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Application of TOPSIS Model with Entropy Weights for Sustainability Assessment at Prefecture-Level Cities in China

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Sustainable development is a multidimensional concept. Many different sets of sustainability indicators including some composite indices have been developed over the years to assess progress to sustainable development in a place. None of the indices has universal acceptance. This paper attempts to evaluate progress toward sustainable development at 242 representative prefecture-level cities in China using a multi-criteria decision making method, TOPSIS, with entropy weights. One of the advantages of TOPSIS method is that it uses cost benefit approach with importance weights of the indices. In order to construct the sustainability evaluation index system, we use 46 indices under 11 criteria that belong to 3 subsystems – economic, social, and resource and environmental. The results show that the Spearman rank-correlation coefficient between the sustainability ranking of cities based on TOPSIS model and the ranking of cities based on per capita GDP is only 0.43, while that between sustainability ranking and GDP ranking is 0.81 with a rank difference as high as 230. Another finding of this study is that resource-based cities top the list based on per capita GDP ranking, but they don't do as well in sustainability ranking based on TOPSIS model with entropy weights.

Keywords: Sustainability assessment; TOPSIS; entropy weight; prefecture-level cities; China

1. Introduction

The concept of sustainable development came to the forefront three decades ago with the publication of the Brundtland Commission Report (1987). It is a multidimensional concept. There is no universally accepted set of sustainability indicators or a composite index. In this study, we will evaluate the progress toward sustainable development at 242 representative prefecture-level cities in China using a multi-criteria decision making method, TOPSIS, with entropy weights.

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TOPSIS stands for the Technique for Order of Preference by Similarity to Ideal Solution. Entropy method is a mechanism to find objective weights for the indicators in sustainability evaluation system. Based on our methodology, we will get a composite score for each city, which will be used to rank the cities. We will also rank the cities based on GDP and GDP per capita and make a comparison of the ranks.

We expect to see a widespread variation in ranking based on income method verses our multi-criteria decision making method. It will help us understand how some cities could make their development more sustainable than the development in some other cities. Also, we may be able to extrapolate if there is a trade-off between higher income and progress toward sustainable development. We may be able to understand the implications of local resource availability and the nature of industries on these rankings as well.

TOPSIS method, developed by Hwang and Yoon (1981), is a ranking method in presence of multiple decision alternatives and performance criteria. Other popular multi-criteria decision analysis (MCDA) methods are the Simple Multiple Attribute Rating Technique (SMART), the Analytic Hierarchy Process (AHP), the Simple Additive Weighting (SAW), etc. TOPSIS ranks alternatives by simultaneously considering distances from the positive ideal solution and the negative ideal solution. It has been used a lot in management science, operations research, energy management, and in various other areas. A survey article by Behzadian, et. al. (2012) reviewed 266 articles from 103 journals since 2000.

In sustainability literature, its use has been limited. Nang Idayu & Lazim (2012), Streimikiene & Balezentis (2013), and Hedayati-Moghadam (2014) used them to assess sustainability in Malaysia, Lithuania, and Iran respectively. In a recent study, Balcerzak and Pietrzak (2016) applied TOPSIS method to analyze sustainable development in EU countries. Their analysis shows that the new members of EU have made significant progress toward sustainable development.

When it comes to sustainability assessment, there is a divide between mainstream economists and others. Mainstream economists prefer monetary indicators, while many others like to use physical indicators. For example, the Genuine Progress Indicator (GPI), the Index for Sustainable Economic Welfare (ISEW), etc. are some kind of GDP corrections. On the other hand, most international agreements including the recent Paris agreement (limit temperature rise to 2^{o} C) emphasize on quantitative indicators. Some indices such as the Genuine Wealth use subjective weights in assessing sustainability. The Human Development Index (HDI), which uses income, education, and health as three major indicators, is not a sustainability index, but is often mentioned along with sustainability indices as it claims to measure end goals of life. The Happy Planet Index (HPI) is another popular index that was developed to measure sustainable well-being.

