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Measuring progress of smart cities: Indexing the smart city indices

Calvin Ming Tsun Lai[a,1,*], Alistair Cole[b]

[a] Lead and corresponding author, Senior Research Assistant, Department of Government and International Studies, Hong Kong Baptist University, Hong Kong
[b] Co-author, Professor of Political Science, Head of the Government and International Studies Department, Hong Kong Baptist University, Hong Kong

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ABSTRACT

The 'smart city' represents a core feature of modern urban development. The appearance of numerous smart city indices, which claim to successfully evaluate and compare smart city performances, is the manifestation of the concept's growing popularity. The central objective of this paper is to address the integrity and quality of the existing smart city indices, and identify those ones which are fit for international comparison. We propose a method for evaluating the integrity and quality of the existing smart city indices in terms of five criteria – Credibility, Reliability, Methodology, Versatility, Precision. The article critically evaluates six smart city indices and concludes that the Cities in Motion Index from the IESE Business School has the best overall performance. To improve the versatility of the existing smart city indices, this paper proposes a new approach based on respecting three main criteria: refining the types of indicator, defining the smart city domains and adopting context-sensitive measurements. These elements are deemed to be essential for any smart city index.

1. Introduction

The smart city concept has been gaining attention internationally. The appearance of numerous smart city indices as assessment tools is the manifestation of the concept's growing popularity (Fernandez-Anez et al., 2018). These assessment tools are becoming influential for cities since their results are often used to plan future development, assess strengths and weaknesses, and, in particular for the high-ranked cities, to promote and attract foreign direct investment and tourists (Kitchin et al., 2015; Le Galès, 2016; Patrão et al., 2020). Nevertheless, we observe diversity not only in the sense of definition, but also in terms of location (i.e. Asia, Europe), content (i.e. smart governance, smart mobility), and structure (i.e. emphasis on ICT, emphasis on citizen engagement), as different countries, and even cities within the same jurisdiction, have distinct interpretations of the smart city (Sharifi et al., 2020). Notwithstanding this differentiation, several organizations and institutions have published smart city indices which claim to have successfully evaluated and compared the cities according to their smart city performances (Bosch et al., 2016; Fernandez-Anez et al., 2018). Using Hong Kong as an example, the IESE Cities in Motion Index 2020 ranked Hong Kong 10th, for instance, while the IMD Smart City Index 2021 ranked Hong Kong 41st (Berrone & Ricart, 2020; The IMD World Competitiveness Center, 2021). The different rankings show how distinctive these frameworks are, an inconsistency that is of questionable scientific value (see Table 1).

Research into smart city assessment tools is limited as this is a relatively new field. The central objective of this paper therefore is to address the integrity and quality of the existing smart city indices, and identify those ones which are fit for international comparison. The next section introduces the smart city definition used in this paper, and hence presents the rationale for selecting six existing smart city indices as benchmarks for comparison and introduces the five criteria used for analysis. Finally, we propose aspects that ought to be taken into consideration for the development of a more comprehensive smart city index that would improve on the existing models.

2. Comparing smart city indices

2.1. Smart city definition

The term "smart city" was first employed in the book entitled "The Technopolis Phenomenon" in 1992 (Gibson et al., 1992), and it has been used in different contexts ever since (Patrão et al., 2020). At its inception, it was employed in the United States to present the increasing application of information and communication technology (ICT) in modern urban infrastructures in the 1990s. While for some, ICT is the fundamental element of smart city development, for others it is mainly a supplementary tool to build social capital and enhance efficiency in daily city operations (Akande et al., 2019; Albino et al., 2015; Vogl et al., 2020). In fact, smart city also needs to consider many other aspects of urban

* Corresponding author.
E-mail address: calvinlai@hkbu.edu.hk (C.M.T. Lai).
[1] Doctoral Researcher, Department of Architecture, The Technical University of Darmstadt, Germany. Email: lai@kritis.tu-darmstadt.de.

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Table 1
Hong Kong's rank in various smart city indices.

Selected Smart City Index	Rank of Hong Kong		1st	2nd	3rd
Cities in Motion Index (Berrone & Ricart, 2020)	10th	Out of 174 cities	London	New York	Paris
Digital City Index (Bloom Consulting, 2018)	4th	Out of 136 cities	Dubai	Singapore	London
Global E-Governance Survey (Holzer et al., 2020)	14th	Out of 100 cities	Seoul	Madrid	Yerevan
Global Innovation Index (Dutta et al., 2020)	11th	Out of 131 economies	Switzerland	Sweden	USA
ICT Development Index (International Telecommunication Union, 2017)	6th	Out of 176 economies	Iceland	Korea	Switzerland
Innovation Cities Index (2thinknow, 2021b)	49th	Out of 500 cities	Tokyo	Boston	New York
Smart City Governments (Eden Strategy Institute, 2021b)	41st	Out of 235 cities	Singapore	Seoul	London
Smart Cities Index (EasyPark Group, 2019)	87th	Out of 500 cities	Oslo	Bergen	Amsterdam
Smart City Index (The IMD World Competitiveness Center, 2021)	41st	Out of 118 cities	Singapore	Zurich	Oslo

life and place human value in the concept in addition to pure technology (Caragliu et al., 2011; Cavada et al., 2014; Dameri, 2013). The different descriptions of "smart" have resulted in numerous similar terms such as digital city, intelligent city, knowledge city, and wired city, in the attempt to specify this "fuzzy concept" – a description used by various scholars (Albino et al., 2015; Camero & Alba, 2019; Caragliu et al., 2011; Cocchia, 2014; Nam & Pardo, 2011; Patrão et al., 2020; Sharifi, 2019). Regardless of these efforts, the smart city is indeed multifaceted, and thus until now there is still no general agreement and standard definition of the term "smart city" (Albino et al., 2015; Patrão et al., 2020; Sharifi, 2019).

Smart city indeed appears as an umbrella definition covering various categories (Mosannenzadeh et al., 2017; Patrão et al., 2020). In general, there are two types of smart city domain – the "hard" domain and the "soft" domain (Albino et al., 2015; Neirotti et al., 2014). The former describes the urban technical infrastructure and system such as buildings, energy grids, mobility, and water management, which are the city settings that are decisive and improved by the ICT application and policy intervention; the latter designates cultural and societal aspects such as education, policy innovations, governance and social inclusion, which are not decisive by the ICT application, but aim at creating the right societal and institutional conditions to cultivate ICT implementation (Albino et al., 2015; Neirotti et al., 2014; Schüle et al., 2021; Sharifi, 2019). There is general agreement on six smart city dimensions – economy, environment, governance, living, mobility, and people (Camero & Alba, 2019; Caragliu et al., 2011; Fernandez-Anez, 2016). These were firstly identified by the center of Regional Science at the Vienna University of Technology (Giffinger et al., 2007), and then widely adapted by other scholars and the European Union (Manville et al., 2014). They cover the two domains, and represent the standard elements of the smart city concept.

