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Analysis of sustainability of Chinese cities based on network big data of city rankings

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ABSTRACT

Background: Achieving urban sustainability is the ultimate destination of urban development. City rankings as one of the sustainability assessment tools have received increasing attention from the scientific community. However, few study assesses Chinese cities' sustainability performance using the big data of existing city rankings.
Aim: This study aims to assess Chinese cities' sustainability performances based on the outcomes of the existing internet big data of city rankings.
Methods: The outcomes of city rankings were used as the raw dataset. The "sustainability" of city rankings, city's appearance frequency, and its ranking place were comprehensively considered during evaluation processes. By considering the above factors, the scores of different cities were calculated in terms of overall sustainability and domain sustainability. Furthermore, the GeoDetector was applied to explore the association between social-economic and overall ranking scores as well as the interrelation among TBL dimensions.
Results: Chinese cities' sustainability performance was extremely uneven in spatial distribution. In terms of overall and domain sustainability, well-performing cities were aggregated in the Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta metropolitan regions. The top ten sustainable cities were Hangzhou, Beijing, Shenzhen, Guangzhou, Zhuhai, Hong Kong, Tianjin, Suzhou, and Xiamen. Most cities did not reach good coordination among the TBL dimensions, instead of developing well in one or two aspects. The results also revealed that current city rankings eyeing more economic and social development, while considering less environmental dimension. Moreover, TBL dimensions mutually reinforce each other in sustainable city construction. The environmental pillar played a critical role and interacting with other dimensions significantly enhanced urban sustainability.
Conclusion: The outcomes of existing city rankings can be used as a new resource to evaluate cities' sustainability performance. Current city rankings in China are not systematically considered in terms of TBL dimensions. Cities should enhance the coordination among TBL pillars, and increase the attention on environmental dimension. More empirical studies involving big data of city rankings will contribute to a new perspective to promote the practice of sustainable urbanization in China.

1. Introduction

Cities are complex systems involving conflicts and interactions among social, economic, and environmental dimensions (Brundtland et al., 1987; Wang et al., 2011). They play an increasingly crucial role during human development processes since there are still amount of people who will move into cities (UN Desa (United Nations, Department of Economic and Social Affairs, Population Division), 2018; Grimm et al., 2008). China is now undergoing rapid urbanization (Fang et al., 2021), and it is conservatively estimated to reach 75% by the year 2050

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(Gu et al., 2017). This massive migration could have adverse effects on the environment and increase the already huge demand on resources (Madlener & Sunak, 2011; OECD, 2010; Phillis et al., 2017). Consequently, the challenges facing environmental, social, and governance are increasing. Therefore, commitment to a new model of urbanization, achieving sustainable outcomes with cities, becomes a primary issue for local and global sustainable development (Bossuyt & Savini, 2018; McManus, 2012; Pappalardo & La Rosa, 2020; Zucaro et al., 2014).

The sustainable city supplements a new pattern to achieve sustainable goals. It not only refers to the strategies and actions applied to meet the end goal of sustainable development, but also a dynamic staged presentation of cities' sustainability (Hassan & Lee, 2015). The construction of a sustainable city also requires combining various dimensions (e.g., physical urban characteristics and sociocultural), and inputs from different stakeholders, such as city planners, specialists, and residents (Haywood et al., 2019; Hueskes et al., 2017; Jepson, 2004; Soma et al., 2018). This consequently caused various definitions (Theodoridou et al., 2012, Rogers, 1997; Murrain, 1993, and Hassan & Lee, 2015). However, all emphasize that achieving sustainability with cities depends on more abstract issues namely the triple bottom line (TBL) to sustainable development. As a universal sustainable performance assessment framework, TBL comprehensively considers environmental, social, and economic aspects (Batten & Edwards, 2016; Montoya et al., 2020; Elkington, 1994). Therefore, TBL has the potential to provide an overall perspective to sustainability performance.

With the introduction of the sustainable city, a series of tools have been proposed to measure cities' sustainable performance in various dimensions. For example, the United Nation's City Prosperity Index (Habitat UN, 2015) obtains thresholds of sustainability based on 17 indicators, the Sustainable Cities Index (Batten & Edwards, 2016) includes 32 indicators covering three dimensions of TBL, and the Global Power City Index (More Memorial Foundation [MMF], 2016) evaluates the attractiveness, business, and talent of cities from six dimensions. After 1997, the Chinese government has also established a series of tools (Table S1) to evaluate cities' sustainability in different aspects. However, previous studies and frameworks on cities' sustainable evaluation are mainly performed by a single organization group or scholar. The used evaluation indexes are established by researchers or selected from existing tools, even some are just suitable for a special region or particular city. Hence, it is a challenge to compare outcomes geographically.

City rankings provide a supplementary to sustainable evaluation (Giffinger et al., 2010; McManus, 2012; Saez et al., 2020). They use a set of indicators to evaluate the development and performance of selected cities in various dimensions during a period (Giffinger et al., 2010; Hoornweg et al., 2007). Compared to traditional methods, city rankings have their unique advantages. Rankings can be easily spread with a wide range of groups as they have straightforward readable list presentations. Thus, they can stimulate extensive public participation in local development and policies, which makes government decisions more transparent and comprehensible (Giffinger et al., 2007). Rankings can result in a clear learning effect and balance urban development between regions by identifying both competitive advantages and relative disadvantages (Chang et al., 2018; Escolar et al., 2019; Giffinger et al., 2010). Additionally, they facilitate decision-makers and governments to optimize development goals and strategies in the future (Escolar et al., 2019; Giffinger et al., 2010; Kaklauskas et al., 2018; Saez et al., 2020; Neirotti et al. 2014). However, scholars also agree that heterogeneity exists among the methodology of rankings (Giffinger et al., 2010; Meijering et al., 2014). For instance, different interest groups have various particular thematic focuses and goals. Thus, diverse indicators and city samples are selected to achieve their final goals, which may result in unexpected ratings or black-box operation for profits (Saez et al., 2020). Second, rankings ignoring either complex causalities between different dimensions, or the various requirements of activities due to their general aim is to find the "best" (or "most attractive") city (Giffinger et al., 2010). Moreover, the differences between regions in terms of development patterns and data availability make the indicators and methods used for ranking are not one-size-fits-all. Nevertheless, the advantages of city rankings still cannot be neglected, especially for various rankings emerged in the internet big data (Jeacle & Carter, 2011; Lansky, 2002; Akande et al., 2019).