One of the reasons why we prefer to use TOPSIS method for sustainability assessment is because of its use of less subjective inputs. The accuracy of TOPSIS method, however, depends on using proper weights (see Olson, 2004). We use entropy method to derive objective weights.

Rank reversal could be a potential problem of TOPSIS method. More complicated fuzzy TOPSIS method can solve that problem. A careful selection of indicators can also minimize that problem. We prefer to use TOPSIS model with entropy weights because it is “computationally simple,” “rational,” and “comprehensible” (Huang, 2008).

One of the important results of this paper is that the Spearman rank-correlation coefficient between the sustainability ranking of cities based on TOPSIS model and the ranking of cities based on per capita GDP is quite small. It means that emphasizing economic growth alone cannot be sufficient for sustainable development. Another finding is that the resource-based cities rank high in terms of per capita GDP ranking, but they rank relatively low in sustainability ranking based on our methodology. It re-iterates the need for re-thinking about resource-based economic development. To our knowledge, no such work has been done with data from prefecture-level cities in China using the same methodology. The remainder of this paper is organized as follows. Section 2 provides the literature review. Section 3 explains the methodology and data selection process. Results are provided in Section 4, and Conclusion is in Section 5.

2. Literature Review

2.1 Research on the Evaluation of Urban Sustainable Development

Data shows that the urban population has been growing steadily in all parts of the world. As a result, urban consumption of resources and energy has been increasing over time, which poses a serious threat to sustainable development for the modern urban environment (Girardet, 2014).

Urban sustainability is defined as "solving problems encountered in cities and problems caused by cities." Evaluation of sustainability is an important part of sustainable development research. The definition of sustainability assessment focuses on the prospects for long-term net income and the acceptability of relevant trade-offs for general equilibrium rules (Gibson, 2006; Pope et al., 2004; Winfield et al., 2010).

The core purpose of sustainability assessment is to provide decision makers with information about the operation of complex natural and social systems, from local to global scales, in the short-term and long-term, to support their management decisions. Devuyst, Hens and De Lannoy (2001) assert that sustainability assessment aims to guide countries in a “more sustainable direction by providing tools that can be used to predict the impact of various initiatives on the sustainable development of society." Sustainability assessment provides decision makers with an assessment of global and local integrated natural and social systems from a short-term and long-term perspective to help them determine what actions should or should not be taken for sustainable social development (Devuyst, 2000; Ness et al., 2007).

Some researchers believe that sustainability indicators may become an important tool for governance of urban sustainability (Puppha and Zuidema, 2017). As pointed out by Yigitcanlar and Teriman (2015), comprehensive and accurate information is needed to support decision-making, policy analysis, and planning. The information is collected and evaluated through a sustainability assessment indicator model.

Sustainability assessment has been developed conceptually and practically in the research on sustainable urban development of Global Cities (George and Kirkpatrick, 2007). Pope et al. (2004) conceptually reviewed several sustainability assessment methods, such as Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), goal-oriented SEA, comprehensive assessment based on EIA, goal-oriented comprehensive assessment, and sustainability assessment relying on principle. In urban sustainability assessment, the triple bottom line method covering the environment, economy, and society is a starting point (Pope et al., 2004).

One of the most well-known indicator frameworks in the study of sustainable urban development assessment is the OECD's Pressure-State-Response Framework (PSR), which is based on “stress” indicators that describe human influence on the environment, national level “state” indicators that assess environmental and resource conditions, and “response” indicators that indicate people’s response to environmental issues (Segnestam, 2002). The urban sustainability framework should be derived from at least three aspects, i.e., society, economy and environment. Some scholars have put forward the FEEM sustainability index (Pinar et al., 2014), such as the Transport Sustainability Index (Reisi et al. 2014), the Sustainable Happiness Index (Cloutier et al. 2014), and the Comprehensive Sustainability Index (Chand et al. (2015). Different types of indicators such as the Water Resources Sustainability Index (Juwana et al., 2016) and the General Distributed Sustainability Index (Duro, 2016) also attempt to assess sustainable urban development. These methods involve dozens of environmental, economic, and social indicators.