Smart city strategies vary with regions. In China, the idea of the smart city emphasizes big data and the internet-of-things, including the usage of smartphones in daily transactions, and deployment of sensors and cameras in public spaces for monitoring and surveillance (Hao et al., 2012; Hu, 2019). In Germany, smart city is oriented towards sustainable development with the aim of achieving climate neutrality, by implementing technologies addressing energy efficiency and mobility infrastructure in the city (Treude et al., 2022). These two examples represent a good comparison of the distinctive nature of smart city concepts between Eastern and Western societies.

The size of a city is another driver of the diverse smart city concepts. Borsekova et al. (2018) have proved that large cities in general have more smart city policies for improving their environmental and living conditions than small and medium-sized cities, mainly due to their higher population densities and thus greater environmental problems. Small cities in fact pay more attention to the economy, and display less technology-focused interpretations of the smart city concept (Borsekova et al., 2018; Esposito et al., 2021). The concern for the size of cities calls into question the one-size-fit-all approach to smart city development, while the term "smart village" is especially used for the research into ICT applications in the context of rural areas (Esposito et al., 2021; Visvizi & Lytras, 2018). Thus, the feature of the Digital Cities Survey that groups cities according their population confirms the pertinence of considering the size of cities in smart city concepts (Grenslitt, 2021).

While various existing smart city assessment tools claim to improve city competitiveness via benchmarking, each of them basically develops its own smart city concept (Patrão et al., 2020). Besides the elements of quality of life, citizen participation and social issues (van den Berg et al., 2020; Xu & Tang, 2020), some formulations suggest a smart city index should trigger interest from the public towards that city, which is similar to a marketing strategy for tourism and investment (Bloom Consulting, 2018; Cohen, 2014; EasyPark Group, 2019; Giffinger et al., 2007; Vidiasova et al., 2017). Cybersecurity is also equally important for the smart city, as real time analysis using digital devices and sensors is one demonstration of ICT application and smartness (Cavada et al., 2014; Grenslitt, 2021). These elements enrich the smart city concept.

As a result, our smart city definition, which draws both on findings from the literature and existing indices, is as follows: a smart city is one that uses different types of information and communication technologies (ICT) including digital devices, sensors for data collection and internet of things (IoT), so that, besides promoting the city in the digital world and ensuring its cybersecurity, the six dimensions of economy, mobility, environment, people, living and governance can be improved.

2.2. Selected smart city indices

While there are plenty of existing smart city indices, they differ in terms of their themes, level of measurement and scope of coverage (Patrão et al., 2020; Sharifi, 2019). Regarding their main foci, indices can be further classified into specific groups in the form of a typology (Sharifi, 2019). Although we acknowledge the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist to ensure systemic reviews, especially the search strategy (Page et al., 2021), databases like SCOPUS are not suitable for this search because several of the most cited smart city indices are not captured, as they are individually commissioned and published by private companies and institutions. Therefore, a mixed-mode was used here with Google Scholar and referral from other literatures (Bosch et al., 2016; Sharifi, 2019). The keywords were "smart city" and "index", or "assessment" and "evaluation",

Table 2
The list of 20 smart city indices.

No.	Selected Smart City Index	Year	Main focus	Orientation	Scale	Scope	Primary developer
1	Cities in Motion Index (Berrone & Ricart, 2020)	2020	Multifaceted	Research-based	City	174 international cities	IESE Business School
2	Digital City Index (Bloom Consulting, 2018)	2018	Smart performance	Market-oriented	City	136 international cities	Bloom Consulting
3	Digital Cities Survey (Grenslitt, 2021)	2020	Smart living	Market-oriented	City	>50 U.S. cities	Center for Digital Government
4	E-Government Development Index (Department of Economic & Social Affairs, 2020)	2020	Smart governance	Research-based	Country	193 UN member countries	United Nations
5	European Digital City Index (Bannerjee et al., 2016)	2016	Smart economy	Research-based	City	60 European cities	European Digital Forum
6	Global Cybersecurity Index (International Telecommunication Union, 2018)	2018	Smart technology	Research-based	Country	194 economies	International Telecommunication Union
7	Global E-Government Survey (Holzer et al., 2020)	2019	Smart governance	Research-based	City	100 international cities	The E-Governance Institute
8	Global Innovation Index (Dutta et al., 2020)	2020	Multifaceted	Research-based	Country	131 economies	Cornell University, INSEAD, WIPO
9	Global Smart City Index (Juniper Research, 2017)	2017	Smart living	Market-oriented	City	Unknown number of international cities	Juniper Research
10	ICT Development Index (International Telecommunication Union, 2017)	2017	Smart technology	Research-based	Country	176 economies	International Telecommunication Union
11	IDC Smart Cities Awards (International Data Corporation, 2021)	2021	Smart project	Market-oriented	Bureau	Unknown number of Asian Pacific municipalities	International Data Corporation
12	Innovation Cities Index (2thinknow, 2021b)	2021	Multifaceted	Market-oriented	City	500 international cities	2thinknow
13	International Digital Economy and Society Index (Foley et al., 2020)	2020	Smart technology	Research-based	Country	45 countries	European Commission
14	Smart City Governments (Eden Strategy Institute, 2021b)	2021	Smart governance	Market-oriented	City	235 international cities	Eden Strategy Institute
15	Smart City Index (The IMD World Competitiveness Center, 2021)	2021	Smart living	Research-based	City	118 international cities	IMD Competitiveness Center
16	Smart City Strategy Index (Roland Berger, 2019)	2019	Smart project	Market-oriented	City	153 international cities	Roland Berger
17	Smart Cities Index (EasyPark Group, 2019)	2019	Multifaceted	Market-oriented	City	100 international cities	EasyPark
18	Smart Cities Prospects (Vidiasova et al., 2017)	2017	Multifaceted	Research-based	City	20 international cities	Individual scholars
19	Smart City Rankings (Cohen, 2014)	2014	Multifaceted	Research-based	City	11 international cities	Individual scholar
20	UK Smart Cities Index (Navigant Consulting, 2017)	2017	Smart project	Market-oriented	City	20 U.K. cities	Huawei, Navigant Consulting

applying the date limit of past five years. Eventually, we identified 20 smart city indices, categorized into seven themes regarding their nature and content, namely smart economy, smart governance, smart living, smart performance, smart project, smart technology, and multifaceted (the last category specifying the indices covering two or more themes). The details of 20 indices are presented in Table 2.

To ensure the smart city indices are equivalent and eligible for comparison, we set out their scale and scope as the central features. The scale of measurement can be defined by the unit of target: whether the evaluated bodies are countries, cities, or communities (Sharifi, 2019). The scope of coverage is determined by the geographic focus, including if they are targeting single or multiple countries for international comparisons, and the number of targets (Sharifi, 2020). Based on the above considerations, the following six indices are selected. They all conducted city-level measurements, and evaluated at least 100 international cities, regardless of their respective typologies. They also have enough information (e.g. comprehensive rankings of all assessed cities, data sources) for assessment. All smart city indices are evaluated using their accessible latest versions during the writing of this paper.

