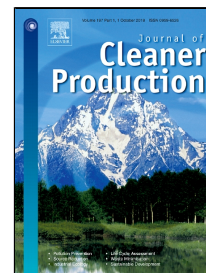


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A holistic evaluation of smart city performance in the context of China

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Abstract

Development of smart city has been increasingly accepted as a new technology-based solution to mitigate urban diseases. The Chinese government has been devoting good efforts to the promotion of smart city through introducing a series of policies. However, policies may have limited effectiveness in application if they do not respond to the practice. There is little study examining what results have been achieved in practice by applying policy measures. This study presents a holistic evaluation of smart city performance in the context of China. The evaluation indicators in this study are selected by applying a hybrid research methodology including literature review and semi-

structured interviews. Indicator data are collected from 44 sample smart cities. The evaluation was conducted by applying Entropy method and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) technique collectively. This study highlights that the overall smart city performance in China is at a relatively low level. There is also a significant unbalance in performance between five smart city dimensions including smart infrastructure, governance, people, economy and environment. The smart performance between cities varies significantly since cities implement smart city programs in different ways. These differences impede experience sharing between cities. Actions have been recommended in this study for promoting further development of smart city in the context of China, such as increasing the investment on smart infrastructure, providing training programs, and establishing evaluation mechanism.

Keywords: Smart city; Evaluation indicators; Holistic view; China.

1. Introduction

According to the World Development Indicators (WDI) database issued by World Bank, the proportion of urban population reached to 53.857% in 2015 (World Bank, 2017), and this figure was predicted to reach to 60% by 2030 (United Nations, 2015). In particular, it was suggested that this figure would increase significantly in those developing countries such as China. In China, the urban population increased from 22% in 1980s to 57.35 % in 2016 (National Bureau of Statistics of PRC, 2016). However, it is widely appreciated that

rapid urbanization has generated many problems usually called “urban diseases”, such as energy shortage, environment pollution, traffic congestion, social inequality, unavailability or shortage of public service, and land loss (Neirotti et al., 2014; Chen, 2007; Cui & Shi, 2012). These problems make cities disordered and unorganized, and hamper the growth of cities (Johnson, 2008). In searching for solutions to address these problems, smart city has been introduced as a new technology-driven mechanism (Eger, 2003; Coe et al., 2001; Hollands, 2008; Lee et al, 2014).

Smart city presents a new city pattern which integrates resources in a way that can provide better urban services based on the use of information and communication technologies (ICT). In a typical definition quoted in International Business Machine (IBM), smart city is a city that could maximize the payment with limited input of resources by the use of techniques to improve urban services in multiple aspects including civilian, business, transportation, communication, water, sources and other urban systems (Dirks and Keeling, 2009). The Chinese government has been devoting good efforts to the promotion of smart city through implementing a series of policies and measures. For example, the Ministry of Industry and Information Technology (MIIT) established the China Smart City Industry Alliance in 2013 to implement smart city programs by providing US\$8 billion for smart city research and projects (Guo et al., 2016). In 2014, eight government departments in China issued jointly the policy paper “Guidance on Promoting the Healthy Development of Smart City”. This guidance includes a plan to build a number of smart cities with individual characteristics. In the

“2015 Report on the Government Work” by Keqiang Li, the Prime Minister, the development of smart city was promoted as the future development direction for cities in China. In line with this direction, an increasing number of cities have been practicing the principles of smart city in China. It was reported by Telecommunication Research Institute of the Ministry of Industry and Information Technology of China (2014), all the cities at provincial or above level, 89% prefecture-level cities, and about 40% county-level cities have smart city development plans. The study by Guo (2016) shows that the investment on smart city in China reached to US\$147 billion by the end of December 2015, and it would remain growing at the rate of about 19% for 2016-2018.

The above literature studies indicate that the smart city program in China is developing rapidly. However, there are many problems exposed in the practice. For example, there is a high risk of public security due to a high dependence on the information technology from overseas. Chinanews (2011) suggested that the information technology from overseas for the development of smart city in China accounts for about 80%. Dang (2014) addressed the main barriers to the successful implementation of smart city development in China from six perspectives, including top-level design and planning, institutional arrangement, regulation, public information security, data standards and norms, and technological innovation. It is considered that policies may have limited effectiveness in application if they do not respond to the practice. In other words, it is important to examine the practice of smart city from a holistic perspective in order to adopt proper measures to mitigate the existing problems and barriers.

However, it appears that there is little existing study examining what results have been achieved in the practice of smart city in the context of China. In previous studies, various individual cases have been conducted for understanding the performance of smart city. For example, the study of Anthopoulos (2017) presents an analysis of 10 smart city cases from of the perspectives of application sectors, sustainability performance and improvement methods. The study by Hin and Subramaniam (2012) presents the performance of smart transportation in Singapore. Other studies have presented indicators for measuring the performance of smart cities. For example, in studying the performance of smart city in Indonesia, Susanti et al. (2016) established smart city indicators particularly from the perspective of housing, as he considered that the primary element of a smart city is the housing density. The study of Debnath et al. (2014) presents a set of indicators to examine the smartness of transportation system in a city. Marco et al. (2015) proposed a methodology for defining smart city indicators from the perspective of public safety. Ilias et al. (2017) introduced a set of indicators to assess the smartness level of energy system in a city. Walravens (2015) introduced a qualitative indicator system to evaluate smart city strategies. Nevertheless, all the above indicator systems fail to reflect the smart city performance in a holistic perspective. Therefore, they cannot help evaluate holistically the performance of a specific smart city program.

There are other studies which have proposed comprehensive indicators to examine the performance of smart city practice. For example, Giffinger et al. (2007) ranked a sample

of 70 smart cities in the Europe context based on a comprehensive set of indicators under six dimensions including smart economy, smart people, smart governance, smart mobility, smart environment and smart living. However, these indicators may not be applicable to the Chinese context as they are established purposely for assessing the performance of cities in Europe. Komninos (2008) proposed a smart city model including four dimensions, namely, skills, knowledge, spaces and innovation, and each dimension is measured by various indicators. The study of Fondazione Ambrosetti (2012) suggests three performance dimensions of a smart city in referring to the practice in Italy, including mobility management, resource management and quality of life, where each dimension is measured with a number of indicators. Again, it is considered that these indicators have limitation in application in the context of China where the social, economic and natural environment are different from that in overseas countries.

There are several typical studies on the subject of smart city in the context of China. Shanghai Pudong Smart City Development Research Institute (SPSCDRI, 2012) proposed smart city indicator system for application in China, which contains 5 dimensions of indicators, including smart infrastructure, public governance and services, economy development, social safety, and education. China Wisdom Engineering Association (CWEA, 2011) developed Smart City (Town) Development Index Evaluation System for measuring the smartness of a city from multiple perspectives, including citizen happiness, governance, and social responsibility. Under these three perspectives, there are a large number of indicators classified into different levels. The

Software and Integrated Circuit Promotion Center (CSIP) in Ministry of Industry and Information Technology of China has proposed an alternative set of indicators to evaluate the smartness of cities in 2012 (CSIP, 2012), where the indicators are organized in three layers. It is nevertheless noted that all the above indicator systems are difficult for application as the data for many bottom-layer indicators are not available. Furthermore, these systems do not include indicators for measuring the performance of environmental smartness, which is considered an essential part of a smart city.

In summary, limitations in previous studies are clear in addressing holistic evaluation of smart city performance in the context of China. Firstly, some indicator systems are not comprehensive in reflecting the smart city performance holistically, thus can not guide the development of smart city. In fact, a smart city pursues for holistic development, which requests for the efforts in all aspects of a city. Secondly, some proposed indicator systems are not applicable in the context of China, as they do not consider the specific backgrounds of the Chinese cities. Thirdly, although some smart city indicator systems are designed in the context of China, they are not applicable as the data required are not obtainable. This study therefore has specific value in presenting a holistic evaluation on the performance of smart city in the context of China. The aim of this study is to construct a holistic indicator framework applicable in the context of China and examine the practice of smart city in this context. The performance of a sample of smart cities in China will be measured and compared by using the holistic indicator framework. The remainder of this paper is organized as follows. Section 2 presents the methodology

adopted in this study. In section 3, a comprehensive set of indicators for measuring the performance of the performance of smart city in China will be established. Section 4 presents the analysis results about the performance of sample smart cities in China followed by Section 5, which provides the discussions on the analysis results. The final part of this paper concludes the research work.

2 Research methodology

The methodology adopted in this research comprises of three procedures, as demonstrated in Figure 1. Firstly, a holistic evaluation indicator framework for measuring the performance of smart city will be established. Secondly, the weighting values between the indicators in the framework will be established. In the third stage of this study, the smart city performance in the context of China will be evaluated.