Koichiro Mori (2015) proposed an evaluation system called "City Sustainability Index (CSI).” The indices in this evaluation system cover the missing factors in the previously proposed sustainability indicators. In the past two decades, a large volume of research work was carried out on sustainable development of Chinese cities. Zhang et al. (2000) empirically showed that real savings can be used as a systematic indicator to measure the degree of sustainable development of the urban environment of China. Jin et al. (2001) developed the coastal zone sustainable development evaluation index system. Sun and Zhang (2006) proposed the basic framework of sustainable urban development, and defined China's sustainable development strategies. Niu (2006) pointed out that the evaluation of urban sustainable development capability should take urban development, coordination, and sustainability into consideration. Li (2007) pointed out that the evaluation method of urban sustainable development is the main basis for measuring the effectiveness of planning, construction and management of Chinese urban ecology and environment.

The “2010 China Sustainable Urban Development Report,” published by the Institute of Urban Environment, Chinese Academy of Sciences, evaluated the sustainable development of 35 major cities in China in 2008, highlighting the importance of sustainable development assessment in cities. Zhang et al. (2015) pointed out that the core factor of sustainable urban development is the satisfaction and happiness of people's lives.

2.2 Methods used for Sustainability Assessment of Chinese Cities in the Existing Literature

Li et al. (2007) proposed an evaluation index system for urban sustainable development, which includes economic development, ecological construction, environmental protection, and social progress. Comprehensive evaluation was performed using a fully-arranged polygonal comprehensive graphic method. The results were quite realistic. Guo et al. (2010) used the combination of subjective and objective weights to generate comprehensive DEA indicators and constructed an urban sustainable development capability evaluation system. Wang and Zhang (2014) used spatial vector method to construct a three-dimensional spatial structure model of urban sustainable development, and assessed the sustainable development capability of Lanzhou City from 1998 to 2009. Liu (2014) adopted a fuzzy comprehensive evaluation method to construct a two-level fuzzy comprehensive evaluation model and conducted empirical research on the 12 major cities in Heilongjiang.

Liu (2014) applied the Delphi method, AHP, and grey relational analysis on the basis of an evaluation index system reflecting social, economic, resource, environmental, and institutional aspects. Furthermore, the principal component analysis method was used to determine the index weights, and the evaluation result was calculated by weighted average of the index values. Chen (2015) and others designed an urban sustainable development capability evaluation system based on the Data Envelopment Analysis (DEA) model to evaluate the sustainability of 15 sub-provincial cities.

Zhu and Yang (2016) used factor analysis to extract four common factors from 17 indicators, and conducted cluster analysis on 30 provinces and cities in China, and comprehensively evaluated their sustainable development capabilities. Zhang (2015) selected 42 indicators and used principal component analysis to evaluate the sustainable development of 264 cities in China from 1990 to 2011. Dong et al. (2016) evaluated 6 typical methods used in urban sustainable development assessment, namely, input-output analysis, life cycle analysis, ecological footprint, carbon footprint, energy analysis, and cost-benefit analysis. In the research of Liu et al (2018), for the first time, an income indicator was used for the classification and assessment of ecological cities.

The literature review in sections 2.1 and 2.2 shows that global studies of urban sustainable development rarely focused on the evaluation of sustainable development of Chinese cities. The literature on sustainability of urban areas in China rarely focused on prefecture-level cities. Furthermore, the usage of entropy-weight TOPSIS model in the evaluation of sustainable development capabilities for Chinese cities is also not common. Therefore, our study uses a relatively new method for sustainability assessment of prefecture-level Chinese cities. The dataset is also unique.

3. Methodology and Data

In evaluating urban sustainable development, a large number of researchers use Delphi method and AHP method. One of the major disadvantages of these methods is the subjectivity of the weighting of the indicators. Compared with these methodologies, entropy-weight TOPSIS method imposes no restrict on index dimension and sample size, and weights of the indicators are assigned objectively. Therefore, we chose to use this method for our study.

