

Research Article

Compilation of Smart Cities Attributes and Quantitative Identification of Mismatch in Rankings

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One practical way to define a “smart city” is to look at the specific qualities listed in a ranking study about smart cities. Such method gives de facto guidelines for classifying a city as being smart or not. Building upon this rationale, the current work in its first objective presents features adopted in evaluating the “smartness” of cities in seven evaluations and in its second objective arranges them in a suggested structure of six scopes with forty-three keywords. With these two objectives, the current study serves as a summary of various ranking studies in terms of being a collection place of many evaluation criteria. Four of the considered studies are the 2018 and 2019 annual editions from two sources, and comparing these criteria shows some changes over one year, and these updates are highlighted. A third objective of this study considers analyzing assigned ranks and utilizing a normalized score (limited to a maximum of unity) derived from the raw scores given in six ranking studies (out of the seven considered, with one ranking study excluded as it does not give raw numerical scores) to the six cities that commonly appear in all of them. This part shows with details the existence of mismatch not just in a one-time ranking, but also in a year-to-year trend, where a city appears to be improving according to one evaluator while appears to be degrading according to another evaluator. As a fourth objective, statistical analysis of the evaluation results was conducted, with quantitative assessment of rankings mismatch.

1. Introduction

There is no universal definition for the term “smart city” [1–3]. The term was introduced in 2008, referring to adopting technology and managing data effectively in an integrated way to solve challenges of a modern urban community [4]. A smart city may be defined as an urban society whose members collaborate using information and communication technology (ICT) to better reach performance targets, improve the quality of life, and have more open governance [5]. Measuring outputs is an important stage of improvement [6]. In this regard, evaluation studies attempt to assess a number of cities for their attained level of smartness. Such evaluations give feedback to the administrative body of the city, to its inhabitants, and to the global public at large. They also provide valuable data and case studies to those interested in realizing the characteristics of a smart city. However, a number of gaps were identified in the assessment tools for smart cities, such as the lack of including temporal change (as compared to a one-time static

evaluation), the inability to adapt to the city size when comparing small and large cities, and missing the stakeholders’ engagement component during both the development phase and the implementation phase [7].

While contradiction in smart cities rankings was reported before for two studies of the same year of 2019 [8], the present work represents a deeper look into this issue, considering not only two ranking studies but also seven studies. The presented work does not merely report qualitatively an instantaneous mismatch of smart cities rankings, but also contributes proposed quantitative analysis methods that helps reach a fairer assessment of cities performance when comparing their status of smartness to each other, as well as when interpreting the evolution of their status over time. The present work utilizes a (normalized score) concept that alleviates the impact of the pool of cities included in a particular ranking study. It also groups various criteria of city smartness in seven (smartness scopes).

In the present work, we analyze seven evaluations of smart cities that are available publicly, where we both

TABLE 1: Key features of the 7 ranking studies considered.

Ranking study	Publisher	Year	Number of cities attempted	Number of cities ranked	Number of distinct ranks	Number of ranking factors (and categories)
Smart Cities Index, 2019 [9]	EasyPark Group	2019	500	119	100	24 (in 7 categories)
Smart Cities Index, 2018 [10]	EasyPark Group	2018	500	121	105	22 (in 8 categories)
Smart City Governments [11]	Eden Strategy Institute and ONG&ONG Pte Ltd	2018	140	50	47	10 (not categorized)
Cities in Motion Index, 2019 [12]	IESE Business School in Barcelona	2019	174	174	171	96 (in 9 categories)
Cities in Motion Index, 2018 [13]	IESE Business School in Barcelona	2018	165	165	162	83 (in 9 categories)
Smart Cities—What’s in it for citizens? [14]	Juniper Research	2017	20	20	20	58 (in 5 categories)
Smart Cities Prospects [15]	Procedia Computer Science	2017	20	20	12	18 (in 6 categories)

examine the criteria used in judging how smart a city is, and examine the coherence among these evaluations, which is related to the reliability of published rankings of smart cities. For two sources, the 2018 and 2019 editions of the evaluation are compared.

This work is motivated by a desire to develop an attribute-based definition of smart cities, as compared to a traditional textual description. The former reflects multiple views of what makes a city a smart city, by independent third parties specialized in assessing the level of smartness observed by a city through measurable qualities, whereas the latter may suffer for an overly subjective narrow view, and high projection onto a local region or one set of national norms. The proposed characterization of the smart city presented here is based on smart city qualities by entities from Sweden (1st and 2nd ranking studies in Table 1), Singapore (3rd ranking study in Table 1), Spain (4th and 5th ranking study in Table 1), the UK (6th ranking study in Table 1), and Russia and the USA (7th ranking study in Table 1).

The problem statement of the present work might be formulated as a number of questions that the present study addresses, as follows: What to look for when classifying a city as smart or as “smarter”? Should the rankings data of smart cities given by a single independent party be assumed to be roughly compatible with other parties? In case of discrepancy in the ranking of the same city by two ranking parties, how big the gap can be, quantitatively? Which metric is more important in smart cities ranking, the positional rank or the absolute score? How does a normalized score (a processed numerical value that always has a maximum attained value of 1.0 by the best performing city in any pool of compared cities) behave in comparison with an absolute raw score while interpreting ranking data of smart cities? Can the ranking contradiction between different parties extend to the trend of change over two years, or is it likely to be limited only to same-year evaluation? If two cities are ranked consecutively (like 9th and 10th) in terms of smartness, does this mean a big performance difference between them? The present work can be viewed as having four objectives: compiling in one place various attributes used to measure smartness of a city, processing these attributes and proposing a structure of indicators for a smart city, performing statistical analysis of a normalized assessment score assigned to all cities that appear commonly in different ranking

studies (which ideally should be equal across ranking studies), and finally attempting to explain the reason of observed discrepancy in the ranking received by the same city in more than one ranking study.