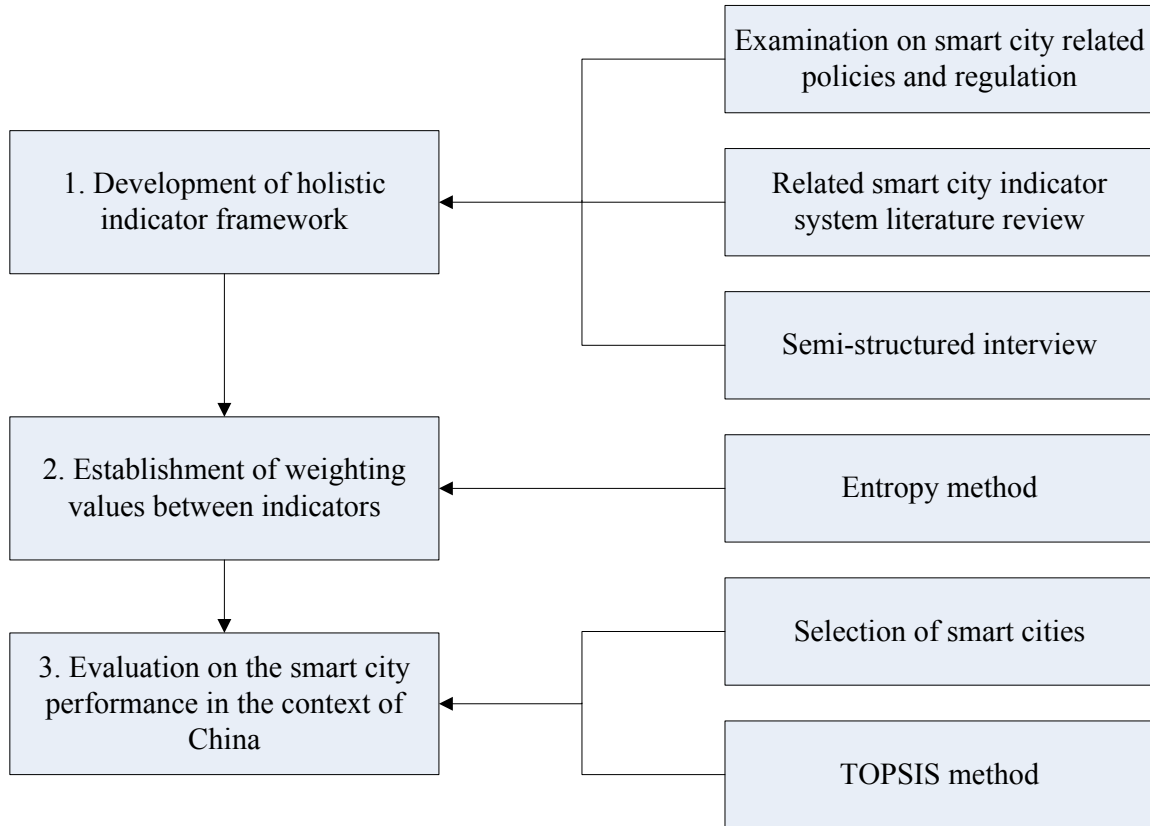


Figure 1 Methodology framework

2.1 A holistic indicator framework for the evaluation of smart city performance

In order to establish a holistic evaluation indicator framework, a comprehensive examination is conducted by literature review. Literature review has been widely used as a method to establish indicator framework for smart city performance assessment (Giffinger et al., 2007; Theng et al., 2016). This method can derive indicators that describe the dimensions and factors of a smart city from available literatures, policy papers and reports. For example, the study of Pan et al. (2011) introduces the developing

of a smart city evaluation index based on the literature concept of smart city. There are many policy papers and literatures identified in this study in addressing the promotion of smart city in China, where indicators for measuring smart city performance have been proposed from a wide range of perspectives. The above tasks lead to the formulation of a list of candidate indicators. Based on this list of candidate indicators, semi-structured interviews with 10 experts are conducted to determine the suitability and significance of each optional indicator. Experts are invited to rank the significance of each indicator based on a nine-point Likert scale, with 9 indicating most significant and 1 the least significant. By analyzing the data collected from semi-structured interviews, the average level of significance of each candidate indicator is obtained. Those indicators with the average significance value of above 6.3 (or 70%) are selected as effective indicators, which will form the holistic indicator framework.

It is appreciated that other methods such as regression analysis and principle component analysis (PCA) have been adopted to assistant indicator selection. For example, Sheng et al. (2016) identified the key factors of afforestation and reforestation using a regression model. Shen et al. (2012) established an indicator system consisting of 19 critical indicators based on the method of PAC. However, regression analysis and PCA can not help select effective indicators for examining the performance of smart city in the context of China. Semi-structured interview is considered more suitable in this study. This is because the experts' opinions and experience though semi-structured interviews can help

obtain a set of indicators suitable to examine the performance of smart city in the specific context of China and ensure that the data for these indicators are obtainable.

2.2 Establishment of weighting values between indicators by applying Entropy method

Weighting values reflect the relative importance between indicators and Entropy method is used in this study to determine the weighting values. Entropy method was first applied in thermodynamics by Shannon in 1948. The method is based on the principle that when the difference between evaluation objects on the value of an indicator is high, the entropy of the indicator is small. A smaller Entropy value illustrates that this indicator provides more useful information, and the weight of this indicator should be set correspondingly high (Jha & Singh, 2008). Previous studies have also appreciated that Entropy method is effective in determining the weightings between evaluation indicators for conducting indicator-based performance evaluation (Shemshadi et al., 2011). The procedures for deriving weighting values between indicators by using Entropy method are summarized as follows.

(a) Normalization for all indicators

Assume that there are n independent indicators for evaluating the smart performance of m sample cities. As different indicators present different dimensions and magnitudes on the

performance of smart city, there is a need to normalize all indicators into dimensionless for effective comparison. The following Equations (1) and (2) are used to normalize indicators.

$$r_{ij} = \frac{x_{ij} - \text{Min}_j \{x_{ij}\}}{\text{Max}_j \{x_{ij}\} - \text{Min}_j \{x_{ij}\}} \quad (1)$$

$$r_{ij} = \frac{\text{Max}_j \{x_{ij}\} - x_{ij}}{\text{Max}_j \{x_{ij}\} - \text{Min}_j \{x_{ij}\}} \quad (2)$$

Equation (1) is used to normalize positive indicators, where a larger value of indicator represents better performance. Equation (2), on the other hand, is used to normalize negative indicators, where a smaller value of indicator represents better performance.

In the above equations, the variable x_{ij} is the original value of the indicator i for the sample city j ($i=1, 2, 3, \dots, n$; $j=1, 2, 3, \dots, m$), and r_{ij} is the normalized value of the variable x_{ij} . The expressions $\text{Max}_j \{x_{ij}\}$ and $\text{Min}_j \{x_{ij}\}$ denote respectively the maximum and minimum original values of the indicator i across all m sample cities.

(b) Entropy value for individual indicators

In applying Entropy method, the Entropy value of indicator i , denoted as H_i , needs to be obtained through the following equation:

$$H_i = -k \sum_{j=1}^m f_{ij} \ln f_{ij} \quad (3)$$

where m is the number of sample cities, and the coefficients f_{ij} and k are calculated from the following Equations (4) and (5).

$$f_{ij} = \frac{r_{ij}}{\sum_{j=1}^m r_{ij}} \quad (4)$$

$$k = \frac{1}{\ln m} \quad (5)$$

In equation (3), when $f_{ij} = 0$, $f_{ij} \ln f_{ij}$ also equal to 0.

(c) Weighting values for all individual indicators

According to Entropy method, the weighting value for indicator i is calculated from the following equation:

$$w_i = \frac{(1 - H_i)}{(n - \sum_{i=1}^n H_i)} \quad (6)$$

Where w_i is the weighting value for indicator i , and n refers to the total number of indicators.

2.3 Evaluation on the smart city performance by applying TOPSIS method

The Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is chosen to conduct the evaluation on the performance of smart city. TOPSIS, developed by Hwang and Yoon (1981), is a useful technique for evaluating, ranking and comparing alternatives (or sample cities in this study) against a set of indicators (Opricovic & Tzeng, 2004; Hwang and Yoon , 1981; Ji et al., 2015). In applying TOPSIS, two Euclidean distances of each alternative (or sample city) need to be obtained: one is the distance from an alternative (or a sample city) to the ideal point, and the other one is the distance from an alternative (or a sample city) to the anti-ideal point. The ideal point is the composite of best performance values of an alternative (or a sample city) across all indicators, whilst the anti-ideal point is the composite of the worst performance values. Then, by integrating the two Euclidean distances, a closeness coefficient will be derived to indicate the overall performance of an alternative (or a sample city). The procedures for applying TOPSIS are described as follows:

(a) Normalization for all indicators

The principle of normalization has been addressed in the above section 2.2(a).

(b) Weighted values of normalized indicators

The weighted values of normalized indicators, y_{ij} , need to be calculated by the following Equation (7):

$$y_{ij} = r_{ij} w_i \quad (7)$$

Where the variables r_{ij} and w_i have been defined in Equations (1), (2) and (6).

(c) *The ideal and the anti-ideal points*

The ideal point (α^+) and the anti-ideal point (α^-) are determined by the following Equations (8) and (9).

$$\alpha^+ = (y_1^+, y_2^+ \cdots y_n^+) \quad (8)$$

$$y_i^+ = \begin{cases} \text{Max}_j \{y_{ij}\} & \text{if } i \text{ is a positive indicator} \\ \text{Min}_j \{y_{ij}\} & \text{if } i \text{ is a negative indicator} \end{cases} \quad \alpha^- = (y_1^-, y_2^- \cdots y_n^-) \quad (9)$$

where

$$y_i^- = \begin{cases} \text{Max}_j \{y_{ij}\} & \text{if } i \text{ is a negative indicator} \\ \text{Min}_j \{y_{ij}\} & \text{if } i \text{ is a positive indicator} \end{cases}$$

and

for $i = 1, 2, \dots, n$.

The expressions $\text{Max}_j \{y_{ij}\}$ and $\text{Min}_j \{y_{ij}\}$ denote respectively the maximum and minimum weighted value of the normalized indicator i across all m sample cities.