1 Cities in Motion Index (CIMI) (2020)
2 Digital City Index (DCI) (2018)
3 Global E-Government Survey (GEGS) (2019)
4 Innovation Cities Index (ICI) (2021)
5 Smart City Governments (SCG) (2021)
6 Smart City Index (SCI) (2021)

The Cities in Motion Index (CIMI), published by IESE Business School in Spain, is an annually updated measurement of the world's major cities since 2014. CIMI defines smart city as a way of city governance to maintain future sustainability and the quality of life of inhabitants, which generate business opportunities for collaboration between public and private sectors. It released its seventh edition in 2020. The latest framework consisted of nine dimensions and 101 indicators, including Human Capital, Social Cohesion, Economy, Governance, Environment, Mobility and Transportation, Urban Planning, International Projection, and Technology (Berrone & Ricart, 2020).

The Digital City Index (DCI) was published only once by a Spanish consulting firm in 2018. DCI defines smart city as one that has triggered proactive interest from global citizens towards itself in the digital world. It evaluated cities in Europe, Asia, the Americas, and Africa. Although the ranking lists were divided according to the four continents, it also published an overall result of world top ten cities. The index was uniquely compiled by the measurement of the total amount of searches performed by worldwide citizens toward cities, matching with its smart city definition. Three dimensions, Work, Live, and Study, were used for analysis, together with nine sub-categories under each dimension (Bloom Consulting, 2018).

The Global E-Government Survey (GEGS) focuses on the websites of municipalities, taken as a viable assessment of smart government (Holzer et al., 2020; van den Berg et al., 2020). GEGS defines that the delivery of public services and citizen participation in governance are the two components of digital governance. It has been published by an American research team biennially since 2003, having the longest history within the six selected indices. The study selected its 100 target cities regarding the top 100 most wired nations published by the International Telecommunication Union (ITU), based on the total number of online users. Five categories, Privacy/ Security, Usability, Content, Service, and Citizen and Social Engagement, with 86 indicators were used for analysis in the latest edition (Holzer et al., 2020).

The Innovation Cities Index (ICI) has been published by a private data agency based in Australia annually since 2007 (with a 1-year break in 2020 due to Covid-19), having the greatest number of evaluated cities. ICI defines smart city as a process of innovation, and thus is about idea generation, implementation, and communication. It further suggests three factors to evaluate the innovation of a city, which are cultural assets, human infrastructure, and networked markets. In its latest version, 162 indicators classified into three factors, Cultural Assets, Human infrastructure, and Networked Markets, were used for the analysis. ICI also further classified cities into four categories regarding their ranks, describe as Nexus, Hub, Node, and Upstart (2thinknow, 2021b).

Smart City Governments (SCG) has been published by a private consulting firm in Singapore since 2018, with its second edition released in 2021. SCG defines smart city as a way of city governance to utilize the investment in digital solutions, to identify and engage with vulnerable population groups, and to become a future-ready and citizen-centric place. The framework of this index consisted of ten indicators, which were Vision, Leadership, Budget, financial Incentives, Support Programmes, Talent Readiness, People Centricity, Innovation Ecosystems, Smart Policies, and Track Record (Eden Strategy Institute, 2021b).

The Smart City Index (SCI) has been conducted by the IMD World Competitiveness Center in Singapore annually since 2019. SCI defines smart city as an urban setting that applies technology to enhance the benefits and reduce the shortcomings of urbanization for local citizens. The latest version in 2021 evaluated cities with a framework of 39 indicators conceptualized into five categories, which were Health and Safety, Mobility, Activities, Opportunities, and Governance. The results of this study directly reflected citizens' perceptions as it gathered the data by citizen surveys (120 residents in each city). It also provided citizens' perspectives including their priority areas and attitudes towards the local smart city development, illustrating the priority of citizen-centric government of smart city concept (The IMD World Competitiveness Center, 2021).

2.3. An evaluation framework

We propose an evaluation framework consisting of five criteria – Credibility, Reliability, Methodology, Versatility, and Precision – to assess the existing indices (see Table 3). The choice of these criteria as tools of smart city evaluation follows recommended qualities in the reviewed literatures, including the well-acknowledged studies by Sharifi (2019, 2020).

Credibility assesses the developer of the indices, as the orientation (research- or market-based) of the developers might influence their transparency and objectivity (Sharifi, 2020). Reputation is the first factor to be considered. We propose that reputation is well-captured by the international ranks of universities (as a measure of intellectual integrity), or by the numbers of followers on social media for organizations (as an indicator of their connectedness). Credibility also requires a high degree of neutrality. Hence, the smart city index ought to be independent from governments, and not closely tied to business interests. The degree of neutrality is determined by our designed reasonableness assessment analysis (see Table 5). The ranks of each index's origin city are extracted from all the six indices and hence compared to assess fairness. The idea is to examine the "home advantage" effect, whereby it is assumed as a potential danger that developers might favor their place of origin. The commercial or non-profit distinction signifies whether the indices are research-based or market-oriented, defining their business interests. As research shows that market-oriented schemes are always outcome-based, stakeholders might understandably be skeptical towards the results (Bosch et al., 2016). In this paper, profitable organizations are associated with market-oriented schemes, and thus indices with profitable organizations as developers will have lower scores.

To provide a reliable assessment of smart cities, the indices should deliver potential benefits such as improving international image, assisting smart city strategy development, simplifying the smart city concept, and motivating stakeholder engagement in smart city development (Caird et al., 2016; Giffinger et al., 2007). By assuming that stakeholders who are satisfied with the received benefits from the indices tend to quote them more often, this paper associates the numbers of referrals with Reliability. Since "Presentation and communication" is another important quality in smart city evaluation tools (Sharifi, 2019), Reliability also assumes an index would regularly be quoted only if its presentation format is comprehensible to the readers. Three types of reference, by municipalities, by scientific journals, and by public media, are examined here. They represent three types of stakeholders: city authorities, researchers and citizens. The "Web of Science" is used as the main search engine for the scientific journals.

Methodology represents concerns about the assessment methodology and the data collection of the indices (Cutter, 2015). Some literature points out that market-oriented assessment tools tend to not publish all necessary information to prevent in-depth analysis by third parties (Kitchin et al., 2015). As this practice can influence transparency, the existence of explanations for the analytic methodologies is evaluated by this criterion. Moreover, usage of primary or secondary data can greatly influence the objectivity of the results. Some scholars believe using the combination of both types is the most desirable as it increases the opportunities for data collection (Sharifi, 2020). This paper recognizes that validated secondary data from publicly reliable sources, such as census data, historical data records and urban audit databases, has higher trustworthiness.

An outstanding smart city index should comprehensively address multiple dimensions of the smart city, be sensitive and relevant to the local context, and be adaptable to different scales and locations (Caird et al., 2016). Therefore, Versatility is used to evaluate these qualities of indices. It includes the consideration of cities with different backgrounds, the aspects covered, and the essential qualities of indicators. The first two elements are directly related to the underlying reasons why specific cities, such as Hong Kong, have diverse rankings in the different smart city indices, implying the necessity of like-for-like comparison. Essential indicators (or "persistently-used indicators") mean they are commonly utilized by various smart city indices, identified by counting the number of times that the indicators occur in the selected indices (Sharifi, 2020). If they are not deemed essential, the indicators are less central. We can read these single indicators in two ways; we might conclude that they ought to be included in the general smart city analysis but have thus far been neglected (unique indicators), or we might equally contend that they are just unrelated. The essential character of indicators is further relevant to the interlinkages between different indicators, which we (and several others) deem as a fundamental quality when considering smart cities (Woods et al., 2017). The essential qual-

Table 3
Five criteria evaluation framework.

