NY, USA, 1993; pp. 255–277.
49. The State Council. Opinions on Promoting the Sustainable Development of Resources-Based Cities. Available online: http://www.gov.cn/zwgk/2013-12/03/content_2540070.htm (accessed on 10 August 2016). (In Chinese)
50. The Central Committee of the Communist Party of China and the State Council. Opinions on the Strategy of Revitalizing Northeast China and Other Old Industrial Bases. Available online: http://www.chinabaike.com/law/zy/0978/1419299.html (accessed on 10 August 2016). (In Chinese)
51. National Development and Reform Commission. Plan of Revitalizing Northeast China. Available online: http://www.sdpc.gov.cn/fzgggz/fzgh/ghwb/gjjgh/200709/P020150630514153248052.pdf (accessed on 10 August 2016). (In Chinese)
52. Xue, B. Honing the Climate Change Message. *Science* **2015**, *348*, 872. [CrossRef] [PubMed]
53. Xue, B.; Mitchell, B.; Geng, Y.; Ren, W.; Müller, K.; Ma, Z.; de Oliveira, J.A.P.; Fujita, T.; Tobias, M. A review on China's pollutant emissions reduction assessment. *Ecol. Indic.* **2014**, *38*, 272–278. [CrossRef]