(d) Euclidean distances

The Euclidean distance from a sample city j to the ideal point is calculated through the following equation (10):

$$\theta_j^+ = \sqrt{\sum_{i=1}^n (y_i^+ - y_{ij})^2} \quad \text{for } j = 1, 2, \dots, m \quad (10)$$

And the Euclidean distance from a sample city j to the anti-ideal point is calculated through the following equation (11)

$$\theta_j^- = \sqrt{\sum_{i=1}^n (y_{ij} - y_i^-)^2} \quad \text{for } j = 1, 2, \dots, m \quad (11)$$

(e) Computation of the closeness coefficient

In using TOPSIS method, the value of closeness coefficient (θ_j) will be established to indicate the relative closeness of a particular sample city j to the anti-ideal point. A larger value of closeness indicates a better performer city.

$$\theta_j = \frac{\theta_j^-}{\theta_j^+ + \theta_j^-} \quad \text{for } j = 1, 2, \dots, m \quad (12)$$

Following the above procedures in applying TOPSIS method, the sample cities can be ranked in descending order according to the value of their closeness coefficient.

3. Selection of smart city indicators

According to the principle of holistic indicator framework addressed in Section 2.1, a set of smart city indicators will be selected in this section. The research team has identified 288 policy and regulation papers relevant to the promotion and practice of smart city in the context of China. Typical documents include *Guidance to the Pilot Smart City Programs through Spatial-Temporal Technology* issued by National Surveying and Mapping Geographic Information Bureau in 2012 (NSMGIB, 2012), *Circular of the “Broadband China” Strategy and Implementation Plan* issued by the State Council of China (2013). Other major literatures have also been referred for identifying candidate smart city indicators, such as *Evaluation Report on the Smartness of China 's Smart City* by the Chinese Academy of Social Sciences Institute (2015). As a result, 154 candidate indicators are obtained and categorized in five groups, namely, smart infrastructure, smart people, smart governance, smart economy, and smart environment. These terminologies have been adopted in previous studies (Giffinger et al., 2007). The candidate indicators are shown in Appendix 1.

The indicators in the group of smart infrastructure measure the performance of applying information and communication technologies (ICT) in a city. ICT is the basic infrastructure to enable cities to develop into smart cities (Palmisano, 2008). In a typical

literature book by Harrison et al. (2010), smart infrastructure mainly refers to the application of various ICT such as sensors, appliances, personal devices, and other similar sensors.

The indicators in the group of smart people concern people not only individuals, but also communities and groups, such as government, enterprise and social organizations. People are the key players in developing smart city. On the other hand, development of smart city will take into account of people's need. Giffinger et al (2007) regards smart city as the smart combination between endowments and human.

The indicators in the group of smart governance are associated with transparency in governance, public participation, service delivery and e-governance. Belissent (2011) pointed out that the core of smart city initiatives is governance. Government plays critical role in promoting the use of smart city infrastructures. Chourabi et al (2012) summarized the main governance-related factors in promoting the development of smart city, including collaboration, leadership, participation, partnership, communication, data-exchange, service, accountability, and transparency.

Indicators in the group of smart economy measure the performance of innovation, competitiveness, and ability to transform and drive urban economy. Economy is the impetus to promote the development of smart city and the main driver to implement

smart city initiatives. A city will be in an advantageous position to implement smart city program if it has better economic performance (Alawadhi et al, 2012). Chourabi et al (2012) suggested that smart economy is mainly reflected by economic competitiveness, contributed by innovation, entrepreneurship, trademarks, productivity, flexibility of the labor market and the integration of national and global markets.

Indicators in the group of smart environment address the issues related to the quality of environment. In fact, it is the mission of smart city to allow for a quality environment and achieve sustainable city development by solving city diseases such as energy shortage, environment pollution and traffic congestion. Therefore, the indicators from environmental perspective are important part of the holistic list of smart city indicator framework.

The significance of each of these candidate indicators is examined by seeking for 10 experts' views through semi-structured interviews, including 5 researchers and 5 professionals. During individual interviews, respondents were invited to provide their judgment on the relative significance of each indicator in evaluating smart city performance in the context of China based on a nine-point Likert scale, with 9 indicating the most significant and 1 the least significant. Finally, according to the selection criterion defined in methodology section 2.1, 18 indicators are chosen as a holistic indicator framework for further study, as shown in Table 1.

Table 1 Holistic indicator framework for examining the smart city practice in the context of China

Category	Indicators
Smart Infrastructure	SI1. Number of telephones per household (Telephones/person)
	SI2. Number of handphones per household (Handphones/person)
	SI3. Percentage of households with Internet access (%)
	SI4. Wi-Fi Coverage
	SI5. Development of cloud platform and application Utilization
Smart Governance	SG1. Availability of E-Government
	SG2. Trading platform for public resources
	SG3. Participation by social media
Smart Economy	SEc1. GDP per head of city population (yuan/capita)
	SEc2. Employment rate in high technology and innovation industries
	SEc3. Quality of entrepreneurship and the level of innovation
Smart People	SP1. Proportion of R&D expenditure to GDP (%)
	SP2. Proportion of education expenditure to GDP (%)
	SP3. Percentage of population with higher education (%)
	SP4. Level of access to network facilities by citizens
Smart Environment	SEn1. Level of waste reuse and recycle (%)
	SEn2. Air pollution index
	SEn3. Green area per capita (m ² /capita)

4.Practice of smart city in China

4.1 Pilot cities

In this study, a sample of 44 pilot smart cities in the context of China are selected to support the analysis on the performance of smart city. By 2015, there are 290 pilot smart city programs endorsed by the Ministry of Housing and Urban-Rural Development (MOHURD) in China (MOHURD, 2015). These programs are implemented at the levels of cities, counties, and towns. This study focused on these pilot programs at city level because of the effective accessibility to the needed data. There is a difficulty of collecting effective data for those programs at county and town levels. Even at city level, the needed data for analysis in some cities are also not available. As a result, 44 cities have been identified to be able to offer effective data for analysis, as shown in Figure 2.



Figure 2 Sample smart cities

4.2 Data collection

The data about the 18 indicators listed in Table 1 for these 44 sample cities are collected from multiple resources, including *China city statistical Yearbook 2015* published by National Bureau of Statistics of China (2014), *Evaluation report on the smartness of China 's smart city* published by the Chinese Academy of Social Sciences Institute (2015), and *Report on air quality of Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl*

River Delta region and municipalities, provincial cities 2015 by China National Environmental Monitoring Centre (2015). The details of the data are listed in Table 2.

Table 2 The data of the indicators

Smart city	Smart Infrastructure					Smart Governance			Smart Economy			Smart People				Smart Environment		
	SI1 ^①	SI2 ^①	SI3 ^①	SI4 ^②	SI5 ^②	SG1 ^②	SG2 ^②	SG3 ^②	SEc1 ^①	SEc2 ^①	SEc3 ^②	SP1 ^①	SP2 ^①	SP3 ^①	SP4 ^②	SEn1 ^①	SEn2 ^③	SEn3 ^①
Beijing	0.0831	0.4074	43.82	2.95	4.00	7.50	3.00	4.08	99995	0.0484	4.80	1.33	3.48	31.50	4.33	87.67	10.71	61.12
Tianjin	0.0361	0.1352	100.00	1.68	3.50	6.50	3.00	2.10	105231	0.0046	3.10	0.69	3.29	17.48	3.23	98.91	9.77	30.39
Shijiazhuang	0.0151	0.1038	52.45	1.07	3.00	2.00	1.50	3.83	48970	0.0044	1.50	0.14	2.32	12.71	1.03	95.10	5.18	28.01
Tangshan	0.0148	0.0734	41.88	1.36	5.10	5.50	2.50	1.10	80450	0.0016	0.60	0.13	1.75	8.79	1.62	70.00	11.32	29.21
Taiyuan	0.0121	0.0743	52.50	2.64	2.80	5.00	4.00	0.40	59023	0.0065	2.00	0.56	2.08	23.53	3.78	55.25	9.26	44.52
Hohhot	0.0083	0.0390	35.21	0.35	2.00	3.00	4.50	1.90	95961	0.0092	1.50	0.12	1.33	20.86	1.27	39.64	8.83	64.29
Shenyang	0.0251	0.1044	30.47	1.74	2.00	3.00	1.50	2.20	85816	0.0048	3.00	0.37	1.65	20.39	1.00	90.20	9.56	54.36
Dalian	0.0240	0.0849	43.38	2.12	2.50	5.00	4.00	0.00	109939	0.0197	2.70	0.56	1.37	17.37	3.49	83.66	7.09	60.27
Changchun	0.0182	0.0881	41.81	1.90	2.00	3.00	1.00	1.60	70891	0.0092	0.90	0.13	1.60	16.27	3.26	99.92	8.44	43.85
Harbin	0.0225	0.1251	34.40	1.41	3.00	5.50	2.50	3.48	53872	0.0075	2.40	0.19	2.09	14.71	3.16	98.07	11.01	28.39
Shanghai	0.0840	0.3293	49.02	4.58	4.00	6.00	1.50	4.80	97370	0.0197	4.60	1.11	2.95	21.95	3.28	97.51	6.74	91.72
Nanjing	0.0283	0.1042	34.99	2.95	1.50	3.50	3.50	4.25	107545	0.0230	3.80	0.51	1.55	26.12	4.06	91.90	7.63	135.76
Wuxi	0.0213	0.0833	62.27	4.70	4.50	9.00	3.00	3.73	126389	0.0091	3.50	0.43	1.38	12.88	3.74	91.10	7.88	75.47
Changzhou	0.0152	0.0520	50.02	2.70	1.50	5.50	2.00	1.60	104423	0.0022	2.60	0.44	1.39	11.72	3.67	98.20	7.88	37.68
Suzhou	0.0341	0.1469	87.70	2.84	4.00	4.50	3.00	3.53	129925	0.0089	3.70	0.55	1.48	12.42	4.10	96.70	7.20	63.99
Yangzhou	0.0134	0.0422	35.81	2.10	1.50	5.50	4.00	1.50	82654	0.0039	1.30	0.31	1.77	9.54	3.36	92.30	6.60	29.89
Hangzhou	0.0311	0.1562	53.13	3.36	4.50	8.00	4.50	4.33	103813	0.0202	4.20	0.57	1.98	18.88	4.65	91.10	7.21	35.01
Ningbo	0.0270	0.1267	100.00	2.84	4.50	8.50	4.50	3.83	98362	0.0050	2.70	0.56	2.10	10.33	3.87	90.76	6.77	49.61
Wenzhou	0.0210	0.1113	100.00	3.55	3.00	8.00	4.00	3.15	47118	0.0035	1.20	0.26	2.90	7.13	1.00	98.15	4.64	47.64
Jiaxing	0.0135	0.0615	100.00	3.00	3.50	7.50	4.50	2.05	73458	0.0045	1.10	0.42	2.26	7.68	2.17	96.01	7.12	55.34
Zhoushan	0.0041	0.0163	100.00	2.45	2.00	8.00	1.50	2.55	88746	0.0047	0.50	0.44	2.42	10.28	3.62	99.80	4.33	188.63
Hefei	0.0171	0.0782	45.23	2.33	3.50	8.50	4.50	2.73	67689	0.0109	3.10	0.56	2.10	19.20	3.79	93.02	7.39	66.02
Fuzhou	0.0195	0.0945	100.00	3.45	1.50	3.50	4.00	1.30	69995	0.0086	3.10	0.18	2.33	12.46	2.27	95.97	3.28	50.82
Xiamen	0.0136	0.0564	71.78	2.99	3.50	6.50	3.50	2.10	86832	0.0101	3.50	0.53	2.72	17.80	4.40	97.95	3.12	89.71
Nanchang	0.0112	0.0601	52.15	2.13	2.50	1.00	4.50	3.73	70373	0.0135	2.00	0.22	2.22	18.84	3.69	95.91	4.49	45.56
Jinan	0.0177	0.1178	56.23	4.65	1.50	3.00	4.00	1.20	82052	0.0229	2.50	0.17	1.62	19.91	3.65	99.56	12.03	36.94