2. Evaluations Considered

Table 1 lists some key properties of the seven ranking evaluations we consider here, such as the year and the number of ranked cities in each study. The 2019 version of the Smart Cities Index evaluation is the 3rd annual edition, while the 2018 version is the 2nd annual edition. The 2019 version of the Cities in Motion Index (CIMI) evaluation is the 6th annual edition, while the 2018 version is the 5th annual edition. Other evaluations are not regularly published. We point out that for the Smart Cities Index 2018 evaluation, the publisher refers to 24 ranking factors. However, counting the actual number of factors given in the detailed scoring table gives only 22 factors. The number of factors is 24 in the 2019 edition of that evaluation source. The number of distinct ranks is not necessarily the number of ranked cities due to occurrence of repeated scores.

There are other related ranking studies that are not included in the analysis here, such as the Digital Economy and Society Index (DESI) [16], which is limited to the European Union (EU) member states, and is not strictly targeting smart cities but is focused on digitized performance in five areas: connectivity, human capital, Internet services, technology integration, and public services.

Another related study is the United Nations (UN) E-Government Survey [17], which is focused on digital government development of the UN member states. It is not at the level of cities and is not well oriented toward smart cities.

3. Observed Evaluation Criteria

A list of the assessment factors (indicators) used in each evaluation study was examined. Most of the evaluation studies grouped their factors into categories. For the (Smart Cities Index) evaluation, there are 7 categories of indicators. For the (Smart City Governments) evaluation, there are 10 factors without parent categories. For the (Cities in Motion Index) evaluation, there are 9 categories of indicators. For the (Smart Cities—What’s in it for citizens?)

evaluation, there are 5 categories of indicators. For the (Smart Cities Prospects) evaluation, there are 6 categories of indicators.

The (Smart Cities Index) evaluation has a distinct category of EXPERT PERCEPTION. Through its factor of TRACK RECORD, the (Smart City Governments) evaluation pays attention to the past performance of city's government in terms of successful initiatives related to city smartness. The (Cities in Motion Index) evaluation is distinguished from other evaluation studies by its INTERNATIONAL OUTREACH category (having for example an indicator about the number of McDonald's chain restaurants). On the other hand, the BASIC INDICATORS category in the (Smart Cities—What's in it for citizens?) evaluation includes special factors such as the city's whole population (as compared to the size of a specific segment) and gross value added (as a city-level version of the GDP, reflecting possibility of economic advancement and also life quality).

For the (Smart Cities Index) evaluation, and the (Cities in Motion Index) evaluation, where two editions are considered (2018 and 2019), the changes in the evaluation criteria are highlighted. As examples, the (Smart Cities Index) ranking studies added in 2019 the indicator E-charge under the category of TRANSPORT AND MOBILITY, while demoting the category of Cyber security to just an indicator under the category of DIGITALIZATION. The (Cities in Motion) ranking studies show a much more change between 2018 and 2019. They added a number of indicators in 2019, such as expenditure on education, suicide rate, mortgage as a percentage of income, hourly wage, Internet speed, percentage of bicycles per household, and presence or absence of the ridesharing service Uber. On the other hand, a number of 2018 indicators were removed in 2019, such as number of gas stations, number of points where flight operations take place within a 40-km radius from the latitude and longitude defining the center of the city, and the number of people who are currently registered in Facebook.

4. Suggested Scopes of a Smart City

This section provides a suggested 6-scope structure with suggested 43 attributes that define smart cities and can be used in benchmarking smart cities. This suggested attribute-based definition is summarized in Table 2. The list is adapted from those criteria collected from the various evaluation studies considered in the present work, based on personal view and guided by recent articles in the literature of smart cities [18–26].

A list of the assessment factors (indicators) used in each evaluation study is provided in Appendix A. Any grouping of factors under categories in that appendix is done as per the evaluation study itself.

Governance orientation (determination and commitment for transition to a smart city) plays a key role into driving a city toward smartness. Also, a smart city is not just about intensive use of high technology devices (although this is an expected feature of a smart city), but this term extends

TABLE 2: Suggested scopes of a smart city.

Serial number	Scope name (total 6)	Keywords (total 43)
1	Governance orientation	Total keywords: 6 (i) Motivated leaders (ii) Community awareness (iii) Revised policies (iv) Dedicated budget (v) City planning (vi) Achievable targets
2	Human capital	Total keywords: 10 (i) Belongingness (ii) Financial security (iii) Recreation ability (iv) Safety (v) Female-friendly (vi) Fairness (vii) Sufficient services (viii) Affordable services (ix) Time from graduation to employment (x) Disability inclusion
3	Transport	Total keywords: 7 (i) Public transportation (ii) Electric bikes (iii) Alternative fuel vehicle (iv) Alternative fueling stations (v) Online transactions (vi) Pedestrian friendly traffic (vii) Ride sharing
4	Outdoor Environment	Total keywords: 6 (i) Green areas (ii) Trees (iii) Heat island control (iv) Natural/artificial shade (v) Free public parks (vi) Decarbonized energy sector
5	Internet and technology	Total keywords: 6 (i) Wi-Fi everywhere (ii) Online access to government services (iii) Mobile access to taxi network (iv) Mobile phone alerts (v) Cybersecurity (vi) Big data analytics
6	Infrastructure	Total keywords: 8 (i) Low consumption buildings (sustainable or smart) (ii) Rain water use (iii) Sensors grid (iv) IoT waste management (v) Recycling (vi) Disaster management (vii) Adaptive lighting system (viii) Distributed generations (DG)

and overlaps with other socially desirable features, such as satisfaction of the public [27], leading to a true passion for the city. This reflects an emphasis on the (Human Capital) scope.

Equipping members of the city with awareness and training programs in order to appreciate the benefits of the transition to a smart (or a smarter) city is important for a

TABLE 3: Summary of ranking of the 6 common cities in all the 7 ranking studies considered.