Criterion	Indicator		Measurement
Credibility	[a]	Reputation of the developers	1: Well-known / high rank organizations 0: Unknown to the public
	[b]	Independence from governments	2: Individual organizations & passing reasonableness assessment analysis 1: Individual organizations / passing reasonableness assessment analysis 0: failing reasonableness assessment analysis
	[c]	Business orientations	2: Non-profit organizations 1: Profitable organizations with no conflict of interests 0: Profitable organizations
Reliability	[d]	Referral by the municipalities	1: Have been quoted by municipal publications 0: Have never been quoted by any municipalities
	[e]	Referral by scientific publications	2: Have been cited for more than five times by scientific publications 1: Have been cited for at least once by scientific publications 0: Have never been cited by any scientific publications
	[f]	Referral by the public media	2: Have been reported at least once by international public media 1: Have been reported by public media 0:Have never been reported by public media
Methodology	[g]	Transparency of the information	2: Methodologies including the compilation of the scores are clarified in the study 1: Methodologies are mentioned 0: No detail of the methodology is provided
	[h]	Trustworthiness of the background data	3: Secondary data from reliable organizations 2: Primary data 1: Secondary data from private organizations 0: No detail for the background data
Versatility	[i]	Specific feature for cities with different backgrounds	1: Existence of specific feature for measuring context-sensitivity (e.g. separated rankings, weightings) 0: No specific feature
	[j]	Coverage of the aspects	2: Covering five to six smart city dimensions* 1: Covering more than one smart city dimensions 0: Covering only one smart city dimension *six smart dimensions – economy, environment, governance, living, mobility, people (Manville et al., 2014)
	[k]	Quality of the indicators	2: Most indicators are essential to smart city 1: Probability of simplifying the indicators 0: Most indicators are seemingly unrelated to smart city
Precision	[l]	Accuracy of the rankings	5: All cities and at least one control group city have the consistent ranks with the reality performance* 4: Three cities and at least one control group city have the consistent ranks with the reality performance 3: Two cities and at least one control group city have the consistent ranks with the reality performance 2: One city and at least one control group city have the consistent ranks with the reality performance 1: At least one control group city has the consistent ranks with the reality performance 0: No consistent ranks *the reality performance is derived from the three data-based factors (total websites hosted in city, total IP [Internet Protocol] addresses in city, top world websites hosted in the city).

ity analysis of indicators is especially important to build up the basic framework of a smart city index.

Finally, Precision determines the accuracy of the indices. It is important to establish whether the indices adopt an iterative approach (via annual or biennial studies) to capture longitudinal and temporal changes, which is valued by Sharifi (2019). Based on our definition, we assume the smartness of cities is positively correlated to the number of websites and IP addresses in the city, representing the virtual dynamic of a city. Referring to an online real-time database (Myip.ms, 2021), we pick out these three data-based factors: total websites hosted in city, total IP (Internet Protocol) addresses in city, top world websites hosted in city, representing ICT usage. To test the precision of the indices by these factors, we selected two Chinese and two German cities (Beijing, Shanghai, Berlin, Munich), while three well-recognized smart cities (London, New York, Toronto) were chosen as the control group, which is the feature to validate the test. The results of the analysis based on the datasets from Myip.ms are shown in Section 2.4.5.

The numbers in the measurement column are the scores of each indicator (see Table 3). Each criterion is scored on a scale of zero to five, representing low to high performance for each of them. The total mark of each smart city index is added up ultimately to represent their performances as evaluation results.

2.4. *Smart city indices analysis*

The results of the analysis, achieved by adding up the scores of each criterion, are compiled in Fig. 1 and Table 4. To demonstrate how the five criteria operate in practice, they are illustrated independently to explain the mechanism.

2.4.1. *Credibility*

The Cities in Motion Index is the only one achieving full scores in Credibility, as universities with research-based positions have indeed higher credit (Sharifi, 2019); Smart City Governments, in contrast, has

Table 4
Analysis of selected smart city indices.