Qingdao	0.0207	0.1301	100.00	4.43	1.10	4.00	4.00	3.93	96524	0.0034	2.60	0.31	2.15	14.86	3.53	95.65	8.33	77.75
Jinan	0.0225	0.1310	39.01	2.12	1.60	7.50	1.50	2.23	72991	0.0047	3.10	0.21	1.84	18.95	3.84	76.77	11.35	28.45
Wuhan	0.0255	0.1644	71.97	3.09	3.50	3.50	4.00	3.73	98000	0.0055	3.50	0.57	1.43	25.20	3.01	98.71	7.68	34.47
Changsha	0.0195	0.1118	50.41	2.02	2.50	7.00	4.00	0.50	107683	0.0072	3.20	0.29	1.61	19.13	3.82	85.50	5.71	33.49
Guangzhou	0.0503	0.3224	92.81	4.14	3.50	4.50	4.50	2.40	128478	0.0139	4.10	0.34	1.37	19.23	2.31	94.47	4.35	190.57
Shenzhen	0.0530	0.3377	100.00	4.11	3.00	4.50	1.50	3.70	149495	0.0399	4.30	0.59	2.07	14.01	4.97	99.81	3.57	293.32
Zhuhai	0.0078	0.0364	66.24	2.39	2.50	9.00	4.50	1.85	116537	0.0182	2.60	0.67	2.63	18.39	4.34	94.89	4.10	77.43
Foshan	0.0295	0.1490	64.32	2.37	3.50	4.50	4.00	4.20	101617	0.0034	2.00	0.21	1.42	9.47	3.84	99.94	4.35	15.32
Jiangmen	0.0138	0.0595	86.49	2.18	1.50	6.50	4.00	2.80	46237	0.0045	0.50	0.25	2.62	5.36	3.31	90.46	3.96	82.49
Dongguan	0.0327	0.1763	100.00	2.39	3.50	4.50	4.00	2.20	70605	0.0042	2.00	0.24	2.02	7.10	4.07	83.42	3.92	203.76
Nanning	0.0103	0.0821	62.59	1.91	2.10	2.00	1.50	3.58	43303	0.0055	2.00	0.23	2.40	11.69	1.52	95.82	4.01	139.98
Haikou	0.0057	0.0425	33.27	2.35	1.30	2.50	1.00	0.00	49943	0.0082	1.50	0.10	2.15	16.80	3.75	100.00	2.60	34.75
Chongqing	0.0583	0.2590	27.78	1.99	3.00	1.00	2.50	3.65	47850	0.0078	3.40	0.27	3.30	8.64	2.34	84.49	5.37	27.27
Chengdu	0.0438	0.2203	49.52	1.62	1.50	5.50	4.00	3.80	70019	0.0174	4.10	0.25	1.82	16.67	3.74	97.44	7.46	33.97
Guiyang	0.0103	0.0810	45.51	1.96	2.50	9.00	1.50	2.18	55018	0.0064	2.00	0.50	3.22	15.26	3.54	48.86	3.92	56.38
Kunming	0.0126	0.0974	47.69	2.23	0.90	1.00	4.00	3.08	56236	0.0045	2.50	0.34	2.30	15.30	3.48	36.87	3.80	56.13
Xian	0.0307	0.2025	47.34	3.03	1.80	1.00	2.50	3.38	63794	0.0117	3.50	0.25	2.03	22.00	3.82	92.40	10.04	28.57
Lanzhou	0.0080	0.0529	30.35	1.67	2.20	5.00	4.50	0.90	54771	0.0037	1.00	0.16	2.57	21.29	3.42	98.46	7.91	27.12

Sources: ①*China City Statistical Yearbook 2015* (National Bureau of Statistics of China, 2014);

②*Evaluation Report on the Smartness of China 's Smart City* (Chinese Academy of Social Sciences Institute, 2015);

③*Report on air quality of Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta region and municipalities, provincial cities 2015* (China National Environmental Monitoring Centre, 2015).

4.3 Weighting values between evaluation indicators

The entropy weighting values between the 18 indicators are calculated by applying the data in Table 2 to the Equations (1) - (6), and the results are shown in Table 3.

Table 3 Entropy weighting values between indicators

Indicators	SI1	SI2	SI3	SI4	SI5	SG1
w_i	0.07381	0.06494	0.10219	0.02374	0.04479	0.04859
Indicators	SG2	SG3	SEc1	SEc2	SEc3	SP1
w_i	0.04324	0.03395	0.05544	0.10263	0.04288	0.08289
Indicators	SP2	SP3	SP4	SEn1	SEn2	SEn3
w_i	0.06191	0.03776	0.03232	0.01592	0.03362	0.09938

4.4 Evaluation results of the smart city performance between sample cities

Based on the Equations (7) - (12), the closeness coefficients of the 44 sample cities can be obtained as shown in Table 4.

Table 4 Results of closeness coefficients and ranks between 44 cities

City	θ_j^I	Rank	θ_j^G	Rank	θ_j^E	Rank	θ_j^P	Rank	θ_j^{En}	Rank	θ_j	Overall Rank
Shenzhen	0.6616	1	0.4233	36	0.8483	1	0.8120	1	0.9681	1	3.7132	1
Beijing	0.5288	5	0.7204	7	0.8166	2	0.7106	2	0.1951	34	2.9715	2
Guangzhou	0.5436	4	0.6136	12	0.4514	6	0.2955	21	0.6521	3	2.5562	3
Shanghai	0.5248	6	0.5267	26	0.4807	5	0.5817	4	0.3319	10	2.4457	4
Hangzhou	0.3429	14	0.9075	1	0.4879	4	0.3891	12	0.1973	30	2.3247	5