Ranking study	Total ranked cities	City					
		Berlin	Chicago	Dubai	Melbourne	New York	Singapore
Smart Cities Index, 2019	119	21	24	75	53	23	9
Smart Cities Index, 2018	121	13	4	101	74	14	41
Smart City Governments	50	29	17	40	8	4	2
Cities in Motion Index, 2019	174	9	17	99	20	2	7
Cities in Motion Index, 2018	165	11	14	60	12	1	6
Smart Cities—What’s in it for citizens?	20	7	5	11	10	3	1
Smart Cities Prospects—repeated scores counted as different ranks	20	18	10	16	3	14	2
Smart Cities Prospects—repeated scores counted as a single rank	12	10	6	10	3	9	2

collective collaboration. The electric bicycles (or e-bikes) are added explicitly under transport scope, as an alternative transportation option for intercity commuting with a favorable environmental impact over private vehicles powered by gasoline or diesel (while not practical for daily roundtrip distances beyond 40 km). A city that caters for bicycling (electric or not) and promotes it as an alternative environment-friendly means of transportation (by having a network of bicycle lanes for example) helps construction projects earning one credit point (out of 110 total attainable points for new projects or projects with major renovation) according to the LEED (Leadership in Energy and Environmental Design) rating system for green buildings, through fulfilling the credit (Bicycle Facilities) under the credits category (Location and Transportation) [28] in its v4 (fourth version), which is currently active. LEED is managed by the U.S. Green Building Council (USGBC), which describes LEED as the most common system for rating green buildings worldwide [29].

5. Cities in Common

Among the seven evaluations of smart cities considered here, there are six cities that appear in all of them. These cities (in alphabetical order) are as follows:

- (i) Berlin (Germany)
- (ii) Chicago (the United States of America)
- (iii) Dubai (United Arab Emirates)
- (iv) Melbourne (Australia)
- (v) New York (the United States of America)
- (vi) Singapore (Singapore)

Having such shared cities in different evaluations oriented to the same scope helps realizing the coherence of these evaluations. One may expect a similar rating or a similar trend over time across the various evaluations.

Table 3 compares the rankings given to the common cities by the different evaluations. These values neglect the effect of duplicate scores, so repeated scores are counted as different ranks. This is a minor issue because the number of repeated scores is relatively small compared to the number

of ranked cities, with the exception of the last evaluation (Smart Cities Prospects), where the number of repetitions (8) is comparable to the number of ranked cities (20). Therefore, two ranking values are given for that evaluation: one where repeated scores are counted as different ranks and another where repeated scores are counted as a single rank. These adjusted rankings are more proper than the ones that neglect the occurrence of repetitions.

The ranking of a city highly depends on the pool of cities assessed in the respective evaluation. Therefore, it is not easy to use it when analyzing the matching across different evaluation studies. Instead, the scores given to the common cities provide a better pool-independent measure for coherence across evaluations. The scores were normalized to have a maximum possible value of unity by dividing the published scores by the maximum attainable score, and the values are presented in Table 4. A similarity of the values of these normalized scores for the same city would be an indication of coherence among evaluations. The evaluation (Smart Cities—What’s in it for citizens?) does not publish scores, but only rank cities relative to each other.

There is notable scatter among the values of the normalized scores. For example, New York received a normalized score of 1 (by Cities in Motion Index, 2018) but also received a score of 0.626 (by Smart City Governments, which is also dated 2018).

However, a fair comparison of the normalized scores should be done for evaluations belonging to the same year. As a result, the normalized scores of the three evaluations with a common year (2018) are repeated in Table 5.

The same table also shows the mean and the sample standard deviation for each city.

The arithmetic mean or simply the mean (\bar{x}) of the 6 normalized scores for each city is calculated as follows:

$$\bar{x} = \frac{x_1 + x_2 + x_3 + x_4 + x_5 + x_6}{6} \quad (1)$$

This follows the given formula [30]:

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \quad (2)$$

TABLE 4: Normalized scores of the 6 common cities in all the 7 ranking studies considered.

Ranking study	Maximum attainable score (the ideal case)	City					
		Berlin	Chicago	Dubai	Melbourne	New York	Singapore
Smart Cities Index, 2019	10	0.672	0.658	0.539	0.604	0.665	0.707
Smart Cities Index, 2018	10	0.671	0.695	0.432	0.521	0.671	0.613
Smart City Governments	50	0.516	0.548	0.48	0.59	0.626	0.646
Cities in Motion Index, 2019	100 (assigned to the top city)	0.809	0.756	0.529	0.751	0.946	0.827
Cities in Motion Index, 2018	100 (assigned to the top city)	0.763	0.736	0.567	0.749	1.000	0.795
Smart Cities—What's in it for citizens?	—	—	—	—	—	—	—
Smart Cities Prospects	100	0.790	0.830	0.790	0.870	0.800	0.880

TABLE 5: Normalized scores of the 6 common cities in the 3 ranking studies dated 2018.

Ranking study	Maximum attainable score (the ideal case)	City					
		Berlin	Chicago	Dubai	Melbourne	New York	Singapore
Smart Cities Index, 2018	10	0.671	0.695	0.432	0.521	0.671	0.613
Smart City Governments	50	0.516	0.548	0.480	0.590	0.626	0.646
Cities in Motion Index, 2018	100 (assigned to the top city)	0.763	0.736	0.567	0.7491	1.000	0.795
	Mean	0.6501	0.6595	0.4930	0.6200	0.7657	0.6847
	Standard deviation (sample formula)	0.1250	0.0987	0.0684	0.1170	0.2042	0.0971

TABLE 6: Comparison of the change in ranking position between 2018 and 2019 for 6 common cities as given by 2 ranking publishers.