Even though city rankings have attracted interest from scientific research, there are still some issues that need to be addressed. Frist, rankings focusing on Chinese cities are not well-explored in scholarly fields (Hazelkorn, 2011; Saez et al., 2020), especially city rankings produced by unofficial groups in internet big data. Second, city rankings are often restricted to a specific purpose or interest (Tang, 2017; Tao et al., 2018), even only focus on specific cities (Jiao, 2017; Shan, 2018). Third, virtually all city ranking evaluations are achieved by establishing an index system where the indicators are constructed by the researchers or referred from the existing frameworks (Huang, 2015; Tu, 2016; Yang, 2007; Zhang et al., 2014; Zheng & Bedra, 2018). However, this may bring subjective bias and reduce the comparability of outcomes geographically. Finally, few studies use both "internet big data" and the outcomes of city rankings per se as core objects to assess cities' sustainability performance.

In light of these gaps, this study aims to evaluate Chinese cities' sustainability performances using the outcomes of existing internet big data of city rankings. And in parallel, comprehensively considering the TBL dimensions to address the following research questions: (1) What is the spatial distribution of urban sustainability performance in China? and (2) How do the TBL dimensions affect the overall city rankings and how the coupling relationship among them? This study contributed to the assessment of cities' sustainability performance based on the outcomes of existing internet big data of city rankings. It also provides a new insight in the datasets used for future city sustainability assessments. Finally, the outcomes of the analysis in different dimensions could help decision-makers have a better understanding and implication of sustainable city construction.

2. Data sources

Big data not only refers to the size of data, but also the attributes of data, technological needs, and social impacts (De Mauro et al., 2016). It provides a new and powerful way to achieve urban sustainability by proving a people-oriented perspective, real-time information and high-resolution spatial dynamics (Kong et al., 2020). Internet rankings, eyeing diverse topics, are produced by different groups and organizations. They have the potential to be used as "big data" to support sustainable city construction for involving extensive information and social impacts (Giffinger et al., 2010). The big data of city rankings used in this study was sourced from the internet (www.baidu.com) with a period ranging from 2000 to 2018. During the retrieval process, the search fields for city rankings collection included "city rankings", "eco-city rankings", "livable city rankings" and other rankings related to sustainable development. The search scope was expanded by the snowball method.

Data cleaning was applied to ensure the quality. It excluded the rankings missing a clear published agency, issuing time, and description of ranking rules. Only the top 10 cities in each ranking were kept for downstream analysis due to the heterogeneity among rankings and the availability of data. Consequently, 100 city rankings with high quality were reserved. The above dataset was checked by other authors, where any disagreement was solved by discussion (detailed information about the city rankings see Table S2). Due to the heterogeneity of ranking criteria and city samples in each ranking, this study did not consider any changes in the sustainability performance of each city over time.

To explore how TBL dimensions contribute to overall sustainability performance, some indicators were chosen to represent the different dimensions of TBL from previous investigations (Kucukvar & Tatari, 2013; Egger, 2006; Labuschagne et al., 2005). These indicators were representative and operable. Also, they were commonly used in sustainable assessment, which could reflect the development status of a certain dimension better. Moreover, the data availability of the selected indicators was high among different geographic areas. Specifically, population was chosen to characterize the social dimension as it was the foundation of social development. The economic dimension was characterized by Gross Domestic Product (GDP) and Per Capita GDP (Lenzen & Dey, 2002). The Normalized Difference Vegetation Index (NDVI) was applied to depict the environmental dimension. The above socioeconomic data were sourced from the statistical bulletin on government websites (http://www.stats.gov.cn/) and China city statistical yearbook. NDVI was extracted from the Geospatial Data Cloud website (http://www.gscloud.cn/).

3. Method

Qualitative and quantitative analyses were involved. The basic structure of the methodological approach was depicted schematically in Fig. 1.

First, all rankings were divided into three categories by the TBL dimensions involved in their ranking basis. The classification of ranking basis was completed independently by two authors (Jiakun Liu & Li Xing) based on previous studies (Brink et al., 2020; Slaper & Hall, 2011; Egger, 2006). Any differences reached an agreement through discussion. During overall ranking analysis, city rankings were classified into "comprehensive rankings" and "special category rankings". The former one's indicators contained all three dimensions of TBL, while the latter only contained two or one TBL dimensions (Fig. 1). Regarding sub-attribute analysis, city rankings were categorized into social attribute, economic attribute, and environmental attribute rankings. Their ranking basis contained social, economic, and environmental dimension, respectively (Fig. 1). In addition, a deviation rectifying process was performed to avoid result interference caused by the inconsistent number of various city ranking types (find the details in Supplementary materials).

Second, rankings with different "sustainability" and different ranking places were assigned weights and scores differently in various analyses, by respective. City rankings' "sustainability" was defined as the TBL dimensions included in their rank basis. The "sustainability" of rankings increased as the included TBL dimensions increase. In addition, rankings with different "sustainability" show various relative importance in different analyses. The Delphi method was applied to support the above process (Linstone & Turoff, 1975). Our expert consulting team consisted of four experts, including three professors and an associate professor. Consequently, the relative importance of rankings diminished with its "sustainability" decline in overall ranking analysis, while the opposite was true for sub-attribute analysis. Thereafter, the Analytic hierarchy process (AHP) (Saaty, 1980) was employed to determine the weight of different city rankings based on above results (Supplementary materials). Additionally, ranking places were divided into three levels. The first place got 10 scores, the place between second and fifth obtained 8 scores, and the remaining places got 7 scores.