Selected Smart City Index	Criterion	Indicator	Score	Sub-total	Observation	Total score
CIMI	Credibility	[a]	1 /1	5 /5	University of Navarra was ranked 266th on the World University Rankings 2022 (Top Universities, 2021b)	**22 /25**
		[b]	2 /2		Research-based university; passing reasonable assessment analysis (Times Higher Education, 2021c)	
		[c]	2 /2		Non-profit organization	
	Reliability	[d]	1 /1	5 /5	Quoted by the Helsinki municipality (City of Helsinki, 2018)	
		[e]	2 /2		Cited for more than five times (Webofscience.com, 2021a)	
		[f]	2 /2		Reported by international public media (Willett-Wei, 2014)	
	Methodology	[g]	2 /2	5 /5	Having an individual publication describing the methodology, indicators calculation and processes	
		[h]	3 /3		Data were mostly from the World Bank, UN and OpenStreetMap	
	Versatility	[i]	1 /1	4 /5	Separated rankings for different continents and populations	
		[j]	2 /2		Covering all six dimensions	
		[k]	1 /2		Few indicators could be simplified	
	Precision	[l]	3 /5	3 /5	Two cities had consistent ranks	
DCI	Credibility	[a]	1 /1	3 /5	More than 3000 followers on Twitter and LinkedIn LinkedIn (2021b); Twitter (2021b)	**15 /25**
		[b]	2 /2		Private organization; passing reasonable assessment analysis (Bloom Consulting, 2021)	
		[c]	0 /2		Profitable organization with aligning business (Bloom Consulting, 2021)	
	Reliability	[d]	0 /1	2 /5	No quote by the municipalities	
		[e]	1 /2		Cited for less than five times (Lammers et al., 2020; Mozūriūnaitė & Sabaitytė, 2021)	
		[f]	1 /2		Reported by public media (Anderson, 2018)	
	Methodology	[g]	1 /2	2 /5	Explained methodology but no score calculation detail	
		[h]	1 /3		Data were from a software which is operated by a private company	
	Versatility	[i]	1 /1	4 /5	Separated rankings for different continents	
		[j]	1 /2		Covering three dimensions	
		[k]	2 /2		Indicators were majorly essential	
	Precision	[l]	4 /5	4 /5	Three cities had consistent ranks	
GEGS	Credibility	[a]	0 /1	4 /5	Suffolk University was not on the World University Rankings 2022 (Top Universities, 2021a)	**18 /25**
		[b]	2 /2		Research-based university; passing reasonable assessment analysis (Times Higher Education, 2021b)	
		[c]	2 /2		Non-profit organization	
	Reliability	[d]	1 /1	4 /5	Quoted by the Hong Kong Government (Choi, 2017)	
		[e]	2 /2		Cited for more than five times (Webofscience.com, 2021d)	
		[f]	1 /2		Reported by public media (Panarmenian.net, 2015)	
	Methodology	[g]	2 /2	5 /5	Detailed methodology and scoring clarifications	
		[h]	3 /3		Evaluations were based on the municipalities' official websites, which were the source of data	
	Versatility	[i]	1 /1	3 /5	Separated rankings for different continents	
		[j]	1 /2		Covering three dimensions	
		[k]	1 /2		One third of the indicators were essential while half of the rest were unique indicators	
	Precision	[l]	2 /5	2 /5	One city had consistent rank	
ICI	Credibility	[a]	0 /1	2 /5	Less than 2000 followers on Twitter and around 200 followers on LinkedIn LinkedIn (2021a); Twitter (2021a)	**17 /25**
		[b]	2 /2		Private company; passing reasonable assessment analysis (2thinknow, 2021c)	
		[c]	0 /2		Profitable organization with payable services for detailed index results (2thinknow, 2021a)	
	Reliability	[d]	1 /1	5 /5	Quoted by the Chicago municipality (Mayor's Press Office, 2018)	
		[e]	2 /2		Cited for more than five times (Webofscience.com, 2021b)	
		[f]	2 /2		Reported by international public media (Suliman, 2019)	
	Methodology	[g]	0 /2	2 /5	No methodology detail	
		[h]	2 /3		Self-collected data as primary source	
	Versatility	[i]	1 /1	3 /5	Separated rankings for different continents	
		[j]	2 /2		Covering all six dimensions	
		[k]	0 /2		Most indicators were seemingly unrelated	
	Precision	[l]	5 /5	5 /5	All cities had consistent ranks	
SCG	Credibility	[a]	0 /1	1 /5	Less than 200 followers on Twitter and 2000 followers on LinkedIn LinkedIn, (2021c), Twitter, (2021c)	**17 /25**
		[b]	1 /2		Private organization (Eden Strategy Institute, 2021a)	
		[c]	0 /2		Profitable organization with aligning business (Eden Strategy Institute, 2021a)	
	Reliability	[d]	0 /1	3 /5	No quote by the municipalities	
		[e]	1 /2		Cited for less than five times (Radu et al., 2019; Tay et al., 2018)	
		[f]	2 /2		Reported by international public media (IndraStra Global, 2021)	
	Methodology	[g]	2 /2	5 /5	Detailed methodology and scoring clarifications	
		[h]	3 /3		Data were mostly from official websites and publications	
	Versatility	[i]	0 /1	3 /5	No specific feature	
		[j]	1 /2		Covering three dimensions	
		[k]	2 /2		Indicators were majorly essential while the rest were unique indicators	
	Precision	[l]	5 /5	5 /5	All cities had consistent ranks	
SCI	Credibility	[a]	1 /1	3 /5	IMD Business School was ranked 25th on the Global MBA Rankings 2021; more than 160k followers on LinkedIn LinkedIn (2021d); TopMBA.com (2021)	**17 /25**
		[b]	1 /2		Independent institution (Times Higher Education, 2021a)	
		[c]	1 /2		Non-profit organization (mixed-mode)	
	Reliability	[d]	1 /1	5 /5	Quoted by the Newcastle municipality (Bishop, 2020)	
		[e]	2 /2		Cited for more than five times (Webofscience.com, 2021c)	
		[f]	2 /2		Reported by international public media (Midha, 2021)	
	Methodology	[g]	1 /2	3 /5	Explained methodology but no score calculation detail	
		[h]	2 /3		Self-collected data as primary source	
	Versatility	[i]	0 /1	4 /5	No specific feature	
		[j]	2 /2		Covering all six dimensions	
		[k]	2 /2		Indicators were majorly essential while the rest were unique indicators	
	Precision	[l]	2 /5	2 /5	One city had consistent rank	

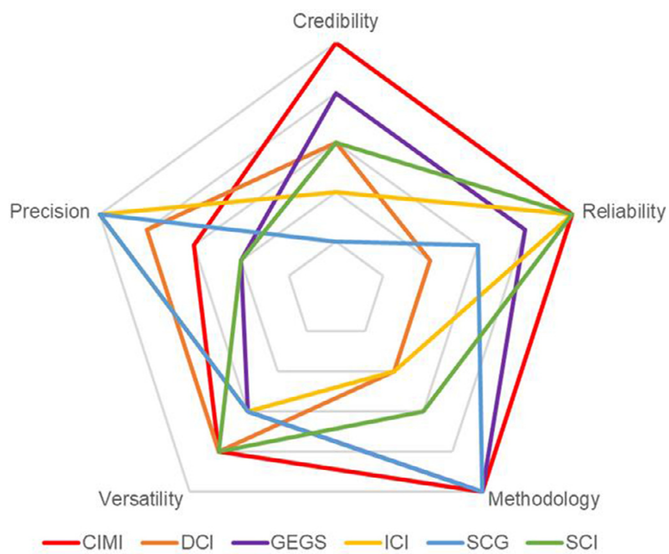

Fig. 1. Results of selected smart city indices analysis.

Table 5
Reasonableness assessment analysis.

Selected Smart City Index	Barcelona	Madrid	Boston	New York	Melbourne	Singapore
CIMI	*26*	25	28	2	37	9
DCI*	2 (EUR) 9 (Top 10)	*8 (EUR)*	6 (AME)	1 (AME) 5 (Top)	6 (Asia)	2 (Asia) 2 (Top 10)
GEGS*	N/A	4	*N/A*	*18*	N/A	10
ICI	52	40	2	3	*33*	5
SCG	4	N/A	32	6	20	*1*
SCI	58	34	57	12	19	*1*

* DCI has five isolated rankings (continents, World Top 10); New York was used for GEGS as Boston (its origin city) was not covered in GEGS; Italic cell: rank of the origin city.

the lowest score. The University of Navarra (the parent organization of CIMI) enjoys a relatively high rank in the World University Rankings (Top Universities, 2021b), which contributes to its leading performance in Credibility. For its part, the Eden Strategy Institute (the parent organization of SCG) does not score highly in terms of organizational reputation as measured by the number of followers on social media (LinkedIn and Twitter) (LinkedIn, 2021c; Twitter, 2021c).

Table 5 sets out the reasonableness assessment analysis. According to this tool, Smart City Governments and the Smart City Index both fall short of the ideal, insofar as they do not substantiate the outstanding performance of Singapore – their "home" city and their champion. This damages their overall Credibility and explains their low score on this measure.

2.4.2. Reliability

Most indices have satisfying performances in Reliability, except the Digital City Index, as it has never been quoted by any municipalities, and has been only rarely referred to by scientific publications and the media (Anderson, 2018; Lammers et al. 2020; Mozūriūnaitė & Sabaitytė, 2021). Smart City Governments is another index which has never been quoted by any municipalities, resulting in a lower score. All indices have been referred to by scientific publications and the media, especially the three indices with full scores (CIMI, ICI, SCI). They have all been cited for more than five times by scientific papers (Webofscience.com, 2021a, 2021b, 2021c), and been reported by international public media (Midha, 2021; Suliman, 2019; Willett-Wei, 2014).

