Sensors and Materials, Vol. 36, No. 7 (2024) 2909–2924
MYU Tokyo

S & M 3709

Evaluation System of Green Smart City

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(Received Januray 22, 2024; accepted July 4, 2024)

Keywords: evaluation indicators, fuzzy Delphi method, analytical hierarchical process

A green smart city is important in the urbanization of countries, and an evaluation system for the functionality and management of the green smart city is inevitable in its construction and maintenance. In this study, we used the fuzzy Delphi method to establish an evaluation index system of the green smart city in line with 5G technology and IoT based on a literature review. The fuzzy hierarchical analysis method was adopted to create questionnaires for experts and extract the weights of the index in the green smart city evaluation system. The method was applied to Shanghai and Taipei in China to assess the level of the application of the green smart city. On the basis of the results, suggestions for the improvement of the evaluation system and development strategies for the green smart city were made, which is an important reference for promoting the construction of green smart cities.

1. Introduction

With the development of technologies including 5G and IoT, big data, fog computing, and edge computing, many green smart cities have been constructed.(1) Therefore, the evaluation system for green smart city construction should be established and improved according to the increasing need for green smart cities. The evaluation system must be used to measure the effect of green smart city construction on its surroundings and provide appropriate information and strategies for its development plan.

Graham(2) and Mitchell(3) laid the foundation for the principles of the smart city in China. Since then, many researchers have claimed that the development of proper urban infrastructure is important in the building of a smart city. Apart from buildings and transportation, information and computer technology (ICT) plays an important role in smart cities.(4) Thus, it is necessary to understand how ICT affects the development and is used for the evaluation of smart cities.(5)

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https://doi.org/10.18494/SAM5004

ISSN 0914-4935

The Natural Resources Defense Council and the European Intelligence Council defined smart cities from different perspectives,[6] but their definitions are consistent in that smart cities have social, public, information, and business infrastructures.[7] Giffinger *et al.*[8] stated that a smart city is a smart society in which various elements such as people, environment, mobility, governance, and economy are built into the smart infrastructure. As stated, smart cities are for their citizens. Thus, they are the key element of a smart city with their continuous interaction in and with smart cities, and they should have the appropriate knowledge to develop smart cities further.[9] With citizens, social infrastructures are also an essential element as they are used to connect people and form relationships.[10] Yigitcanlar *et al.*[11] proposed six subthemes of productivity, sustainability, accessibility, well-being, livability, and governance as the desirable outcomes of smart cities. On the basis of the elements and themes, the smart city blends education, culture, arts, business, economics, and commerce. For smart cities, it is important to understand how a smart city has been built and benefits citizens considering its purposes and functionality, which requires an appropriate evaluation system for the inherent purposes of smart cities and their management.

Therefore, in this study, a new evaluation system was developed on the basis of the interview results of experts and scholars. The system was designed to apply to Shanghai and Taipei in China, and the results were compared to validate its applicability. A fuzzy Delphi method was used to develop the evaluation system with the fuzzy hierarchical analysis. The results of questionnaire surveys and interviews were analyzed to obtain the weights of the indices in the evaluation system. The verified indices were reviewed and verified to propose countermeasures and suggestions for the infrastructure, economy, services, governance, innovation, productivity, and smart living. Smart cities and their applications aim to maintain a high quality of life by using smart technologies and enhancing economic productivity.[12,13]

2. Literature Review

2.1 Smart city

The Intelligent Community Forum (ICF) has been selecting the smart city of the year since 1999[14,15] on the basis of six dimensions, namely, smart economy, mobility, environment, population, housing, and governance, which were identified by the Centre for Regional Science at the Vienna University of Technology. These six dimensions are based on regional competitiveness, transport, ICT economy, natural resources, human and social capital, the quality of life, and the participation of members of the society, and are linked to urban growth and development.[16] For the governance of large cities, France launched the “Greater Paris Plan” to promote the green, low-carbon, and sustainable development of Paris, reorganize its transportation network, and integrate suburban development.[17,18]

China’s research on the smart city has been conducted lately but research on the evaluation system of the smart city has been widely carried out.[19,20] In 2015, China put forward a new development concept for cities: “innovation, coordination, green, openness, and sharing”. Since then, these have become new connotations to city construction. The concept of a “new smart city" was also proposed. Currently, China's smart city construction is aimed to provide for "ubiquitous people's services, transparent and efficient online government, integrated and innovative digital economy, precise and fine urban governance, and safe and reliable operation system" by emphasizing "people-oriented, integrated, and coordinated development" with "interconnection, interoperability, and mechanism innovation".[21,22]