3.1 TOPSIS and Entropy Weights

This paper makes an attempt to evaluate progress toward sustainable development at prefecture-level cities in China using the TOPSIS model with entropy weights. Following is a brief description of entropy weight based TOPSIS method. Suppose that there exist m feasible solutions to be evaluated and n indices in the index system. The values of the indices in each feasible solution make up the decision-making matrix Y in which y_{ij} represents the element in the matrix, representing the value of the j^{th} index in the i^{th} feasible solution ($i=1,2,...,m$; $j=1,2,...,n$). In order to use the entropy weight based TOPSIS method as an evaluation technique, the following steps need to be performed:

Step 1: Normalize the decision-making matrix.

Normalize the decision-making matrix Y as follows to obtain the normalized matrix Z:

$$z_{ij} = y_{ij} / \sqrt{\sum_{i=1}^{m} y_{ij}^2} \quad (1)$$

Step 2: Calculate the entropy values of the indices.

According to the definition of *entropy* in the information theory, the entropy of the j^{th}

index is determined as follows:

$$H_j = -k\sum_{i=1}^{m} f_{ij} \ln f_{ij} \qquad (2)$$

Where $f_{ij} = y_{ij} / \sum_{i=1}^{m} y_{ij}$, $k = 1/\ln m$, $i = 1,2,...,m$; $j = 1,2,...,n$.

Step 3: Calculate the entropy weights of the indices.

The entropy weight of the j^{th} index is determined by transforming the entropy value, H_j, as follows:

$$w_j = (1 - H_j) / (n - \sum_{j=1}^{n} H_j) \qquad (3)$$

Where $j = 1,2,...,n$.

Through this transformation of all entropy values, the entropy weight matrix , W, is obtained, where $W = (w_1 , w_2 ,..., w_n)$.

Step 4: Calculate the normalized weighted matrix X.

The calculation is done using the following formula:

$$x_{ij} = w_j \times z_{ij} \qquad (4)$$

Where $i = 1,2,...,m$; $j = 1,2,...,n$.

Step 5: Determine the ideal positive solution X^* and the ideal negative solution X^0.

Suppose that x_j^* is the value of the ideal positive solution of the j^{th} index in X^* and x_j^0 is the value of the ideal negative solution of the j^{th} index in X^0.

Then for each x_j^* :

$$\begin{cases} x_j^* = \max_i x_{ij}, \text{if the } j^{th} \text{index is a benefit index} \\ x_j^* = \min_i x_{ij}, \text{ if the } j^{th} \text{index is a cost index} \end{cases} \qquad (5)$$

Furthermore, for each x_j^0 :

$$\begin{cases} x_j^0 = \max_i x_{ij}, \text{if the } j^{th} \text{index is a cost index} \\ x_j^0 = \min_i x_{ij}, \text{ if the } j^{th} \text{index is a benefit index} \end{cases} \qquad (6)$$

Step 6: Calculate the Euclidean distances of each feasible solution from the ideal positive solution and the ideal negative solution.

The Euclidean distance for each feasible solution from the ideal positive solution and the ideal negative solution are calculated by using equations (7) and (8).

$$d_i^* = \sqrt{\sum_{j=1}^{n}(x_{ij} - x_j^*)^2}\ ,\quad i = 1,2,...,m\ ;\quad j = 1,2,...,n \tag{7}$$

$$d_i^0 = \sqrt{\sum_{j=1}^{n}(x_{ij} - x_j^0)^2}\ ,\quad i = 1,2,...,m\ ;\quad j = 1,2,...,n \tag{8}$$

Where d_i^* denotes the distance of the i^{th} unit from the ideal positive solution, d_i^0 denotes the distance of the i^{th} unit from the ideal negative solution.

Step 7: Calculate the relative degree of approximation.