Finally, the overall top 20 cities and the top 20 cities of different dimensions (i.e., social, economic, and environmental) were obtained by considering cities' appearance frequency, city rankings' "sustainability" and ranking places. Subsequently, the top 10 with a good level of

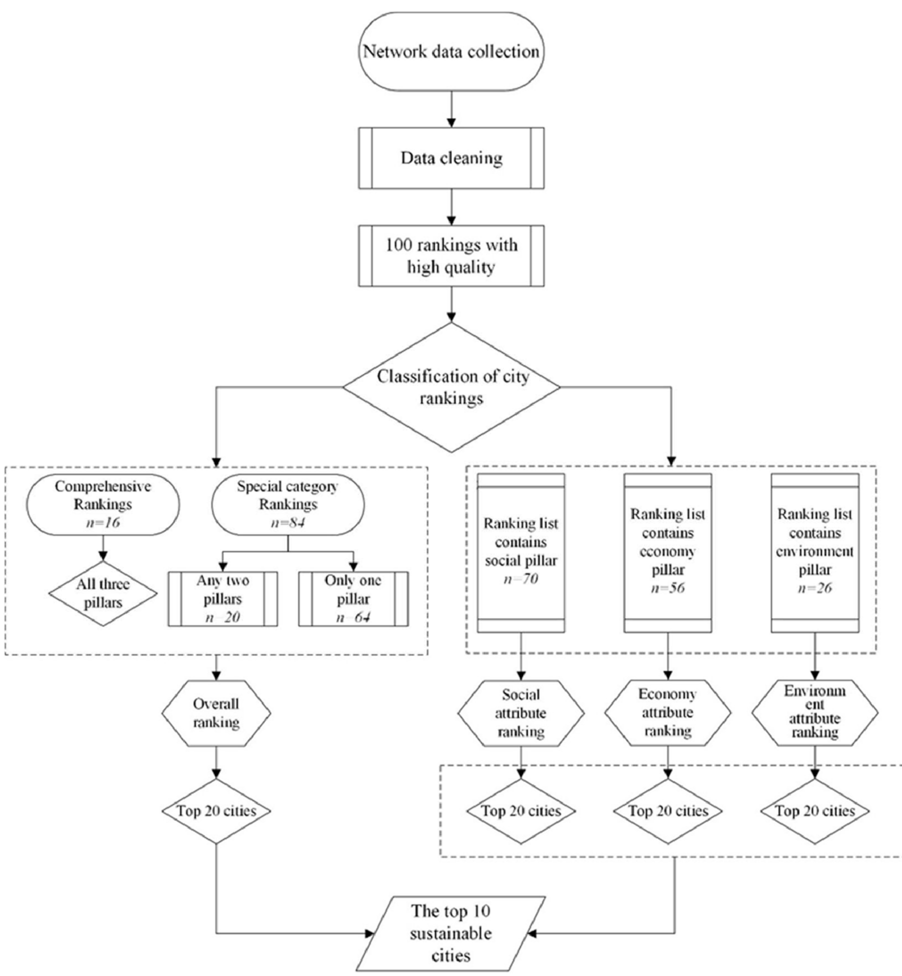

Fig. 1. Methodological scheme.

sustainability were evaluated based on the results of overall rankings and the sub-attribute rankings. The specific calculation methods were shown in sections 3.1 and 3.2, and all the calculations were achieved via excel.

3.1. Overall analysis and sub-attribute analysis

The overall ranking score of each participated city was calculated based on the results of the deviation rectifying process and AHP (Table S3 and Table S4). The formulas were:

$$Q = \frac{\left(\sum q_1 + \sum q_{2-5} + \sum q_{6-10}\right)}{Q_{max}} \times 100 \tag{1}$$

$$q_1 = \left(\sum r_{a_1} \times 50\% \times 0.4878 + \sum r_{b_1} \times 30\% \times 0.3902 + \sum r_{c_1} \times 20\% \times 0.1220\right) \times 10 \tag{2}$$

$$q_{2-5} = \left(\sum r_{a_{2-5}} \times 50\% \times 0.4878 + \sum r_{b_{2-5}} \times 30\% \times 0.3902 + \sum r_{c_{2-5}} \times 20\% \times 0.1220\right) \times 8 \tag{3}$$

$$q_{6-10} = \left(\sum r_{a_{6-10}} \times 50\% \times 0.4878 + \sum r_{b_{6-10}} \times 30\% \times 0.3902 + \sum r_{c_{6-10}} \times 20\% \times 0.1220\right) \times 7 \tag{4}$$

Where Q represented the score of cities' sustainability performance in the overall rankings. q_1 was the score of the city ranked first place in all rankings; q_{2-5} was the score of the cities ranked 2nd to 5th place; q_{6-10} represented the score of the cities ranked 6th to 10th place. r_{a_1} , $r_{a_{2-5}}$, $r_{a_{6-10}}$ represented the frequency of the cities ranked 1st, 2nd-5th, and 6th-10th in rankings that belonged to comprehensive rankings, respectively; r_{b_1} , $r_{b_{2-5}}$, $r_{b_{6-10}}$ represented the frequency of the cities ranked 1st, 2nd-5th, 6th-10th in rankings that belonged to special category rankings containing two pillars of the TBL; r_{c_1} , $r_{c_{2-5}}$, $r_{c_{6-10}}$ represented the frequency of the city ranked 1st, 2nd-5th, 6th-10th in rankings that containing only one dimension, respectively. Q_{max} was the maximum value.