Dongguan	0.4573	10	0.5757	19	0.1640	33	0.3797	14	0.6947	2	2.2714	6
Suzhou	0.4085	11	0.5454	23	0.3958	10	0.6395	3	0.2559	19	2.2452	7
Jiaxing	0.5080	7	0.7374	6	0.1402	38	0.5624	5	0.2382	23	2.1863	8
Wuxi	0.3230	17	0.7516	5	0.3855	12	0.4547	7	0.2688	17	2.1835	9
Zhuhai	0.2045	28	0.7607	4	0.4417	8	0.4298	8	0.3341	9	2.1708	10
Zhoushan	0.4903	8	0.5332	24	0.1833	28	0.2671	25	0.6473	4	2.1211	11
Wenzhou	0.5499	3	0.8067	3	0.0662	43	0.3997	11	0.2704	16	2.0929	12
Nanjing	0.1967	31	0.5606	20	0.5216	3	0.3346	18	0.4474	6	2.0609	13
Qingdao	0.5559	2	0.6118	13	0.2505	23	0.3481	16	0.2725	15	2.0388	14
Tianjin	0.4859	9	0.5902	16	0.2950	16	0.4913	6	0.1589	37	2.0213	15
Hefei	0.2215	24	0.8146	2	0.2730	18	0.4283	9	0.2544	20	1.9917	16
Xiamen	0.2720	21	0.6364	11	0.3148	14	0.3808	13	0.3778	7	1.9816	17
Chengdu	0.3255	16	0.6965	9	0.3930	11	0.2636	26	0.1981	29	1.8767	18
Dalian	0.1989	29	0.5122	28	0.4511	7	0.4262	10	0.2385	22	1.8270	19
Wuhan	0.3409	15	0.5795	17	0.2993	15	0.3679	15	0.1963	32	1.7840	20
Fuzhou	0.3531	13	0.4944	32	0.2528	22	0.3175	19	0.2981	11	1.7158	21
Changsha	0.2101	27	0.6098	14	0.3219	13	0.3467	17	0.2204	25	1.7089	22
Foshan	0.3209	18	0.6474	10	0.2442	25	0.2239	33	0.2413	21	1.6777	23
Jiangmen	0.2611	22	0.7126	8	0.0520	44	0.2251	32	0.3452	8	1.5960	24
Jinan	0.2340	23	0.4707	33	0.4379	9	0.2497	28	0.1527	38	1.5450	25
Nanchang	0.1738	35	0.5074	30	0.2660	19	0.2741	23	0.2683	18	1.4897	26
Guiyang	0.1637	36	0.5534	21	0.1510	35	0.2712	24	0.2751	13	1.4144	27
Changzhou	0.1526	38	0.4226	37	0.2642	20	0.3072	20	0.1967	31	1.3432	28
Xian	0.2832	19	0.3531	39	0.2941	17	0.2548	27	0.1429	39	1.3281	29
Chongqing	0.3820	12	0.3658	38	0.2340	26	0.1224	43	0.2197	26	1.3239	30
Taiyuan	0.1986	30	0.5263	27	0.1582	34	0.2853	22	0.1400	41	1.3085	31
Kunming	0.1468	39	0.4600	34	0.1662	32	0.2478	29	0.2751	14	1.2960	32
Yangzhou	0.1029	41	0.5950	15	0.1711	31	0.2161	34	0.2042	27	1.2893	33
Hohhot	0.0891	42	0.5286	25	0.2593	21	0.2113	36	0.1952	33	1.2835	34
Harbin	0.2135	25	0.5485	22	0.1831	29	0.1909	39	0.1426	40	1.2786	35
Nanning	0.1939	32	0.3193	41	0.1320	39	0.1257	42	0.4997	5	1.2707	36
Zhengzhou	0.1877	33	0.5040	31	0.2272	27	0.2466	30	0.1021	42	1.2676	37
Lanzhou	0.1092	40	0.5763	18	0.0721	42	0.2344	31	0.1834	36	1.1754	38
Shenyang	0.1774	34	0.2728	42	0.2490	24	0.2123	35	0.1930	35	1.1045	39
Tangshan	0.2740	20	0.4480	35	0.1428	36	0.1398	40	0.0915	43	1.0961	40
Shijiazhuang	0.2117	26	0.3336	40	0.0949	41	0.1320	41	0.2324	24	1.0046	41

Changchun	0.1602	37	0.2142	43	0.1785	30	0.2028	38	0.1995	28	0.9551	42
Haikou	0.0837	43	0.1186	44	0.1420	37	0.2078	37	0.2905	12	0.8426	43
Ningbo	0.0678	44	0.5119	29	0.1160	40	0.0842	44	0.0620	44	0.8418	44
Average	0.4070		0.6452		0.3830		0.4481		0.3599		2.2432	

In Table 4, the variables θ_j^I , θ_j^G , θ_j^E , θ_j^P and θ_j^{En} are the closeness coefficients of city j in five smart dimensions. And θ_j is the closeness coefficient from an overall perspective, which is the sum of the five dimensional closeness coefficients. The values of these coefficients in Table 4 indicate the smart performance of the 44 sample cities respectively from the perspectives of smart infrastructure, smart governance, smart economy, smart people, smart environment, and the overall profile. These results can also be presented graphically in Figure 3-8.