Smart sensors play a crucial role in the development and implementation of smart city programs. These small smart devices are capable of collecting, processing, and transmitting data in real time, enabling cities to gather insights, make informed decisions, and optimize all aspects of urban life. In short, smart sensors are integral to the development of smart cities, data-driven decision-making, resource optimization, improved public safety, enhanced sustainability, civic engagement, and efficiency in transportation. With their ability to collect and analyze real-time data, smart sensors are transforming cities into more efficient, liveable, and sustainable urban environments. The application of sensors in smart cities is shown in Fig. 1.

2.2 Green smart cities

In the 1980s, the report Limits to Growth introduced the idea of sustainable economic growth.[23] The Our Common Future states that economic growth, environmental protection, and social development must be reconciled.[24] The New Urbanism Movement advocated limiting urban fragmentation and sprawling by using eco-friendly designs such as walkable neighborhoods, hybrid land use, and transit-oriented development.[25] Sustainability emphasizes social equity, economic growth, environmental protection, and urban development in a sustainable, green, liveable, and compact city. Since the early 2000s, climate change has become an important issue for the global community. It was incorporated into the political agenda, and

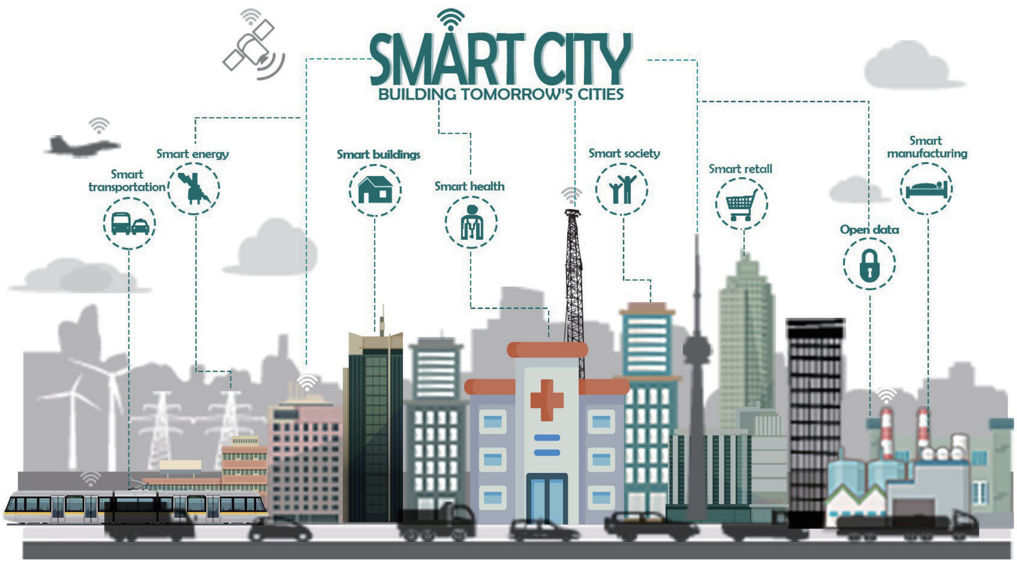

Fig. 1. (Color online) Application of sensors in smart cities.

the efficient use of energy and resources has been at the center of discussions on sustainable development. Such discussions have brought the term ‘green’. The concept of the green city is a response to decentralized development in cities for a more sustainable, less fragmented, and more liveable environment.[26] Green urban planning implies the construction of livable ecological cities based on “people-centered” and “protection of natural resources”. In it, nature is regarded as the source of innovation and protection.[27] Various definitions and concepts for the green city address issues related to sustainability theory, health, greenness, resilience, and equity.[28,29] The concepts of green and smart cities have much in common in terms of their origins and mutual impact on progress.[30] Scientists have cooperated to develop the concepts of green and smart cities on the basis of their common purposes. Smart cities require the optimization of urban management to facilitate people’s daily lives through continuous development, in which ICT provides technical support. The green smart city requires green ecology and the deepening of sustainable development.