The same methods as the overall ranking were used to obtain the top 20 cities in sub-attribute ranking analysis. However, the weights and correction coefficients of different types of rankings were varied in the analysis of different attributes (see Table S3 and Table S4). The formulas for social attribute analysis were:

$$Q_s = \frac{\left(\sum q_1 + \sum q_{2-5} + \sum q_{6-10}\right)}{Q_{max}} \times 100 \tag{5}$$

$$q_1 = \left(\sum r_{a_1} \times 20\% + \sum r_{b_1} \times 30\% \times 0.1736 + \sum r_{c_1} \times 50\% \times 0.0925\right) \times 10 \tag{6}$$

$$q_{2-5} = \left(\sum r_{a_{2-5}} \times 20\% + \sum r_{b_{2-5}} \times 30\% \times 0.1736 + \sum r_{c_{2-5}} \times 50\% \times 0.0925\right) \times 8 \tag{7}$$

$$q_{6-10} = \left(\sum r_{a_{6-10}} \times 20\% + \sum r_{b_{6-10}} \times 30\% \times 0.1736 + \sum r_{c_{6-10}} \times 50\% \times 0.0925\right) \times 7 \tag{8}$$

Where Q_s represented the score of cities' sustainability performance in the social dimension. q_1 , q_{2-5} , q_{6-10} , r_{a_1} , $r_{a_{2-5}}$, $r_{a_{6-10}}$ were the same meaning with the overall ranking calculation. r_{b_1} , $r_{b_{2-5}}$, $r_{b_{6-10}}$ represented the frequency of the city ranked 1st, 2nd-5th, 6th-10th in rankings which belonged to the special category rankings containing two dimensions of the sustainability pillars and one of the pillars was society; r_{c_1} , $r_{c_{2-5}}$, $r_{c_{6-10}}$ represented the frequency of the city ranked 1st, 2nd-5th, 6th-10th in rankings which only containing the social pillar. Q_{max} was the maximum value. The same calculation method was then used for the economic and environmental attributes rankings (Supplementary materials).

3.2. Top ten sustainable cities

The top 10 sustainable cities were obtained by combing the results of section 3.1. Among the above-ranking result, cities ranked first place received 10 points, second to fifth places were given 9 points, sixth to tenth places got 8 points, eleven to 15th places got 7 points, and 16th to 20th places got 6 points based on the results of the Delphi Method. Then, cities listed in the overall rankings got 50% weight, while those listed in the three sub-attributes rankings got one-sixth weight (weights were calculated using AHP). The final score of cities' sustainability level was equal to the sum of the scores of the above sub-items.

3.3. Spatial autocorrelation

Moran's I is an index to measure spatial autocorrelation based on the Pearson coefficient, which reflects the spatial trend and the correlation among nearby locations (Moran, 1950; Zhang et al., 2020). The values of Moran's I range from − 1 (negative spatial autocorrelation) to + 1 (positive correlation). This study applied the global Moran's I to analyse the spatial correlation of cities with better performance in overall rankings. This calculation was achieved within ArcGIS.

3.4. GeoDetector

GeoDetector was proposed to detect the influence mechanism of geospatial factors on disease risk (Wang et al., 2010), but now widely used in detecting socio-economic mechanisms (Liu & Yang, 2012; Zhou et al., 2018). It also included the interaction detector, which was able to find the interaction between two determinants and to answer whether the relationship was weakened, enhanced, or independent when two determinants (C & D) were taken together (Wang & Hu, 2012) (Table 1). This study utilized the GeoDetector to explore the relationship between socioeconomic factors and overall rankings. The formula (Wang & Hu, 2012; Wang et al., 2016) was as follows:

$$q = 1 - \frac{1}{N\sigma^2}\sum_{i=1}^{L} N_i\sigma_i^2 \tag{9}$$

Where L was the classification or zoning of geographical things or independent variables; σ^2 and N represented the variance of the event of the study area and the area, respectively; $q \in [0, 1]$. If the stratification was generated by the independent variable factor, the model had a stronger explanatory power of the geographical things when the q value was larger and vice versa.

4. Results

4.1. Overall analysis of cities' ranking

A total of 202 county-level and above cities were included in 100 city rankings. There were 158 prefectural cities, 31 county-level cities, 6

Table 1
The interaction relationship between two factors.

Interaction	Description
Enhance, bi-	q (C ∩ D) > Max (q (C), q (D))
Enhance, nonlinear	q (C ∩ D) > q (C) + q (D)
Weaken, uni-	Min (q (C), q (D)) < q (C ∩ D) < Max (q (C), q (D))
Weaken, nonlinear	q (C ∩ D) < Min (q (C), q (D))
Independent	q (C ∩ D) = q (C) + q (D)

autonomous prefectures, 4 municipalities and 2 special administrative regions. Geographically, the listed cities were mainly located in central and eastern China, but rarely in the western regions. By only considering the appearance frequency, the top 10 cities including the equal frequency were Guangzhou, Hangzhou, Beijing, Shenzhen, Shanghai, Nanjing, Suzhou, Tianjin, Chengdu, and Chongqing. However, their ranking places were quite different. For instance, Beijing ranked first more often, while Shanghai, Shenzhen, and Guangzhou mostly ranked between the second and fifth places (Fig. 2).

The top 20 cities of the overall ranking were different from the results by just considering appearance frequency (Fig. 3). After comprehensive consideration, Guangzhou dropped from first to fourth place, whilst Hangzhou rose from second to first place. Although both Hong Kong and Fuzhou were with an appearance frequency of 18, they ranked 9th and 18th in the overall rankings, respectively. A perspective analysis found that Hong Kong ranked the top, accounting for 58.82%, while Fuzhou did not. Thus, the overall ranking of a city was shaped by its ranking places (especially the number of times ranked high) and the “sustainability” of rankings. In conclusion, a city would still get a lower score when it had a higher appearance frequency but most of the ranking places and the rankings’ “sustainability“ were low, and vice versa.