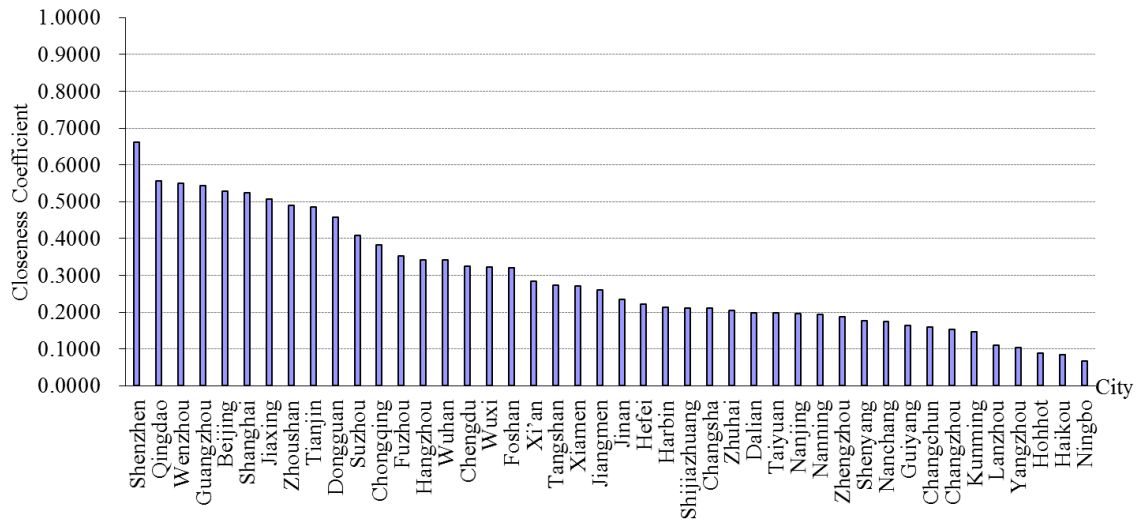


Figure 3 The performance of smart infrastructure between 44 sample cities

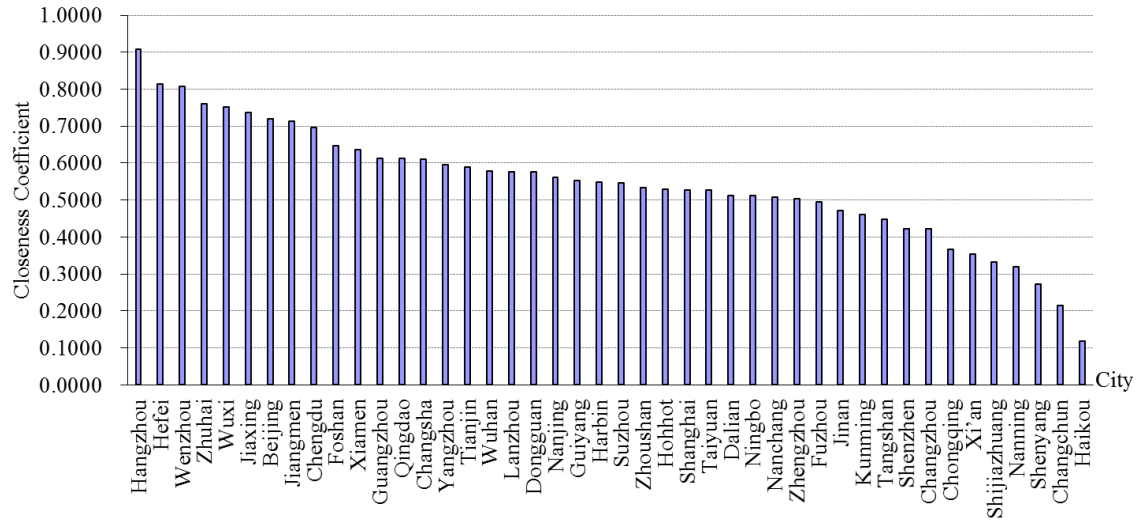


Figure 4 The performance of smart governance between 44 sample cities

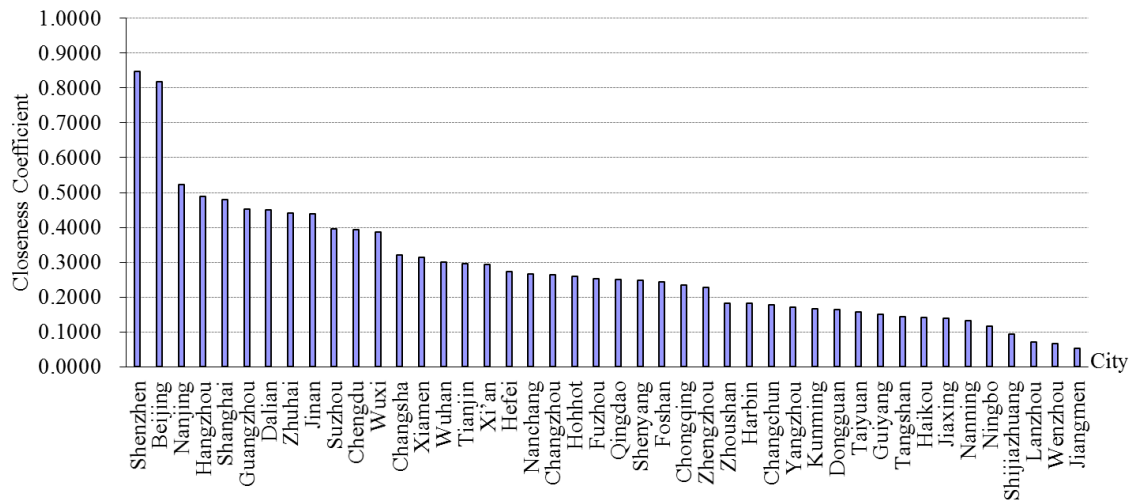


Figure 5 The performance of smart economy between 44 sample cities

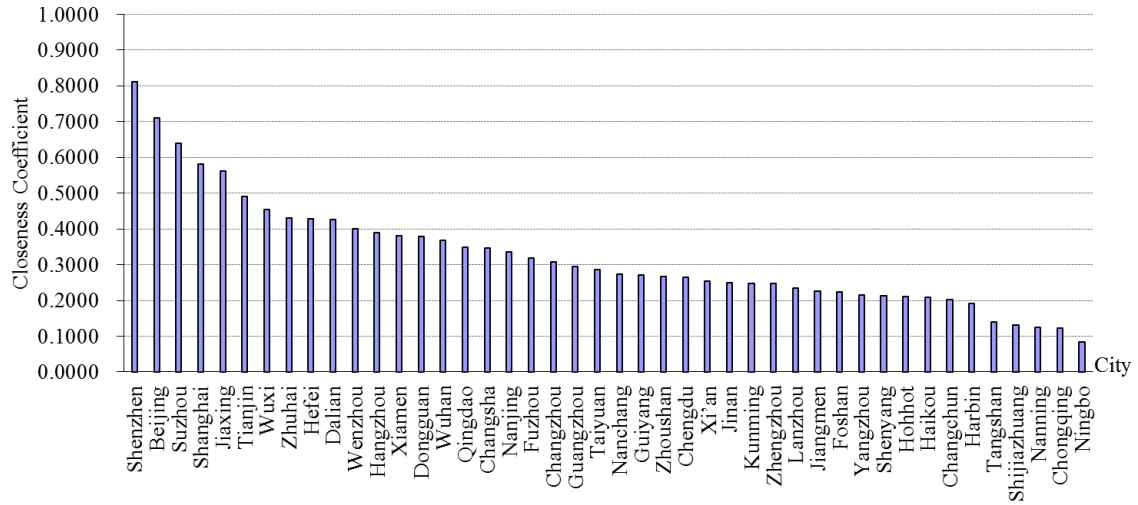


Figure 6 The performance of smart people between 44 sample cities

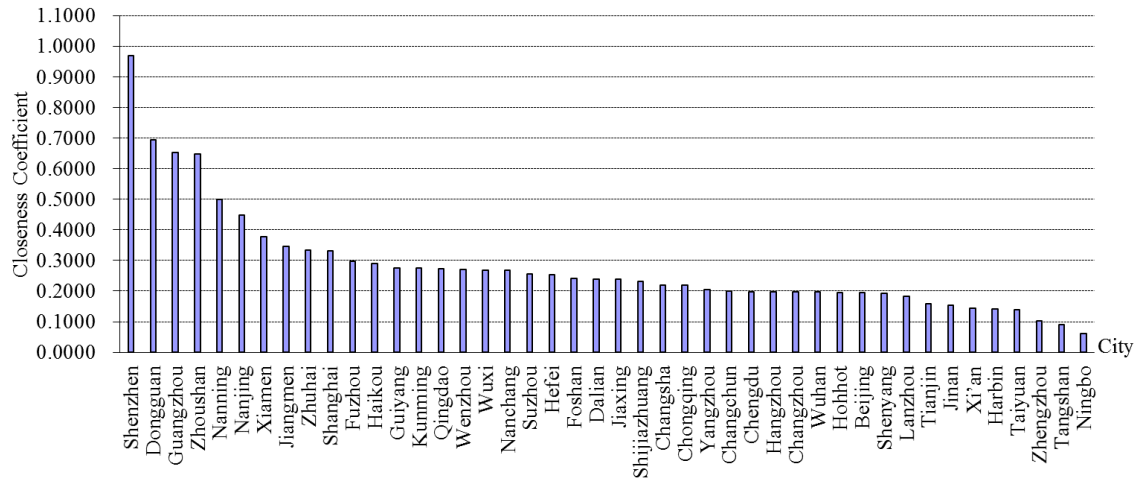


Figure 7 The performance of smart environment between 44 sample cities

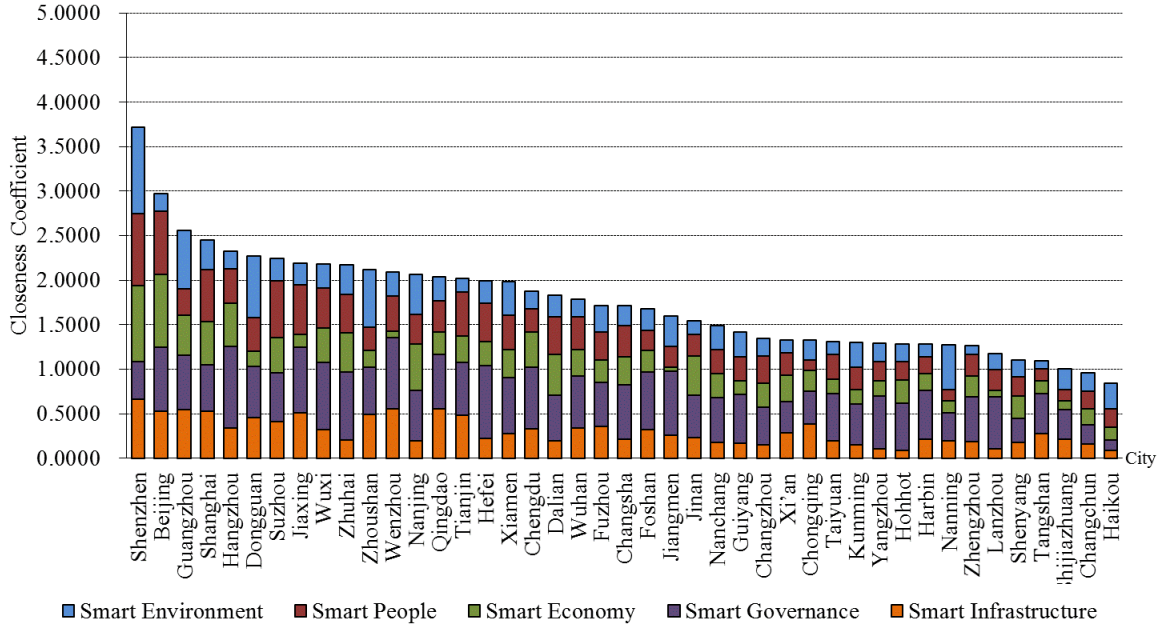


Figure 8 The overall smart performance between the 44 sample cities

5 Discussion

5.1 Smart city performance across five different dimensions

Smart Infrastructure

In referring to Figure 3, the best five cities in smart infrastructure are Shenzhen, Qingdao, Wenzhou, Guangzhou and Beijing, with the worst five of Lanzhou, Yangzhou, Hohhot, Haikou and Ningbo. In fact, it can be seen from Table 4 that most sample cities have the problem of insufficiency in smart infrastructure. 37 out of 44 sample cities (84.09%) have the value of smart infrastructure (θ_j^I) of less than 0.5 whilst the maximum value is 1. The

cities performing well in this dimension are mostly located in Southeast China, where cities have higher level of ICT and better information infrastructure system. In fact, effective measures have been adopted in these well-performed cities for enhancing the ability of smart infrastructure. For example, the smart program “Zhiwang Project” launched in Shenzhen’s Pingshan District in 2014 has resulted in full coverage of free Wi-Fi across the whole district. For another example, the planning and information departments Qingdao have established jointly an information sharing platform to provide service for city planning.

The poor performance in smart infrastructure is mainly due to the lack of advanced smart technology. It was reported that China is still dependent on the technical support from overseas countries in developing smart cities as there is a severe shortage of core technologies of information system and database management in the country (Wu et al., 2017). (Su, 2011) also opinioned that there are problems not addressed such as how to manage and coordinate data processing equipment including sensors, controllers and computing terminals in the practice of implementing smart city programs in China.

Smart Governance

Figure 4 shows that Hangzhou, Hefei, Wenzhou, Zhuhai and Wuxi are the best five performers in smart governance, whilst Shijiazhuang, Nanning, Shenyang, Changchun and Haikou are the five worst. These good performers have certain experiences in

common, as appreciated in other studies (China Smart City Yearbook, 2014): 1) they have smart city development plans; 2) they have financial support programs; 3) they have good on-line services; 4) the citizens in these cities are provided with good access to ICT infrastructure services; and 5) these cities have provided citizens with various training programs about information technologies.

Table 4 shows that the smart governance performance is significantly better than other smart dimensions, with the average value of 0.6452. This may be because that the implementation of smart city programs can bring better efficiency in governance, thus it can receive the support and participation from the public. The study of Poplin et al. (2013) suggests that the quality and efficiency of governance can be improved where smart city programs are implemented. The application of ICT facilities in governance provides the public with better access for expressing views on public issues, thus decisions can better reflect the public demands. This is particularly true in almost all cities in China where the governance systems have introduced better ICT facilities in recent years and public services are in better efficiency and quality. The benefits brought by smart governance in China have been well recognized by both the government and the public. The Chinese government has been devoting good deal of efforts to promoting the development of smart governance through implementing a series of policies and regulations. For example, National Development and Reform Commission (NDRC) issued Policy for the Development of National E-Government (NDRC, 2013). NDRC also jointly issued the policy *Integration and Sharing of Governance Information* with

other four departments including Office of the Central Leading Group for Cyberspace Affairs (OCLGCA), State Commission Office of Public Sectors Reform (SCOPSR), Ministry of Finance, and National Audit Office of the PRC (NAOPRC) (NDRC et al., 2017). Smart governance has made good development at city level across the country, even at village level in those developed regions. These efforts have contributed significantly to the development of smart governance in China.

Smart Economy

Figure 5 demonstrates the performance of smart economy across the 44 sample cities. It can be seen that the top five best performers are Shenzhen, Beijing, Nanjing, Hangzhou and Shanghai, whilst Ningbo, Shijiazhuang, Lanzhou, Wenzhou and Jiangmen are ranked the worst five. The data in Table 4 shows that the average value of smart economy is relatively low, with the value of 0.3830, suggesting that the performance of smart economy in Chinese cities is at a low level. Shenzhen city is a special case where the performance of smart economy is exceptionally good, and the economy is dominated by the services sector with a higher employment rate in high technologies and innovation industries. Furthermore, the good smart infrastructure in Shenzhen is also the driving force to the promotion of smart economy of the city. It is reported that the wireless broadband access covers 98% of the population in Shenzhen by June 2017 (Shenzhen News, 2017), which enable all population to access to network, thus communicate effectively for live, work, learn, and play.