Ranking publisher	City					
	Berlin	Chicago	Dubai	Melbourne	New York	Singapore
Smart Cities Index (SCI)	-8 ↓	-20 ↓	26 ↑	21 ↑	-9 ↓	32 ↑
Cities in Motion Index (CIMI)	2 ↑	-3 ↓	-39 ↓	-8 ↓	-1 ↓	-1 ↓

A positive value or an upward arrow means that the city improved from 2018 to 2019. A negative value or a downward arrow means that the city stepped back relative to peer cities from 2018 to 2019.

where ($n=6$) is the sample size, which is the number of data values used to calculate the mean.

The standard deviation (s) of the 6 normalized scores for each city is calculated using the sample formula as follows:

$$s = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + (x_3 - \bar{x})^2 + (x_4 - \bar{x})^2 + (x_5 - \bar{x})^2 + (x_6 - \bar{x})^2}{5}} \quad (3)$$

This follows the given formula [31]:

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \quad (4)$$

where ($n=6$) is the sample size, as mentioned before. It is worthy of clarifying that the division by ($n-1=5$) not by ($n=6$) in equations (3) or (4) is intentional. The division by ($n-1$) happens when the calculation is for a sample, while the division by (n) should happen if all cities in the world (which is referred to as “the population”) are included [32], but this is not the case here.

The standard deviation measures the spread (scatter) of normalized scores, and it is zero in the very special case of identical scores. However, one can see that it goes as high as 0.2042 for New York, which is 26.7% of the mean value for

that city. The smallest standard deviation (0.0684) corresponds to Dubai, and it is 13.9% of the mean normalized score for that city.

Comparing the changes in the rankings and the normalized scores for a city by two different evaluation sources over the same period helps revealing the coherence or mismatch between them. This is done for the 2 sources with annual evaluations, and the change from 2018 to 2019 is examined in Table 6 for the rankings and in Table 7 for the normalized scores. The two evaluating sources are the Smart Cities Index (SCI) and the Cities in Motion Index (CIMI). The normalized score is a more appropriate measure as the ranking position can be highly influenced by the other peer cities in the evaluation. The case of Dubai appears to be surprising, where according to the SCI evaluation, its ranking improved by 26 positions. On the other hand, its

TABLE 7: Comparison of the change in the normalized score between 2018 and 2019 for 6 common cities as given by 2 ranking publishers.

Ranking publisher	City					
	Berlin	Chicago	Dubai	Melbourne	New York	Singapore
Smart Cities Index (SCI)	0.001 ↑	-0.037 ↓	0.107 ↑	0.083 ↑	-0.006 ↓	0.094 ↑
Cities in Motion Index (CIMI)	0.045 ↑	0.020 ↑	-0.038 ↓	0.002 ↑	-0.054 ↓	0.032 ↑

A positive value or an upward arrow means that the city improved from 2018 to 2019. A negative value or a downward arrow means that the city stepped back from 2018 to 2019.

TABLE 8: Basic statistical analysis of the normalized scores in the 7 ranking studies considered.

Ranking study	Range	Maximum	Minimum	Mean	Median
Smart Cities Index, 2019	0.438	0.763	0.325	0.562	0.570
Smart Cities Index, 2018	0.448	0.724	0.276	0.546	0.567
Smart City Governments	0.27	0.670	0.400	0.528	0.527
Cities in Motion Index, 2019	0.9543	1.000	0.046	0.538	0.557
Cities in Motion Index, 2018	0.8277	1.000	0.172	0.523	0.523
Smart Cities—What’s in it for citizens?	—	—	—	—	—
Smart Cities Prospects	0.15	0.890	0.740	0.824	0.825

ranking degraded by 39 positions according to the CIMI evaluation.

From the qualitative view, the direction of change for a city (improving by increased normalized score or degrading by decreased normalized score) should ideally be the same for both evaluation sources (SCI and CIMI). However, this is not the case for Chicago and Dubai. However, for the other four cities, the trends of change are consistent in the two evaluation sources. Despite this, the changes quantitatively differ by two orders of magnitude in the case of Berlin (improvement case), and by one order of magnitude in the case of New York (degrading case).

6. Statistical Analysis

This section gives a summary of some statistical features of the seven evaluations of smart cities considered in our work. The analysis excludes the (Smart Cities—What’s in it for citizens?) evaluation because it does not report numerical scores.

Table 8 presents the range, maximum, minimum, mean, and median of the normalized scores for all cities assessed in each evaluation (not just the six common ones). The range is the difference between the maximum value and the minimum value. The median is the value separating the upper half subset of data from the lower half subset. In calculating the median, a pair of duplicate scores is counted as two different ranks.

The mean and median values are close to each other in all studies. This indicates high symmetry of data around the mean value. Moreover, these mean and median values are similar across all evaluations except for the (Smart Cities Prospects) evaluation, where they are noticeably higher. This is related to the high value of the minimum normalized score in that study, being 0.74. This is not very far from the maximum normalized score in that study, which is 0.89.

The evaluations of Smart City Governments and Smart Cities Prospects have relatively narrow ranges of 0.27 and

TABLE 9: Two measures of the spread of the normalized scores for the 7 ranking studies considered.

Ranking study	Top-to-maximum	Median-to-minimum
Smart Cities Index, 2019	0.193	0.245
Smart Cities Index, 2018	0.157	0.291
Smart City Governments	0.143	0.127
Cities in Motion Index, 2019	0.443	0.512
Cities in Motion Index, 2018	0.477	0.351
Smart Cities—What’s in it for citizens?	—	—
Smart Cities Prospects	0.065	0.085

0.15, respectively. One should keep in mind that these two studies have the smallest number of cities assessed, being 50 and 20, respectively. Between 2018 and 2019, the mean value of the normalized score has increased in both evaluations of the Smart Cities Index and the Cities in Motion Index. This does not necessarily mean an overall improvement because the cities assessed in the two editions are not the same.