The relative degree of approximation is obtained by calculating the Euclidean distance of each feasible solution from the ideal positive solution and the ideal negative solution as follows:

$$]\,C_i^* = d_i^0 / (d_i^0 + d_i^*)\ ,\ 0 \le C_i^* \le 1\ ,\quad i = 1,2,...,m \tag{9}$$

After these calculations, the feasible solutions could be ranked according to the values of the relative degree of approximation. The feasible solution with a higher C_i^* is a better solution.

3.2 Selected Cities, Indices and Data

According to the definition and classification of *China City Statistical Yearbook (2013),* published by the National Bureau of Statistics of China, this paper selects 242 representative prefectural cities in China in order to evaluate the level of sustainable development at prefecture-level cities. Based on existing research and consideration of comprehensiveness, representativeness, comparability, and availability, this paper uses 46 indices under 11 criteria that fall under three subsystems – economic development, social development, and resource and environment system – to construct the evaluation index system of sustainable development level. The details of the subsystems, criteria, and indices are shown in **Table 1**. The source of the data is *China City Statistical Yearbook (2013),* which contains data for each index in 2012.

Table 1: Evaluation Index System of Sustainable Development Level for Prefecture-Level Cities

Objective	Subsystem	Criteria	Index	+/-	Code
Sustainable Development Level	Economic Development (A)	Economic Scale A1）	Per Capita GDP	+	A11
			Investment in Fixed Assets	+	A12
			Total Retail Sales of Consumer Goods	+	A13
			Gross Industrial Output Value above Designated Size	+	A14
			Ratio of Deposits of Banking System to GDP	+	A15
		Industrial Structure A2）	Secondary Industry as Percentage to GDP	+	A21
			Tertiary Industry as Percentage to GDP	+	A22
			Composition of Employed Persons in Secondary Industry	+	A23
			Composition of Employed Persons in Tertiary Industry	+	A24
		Economic Benefit A3）	Local Government General Budget Revenue	+	A31
			General Budget Revenue-Expenditure Ratio of Local Public Government	+	A32
			Per Capita Household Saving Deposits at Year-end	+	A33
			Average Wage of Employed Staff and Workers	+	A34
	Social Development (B)	Infrastructure B1）	Population Density	+	B21
			Per Capita Area of Paved Roads in Districts under City	+	B22
			Number of Local Telephone Subscribers Per 10000 Population	+	B23
			Number of Mobile Telephone Subscribers Per 10000 Population	+	B24
			Length of City Sewage Pipes on Total Land Area of Administrative region in Districts under City	+	B25
			Ratio of Expenditure for Maintaining and Building Cities to GDP in Districts under City	+	B26
		Science & Education Support B2）	Ratio of Science and Technology Expenditure in Local Government General Budget Expenditure	+	B21
			Ratio of Education Expenditure in Local Government General Budget Expenditure	+	B22
			Number of Full-time Teachers in Regular Institutions of Higher Education per 10000 Population	+	B23
			Number of Full-time Teachers in Vocational Secondary Schools per 10000 Population	+	B24
			Number of Full-time Teachers in Regular Secondary Schools per 10000 Population	+	B25
			Number of Full-time Teachers in Primary Schools per 10000 Population	+	B26
			Number of Collections of Public Libraries per 100 Population	+	B27

Source: China City Statistical Yearbook (2013)

Table 1 (Cont'd): Evaluation Index System of Sustainable Development Level for Prefecture-Level Cities