Geographically, cities with a high score in the overall rankings had an agglomeration of hot spots in space. The results of spatial autocorrelation are shown in Figure S1. The Moran’s I was 0.06 (z-score: 2.70, p-value: 0.007). Cities that performed well in overall rankings were significantly aggregated in three urban agglomerations, namely the Beijing-Tianjin-Hebei, the Yangtze River Delta and the Pearl River Delta metropolitan regions. The result showed that cities with relative higher achievement in sustainable performance played a role model and a radiating driving effect on the development of surrounding cities.

4.2. Sub-attribute ranking analysis

4.2.1. Social attribute ranking analysis

The top 20 cities in the social attribute rankings were similar as the ones in the overall rankings. Hangzhou was ahead of other cities in terms of social development. Moreover, the top 10 cities were same in the above rankings (Fig. 3). Thus, it reflected that the social dimension might play a critical role in overall sustainable development. Beijing and Guangzhou had the same appearance frequency, however, their scores differed by 5.82 points resulting in different social sustainability performances. This similar situation also existed in other cities with an equal appearance frequency. It could be explained by that the cities with higher scores were normally ranked higher in most city rankings. In sum, ranking “quality” (i.e., ranking high or low in place) mattered more than appearance frequency.

4.2.2. Economic attribute ranking analysis

The top 5 cities were in the same order in both overall rankings and social attribute rankings (Fig. 3). Among the top 20 cities, 3 cities were Special Economic Zones (i.e., Shenzhen, Zhuhai, and Xiamen), 12 cities were coastal cities, and most of the remaining cities were provincial capitals. The results proved, indirectly, that the economic development of coastal cities was superior to inland cities in China. Compared to the overall rankings and the social attribute rankings, economic attribute analysis indicated that cities with a well-developed economy also developed well in their social dimension. In turn, the development of social undertakings would promote economic development.

4.2.3. Environmental attribute ranking analysis

The results of the environmental attribute analysis were different from that of the other two sub-attribute analyses. The top five cities were Hangzhou, Zhuhai, Shenzhen, Xiamen, and Beijing (Fig. 3). As the analysis results showed, Hangzhou put the environment and social and economic development in equal importance during urban developing process. Xiamen, as a Special Economic Zone, performed better in the environmental dimensions (ranked 4th) than it did in social (14th) and economic (11th) dimensions. Beijing ranked 5th in the environmental attribute rankings and 2nd in other types of analysis. Thus, the environmental development of Beijing was relatively backword compared to its social and economic development.

Comparing the cities across all sub-attribute rankings, only a few

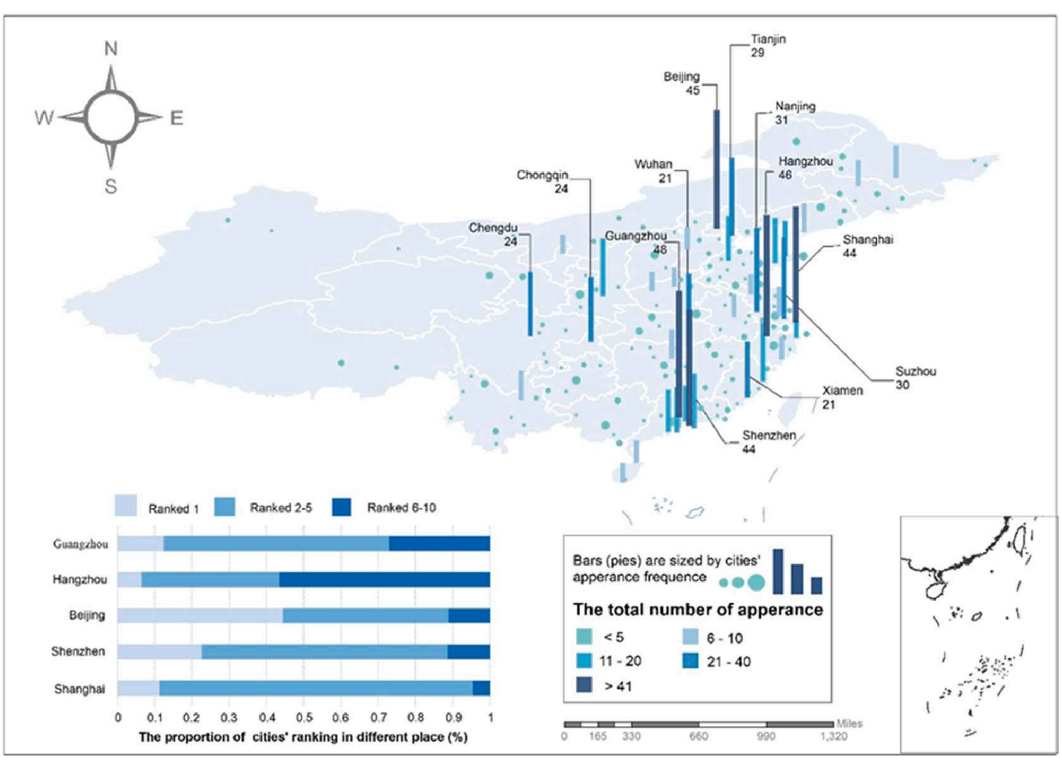

Fig. 2. Nationwide distribution of participating cities in China.

Fig. 3. The results of different ranking analysis.