The Shanghai Pudong Smart City Development Research Institute proposed in 2012 a smart city indicator system that includes five dimensions, namely, smart infrastructure, public governance and services, economic development, social security, and education.[31] The China Wisdom Engineering Association developed in 2011 an index system for smart city development to measure the degree of citizen’s happiness, governance, and social responsibility. A large number of indicators were included at different levels of the proposed systems. The Centre for Software and Integrated Circuit Promotion of China’s Ministry of Industry and Information Technology proposed a set of alternative indicators to assess the smartness of cities at three different levels.

However, the limitations of the systems mentioned above are still evident in the effectiveness of the evaluation of green smart cities in China as the systems do not reflect the level of green smart cities, and their results have limits to be used for the development of smart cities. In addition, unique and inherent factors of China are not considered so the previous systems cannot be applied to Chinese smart cities as necessary data are lacking. Therefore, it is required to construct a new evaluation system that is more applicable to Chinese smart cities.

3. Methodology

3.1 Indicators for evaluation

We defined six evaluation constructs, namely, smart infrastructure, economy, services, governance, innovation, and green production and living, each of which corresponds to four evaluation indicators based on the literature review (Table 1). The developed evaluation system in this study had three layers, namely, the target, construct, and indicator layers, in which each indicator was coded as shown in Table 1.

Table 1
Green smart city evaluation indicator system.

Target layer	Construct layer	Indicator layer	Original Code
Green Smart City	Smart Infrastructure	Mobile Phones	OC_1
		Artificial Intelligence Network	OC_2
		Outlet Bandwidth	OC_3
		Data Centre	OC_4
	Smart Economy	Interactive Design	OC_5
		Software Development	OC_6
		Digital Applications	OC_7
		Capacity	OC_8
	Smart Services	Healthcare	OC_9
		Public Transportation	OC_{10}
		Smart Education	OC_{11}
		Employment Information	OC_{12}
	Smart Governance	Data Development	OC_{13}
		Public Safety	OC_{14}
		Public Engagement	OC_{15}
		Sustainability	OC_{16}
	Smart Innovation	University Strengths	OC_{17}
		Research and Development	OC_{18}
		Innovation and Entrepreneurship	OC_{19}
		Talent Capacity	OC_{20}
	Green Production and Life	Resource Utilization	OC_{21}
		Green Transport	OC_{22}
		Ecological Environment	OC_{23}
		Water Environment	OC_{24}

3.2. Shanghai and Taipei

Shanghai is located in the eastern part of China at the mouth of the Yangtze River. It is bordered by the East China Sea in the east, Hangzhou Bay in the south, Jiangsu and Zhejiang in the west, and the Yangtze River in the north. The city has 16 districts with a total area of 6340.5 km^2. Shanghai represents the advanced Chinese economy and is a leading smart green city. Taipei is located in the Taipei Basin in the northern part of Taiwan Island. It is bordered by the Danshui River and its tributary Xindian River in the west, Nangang in the east, the hilly area south of Muji in the south, and the south foothill of Datun Mountain in the north. It consists of 12 districts, covering an area of 271.8 km^2 (Fig. 2). The Taipei City Government has developed it as a smart city and has won international recognition. Since 2006, it has been recognized as the best "ICF Global Smart City". The Global Smart City Index was developed by the International Institute for Management Development and the Singapore University of Technology and Design. They surveyed 15000 people in 118 cities around the world to demonstrate how technology addressed health, safety, socialization, and working environment. In the 2021 Global Smart City Index, Taipei was ranked 4th in the world and 2nd in Asia, while Shanghai was ranked 71st. According to the "Top 50 Smart City Governments 2021" by the Singapore-based Eden Strategy