2.4.3. Methodology

The Digital City Index and the Innovation Cities Index have the lowest score in Methodology. The former does not explain the scoring, and uses secondary data from a private company. The latter required purchase to unlock detailed information such as scoring and data interpretation. As a market-oriented scheme, the limited availability of free accessed information questions the ICI's veracity and quality (Kitchin et al., 2015; Sharifi, 2019). The three indices (CIMI, GEGS, SCG) obtaining full scores in Methodology provided explanations of the methodologies they employed and, in their majority, used data from the officially published reports and international organizations (e.g. the World Bank).

2.4.4. Versatility

For the criterion of Versatility, all indices have above-average performance. Besides Smart City Governments and the Smart City Index, all indices had separate rankings regarding continents, taken as a measure of the regional context sensitivity (Sharifi, 2019). In addition, all indices covered at least three smart city dimensions, while three indices (CIMI, ICI, SCI) even covered all six dimensions, validating their adequate versatility (Camero & Alba, 2019; Caragliu et al., 2011; Fernandez-Anez, 2016; Giffinger et al., 2007; Manville et al., 2014).

Regarding the essential quality analysis of indicators, all indices were composed in their majority of essential indicators and unique indicators, except the Innovation Cities Index. Although ICI claimed to be measuring cities on a broader basis than the other indices, so that it could capture potential changes in cities before the others, most indicators were seemingly irrelevant to the smart city (2thinknow, 2021b).

2.4.5. Precision

All indices had consistent ranks with at least one control group city, hence validating the assessment. Nevertheless, diversity is observed in Precision (see Table 7). The Global E-Government Survey and the Smart City Index have the lowest score, as they only had one consistent rank among the four selected cities. It is reasonable for GEGS as it only covered Shanghai and Berlin due to its city selection methodology (Holzer et al., 2020). For SCI, as its results represent the local citizens' subjective viewpoint instead of the city data (e.g. GDP, internet speed), the low consistency might suggest that citizens' perception does not necessarily match with the cities' performance in reality. The Innovation Cities Index and Smart City Governments obtain the full score in Precision since all cities had consistent ranks.

2.5. Overview of selected smart city indices

From the analysis in Section 2.4, the Cities in Motion Index from the IESE Business School has the highest score, indicating the best performance compared to the other selected indices. It obtains full scores in three criteria – Credibility, Reliability, and Methodology – which suggests a trustworthy background organization, numerous referrals by other parties, and transparent methodology. The runner-up index is the Global E-Government Survey, which has a full score in Methodology.

The Digital City Index has the lowest score, especially in the Reliability and Methodology. Besides being rather dated, its market-oriented nature, low reputation, and unclear data source hinder its integrity. That being said, its smart city definition and perspective are exclusive. Unlike the others determining smartness of cities by city data and surveys, this index used the number of internet searches towards targeted cities as measurement. This provide an innovative aspect while studying smart city development.

While the Cities in Motion Index is the best index among the six selected smart city indices, the analysis in this paper shows some of its indicators were not commonly used and apparently irrelevant, resulting in a relatively poor performance in Precision.

Table 6
The three data-based factors from Myip.ms database, 17 June 2021.

Selected City	Total websites hosted in city (sites)	Total IP Addresses in this city (IP)	Top world websites hosted in this city (sites)
Beijing	16,337	167,469	172
Shanghai	10,317	129,044	123
Berlin	43,202	64,801	65
Munich	20,550	47,585	93
London	29,310	95,415	183
New York	125,058	93,173	319
Toronto	16,697	57,748	56

Table 7
Precision analysis.

Selected City		Ranking						
		CIMI	DCI	GEGS	ICI	SCG	SCI	Reality Performance
Chinese City	Beijing	7	7	N/A	***4***	***4***	6	3
	Shanghai	***6***	***5***	1	***3***	***3***	7	4
German City	Berlin	***3***	***4***	***4***	***5***	***5***	***5***	5
	Munich	4	***6***	N/A	***6***	***6***	2	7
Control Group	London	***1***	***1***	5	***2***	***1***	***3***	2
	New York	***2***	***2***	***3***	***1***	***2***	***1***	1
	Toronto	***5***	3	2	***7***	***7***	***4***	6
No. of consistent ranks (Excluding control group)		2 /4	3 /4	1 /4	4 /4	4 /4	1 /4	

*Data were collected on 17th June,2021; Reality performance: ranking based on real-time data (see Table 6); Italic and bold cell: consistent ranks (difference with ranks of reality performance ≤2).

3. Towards a new smart city index

Though none of the selected smart city indices obtained the full score in Versatility, this criterion is fundamental in elaborating the framework of a smart city index. Versatility encompasses three main aspects of value for any smart city index: the types of indicator, the smart city domains and the context-sensitive measurements.

3.1. Types of indicator

During the meta-analysis of the existing smart city indices, the essential quality analysis distinguished three types of indicator: essential indicators, unique indicators, unrelated indicators. Essential indicators represent the common idea and generally agreed features of smart city analysis using various assessment tools (Sharifi, 2020); while unique indicators make specific indices stand out from the others. The essential indicators should be included in the framework of an ideal smart city index, while the unique indicators ought to be additionally considered. Table 8 shows some identified essential, unique and unrelated indicators from the analysis.

3.2. Smart city domains

Building on the text above on domains and definitions of the smart city, we propose nine categories as the fundamental basis for an index, consisting of six generally agreed smart city dimensions – economy, environment, governance, living, mobility, people – and the three elements that are extracted from the themes of existing smart city indices, namely perception, privacy and cybersecurity, and technology.

- Economy: the use of ICT in business operations, the status of economic development, and the preparation of enterprises to embrace smart city era
- Environment: the application of ICT to monitor resources and impacts on the environment, with the aim of achieving sustainable development

Table 8
Essential quality analysis – essential and unique indicators.

Type	Indicator	References
Essential indicators	Air quality	CIMI, ICI, SCI
	Airport connectivity	CIMI, DCI, ICI
	Bike sharing	CIMI, SCI
	Citizen participation	GEGS, SCG, SCI
	Digitalization of government	CIMI, GEGS, SCG
	Education level	CIMI, DCI, ICI, SCI
	Internet speed	CIMI, SCI
	Metro connection	CIMI, ICI
	Open data platform	CIMI, GEGS, SCI
	Reserves for smart city projects	CIMI, ICI, SCG
	Social Media	CIMI, GEGS, ICI
	Waste disposal	CIMI, ICI, SCI
	Water supply	CIMI, ICI
	Wi-Fi hotspots	CIMI, GEGS, ICI, SCI
Unique indicators	Citizen perception	SCI
	Collaborative economy	CIMI
	Data collection	GEGS
	Food supply	ICI
	Foreign languages	ICI
	Green buildings	ICI
	Leadership	SCG
	Mobile telephony	CIMI
	Privacy policy	GEGS
	Smart parking	SCI
	Tourism	DCI
	Track record	SCG
Unrelated indicators	Classical music	ICI
	Customization of official webpage	GEGS
	Font color of official webpage	GEGS
	Infant mortality rate	ICI
	Magazine availability	ICI
	McDonald’s	CIMI
	Places of worship	ICI
	Suicide rate	CIMI