Objective	Subsystem	Criteria	Index	+/-	Code
Sustainable Development Level	Social Development (B)	City Construction B3）	Total Passenger Traffic	+	B31
			Total Freight Traffic	+	B32
			Real Revenue from Postal Services	+	B33
			Real Revenue from Telecommunication Services	+	B34
			Number of Public Transportation Vehicles per 10000 Population in Districts under City	+	B35
			Number of Hospitals and Health centers per 10000 Population	+	B36
			Number of Beds of Hospitals and Health Centers per 10000 Population	+	B37
			Number of Doctors (Licensed Doctors + Assistant Doctors) per 10000 Population	+	B38
		Social Security B4）	Ratio of Persons Covered by Basic Pension Insurance to Total Population	+	B41
			Ratio of Persons Covered by Basic Medical Care Insurance to Total Population	+	B42
			Ratio of Persons Covered by Unemployment Insurance to Total Persons Employed	+	B43
	Resource & Environment System C）	Resource Utilization C1）	Per Capita Water Consumption for Residential Use in Districts under City	-	C11
			Ratio of Industrial Electricity Consumption to GDP in Districts under City	-	C12
		Environmental Pollution C2）	Volume of Industrial Waste Water Discharged per GDP	-	C21
			Volume of Sulfur Dioxide Emission per GDP	-	C22
			Volume of Industrial Soot(dust) Emission per GDP	-	C23
		Environmental Protection C3）	Ratio of General Industrial Solid Wastes Comprehensively Utilized	+	C31
			Ratio of waste Water Centralized Treated of sewage work	+	C32
		Ecological Construction C4）	Per Capita Area of Green Land in Districts under City	+	C41
			Green Covered Area as Percentage of Completed Area in Districts under City	+	C42

Source: China City Statistical Yearbook (2013)

4. Analysis of the Level of Sustainable Development at Prefecture-Level Cities in China

Using equation (1), this paper first normalizes the original dataset that includes data on 46 indices from 242 prefecture-level cities in 2012. Next, we calculate entropy value and entropy-weight of each index according to equations (2) and (3). The results are shown in **Table 2**.

Table 2: Entropy Weights of Index System of Sustainable Development Level for Prefecture-Level Cities

Objective	Subsystem	Weight	Criteria	Weight	Index Code	Entropy Value	Weight
Sustainable Development Level	Economic Development (A)	17.87%	Economic Scale A1）	10.94%	A11	0.97240433	0.0132377
					A12	0.95694278	0.0206546
					A13	0.94004131	0.0287623
					A14	0.91822261	0.0392288
					A15	0.98434548	0.0075095
			Industrial Structure A2）	1.10%	A21	0.99652405	0.0016674
					A22	0.99564635	0.0020885
					A23	0.99067268	0.0044743
					A24	0.99428274	0.0027426
			Economic Benefit A3）	5.84%	A31	0.93452541	0.0314083
					A32	0.98200632	0.0086316
					A33	0.96490145	0.0168369
					A34	0.99688196	0.0014957
	Social Development (B)	54.21%	Infrastructure B1）	15.21%	B21	0.95720439	0.0205291
					B22	0.97409497	0.0124267
					B23	0.97256137	0.0131624
					B24	0.97828319	0.0104176
					B25	0.88370077	0.055789
					B26	0.91718551	0.0397263
			Science & Education Support B2）	10.54%	B21	0.95505405	0.0215607
					B22	0.99657017	0.0016453
					B23	0.90418772	0.0459614
					B24	0.97957879	0.0097961
					B25	0.99634765	0.001752
					B26	0.99629411	0.0017777
					B27	0.95218098	0.0229389

Table 2 (Cont'd): Entropy Weights of Index System of Sustainable Development Level for Prefecture-Level Cities

Objective	Subsystem	Weight	Criteria	Weight	Code	Entropy Value	Weight
Sustainable Development Level	Social Development (B)	54.21%	City Construction B3）	21.42%	B31	0.90013493	0.0479055
					B32	0.88821301	0.0536245
					B33	0.93326932	0.0320109
					B34	0.94041509	0.028583
					B35	0.97036504	0.014216
					B36	0.94608216	0.0258645
					B37	0.99070061	0.0044609
					B38	0.98433291	0.0075155
			Social Security B4）	7.05%	B41	0.94986646	0.0240492
					B42	0.96245303	0.0180114
					B43	0.94077561	0.0284101
	Resource & Environment System C）	27.91%	Resource Utilization C1）	4.28%	C11	0.96355168	0.0174843
					C12	0.94732601	0.0252678
			Environmental Pollution C2）	20.29%	C21	0.95639571	0.0209171
					C22	0.93741128	0.0300239
					C23	0.68330291	0.1519203
			Environmental Protection C3）	0.62%	C31	0.99107305	0.0042823
					C32	0.99591703	0.0019586
			Ecological Construction C4）	2.73%	C41	0.9478023	0.0250394