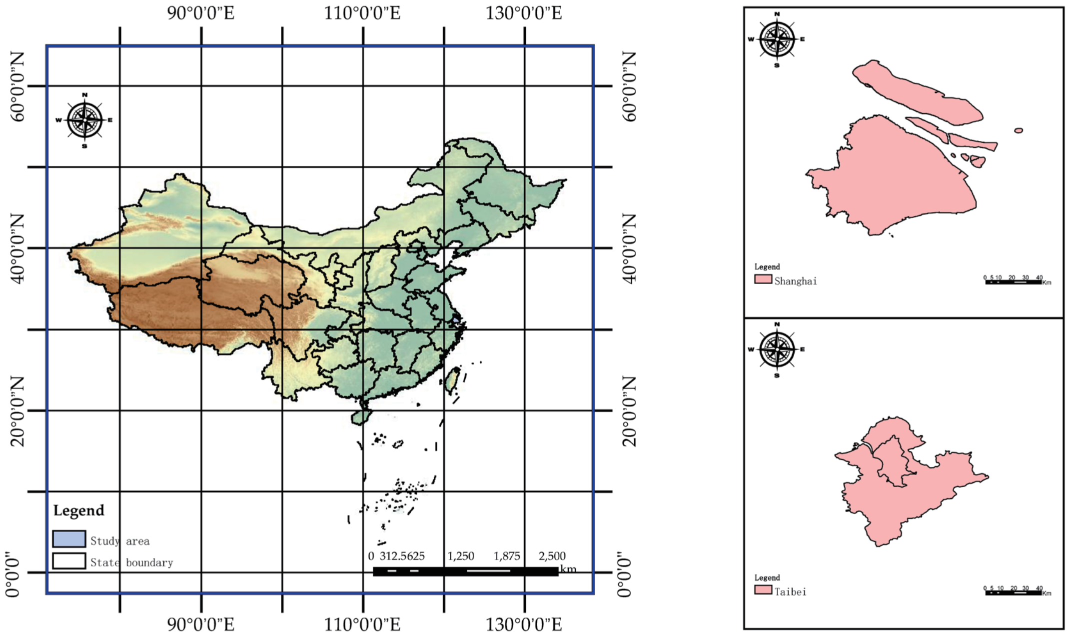

Fig. 2. (Color online) Locations of Shanghai and Taipei.

Institute, Shanghai and Taipei were ranked 8th and 19th among 235 cities, respectively. Its criteria included vision, leadership, budget, financial incentives, support programs, talent readiness, people, innovation ecosystems, smart policies, track record, and rank.

3.3 Fuzzy theory

The concept of fuzzy sets was introduced by Zadeh for the automatic control of uncertainty.(32) Ishikawa *et al.* developed algorithms for two problems and compared the results with those obtained by the Delphi method to obtain feasible results.(33) The fuzzy Delphi method identifies two types of affiliation functions, *i.e.*, “highly reachable” and “highly unreachable” periods. By the maximum–minimum fuzzy Delphi method and the new Delphi method with fuzzy integration, new methods have been proposed to be more effective and applicable. The fuzzy Delphi method effectively determines the indicators for mixed criteria decision-making (MCDM) based on experts’ inputs.(34–36) To integrate fuzzy mathematics into the Delphi method, we used fuzzy hierarchical analysis.

The process of the maximum–minimum projection method of the fuzzy Delphi method is summarized as follows.

Step 1: The cumulative number of times function $F_1(x)$ is established to obtain the maximum value of the degree of agreement and the cumulative number of times function $F_2(x)$ for the minimum value of the degree of agreement.

Step 2: The 1st quartile, median, and 3rd quartile of $F_I(x)$ (C_1, M_1, and D_1) and $F_2(x)$ (C_2, M_2, and D_2) are calculated in trigonometrics. Then, the most and least probable time attainment functions are obtained by concatenating (C_1, M_1, D_1) and (C_2, M_2, D_2). The two affiliation functions with the triangular fuzzy number of overlapping parts (C_1, D_2, M) are defined as the grey zone whose intersection of the point X^* is shown in Fig. 3.

Step 3: The predicted value X^* is obtained using (C_1, M_1, D_1) and (C_2, M_2, D_2). After the predicted value (M_i) of each assessment factor (A_i) is counted, the required assessment factors are screened by defining the threshold value (S).

3.4 Fuzzy Delphi method

The Delphi method was initiated and implemented in the 1950s. The method is characterized by anonymity, feedback, and statistics. Experts are involved in the solicitation of opinions and feedback until a consensus is reached. The Delphi method is a back-to-back approach with each expert's independent judgment. It gets rid of subjective differences caused by different opinions, experiences, and perceptions of experts.(37) In the Delphi method, experts with professional knowledge and experience are invited to define indicators.(38) Experts are fed with as much information as possible to seek consensus in multiple rounds of feedback.(39) The fuzzy Delphi method was developed on the basis of the Delphi method and the fuzzy theory to overcome the difficulties in the conventional Delphi method. The fuzzy Delphi method can deal with semantic ambiguity by retaining more expert information.(33) It combines the prediction or trends of experts' feedback that is presented with fuzzy numbers using a cumulative frequency