In addition to the range, Table 9 presents two additional measures of the spread of the normalized scores, which are the distance between the median and the maximum or the minimum. The sum of these two distances is the range. In perfectly symmetric data, the two distances are equal. This is roughly the case here except for the Smart Cities Index (2018) evaluation, where the minimum normalized score is nearly twice as far from the median as the maximum normalized score.

Table 10 presents the average increment in the normalized scores in each evaluation. We calculate this increment as follows:

$$\text{increment} = \frac{\text{range}}{\text{ranked cities} - 1}. \quad (5)$$

With the exception of the evaluation (Smart Cities Prospects), the average increments are at a similar level of about 0.004. This is so small and indicates that the difference

TABLE 10: Average increment of the normalized scores for the 7 ranking studies considered.

Ranking study	Average increment
Smart Cities Index, 2019	0.00368
Smart Cities Index, 2018	0.00370
Smart City Governments	0.00540
Cities in Motion Index, 2019	0.00548
Cities in Motion Index, 2018	0.00502
Smart Cities—What’s in it for citizens?	—
Smart Cities Prospects	0.00750

in smartness between two assessed cities may not be decisive. On the other hand, the difference when the cities are ordered in ranks is always unity (no matter how small the score difference is). This observation may help justify the existence of mismatch across evaluations and calls for attention when interpreting published rankings of smart cities. It is thus suggested to consult normalized scores and not rely just on the ranking. For the evaluation (Smart Cities Prospects), the average increment is about twice those in the other evaluations. Despite the small range of that particular study (which favors a smaller average increment), the number of ranked cities is also small (which favors a larger average increment). The influence of the few cities is stronger than the influence of the narrow range.

7. Conclusions

Published rankings of smart cities worldwide are valuable studies that not only assess the smartness level of various cities in the world but also give guidelines about the features of a smart city and help reshape its definition over time. For someone curious about the reliability of a ranking report, this work can be useful. It considered 7 evaluations of smart cities from 5 sources, spanning the years 2017–2019, and examined their consistency when assessing a common set of 6 cities. The work also provides fundamental statistical analysis of the scores given by these evaluations. There is some mismatch in rankings. For example, one evaluation may suggest that a city has improved and became smarter, while another suggests that the same city has become less smart. It is noted that cities can have tiny differences in their scores and this can justify a lack of robustness of the ranking results. This work also compares the criteria used by the considered evaluations and groups them into 7 scope areas.

Based on the present study, the following recommendation can be made: smart cities should excel in six scopes (groups of attributes), which are Municipality Orientation, Human Capital, Transport, Outdoor Environment, Internet and Technology, and Infrastructure. When comparing the smartness of several cities, the comparison criteria should be clearly communicated along with the ranking results. A positional rank of a city relative to other cities is not a good metric to judge the smartness of that city due to the heavy dependence on the pool of other cities of comparison. A normalized numerical score should be used to examine the level of smartness of a city, and it is computed from the raw score by assigning a score of 1.0 to the best city in the

comparison list. Looking at two ranking studies rather than only one and taking the average normalized scores of cities give a more reliable view of how well different cities are performing relatively.

Possible directions of extension for the present work by others include regular monitoring of features of smart cities as considered in independent evaluation studies, with attention paid to those features that either appear or disappear over time. Another extension is to conduct an expert survey where personnel with immediate and ongoing interaction with smart cities planning, development, or operation give their priority list of smart city attributes, as well as some smart city challenges. A third possible extension is to derive a numerical index based on analysis of some ranking studies such that it shows more consistency across these studies. It may, for example, be weighted by factors such as specific criteria included in the ranking evaluation, the number of cities included, or the ranking score in the previous year (the trend, rather than the one-time status).

Nomenclature

4G LTE:	Fourth-generation long-term evolution
μm :	Micrometer (one millionth of a meter)
CIMI:	Cities in Motion Index
CO_2 :	Carbon dioxide
DESI:	Digital Economy and Society Index
DG:	Distributed generation (small-scale electrical energy production near consumers, using wind and solar stations for example)
E-charge:	Electric vehicle charging
EGDI:	E-Government Development Index
e/m payment:	Electronic/mobile payment
EPI:	Environmental Performance Index
EU:	European union
GDP:	Gross domestic product
GVA:	Gross value added
ICT:	Information and communication technology
IESE:	Instituto de estudios superiores de la empresa (Spanish for Institute of Higher Studies of Business)
IoT:	Internet of things
kt:	Kiloton (one million kilograms)
LEED:	Leadership in energy and environmental design
Median:	A middle member of a group of values, having midway position if the values are ordered ascendingly
PM2.5:	Particulate matter (pollution), size 2.5 micrometers or smaller
PM10:	Particulate matter (pollution), size 10 micrometers or smaller
SCI:	Smart Cities Index
Standard deviation:	A statistical measure of spread of data (scatter from the average)
s:	Standard deviation of a group of values labeled as (x_1, x_2, \dots)

TEA:	Total early-stage entrepreneurial activity
x :	A general symbol of a value in a group of values (x_1, x_2, \dots)
\bar{x} :	The average value of a group of values labeled as (x_1, x_2, \dots).

Appendix

A. Factors Defining a Smart City from Analyzed Ranking Studies

A list of the assessment factors or criteria used in each evaluation study is provided here. When the factors are grouped in categories by the evaluation itself, this is also indicated.

For the Smart Cities Index evaluation, and the Cities in Motion Index evaluation, where two editions are considered (2018 and 2019), the changes in the evaluation criteria are highlighted with underlined bold text between parentheses.

A.1. Assessment Factors for the Smart Cities Index Ranking Studies.