Based on the entropy weights of the indices in **Table 2**, the scores in the evaluation of sustainable development level of prefecture-level cities are calculated. The cities are ranked according to the scores. **Table 3** shows comparative ranks based on TOPSIS method with entropy weights, GDP, and GDP per capita for the top 10 cities based on TOPSIS ranking. **Figure 1** shows the relationship between TOPSIS ranking and per capita GDP ranking with a scatter diagram. **Figure 2** shows the GDP, per capita GDP and TOPSIS ranking with line graphs.

Table 3: Comparison of TOPSIS Ranking with GDP and GDP Per Capita Rankings

City	Score	S Rank	G pc Rank	G Rank
Wuwei	0.76926351	1	218	231
Suzhou	0.71822464	2	7	1
Wuxi	0.69585518	3	5	2
Hefei	0.69405912	4	44	11
Zhengzhou	0.69361209	5	28	5
Foshan	0.69159036	6	11	3
Shijiazhuang	0.69009984	7	77	9
Changsha	0.68945311	8	12	4
Yantai	0.68501617	9	22	6
Nantong	0.683986	10	27	8

Figure 1: TOPSIS and Per Capita GDP Rankings

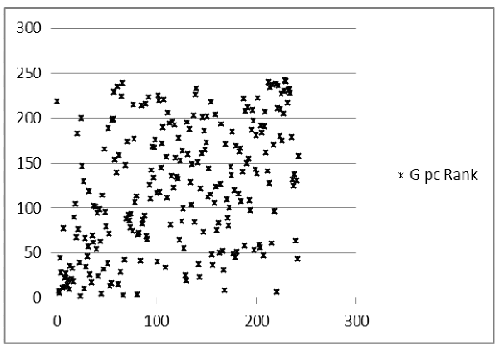
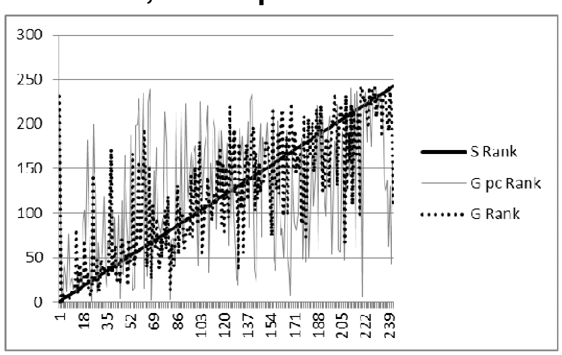


Figure 2: TOPSIS, Per Capita GDP and GDP Rankings



Based on the comparative ranks, it is evident that sustainable development level does not solely depend on GDP or GDP per capita. The Spearman rank-correlation coefficient between the sustainability ranking of cities based on TOPSIS model and the ranking based on per capita GDP is only 0.43, while that between sustainability ranking and GDP ranking is 0.81 (showed in **Table 4**) with a rank difference as high as 230.

Table 4: Spearman Rank-Correlation Matrix

	Score	S Rank	GDP pc	G pc Rank	GDP	G Rank
Score	1					
S Rank	-0.31238	1				
GDP pc	0.127617	-0.411	1			
G pc Rank	-0.11836	0.430948	-0.84731	1		
GDP	0.195162	-0.69007	0.569464	-0.51541	1	
G Rank	-0.13812	0.814668	-0.46176	0.517138	-0.7887	1

The implication of these results is that per capita GDP alone is not a good indicator to measure progress toward sustainable development.

Table 5: Geography and Major Economic Driving Forces in Five Top Ranked Cities Based on TOPSIS Model

City	S rank	Province	Population	Geography	Industries	GDP pc rank
Wuwei	1	Gansu	1.8 m	3 plateaus	Agriculture	218
Suzhou	2	Jiangsu	5.4 m	Canals, bridges, gardens	Manufacturing	7
Wuxi	3	Jiangsu	6.4 m	Alluvial plain	Manufacturing	5
Hefei	4	Anhui	7.5 m	Largest fresh water lake	Manufacturing	44
Zhengzhou	5	Henan	8.6 m	River, plain, mountains	Agri, mining & manufacturing	28

Source of population data: 2010 Population Census, The National Bureau of Statistics of China.