- Governance: the digitalization of local municipalities, measured by the advancement of official municipal websites (Holzer et al., 2020), the availability of online city services, and the expenditure on ICT
- Living: the utilization of ICT in the citizens’ quality of life, the improvement of living standards by advancing health systems, public security, urbanization, and the distribution of basic needs
- Mobility: the mobility infrastructures, user patterns and innovations of cities’ transportation systems, including the integration of traffic within mobile apps (EasyPark Group, 2019)
- People and Society: the citizen-centric concepts, social inclusion and education, assessed by the impact of ICT development on cultural values, public acceptancy and citizen power (van den Berg et al., 2020)
- Perception: the impressions of cities from external players, including local citizens and experts, as well as the results from search engines; inspired by SCI and DCI, since the main feature of SCI is to solely evaluate the cities’ performance by the local citizens’ opinions, and DCI depends on the cities’ results from searching engines, substantiating the inclusion of subjective perception (Bloom Consulting, 2018; The IMD World Competitiveness Center, 2021)

- Privacy and Cybersecurity: the regulations, restrictions and measures regarding data protection, internet monitoring and security; extracted from Global Cybersecurity Index (GCI) and GEGS, as GCI believes cybersecurity is part of the core of ICT, and GEGS outlines several privacy factors to be considered especially for the development of smart government (Holzer et al., 2020; International Telecommunication Union, 2018)
- Technology: the infrastructures supporting the internet connection, the use of ICT among citizens, and their internet practice habits; including all common indicators relating to accessibility and coverage of telecommunication, and referring to ICT Development Index (IDI) and IESE, as IESE has a standalone technology dimension to discuss the features of telecommunication, and IDI is an adapted framework aiming to monitor the ICT development between countries (Berrone & Ricart, 2020; International Telecommunication Union, 2017)

Most of the indicators proposed under the nine categories are defined as essential indicators, in that they are identified by more than one smart city index. We also include some indicators best described as unique. The source for most indicators is the corpus of six assessed smart city indices, though some of the indicators are drawn more widely from other sources (namely other indices quoted in Table 2).

The use of international standards in implementing smart city development and standardizing assessment tools should also be acknowledged, as it supports data interoperability, and facilitates meaningful comparisons among smart cities performance (Lai et al., 2020). Therefore, we follow the smart city standards – ISO 37,122 – to build up the format and measurement of the smart city indicators (International Organization for Standardization, 2019). Examples of indicator are presented in Table 9, regarding the "hard" and "soft" domains in each category. More indicators should be employed in the ideal smart city index framework, which will be formally presented in a future paper.

3.3. Context-sensitive measurements

Unreasonable comparison between cities should be avoided, because "winners" could excessively claim that the results improve their public image while "losers" would tend to ignore findings which might threaten their competitiveness (Giffinger et al., 2007). Therefore, it is essential to develop an approach which compares cities with similar backgrounds (Kitchin et al., 2015). To ensure like-for-like comparison and fair assessment, context-sensitive measurements should be presented in the ideal smart city index. The measurements can be achieved by grouping the cities under evaluation according to their population and the specific definition of the smart city they adopt.

Considering the range of distinct developments classified by the smart city, we suggest a definition tailored to encompass distinct types of development. It consists of a general smart city definition, and the specific descriptions of distinct smart city types representing qualitatively different smart city development concepts. Two types of smart city developments – Big Data Policy and Sustainable Smartness – are identified from our smart city definition (see Table 10). The Big Data Policy is inspired by the smart city concepts of China, while the Sustainable Smartness is inspired by that of Germany (see Section 2.1).

Although it is possible to have other concepts (e.g. Smart City Marketing, Privacy Safeguard), for now only two are defined with the possibility of further exploration in a future paper. Together with population as described in Section 2.1, we suggest the following groupings in Table 11 for an ideal smart city index (Grenslitt, 2021). Hong Kong for instance belongs to group 1.

The ultimate goal of grouping the cities is to apply weighting factors, as they can attribute different levels of importance to different indicators within an assessment scheme, and thus make the results reasonable and comparable, as an effective context-sensitive measurement (Manville et al., 2014). Therefore, the differences of smart city concepts are reflected in the weightings of each category, so that the cities are

Table 9
Examples of indicator.

Category	Domain	Indicator	Measurement	Refs.
Economy	Hard	E-payment	Percentage of population making digitally enabled payment transactions	GEGS
	Soft	ICT employees	Percentage of labor force employed in occupations in the ICT sector	EDCI*, IDI*
Environment	Hard	Smart grids	Storage capacity of the city's energy grid per total city energy consumption (GJ)	ISO
	Soft	Waste recycling	Percentage of total amount of solid waste recycled in the city	CIMI, EasyPark*, ICI, SCI
Governance	Hard	Open data platform	Existence of a municipal open data platform (binary variable)	CIMI, GEGS, SCI
	Soft	Leadership for smart city projects	Existence of government offices to steer smart city projects (binary variable)	SCG
Living	Hard	Safety	Number of surveillance cameras per 100,000 population	CIMI, ICI, SCI
	Soft	Urban population	Percentage of population living in urban areas	EasyPark*
Mobility	Hard	Electric vehicles	Percentage of electric vehicles registered in the city	EasyPark*
	Soft	Airport connectivity	Number of yearly incoming flights per 100,000 population	CIMI, DCI, EDCI*, ICI
People and Society	Hard	Interaction platform	Existence of platforms for direct communication between the government and citizens (binary variable)	GEGS, SCI
	Soft	STEM students	Number of STEM higher education students per 100,000 population	CIMI, EasyPark*, DCI, ICI, ISO, SCI, SCSI*
Perception	Hard	Expert perception	Rating from the experts to address the smartness of a city	EasyPark*
	Soft	Citizen perception	Percentage of interviewees choosing the city as the best in the development of smart city	SCI
Privacy and Cybersecurity	Hard	Existence of CERT/ CIRT	Percentage of enterprises with a CERT/ CIRT	GCI*, GEGS
	Soft	Cybersecurity regulation	Imprisonment duration of the maximum sentence when violating cybersecurity law	EasyPark*, GCI*, ICI
Technology	Hard	Broadband subscriptions	Percentage of population with access to internet	CIMI, ICI, IDI*
	Soft	Social media	Percentage of population using social media	CIMI, GEGS, ICI

* EasyPark – Smart Cities Index (EasyPark Group, 2019); EDCI – European Digital City Index (Bannerjee et al., 2016); GCI – Global Cybersecurity Index (International Telecommunication Union, 2018); IDI – ICT Development Index (International Telecommunication Union, 2017); SCSI – Smart City Strategy Index (Roland Berger, 2019).

Table 10
Smart city definition.

Smart City Definition of the ideal Smart City Index		
Type	**General Definition** +	**Description**
Big Data Policy	A smart city is a municipality using different types of information and communication technologies (ICT) to improve the quality of life	Cities emphasizing smart governance by implementing sensors for data collection to manage the society and improve the city services
Sustainable Smartness		Cities emphasizing smart environment by implementing technologies for monitoring city operations such as transportation and energy usage to be more sustainable

Table 11
Grouping of cities.