- (i) Transport and mobility
 - (1) Smart parking
 - (2) Car sharing services
 - (3) Traffic
 - (4) Public transport
 - (5) E-charge (new in 2019)
 - (6) Infrastructure investment (new in 2019)
- (ii) Sustainability
 - (1) Clean energy
 - (2) Smart building
 - (3) Waste disposal
 - (4) Environment protection
 - (5) Environmental Performance Index
- (iii) Governance
 - (1) Citizen participation
 - (2) Digitalization of government
 - (3) Urban planning
 - (4) Education
- (iv) Innovation economy
 - (1) Business ecosystem
 - (2) Blockchain ecosystem
- (v) Digitalization
 - (1) 4G LTE
 - (2) Internet speed
 - (3) Wi-Fi hot spots
 - (4) Smartphone penetration
 - (5) Cyber security (was a separate category in 2018)
- (vi) Living standard
 - (1) Living standard
- (vii) Expert perception
 - (1) How the city is becoming smarter

A.2. Assessment Factors for the (Smart City Governments) Ranking Study.

- (i) Vision: a clear and well-defined strategy to develop a “smart city”
- (ii) Leadership: dedicated City leadership that steers smart city projects
- (iii) Budget: sufficient funding for smart city projects
- (iv) Financial incentives: financial incentives to effectively encourage private sector participation (e.g., grants, rebates, subsidies, and competitions)
- (v) Support programs: in-kind programs to encourage private actors to participate (e.g., incubators, events, and networks)
- (vi) Talent readiness: programs to equip the city’s talent with smart skills
- (vii) People centricity: a sincere, people-first design of the future city
- (viii) Innovation ecosystems: a comprehensive range of engaged stakeholders to sustain innovation
- (ix) Smart policies: a conducive policy environment for smart city development (e.g., data governance, IP protection, and urban design)
- (x) Track record: the government’s experience in catalyzing successful smart city initiatives

A.3. Assessment Factors for the (Cities in Motion Index) Ranking Studies.

- (i) Human capital
 - (1) Higher education: proportion of population with secondary and higher education
 - (2) Business schools: number of business schools (top 100)
 - (3) Movement of students: international movement of higher-level students (number of students)
 - (4) Universities: number of universities in the city that are in the top 500
 - (5) Museums and art galleries: number of museums and art galleries per city
 - (6) Schools: number of public or private schools per city
 - (7) Theaters: number of theaters per city
 - (8) Expenditure on leisure and recreation: expenditure on leisure and recreation per capita
 - (9) Expenditure on leisure and recreation: expenditure on leisure and recreation (in millions of dollars)
 - (10) Expenditure on education: expenditure on education per capita (new in 2019)
- (ii) Social cohesion
 - (1) Mortality: ratio of deaths per 100,000 inhabitants
 - (2) Crime rate: Crime Index. This index (from 0 to 100) represents the overall level of crime using data up to 3 years old

- (3) Health: Healthcare Index. It is a measure on a scale from 0 (worst) to 100 (best) that depends on overall quality of the professionals and equipment, and the cost and system of health care
- (4) Unemployment: unemployment rate (number of unemployed out of the workforce)
- (5) Gini index: measure of social inequality. It varies from 0 to 100, with 0 being a situation of perfect equality and 100 that of perfect inequality
- (6) Price of property: price of property as percentage of income
- (7) Female workers: ratio of female workers in the public administration
- (8) Global Peace Index: an index that measures the peacefulness and the absence of violence in a country or region
- (9) Hospitals: number of public and private hospitals and health centers per city
- (10) Happiness Index: an index that measures the level of overall happiness of a country
- (11) Global Slavery Index: ranking that considers the proportion of people in a situation of slavery in the country
- (12) Government response to situations of slavery: this variable measures how the government deals with situations of slavery in the country
- (13) Terrorism: number of terrorist incidents by city in the previous three years
- (14) Female-friendly: the variable seeks to measure whether a city provides a friendly environment for women on a scale of 1 to 5 (new in 2019)
- (15) Suicides: suicide rate by city (new in 2019)
- (16) Homicides: homicide rate by city (new in 2019)

(iii) Economy

- (1) Productivity: labor productivity calculated as GDP per working population
- (2) Time required to start a business: number of calendar days needed so a business can operate legally
- (3) Ease of starting a business: measures the regulatory environment for creating and developing a local company
- (4) Headquarters: number of headquarters of publicly traded companies
- (5) Motivation to get started in TEA (total early-stage entrepreneurial activity): percentage of people involved in TEA (i.e., novice entrepreneurs and owners or managers of a new business), driven by an opportunity for improvement, divided by the percentage of TEA that is, in turn, motivated by need
- (6) GDP estimate: estimated annual GDP growth
- (7) GDP: GDP in millions of dollars at 2016 prices
- (8) GDP: per capita GDP per capita at 2016 prices

- (9) Mortgage: mortgage as a percentage of income. It is calculated as a proportion of the real monthly cost of the mortgage with respect to the family income (estimated via the average monthly salary). The lower the percentage, the better it is (new in 2019)
- (10) Glovo: the variable assumes the value of 1 if the city has the Glovo service (local delivery app) and 0 otherwise (new in 2019)
- (11) Uber: the variable assumes the value of 1 if the city has the Uber (ridesharing app) service and 0 otherwise (new in 2019)
- (12) Salary: hourly wage in the city (new in 2019)
- (13) Purchasing power: purchasing power (determined by the average salary) for the purchase of goods and services in the city, compared with the purchasing power in New York City (new in 2019)