Table 6: Geography and Major Economic Driving Forces in Five Top Ranked Cities Based on GDP Per Capita

City	GDP pc rank	Province	Population	Geography	Industries	S rank
Erdos	1	Inner Mongolia	1.9 m	Deserts, hills	Natural resources	24
Dongying	2	Sandong	2.0 m	River delta	Petroleum	67
Daqing	3	Heilongjiang	2.9 m	Wetland & prairies	Petroleum & related industries	81
Baotou	4	Inner Mongolia	2.7 m	River, plateau & mountains	Mining	45
Wuxi	5	Jiangsu	6.4 m	Alluvial plain	Manufacturing	3

Source of population data: 2010 Population Census, The National Bureau of Statistics of China.

It is somewhat evident from these two tables that resource based and manufacturing based cities are in general ahead in terms of average income (GDP per capita). However, not all of them do as well in sustainability ranking. Geographical location and provincial government policies have some implications on that. It is interesting to see that Wuwei city, which ranks #1 in sustainability ranking is one of the poorest cities in terms of average income. And, its economy is dependent on agriculture. Rostow's stages of economic growth theory states that industrialization is the key for take-off of an economy. The low average income at Wuwei City may seem to be consistent with that theory, but the astounding development in other indicators can be seen as a challenge to Rostow's theory. We will explore the Environmental Kuznets curve relationship in a future study.

5. Conclusion

As there is no linear relationship between GDP per capita and overall well-being of the people in present and future generations, it is important to focus on sustainable economic growth and development. Sustainable economic development being a multidimensional concept, its measurement is complex. Researchers have used various monetary and non-monetary approaches to measure sustainable level of development. However, none has gained universal acceptance.

When multiple "imperfect" methods are used to assess the same performance, probability rule tells us that the likelihood of the same or similar conclusion based on multiple methods to be incorrect is much lower. Therefore, we recommend using multiple methods to assess the level of sustainable development so that the biasness of a method toward anything can be minimized.

In this study, we used TOPSIS method with entropy weights to assess sustainable level of development at 242 prefecture-level cities in China. The results show that the sustainability rankings of cities are much different from GDP and GDP per capita rankings.

A low average income city, whose economy is dependent on agriculture, topped the chart of sustainable cities. A few cities have both high average income and sustainability score. When we compare top cities in terms of average income and sustainability score, it appears that their economies are mainly resource-based or manufacturing-based. Geographical location, government policies about industrialization and environmental regulations seem to have significant impact on their performance, measured by our evaluation index system. We must also note that higher sustainability ranking is not indicative of better air quality in the city. We used a composite index based on both costs and benefits considerations (e.g., income, pollution level, etc.). And, we would not expect a negative linear relationship between pollution or air quality index and sustainability score. A future study will look into PM 2.5, CO_2, and other available emission data and rank the cities in order to compare them with the sustainability ranks based on TOPSIS method with entropy weights.

We believe that by providing an evaluation index system and applying TOPSIS method with entropy weights, this study makes its contribution to the sustainability assessment literature. In the study of urban sustainable development index system, the quantification of the value of environmental resources is still controversial. Therefore, in this study, the value of environmental resources is not taken into consideration, which is one of the limitations of the study. In addition, although sustainable development is an important economic development goal throughout the world today, and many research institutions have also put forward various indicator systems for measuring sustainable urban development, the complexity of the index systems, and the lack of consensus is still a problem. Future studies should focus on the complexity of the index system, and on developing a more acceptable index system. Based on the current state of knowledge in this area, we believe that our methodology provides a valuable assessment of sustainability at the prefecture-level cities in China, which the policy-makers may find useful.

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