Smart People

It can be seen in Figure 6 that the best five performers in the dimension of smart people are Shenzhen, Beijing, Suzhou, Shanghai and Jiaxing, while Tangshan, Shijiazhuang, Nanning, Chongqing and Ningbo are evaluated as the worst five. People in these good performance cities have better public access to ICT services. This was echoed in the study of Wu et al. (2017), showing that an increasing number of ICT-supported platforms have been integrated in people's daily life in these more developed Chinese cities such as Beijing, Shenzhen and Shanghai. Typically, these platforms include TaoBao shopping platform (the most popular on-line shopping platform in China), Fast Taxi platform (an APP similar to Uber), and 12306 platform (the Chinese official website for railway ticket service).

Although the average performance of smart people is not high, with the value of 0.4481 in Table 4, it appears that the Chinese people particularly in these well-performed cities are better equipped with ICT devices such as Free Wi-Fi in public places. It was reported that in Beijing there are about 300 public places such as subway stations and shopping malls, where citizens can enjoy Free Wi-Fi services (Beijing Daily, 2016). Nevertheless, as addressed early that the infrastructure for implementing smart city programs is insufficient in China, people in general have the difficulty to access to ICT services, thus the overall performance of smart people is not high. Therefore, the improvement of smart infrastructure particularly in those less developed cities is considered the key for improving the overall performance of smart people in China.

Smart Environment

According to Figure 7, Shenzhen, Dongguan, Guangzhou, Zhoushan and Nanning are the best five in referring to smart environment, whilst Harbin, Taiyuan, Zhenzhou, Tangshan, and Ningbo are the worst five. In fact, the overall performance in smart environment is poor in China, evidenced with the average performance value of 0.3599 in Table 4. The poor environment performance in China is well appreciated as the results of the rapid urbanization and industrialization in the country in the past several decades. With the priority of developing its economy, China has been giving insufficient attention to addressing environment issues. As pointed out by Chen et al (2013), the “economic miracles” in China are at the expense of environment pollution. Liu et al (2014) opined that the practice of smart city in China emphasizes largely on smart infrastructure, smart governance, smart people, and smart economy, whilst smart environment is less addressed. It is considered possible to achieve better performance of smart environment through improving the efficiency of energy use and resource utilization, by use of ICT and innovation technologies.

The above discussions demonstrate that the development of the Chinese smart city programs across five dimensions is not balanced. When the average performance of the 5 smart dimensions are presented graphically, as shown in Figure 9, it can be seen that the average smartness values between the 5 dimensions are very different. Although this unbalance is contributed by many factors, the most significant factor is considered due to the fact that cities are designated differently by nature, attached with different

characteristics and functions. Therefore, individual cities take different actions and measures for implementing smart city programs, with giving different priority to different smart city dimension. These differences also impede experience sharing between cities. However, it is considered that, in the long run, the development of smart city across five dimensions should be balanced in order to attain the sustainability of smart city.

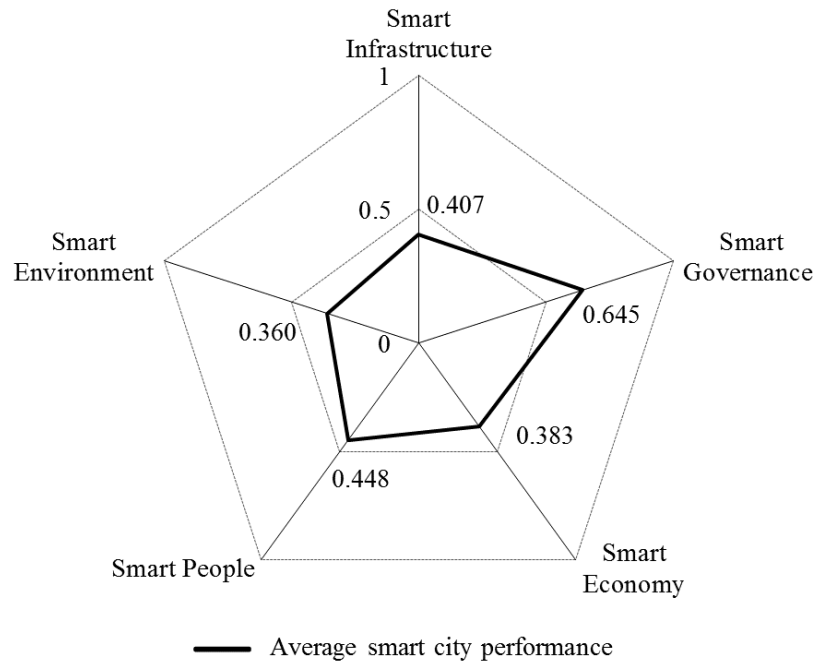


Figure 9 The average smartness performance across 5 dimensions

5.2 Overall smart city performance

Table 4 gives an average of overall smartness (θ_j) of 2.2432 between 44 sample cities, whilst the maximum value (θ_j) is 5. Therefore, it is considered that the overall smart city performance in China is poor. According to Figure 8, Shenzhen, Beijing, Guangzhou,

Shanghai and Hangzhou are the five best smart performers from overall perspective, whilst Tangshan, Shijiazhuang, Changchun, Haikou and Ningbo are the five worst.

Considering that the value of the overall smart performance θ_j is within the range from 0 to 5, five grades of overall performance can be classified, namely, best, good, average, poor, and worst, which are defined as follows:

$$\text{smartness grade} = \begin{cases} \text{worst} & 0 \leq \theta_j < 1 \\ \text{poor} & 1 \leq \theta_j < 2 \\ \text{average} & 2 \leq \theta_j < 3 \\ \text{good} & 3 \leq \theta_j < 4 \\ \text{best} & 4 \leq \theta_j \leq 5 \end{cases}$$

By incorporating the above grading criteria with the data listed in the column of θ_j in Table 4, the number of cities in each grading category can be obtained. It can be derived that 6.82% sample cities are in worst performance, 59.09 % poor, 31.82% average, 2.27% good, and no sample city is in best smart performance. These data can be expressed graphically in Figure 10.

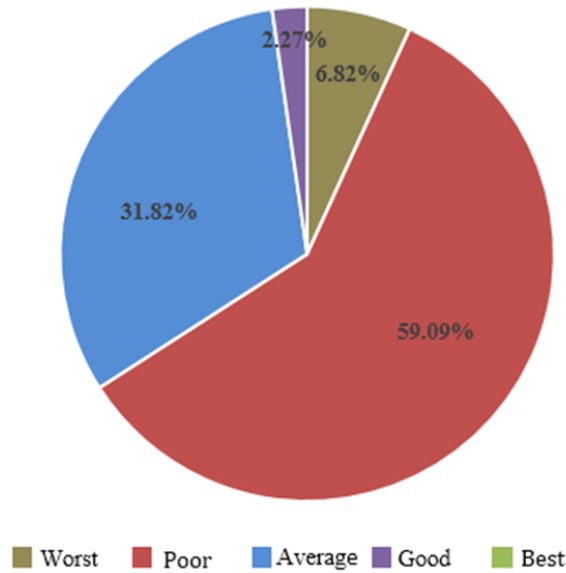


Figure 10 Proportion of sample cities in different smartness grade

The cities in different grading categories are listed in Table 5. There is only one city rated as good performer and 14 as average performers. They are considered satisfactory in the practice of smart city, and can share with other cities the good experience they have generated in promoting smart city programs.

Table 5 Cities in different smartness grades

Smartness grade	Cities
Good	Shenzhen
Average	Beijing, Guangzhou, Shanghai, Hangzhou, Dongguan, Suzhou, Jiaxing, Wuxi, Zhuhai, Zhoushan, Wenzhou, Nanjing, Qingdao and Tianjin.
Poor	Hefei, Xiamen, Chengdu, Dalian, Wuhan, Fuzhou, Changsha, Foshan, Jiangmen, Jinan, Nanchang, Guiyang, Changzhou, Xian, Chongqing, Taiyuan, Kunming, Yangzhou, Hohhot, Harbin, Nanning, Zhengzhou, Lanzhou,

	Shenyang, Tangshan and Shijiazhuang
Worst	Changchun, Haikou and Ningbo

Furthermore, according to the data and information in Table 4 and Figure 8, individual sample cities have different performance in five smart dimensions. For example, Beijing is ranked second from overall smart perspective, but it stands at 5th, 7th, 2nd, 2nd, and 34th respectively in the dimensions of smart infrastructure, governance, economy, people and environment. It is appreciated that a specific city will have its own strategies and plans to promote the practice of smart city pertinent to its urban functions and backgrounds. For example, Beijing, as the capital of China, assumes the central functional roles in political, science and technology, cultural and education, and other functions. The strategy for Beijing to promote the development of smart city is therefore to improve smart infrastructure so as to reinforce its functional roles (Li, 2015).

5.3 Actions recommended for improving smart city performance in the context of China

As appreciated in early discussions, smart infrastructure is the key to implement smart city programs as it provides the basic needs for improving the performance of other smart dimensions. Other previous studies argue that the efficient smart infrastructure in a country can contribute to not only better national GDP performance, but also better individual income and better quality life (Comin, 2004; Beaudry, 2002). Currently, the

smart infrastructure is not sufficient in China. It recommended to contribute more investment to build up the infrastructure including internet facilities, big data platforms, cloud computation devices, corporate optical fiber network, Wi-Fi mesh network, sensor network, public Wi-Fi network, and others. These infrastructure facilities will enable the development of smart governance, smart people, smart economy and smart environment. For example, meters can be installed in residential and commercial buildings to collect the real-time data about energy and water consumption. These data can be further used to analyze and monitor customers' consumption behavior, thus proper measures may be taken to guide customers towards energy saving life style. This way will help improve the performance of smart governance and smart people. For another example, sensors can be installed in transportation management system, including radio frequency identification, laser scanning, and automatic photographing. These sensors can provide transport users or travelers with real-time information about the traffic conditions, thus help them avoid as much as possible traffic jams. This way will reduce the time wasted on transportation and increase productive time, and as a result, the performance of smart economy can be improved. Further to this, carbon emissions will be reduced because of the improvement of transportation operation, which in turn can contribute to the performance improvement of smart environment, as echoed in the study by Letaifa (2015).