(iv) Governance

- (1) Reserves: total reserves in millions of current dollars. Estimate at city level according to the population
- (2) Reserves per capita: reserves per capita in millions of current dollars
- (3) Embassies: number of embassies and consulates per city
- (4) ISO 37120 certification: certified cities are committed to improving their services and quality of life. It is a variable coded from 0 to 6. Cities that have been certified for the longest time have the highest value. The value 0 is for those cities without certification
- (5) Research centers: number of research and technology centers per city
- (6) Government buildings: number of government buildings and premises in the city
- (7) Strength of legal rights index: the strength of legal rights index measures the degree to which collateral and bankruptcy laws protect the rights of borrowers and lenders and thus facilitate access to loans
- (8) Corruption perceptions index: countries with values close to 0 are perceived as very corrupt and those with an index close to 100 as very transparent
- (9) Open data platform: this describes whether the city has an open data system
- (10) E-Government Development Index (EGDI): the EGDI reflects how a country is using information technology to promote access and inclusion for its citizens
- (11) Democracy ranking: ranking where the countries in the highest positions are those considered more democratic
- (12) Employment in the public administration: percentage of population employed in public administration and defense; education; health; community, social, and personal

service activities; and other activities (new in 2019)

(v) Environment

- (1) CO₂ emissions: CO₂ emissions from the burning of fossil fuels and the manufacture of cement, measured in kilotons (kt)
- (2) CO₂ emission index: CO₂ emission index, on a scale from 0 (best) to 100 (worst)
- (3) Methane emissions: methane emissions that arise from human activities such as agriculture and the industrial production of methane. Measured in kt of CO₂ equivalent
- (4) Access to the water supply: percentage of the population with reasonable access to an appropriate quantity of water resulting from an improvement in the supply
- (5) PM2.5: the indicator PM2.5 measures the number of particles in the air whose diameter is less than 2.5 micrometers (μm), annual mean
- (6) PM10: the indicator PM10 measures the amount of particles in the air whose diameter is less than 10 μm , annual mean
- (7) Pollution index: a number on a scale from 0 (best) to 100 (worst). It accounts for the overall pollution in a city, but the largest weight is given to air pollution. Then comes water pollution/accessibility. Other pollution types (like noise) contribute with a small weight
- (8) Environmental Performance Index (EPI): this measures environmental health and ecosystem vitality, on a scale from 1 (poor) to 100 (good)
- (9) Renewable water resources: total renewable water sources per capita
- (10) Future climate: percentage of the rise in temperature in the city during the summer forecast for 2100 if pollution caused by carbon emissions continues to increase
- (11) Solid waste: average amount of municipal solid waste (garbage) generated annually per person (kg/year)

(vi) Mobility and transportation

- (1) Traffic index: consideration of the time spent in traffic, the dissatisfaction this generates, CO₂ consumption, and other inefficiencies of the traffic system
- (2) Inefficiency index: estimation of traffic inefficiencies (such as long journey times)
- (3) Index of traffic for commuting to work: index of time that takes into account how many minutes it takes to commute to work
- (4) Bike sharing: this factor depends on the level of development of a bike sharing system (if it exists) with automated services for the public

use of shared bicycles that provide transport from one location to another within a city

- (5) Length of the metro system: length of the metro system per city
- (6) Metro stations: number of metro stations per city
- (7) Flights: number of arrival flights (air routes) in a city
- (8) High-speed train: binary variable that shows whether the city has a high-speed train or not
- (9) Gas stations: number of gas stations per city (was in 2018; but removed in 2019)
- (10) Vehicles: number of commercial vehicles in the city (in thousands) (new in 2019)
- (11) Bicycles per household: percentage of bicycles per household (new in 2019)

(vii) Urban planning

- (1) Bicycles for rent: number of bike-rental or bike-sharing points, based on docking stations where they can be picked up or dropped off
- (2) Percentage of the urban population with adequate sanitation facilities: percentage of the urban population that uses at least basic sanitation services—that is, improved sanitation facilities that are not shared with other households and efficiently avoid the contact of humans, animals, and insects with excreta
- (3) Number of people per household: number of people per household. Occupancy by household is measured compared to the average. This makes it possible to estimate if a city has overoccupied or underoccupied households
- (4) High-rise buildings: percentage of buildings considered high rises. A high rise is a building of at least 12 stories or 35 meters (115 feet) high
- (5) Buildings: this variable is the number of completed buildings in the city. It includes structures such as high rises, towers, and low-rise buildings but excludes other various others, as well as buildings in different states of completion (in construction, planned, etc.)

(viii) International outreach

- (1) McDonald's: number of McDonald's chain restaurants per city
- (2) Number of passengers per airport: number of passengers per airport in thousands
- (3) Sightsmap: ranking of cities according to the number of photos taken there and uploaded to Panoramio (community where photographs were shared online). Note that Panoramio was officially closed on November 4, 2016. It was owned by Google
- (4) Number of conferences and meetings: number of international conferences and meetings that are held in a city
- (5) Hotels: number of hotels per capita

- (6) Airports: number of points where flight operations take place within a 40-km radius from the latitude and longitude defining the center of the city. It includes airports, aerodromes, airfields, and landing strips whether international, private, military, or otherwise. Also included are the buildings used for processing passengers and cargo (terminals) (was in 2018; but removed in 2019)
- (7) Restaurant index: the index shows the prices of food and beverages in restaurants and bars compared to New York City (new in 2019)

(ix) Technology

- (1) Twitter: registered Twitter (a social media platform) users in the city
- (2) LinkedIn: number of LinkedIn (a social media platform) users in the city
- (3) Mobile phones: number of mobile phones in the city via estimates based on country-level data
- (4) Wi-Fi hot spot: number of wireless access points globally. These represent the options in the city for connecting to the Internet
- (5) Innovation Cities Index: innovation index of the city. Valuation of 0 (no innovation) to 60 (a lot of innovation)
- (6) Landline subscriptions: number of landline subscriptions per 100 inhabitants
- (7) Broadband subscriptions: broadband subscriptions per 100 inhabitants
- (8) Internet: percentage of households with access to the Internet
- (9) Mobile telephony: percentage of households with mobile phones in the city
- (10) Facebook: number of people who are currently registered in Facebook (a social media platform) in the city (was in 2018; but removed in 2019)
- (11) Apple Store: number of Apple Stores per city (was in 2018; but removed in 2019)
- (12) Web Index: the Web Index seeks to measure the economic, social and political benefit that countries obtain from the Internet (new in 2019)
- (13) Telephony: percentage of households with some kind of telephone service (new in 2019)
- (14) Internet speed: Internet speed in the city (new in 2019)
- (15) Computers: percentage of households with a personal computer in the city (new in 2019)

A.4. Assessment Factors for the (Smart Cities—What's in it for citizens?) Ranking Study.