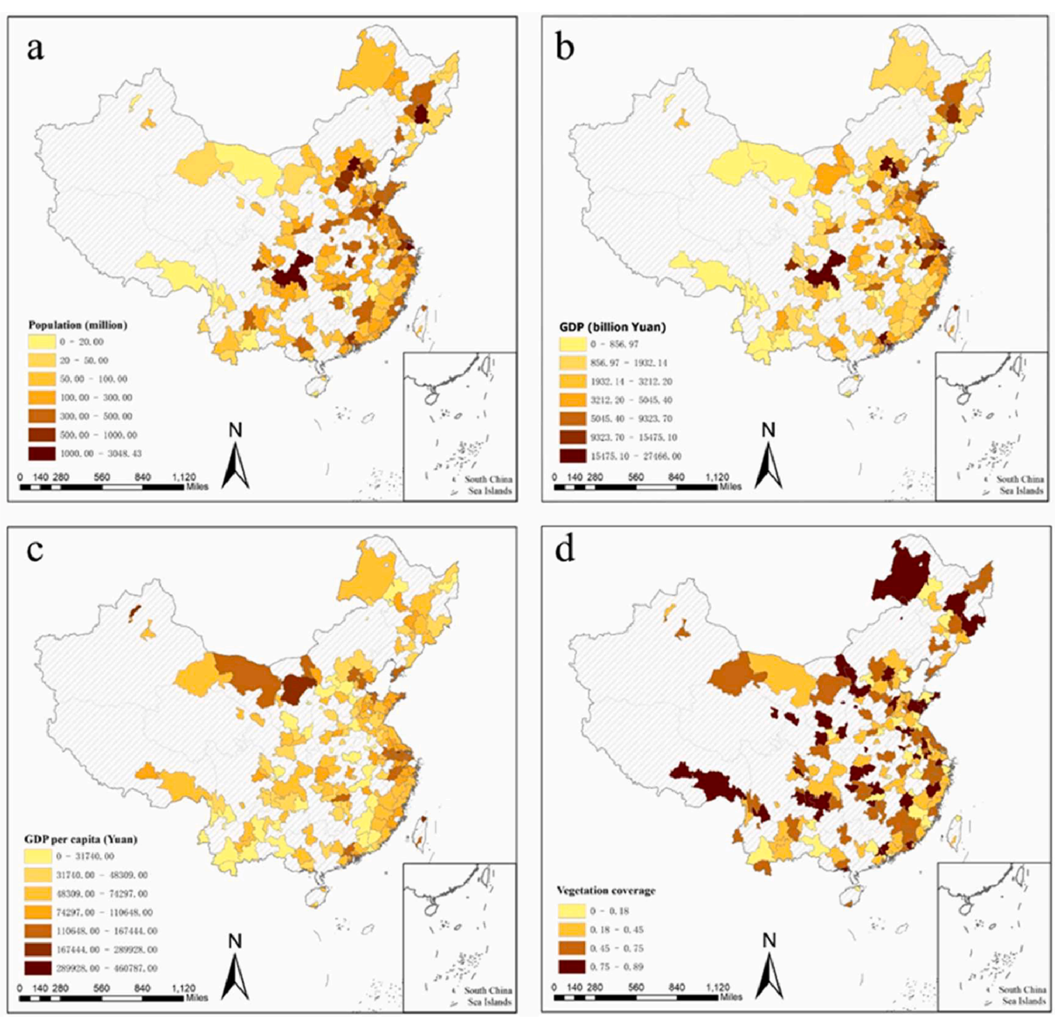

Fig. 4. The spatial distribution of each factor.

cities were balanced in the three dimensions of TBL. Most cities developed well in the social and economic dimensions, while, relatively speaking, they fell behind in the environmental dimension.

4.3. Sustainable city ranking analysis

The top 10 cities at a relatively high level of sustainability were different from other rankings (Fig. 3). Hangzhou ranked 1st with a score that was equal to the maximum ideal value. The top 5 cities, except for Hangzhou, were first-tier cities and ranked with the same order in overall rankings, social attribute rankings and economy attribute rankings. Hangzhou, Shenzhen, and Beijing had a relative well coupling and coordination between social economic dimensions and environmental dimension. In addition, Xiamen ranked 10th in the sustainable city rankings, but it only ranked in the top ten cities (i.e., ranked 4th) in the environmental attribute ranking. In contrast, Nanjing ranked in the top ten of the overall rankings, the social attribute rankings, and the economy attribute rankings, but its environmental performance was below 20th. This resulted that it did not enter the rank of top 10 sustainable cities.

4.4. Influential factors detection analysis

The spatial distribution of each factor was shown in Fig. 4. The spatial distribution of population in 2016 was similar to the GDP distribution (Fig. 4a, 4b). Cities with high per capita GDP were in inner Mongolia and some coastal areas (Fig. 4c). Cities with higher vegetation coverage were distributed in the southwestern regions and Yakeshi (Fig. 4d).

The results of the GeoDetector revealed the explanatory power of the TBL dimensions on cities' overall ranking scores. Collectively, current city rankings mainly depended on the social and economic dimensions instead of the environmental dimension. For instance, the explanatory power of GDP was 66.55%, while the ones of population and vegetation coverage were only 34.74% and 5.78%, respectively. There were nonlinear enhanced interactions between NDVI and population as well as between NDVI and per capita GDP. The interactions between remaining factors were shown as two-factor enhancements. Although the single-factor contribution rate of NDVI was only 5.78%, the interaction with other factors resulted in a great enhancement effect (Table 2). The performance of the top 10 sustainable cities in different TBL dimensions also verified the above results. Most of them had considerably higher scores in the economic and social attribute rankings than ones in the environmental dimension, except for Zhuhai and Xiamen (Figure S2).

Table 2
The interactions among the factors.

x ∩ y	q(x)	q(y)	q(x ∩ y)	Interaction
Population ∩ Per Capita GDP	0.3474	0.3125	0.6484	Enhance, bi-
Population ∩ GDP	0.3474	0.6655	0.7208	Enhance, bi-
Population ∩ Vegetation coverage	0.3474	0.0579	0.5480	Enhance, nonlinear
Per Capita GDP ∩ GDP	0.3125	0.6655	0.7852	Enhance, bi-
Per Capita GDP ∩ Vegetation coverage	0.3125	0.0578	0.4103	Enhance, nonlinear
GDP ∩ Vegetation coverage	0.6655	0.0578	0.7238	Enhance, bi-

5. Discussion and implication

5.1. A perspective of Xiamen city

The results show that Xiamen is the only city that far outperforms other dimensions in terms of environmental dimension. The comparison among the top 10 sustainable cities also suggests that Xiamen's advantages in environmental dimension to a certain extent complete the relative deficiencies of the other two dimensions. In addition to the above reasons, Xiamen also makes remarkable achievements in eco-city construction and then obtains a wide range of recognition and good reputations among various groups (Liu et al., 2020). Therefore, a perspective of "Xiamen's experience" could benefit other cities to promote sustainable city construction.