On the other hand, the implementation of smart city programs in China is at early stages. Actions should be taken to contribute resources for providing the public with various training programs about the knowledge of ICT application, energy saving, principles and

practice of smart city. These actions will empower the public's ability in using ICT, in turn, people's mobility, productivity and participation access to the public affairs will be improved. These actions can also shape the people's behavior towards more civilized and environmental friendly. Consequently, smart city performance in the dimensions of governance, people, economy and environment will be improved, collectively.

It is also recommended to introduce policy instruments for encouraging professionals' and industries' participation in promoting smart city practice. For example, tax reduction measures can be adopted in those industries or businesses where high-technology jobs are offered. This way will promote the development of ICT and cutting-edge infrastructure and technological economies. Accordingly, smart economy performance can be improved.

Furthermore, it is recommended to establish an evaluation mechanism to assess the real-time progress of smart city practice across the whole country. This mechanism will enable the government to identify the problems existed in the practice and generate good experiences that can be promoted. The results of the real-time evaluation will also enable different cities to share information and experience, based on which effective measures can be formulated and taken timely in order to ensure the healthy development of smart city in the whole country.

Conclusions

Smart city is widely considered as an effective solution to mitigate urban diseases. However, there are many challenges in planning and implementing smart city. A holistic evaluation on the performance of smart city is therefore essential to help identify properly the existing problems, thus effective measures can be taken for improving the performance. This study presents a holistic picture of smart city practice in the context of China. The results of the study show that the overall performance of smart city practice in China is at a relatively lower level. 6.82% sample cities are rated as worst performers, 59.09 % as poor, 31.82% as average, and 2.27% as good. There is no sample city rated as best smart performer. Furthermore, the performance levels between five smart dimensions are significantly imbalanced in the country. Overall, smart governance has gained good performance, followed by people and infrastructure dimensions. The smart performance in economy and environment is poor. However, it is considered that, in the long run, the development of smart city across five dimensions should be balanced in order to attain the sustainability of smart city. On the other hand, there are significant differences in smart performance between cities. Those better performers are mostly from the eastern and southern coastal areas. The study suggests that the improvement of smart infrastructure is the key for improving the overall smart city performance of in China, which will enable the development of smart governance, people, economy and environment.

The evaluation indicator framework is established from a holistic perspective, which facilitate a rigorous analysis on the smart city performance in China. The evaluation results are considered effective and proper, which help properly understand the strength and weakness of individual cities in the process of implementing smart city programs. This understanding helps identify experiences and references from better performing cities for those poor performers in formulating improvement strategies. The analysis also suggests that methods for promoting smart city programs should be designated by considering the background of a specific city, such as natural condition, resources endowment, and policy environment. The holistic evaluation framework adopted in this study can serve as a guidance for developing policies and measures to promote smart city programs. The integrative application of the method of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Entropy method presents a new methodology for conducting performance evaluation of smart city. It contributes to the development of research in the discipline of smart city.

It is recommended for further study to apply the evaluation methodology introduced in this study to examine the smart performance of other Chinese cities.

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Appendix 1

Candidate indicators for measuring the smart city practice in the context of China

No.	Candidate examination indicators	No.	Candidate examination indicators
1	Smart infrastructure	1.6	Network security
1.1	Local accessibility	1.6.1	Network security management
1.2	(Inter-)national accessibility	1.6.2	System and data security
1.3	Availability of ICT-infrastructure	1.7	Availability of public transport (Number of public transit vehicles per capita)
1.4	Network infrastructure	1.8	Inforware Component
1.4.1	Computer quantity per household	1.8.1	Newspapers purchase per household
1.4.2	Modem capacity per household	1.8.2	Magazines purchase per household
1.4.3	Percentage of households with Internet access at home	1.8.3	Frequency referring to information in Internet
1.4.4	Alternative internet facility	1.8.4	Frequency of communication via e-mail
1.4.5	Telephones quantity per household	1.8.5	Frequency observing market and share Commodity in ICTs
1.4.6	Handphones quantity per household	1.8.6	Quantity channel types of TV satellite
1.4.7	TV property per household	1.8.7	Frequency of communication with international friends
1.4.8	Radio property per household	1.8.8	Activeness in dissemination and sharing information
1.4.9	Fax machine property per household	1.8.9	Educational reads purchase per household
1.4.10	Wireless networks	2	Smart governance
1.4.11	Broadband subscription per capita	2.1	Participation in decision-making
1.4.12	The new television network	2.2	Public and social services
1.5	Public database	2.3	Transparent governance
1.5.1	Public database about urban infrastructure	2.4	Political strategies & perspectives
1.5.2	Public database about urban economy and society	2.5	Basic public services

2.6	(percentage individuals aged 16-74 who have used the Internet, in the last 3 months, for interaction with public authorities)	3	Smart economy
2.7	E-Government on-line availability (percentage of the 20 basic services that are fully available online)	3.1	Innovative spirit
2.7.1	Basic public health education	3.2	Entrepreneurship
2.7.2	Employment service	3.3	Economic image & trademarks
2.7.3	Social insurance	3.4	Productivity
2.7.4	Social services	3.5	Flexibility of labor market
2.7.5	public cultural and sports	3.6	Ability to transform
2.7.6	Service for the Disabled	3.7	Employment rate
2.7.7	Housing safeguard system	3.7.1	Employment rate in renewable energy and energy efficiency systems
2.7.8	Medical Treatment and Public Health	3.7.2	Employment rate in financial intermediation and business activities
2.8	Governance	3.7.3	Employment rate in culture and entertainment industry
2.8.1	Urban management	3.7.4	Employment rate in commercial services
2.8.2	Public security	3.7.5	Employment rate in transport and communication
2.9	Government expenditure	3.7.6	Employment rate in hotels and restaurants
2.9.1	Percent of government expenditure on education	3.7.7	Employment rate in high tech and creative industries
2.9.2	Percent of government expenditure on health	3.8	GDP per head of city population
2.9.3	Percent of government expenditure on science	3.9	Median or average disposable annual household income
2.10	Public resources trading platform	3.10	Debt of municipal authority per resident

3.11	Energy intensity of the economy-gross inland consumption of energy divided by GDP	4.9	City representatives per resident
3.12	Percentage of projects funded by civil society	4.10	Foreign language skills
3.13	Components of domestic material consumption	4.11	Participation in life-long learning (%)
3.14	Public expenditure on R&D-percentage of GDP per head of city population	4.12	Percentage of population aged 15-64 with secondary-level education living in Urban Audit
3.15	Number of research grants funded by international projects	4.13	Percentage of population aged 15-64 with higher education living in Urban Audit
3.16	Public expenditure on education-percentage of GDP per head of city population	4.14	Voter turnout in national and EU parliamentary elections
3.17	New industries	4.15	Promotion of city function
3.17.1	High Tech and creative industries	4.15.1	Water system
3.17.2	Modern services	4.15.2	Drainage system
3.18	E-Commerce services	4.15.3	Water saving
3.19	Costs variation by service suspension	4.15.4	Gas system
3.20	International trade	4.15.5	Waste separation and disposal material
3.20.1	Foreign direct investment	4.15.6	Heating systems
3.20.2	Foreign trade export	4.15.7	Lighting system
4	Smart people	4.15.8	Underground pipelines
4.1	Level of Citizens' Networking Life	4.16	School establishment
4.2	Social and ethnic plurality	4.16.1	Number of secondary schools per capita
4.3	Flexibility	4.16.2	Number of higher institution per capita
4.4	Creativity	4.17	Cultural facilities
4.5	Cosmopolitanism/Openmindedness	4.18	Individual safety
4.6	Participation in public life	4.19	Housing quality
4.7	Individual level of internet skills	4.20	Education facilities
4.8	Patent applications per inhabitant	4.21	Touristic attraction

4.21.1	International visitor arrival	5.11	Sustainable resource management
4.21.2	Domestic tourist arrival	5.12	Total CO2 emissions, in tons per head
4.22	Accessibility to healthcare services	5.13	Ecological and livable civic environment
4.22.1	Number of hospitals per capita	5.13.1	Protecting urban environment
4.22.2	Number of hospitals beds per capita	5.13.2	Energy saving
5	Smart environment	5.14	Greenhouse Gases
5.1	Attraction of natural conditions	5.15	Acid Gases
5.2	An assessment of the extensiveness of city energy efficiency standards for buildings	5.16	Particulate
5.3	Total annual energy consumption, in gigajoules per head	5.17	Energy used
5.4	Greenhouse gas emission intensity of energy consumption	5.18	Renewable energy used
5.5	The total percentage of the working population traveling to work on public transport, by bicycle and by foot	5.19	Fossil energy used
5.6	An assessment of the extensiveness of efforts to increase the use of cleaner transport	5.20	Green space (Green area per capita)
5.7	Waste separation and disposal	5.21	Efficient use of resources
5.8	Percentage of citizens engaged in environmental and sustainability-oriented activity	5.21.1	Water consumption per GDP
5.9	Combined heat and power generation - percentage of gross electricity generation	5.21.2	Electricity consumption per GDP
5.10	The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption, in terajoules	5.22	Air pollution integrated index