(i) Basic indicators

- (1) Smart city vision: depth and overall strategy, KPIs, and success measures

- (2) Horizontal platform deployment: interagency integration potential
- (3) Open/proprietary technology: future proof/effectiveness
- (4) Open data: open data breadth and potential
- (5) Communications technology: city/citizen preparedness for smart city services
- (6) Life expectancy: life expectancy improvement potential
- (7) GVA (gross value added): quality of life indicator and economic improvement potential
- (8) Population: city size

(ii) Mobility

- (1) Average vehicle speed: peak time congestion and time-benefit potential indicator
- (2) Private vehicles per capita: congestion driver
- (3) Cycle scheme roll-out: congestion reduction and health improvement driver
- (4) Mobility-as-a-service: congestion reduction driver
- (5) Congestion charge: air quality improvement and congestion reduction driver
- (6) Road accident injuries per capita: public health reduction driver
- (7) Air quality: public health reduction driver
- (8) Electric vehicle charging stations: next-generation transport preparedness
- (9) Public transport journeys per capita: network performance, availability, and uptake
- (10) E/M-payment infrastructure transport: transport payment convenience and time-benefit indicator
- (11) Autonomous vehicle testing: next-generation transport preparedness
- (12) Smart transport initiatives: smart traffic light phasing, smart parking, open data for transport, strategy to reduce motor vehicle use, strategy to increase public transport use, citizen information dissemination solutions, interagency collaboration strategy, and road safety strategy

(iii) Health care

- (1) Hospital beds per capita city: bed availability and time-benefit indicator
- (2) Hospital bed occupancy rate: bed availability and time-benefit indicator
- (3) Congestion charge: air quality improvement and congestion reduction driver
- (4) Cycle scheme roll-out: congestion reduction and health improvement driver
- (5) Public transport journeys per capita: network performance, availability, and uptake
- (6) Road accident injuries per capita: public health reduction driver
- (7) Violent crime rate: public health and safety reduction driver

- (8) Police force size: public health and safety improvement driver
 - (9) Higher education: public health and safety improvement driver
 - (10) City terrorist attacks since 2013, Domestic and Foreign Initiated: public health and safety reduction driver
 - (11) Public Safety Index: general safety and health indicator
 - (12) Air quality: public health reduction driver
 - (13) Electric vehicle charging stations: public health improvement driver
 - (14) Autonomous vehicle testing: public health improvement driver
 - (15) Smart healthcare initiatives: telehealth/remote healthcare services, digital health portals, chatbot services, digital health care for elderly strategy, transparent healthcare KPIs, active lifestyle strategy, and road safety strategy
- (iv) Public safety
- (1) Smart street lighting: public safety improvement indicator
 - (2) Intelligent video surveillance: public safety improvement and time-benefit indicator
 - (3) Congestion charge: public safety/road traffic safety improvement indicator
 - (4) Cycle scheme roll-out: public safety reduction indicator
 - (5) Emergency services response co-ordination: public safety improvement and time-benefit indicator
 - (6) Violent crime rate law enforcement: public health and safety reduction driver
 - (7) Police force size: public health and safety improvement driver
 - (8) Predictive crime software: public safety improvement and time-benefit indicator
 - (9) Fire/flood prediction software: public safety improvement and time-benefit indicator
 - (10) Higher education: public health and safety improvement driver
 - (11) City terrorist attacks since 2013, Domestic and Foreign Initiated: public health and safety reduction driver
 - (12) Public Safety Index: general safety and health indicator
 - (13) Smart public safety initiatives: emergency services integration, road safety strategy, disaster plan, crime reduction strategy, and cybersecurity strategy
- (v) Productivity
- (1) Project funding sources: service expansion and productivity improvement indicator
 - (2) Public-private partnership incentives: service expansion and productivity improvement indicator
 - (3) Talent acquisition incentives: service expansion and productivity improvement indicator
 - (4) Ease of doing business: time-benefit potential
 - (5) Digital education policies: productivity improvement indicator
 - (6) City governance: regulatory complexity and time-benefit indicator
 - (7) City chief technology office/equivalent: service expansion and productivity improvement indicator
 - (8) Smart city conference hosting: engagement and productivity improvement indicator
 - (9) Smart city Hackathons: engagement and productivity improvement indicator
 - (10) Smart productivity initiative: digital services access, smart education projects, cybersecurity and privacy strategy, equality strategy, and retail and city services cashless payments
- A.5. Assessment Factors for the (Smart Cities Prospects) Ranking Study.*
- (i) Smart economy
 - (1) Opportunity
 - (2) Productivity
 - (3) Local and Global interconnectedness
 - (ii) Smart Living
 - (1) Health
 - (2) Safety
 - (3) Culture and happiness
 - (iii) Smart government
 - (1) Online services
 - (2) Infrastructure
 - (3) Open government
 - (iv) Smart people
 - (1) Education
 - (2) Inclusive society
 - (3) Creativity
 - (v) Smart mobility
 - (1) Mixed-modal access
 - (2) Clean and nonmotorized mobility
 - (vi) Smart environment
 - (1) Smart buildings
 - (2) Resource management
 - (3) Urban planning
- Data Availability**
- Previously reported ranking data were used to support this study and were made available publicly online. These prior studies (and datasets) are cited at relevant places within the text, such as references [9–15].

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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