Review the development history of Xiamen, it did not achieve the balanced development of the TBL in the initial stage. In the 1950 s, Xiamen focused on social development. After a period of rapid urban construction and economic development, Xiamen gradually realized the importance of ecological environment construction. Subsequently, Xiamen began to balance the development between social economic and ecological environment dimensions though highlight the importance of environment construction in its municipal work. For example, Xiamen had carried out the ecological restoration and protection projects of Yundang Lagoon since 1988. Additionally, a series of local regulations/laws had been issued to protect the ecological environment. In 1994 and 2001, two rounds of integrated coastal zone management were applied to protect and restore the ecological environment of Xiamen's coastal area. Moreover, to promote the healthy co-development of economy and environment, Xiamen had continuously optimized its industrial structure to reduce environmental pollutions from heavy industry (Fig. 5).

To achieve sustainability within city, Xiamen continually deepen ecological environment construction. During its rapid urbanization period, the built-up area is scaled up, where the green space coverage rate even increased instead of being sharp decrement (Fig. 5). In addition, Xiamen form a high-level leadership mechanism to supervise ecological environment construction, and implement the "Multiple compliance" to optimize management efficiency (Ye & Huang, 2018). Furthermore, Xiamen has incorporated sustainable urban development into the top-level design of the city and implement "drawing a blueprint to the end". Collectively, Xiamen not only attach importance to environmental dimension, but also couple TBL dimensions during the city construction, which play a key role in the success of "Xiamen experience".

The "Xiamen experience" echoes the statement that sustainable city is both a state and a process of dynamic construction (Hassan & Lee, 2015). It also highlights that the environmental dimension plays a critical role and cannot be underestimated or ignored in sustainable city construction.

5.2. Spatial heterogeneity in cities' sustainability performance

In line with Tan et al. (2016) and Fan & Qi (2010), well-developed cities are unevenly distributed in space. First, it is possible that the unreasonable allocation of resources leads to the heterogeneity of cities' sustainability performance geographically (Christiaensen & Kanbur, 2017). Megacities have more excellent resources and opportunities, which provide impetus for their development in different dimensions. This also leads to a snowball effect. In contrast, small and medium-sized cities are backward due to the limited talent and excellent resources. However, unlimited and continuous growth in one dimension does not meet the goal of sustainable development. On the contrary, it can bring unexpected challenges and problems. Hence, megacities should critically consider the rational allocation, development and utilization of their resources. Additionally, both scarcity and over-saturation of resources in a region need to be addressed by countries or regions from the macro-level to balance the development of the entire urban ecosystem. As the main force of future urbanization, small and medium-sized cities have to gain appropriate resources and power to explore a sustainable development pattern (Zhao et al., 2009). Second, geographical location can be another reason that results in unbalanced spatial distribution (Sun & Ye, 2011). Compared to western cities, coastal cities have unique geographical advantages in economic development, cultural exchanges, and urban constructions (Bao et al., 2002; Liu et al., 2020).

The top 20 cities in sub-attribute rankings involve a total of only 26 cities (i.e., 26 cities were ranked 60 times). All these cities had

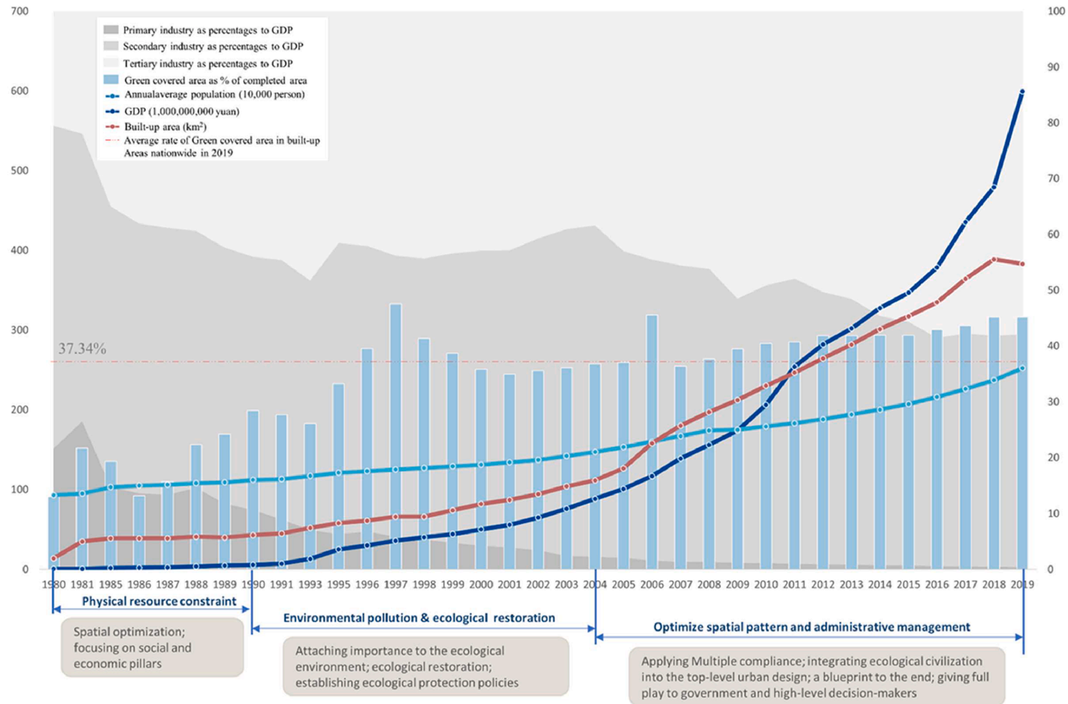

Fig. 5. The development trend of different dimensions of Xiamen from 1980 to 2019.

advantages in at least one TBL dimension. Therefore, the 26 cities can serve as the basis to optimize cities' sustainability performance from east to west. Additionally, using their advantages in different dimensions to drive the development of surrounding cities. However, with different resource allocations and actual development conditions, cities should focus on the TBL dimensions in batches and consider the synergetic and complementary effects among TBL dimensions.