Population / Type	Big Data Policy	Sustainable Smartness
500,000 or more	Group 1	Group 2
250,000 to 499,999	Group 3	Group 4
125,000 to 249,999	Group 5	Group 6
75,000 to 124,999	Group 7	Group 8
Fewer than 75,000	Group 9	Group 10

Table 12
Differentiation of weightings.

Category	Big Data Policy (%)	Sustainable Smartness (%)
Economy	17.5	7.5
Environment	7.5	17.5
Governance	17.5	7.5
Living	10	10
Mobility	10	10
People and Society	7.5	17.5
Perception	10	10
Privacy and Cybersecurity	7.5	10
Technology	12.5	10

evaluated on a common basis. A higher ratio is given to the categories which are salient within a given definition, while lower ratio is provided for the categories which are barely considered. The preliminary of weightings are suggested and presented in Table 12.

4. Preliminary operationalization

To better explain our suggested three dimensions of an ideal smart city index, and to justify the weightings of the two smart city concepts, this section uses Berlin, Beijing and Hong Kong as three cities to demonstrate the operationalization. Berlin and Beijing are deemed to represent the group of Big Data Policy and Sustainable Smartness respectively, while Hong Kong is the research basis of this paper, which is hence also included as the group of Big Data Policy. Due to the limitation of data access and inconsistent timing of the latest data sources, only one indicator of each category is used for evaluation. Table 13 shows the indicators and data (see Table 9 for measurements and Appendix for data sources). In this demonstration, the measurement of “Perception” is replaced by the ranks of the Smart City Index (SCI) from the IMD Competitiveness Center due to the restriction of carrying out a survey regarding the citizen perception, and the basis of SCI on the citizen survey. SCI’s second-highest score from the previous analysis also approves the trustworthiness for this temporal replacement.

After the data collection, the data is normalized by the “Min-max technique”, which normalizes the value to within the 0 to 1 range by subtracting the minimum value and then dividing by the range of values, presenting by the following equation. The advantage of this method is to enlarge the minor differences between values (Bannerjee et al., 2016).

$$Z(X) = \frac{X - \min(X)}{max(X) - min(X)}$$

X=original value; Z(X)=normalized value;
$\min$*(X)=the minimum value;* $\max$*(X)=the maximum value*

Table 14 shows the results with and without weightings application (see Appendix for calculation). The range of the score is from 0 to 10, while “10″ is the maximum score.

Using the weightings applied results as reference, the scores show that Hong Kong is a better developed smart city than Beijing and Berlin, especially in the category of economy, and people and society. While Berlin has higher score than Beijing before applying the weightings, the deviations between each city are reduced after applying the weightings, which substantiates the effectiveness of the designated weightings in respect of the smart city concepts to standardize the cities’ performance,

Table 13
Example of city data.

Category	Indicator	Beijing	Berlin	Hong Kong
Economy	ICT employees	10.2%	6.4%	3.4%
Environment	Waste recycling	35%	76%	40%
Governance	Open data platform	Yes	Yes	Yes
Living	Safety	5503 cameras	625 cameras	710 cameras
Mobility	Electric vehicles	6.09%	1.33%	3.7%
People and Society	STEM students	1595.22	1930.73	37,501
Perception*	Citizen perception	69 /118	50 /118	41 /118
Privacy and Cybersecurity	Cybersecurity regulation	15 days	5 years	5 years
Technology	Broadband subscriptions	94.1%	99.5%	93.9%

* Measurement of "Perception" is replaced here by the ranks of the Smart City Index (SCI).

Table 14
Score calculation.

Category	Without Weightings			With Weightings applied		
	Beijing	Berlin	Hong Kong	Beijing	Berlin	Hong Kong
Economy	0.113	0.071	0.038	0.179	0.048	0.06
Environment	0.389	0.844	0.444	0.263	1.33	0.3
Governance	1.11	1.11	1.11	1.75	0.75	1.75
Living	1.11	0	0.019	1	0	0.017
Mobility	0.068	0.014	0.041	0.061	0.013	0.037
People and Society	0	0.01	1.11	0	0.016	0.75
Perception	0.461	0.64	0.724	0.415	0.576	0.653
Privacy and Cybersecurity	0	1.11	1.11	0	1	0.75
Technology	1.045	1.104	1.042	1.176	0.995	1.174
Score	4.29	4.9	5.64	4.84	4.73	5.49

aiming to get a fair result. Alternatively, the scores without weightings should also be acknowledged as complementary data while evaluating the smartness of a city. As a precaution, we recall that above results are only the demonstration of a partial operationalization, as only one indicator is used for each category and the timing of data sources is inconsistent. But the exercises demonstrates its utility.

5. Discussion and conclusion

This article selects six existing smart city indices for analysis, which uses a self-developed evaluation framework consisting of five criteria: Credibility, Reliability, Methodology, Versatility, Precision (see Table 3). While limitations are presented in the analysis, which are discussed below, the results show that the Cities in Motion Index from IESE Business School has the best performance, especially in Credibility, Reliability and Methodology. Though all selected smart city indices generally have satisfactory results, meaning their quality and integrity are guaranteed, this article has explored ways to improve smart city indices.

Some of the indices underperform because of their nature as market-based tools based on confidentiality, rather than research intensive enterprises organized according to the principle of transparent open data. The element of process might misrepresent the authenticity and rigor of some of the indices. The Innovation Cities Index, for example, suffers because of the limited availability of free accessed information. The lack of open data represents the dilemma between revenue and knowledge sharing.

Even the best ranking index – the Cities in Motion Index – falls down in terms of Precision, while competitors such as the Innovation Cities Index and Smart City Governments perform much better on this criterion. This illustrates another major limitation concerning the date of publication of the indices. The latest edition of CIMI was published in 2020, for example, while both ICI and SCG had editions in 2021. This only matters because the inconsistent years of the latest edition might marginally influence the preciseness of indices. More problematical is the comparison between indices with only one iteration (for example, the Digital City Index) and those that are more regularly updated.

Finally, there are questions about the consistency of coding. While the Global E-Government Survey implemented an approach of assigning two evaluators for assessment to ensure its reliability (Holzer et al., 2020), we suggest the need for multiple evaluators of reapplying this smart city indices evaluation framework in the future to assure consistency and harmonization of the evaluation.

To conclude, we propose three dimensions of an ideal smart city index that fulfill the criterion of Versatility. These are the types of indicator, smart city domains, and context-sensitive measurements. First, our proposed essential quality analysis suggests that essential and unique indicators are the two main types of smart city indicators, and that unrelated indicators should be kept to a minimum. Second, a broad understanding of smart city domains is essential to ensure a holistic assessment that measures what an index sets out to measure. Building on our definition of the smart city, we propose nine categories that can each be understood in terms of "hard" and "soft" domains in each category. Third, the context-sensitive measurements correspond to the specific features for cities with different backgrounds. We suggest using grouping and weightings according to cities' population and smart city development concept to assure like-for-like comparison, and thus perform a fair assessment. We recommend that future studies center on developing a comprehensive smart city index that fulfills the five criteria developed in this paper, which covers the potential smart city development concepts, the holistic smart city indicators, the subsequent validation of indicators, and operationalization. We will continue our reflection in a subsequent paper.

Declaration of Competing Interest

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Supplementary materials

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