5.3. Sustainable cities require coordinated development in different dimensions

Our results show that current city rankings still use the economic and social dimensions as basic references. A potential explanation is that the traditional political evaluation system leads to the non-official sustainable assessment system of economic and social value orientation. In China's early industrialization, the government focused more on economic development rather than environmental protection. Thus, most cities applied the patterns of treatment after pollution rather than protecting ecological and developing social and economic hand in hand. However, sustainable cities require coordinated development and cross-cooperation in different dimensions rather than being well-developed in a single aspect (Frey & Yaneske, 2007; Blackburn, 2007). The findings also suggest that economic benefits should not be obtained by sacrificing the environmental dimension (Dong et al., 2020; Lin & Grimm, 2015). Therefore, in the top-level design of the city, the three dimensions of TBL should be organically combined, instead of sacrificing any dimension for other developing dimensions.

5.4. Putting city rankings in perspective and strengthening sustainability

We argue that the role of city rankings needs to be put into proper perspective in the increasing city competition. Although rankings promote urban development and guide policy implications (Escolar et al., 2019; Meijering et al., 2014), they also have negative effects on cities' development (Mercer, 2014). For instance, cities deliberately focus on "what counts" based on preferred rankings to obtain honorary titles. This may bring economic benefits, but also lead to unsustainable development and make all cities and towns look the same. In addition, most rankings have a strong target or profit-driven goal. Therefore, city managers and decision-makers should treat city rankings rationally and correctly, rather than formulate a special remediation plan for short-term benefits depending on one ranking.

Integrating public participation into city rankings can enhance rankings' reliability and promote sustainable urban construction. City rankings are generally easy to be accessed and recognized by the public, which can stimulate public participation in local urban development. High-quality public participation can address the disagreements and conflicts between local governments and the public (Holden, 2011). It can also promote social learning and urban governance, thereby improving urban sustainability (Bell & Morse, 2001; Garmendia & Stagl, 2010; McManus, 2012). In addition, the public has their personal experience as they are practitioners of urban changes and development. Hence, they can better recognize the strengths and weaknesses of different dimensions from their perspectives. High-quality broad public participation also can reduce the profit-based black-box manipulation in city rankings, and complement the decision-making. Therefore, city ranking with high-quality public participation can provide an approach to combine top-down and bottom-up urban management and development. Forthcoming city rankings should comprehensively consider the TBL dimensions and integrate public participation to support decision-making and urban planning.

5.5. Strength and limitations

This study provides a new perspective for using big data of city rankings to evaluate cities' sustainability. Previous studies evaluated cities' sustainability by establishing indicators by researchers or selecting from other tools. Compared to the traditional methods, our approach reduced human subjective basis during the process of indicators establishment or selection. In addition, the big data on city rankings used in our study not only involves different producers but also has good dissemination and influence among the public. This consequently makes our results reliable and stable. Although our method has been used in empirical research for the first time, our results are highly consistent with previous studies based on selectivity indicators. For example, the result shows that Hangzhou, Beijing, and Shenzhen have a good coupling and coordination among the three dimensions of TBL, which is consistent with Fan et al. (2019). Aligns with Tan et al. (2016), we also found that Shenzhen, Beijing and Guangzhou were all among the top ten in the economic dimension. Additionally, cities with better overall performance were mainly located in the southeast coast, and there is uneven development among the TBL dimensions (Tan et al., 2016). Another agreement with previous study is that economic dimension has an important impact on cities sustainability (Yu & Wen, 2010). Finally, the well-known big cities were well-developed and had higher scores in the city sustainability assessment (Chen & Zhang, 2020; Li et al., 2018).

However, this study still has some limitations, such as certain errors in internet big data, systematic bias during the integration of different rankings and subjective bias in the manual classification of indicators. In addition, our results are difficult to be compared with SDGs for benchmark analysis, as we cannot obtain detailed indicators of each ranking. In future research, more empirical analyses need to be performed by using big data of city rankings to evaluate cities' sustainability and link city rankings to SGDs.

6. Conclusion

This study provides a new insight in assessing cities' sustainability based on internet big data of city rankings and broadens the dataset used for urban studies. The results reveal that the spatial distribution of urban development is extremely uneven in China. Most well-developed cities are well-known large cities, being concentrated in the Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta metropolitan regions. Current city rankings are normally based on economic and social dimensions. These rankings prefer to rank prefecture-level and well-known cities instead of county-level and medium-sized cities. Moreover, three TBL dimensions interact with each other, where the environmental dimension plays a critical role in sustainable development. More empirical research involving big data are needed to explore the potential role of city rankings in sustainable city development. Future research should rank rankings themselves to establish a sustainable ranking ecosystem rather than a chaotic and market-driven one.

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CRediT authorship contribution statement

Jiakun Liu: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Yu Zhao:** Writing – original draft, Writing – review & editing. **Tao Lin:** Conceptualization, Writing – review & editing, Supervision. **Li Xing:** Formal analysis, Investigation, Data curation. **Meixia Lin:** Writing – review & editing, Investigation. **Caige Sun:** Writing – review & editing, Investigation. **Zhiwei Zeng:** Investigation. **Guoqin Zhang:** Data curation, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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