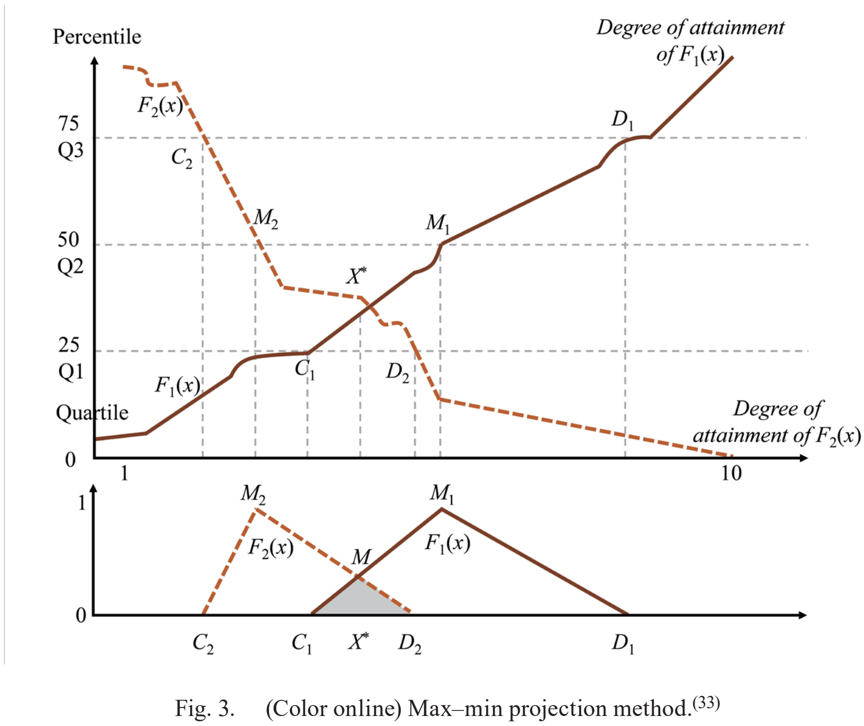

Fig. 3. (Color online) Max–min projection method.(33)

distribution function and the intersection of the fuzzy numbers. The maximum-to-minimum range is set through fuzzy synthesis, transforming the subjective opinions of experts into quasi-objective data.[40]

In this study, the six assessment constructs and 24 indicators were defined through the literature review and the questionnaire survey for 11 experts. The defuzzified indicators were converted into fuzzy evaluation scores as shown in Table 2, and then the fuzzy scores were calculated. The conversion of the fuzzy number into the best fuzzy number (*BNP*) was calculated as

$$BNP = \left[\left(U_{\tilde{w}_i} - L_{\tilde{w}_i}\right) + \left(M_{\tilde{w}_i} - L_{\tilde{w}_i}\right)\right] \div 3 + L_{\tilde{w}_i}, \ \forall i, \tag{1}$$

where i denotes the indicator code, $L_{\tilde{w}_i}$ is the average of the low rating given to the indicator weight by the expert group, $M_{\tilde{w}_i}$ is the average of the medium rating given to the indicator weight by the expert group, and $U_{\tilde{w}_i}$ is the average of the high rating given to the indicator weight by the expert group.

The fuzzy comparison matrix score table was calculated according to Eq. (1). The indicators and the values of each term in Eq. (1) are shown in Table 3. After multiple rounds of questionnaire

Table 2
Defuzzification results.

Construct layer	Indicator layer	Overall value	*LRi*	*MRi*	*URi*	*BNP*	Rank	Overall rank
Smart Infrastructure	Mobile Phones	4.27	6.27	7.27	8.09	7.21	4	14
	Artificial Intelligence Network	4.27	6.36	7.27	8.18	7.27	3	12
	Outlet Bandwidth	4.36	6.64	7.64	8.18	7.49	2	9
	Data Centre	4.73	7.18	8.09	8.55	7.94	1	2
Smart Economy	Interactive Design	4.00	6.00	7.00	7.82	6.94	2	18
	Software Development	3.82	5.27	6.55	7.36	6.39	3	21
	Digital Applications	4.36	6.45	7.27	8.18	7.30	1	11
	Capacity	3.64	5.09	6.18	7.09	6.12	4	22
Smart Services	Healthcare	4.36	6.64	7.64	8.27	7.52	2	7
	Public Transportation	4.73	7.09	8.00	8.73	7.94	1	3
	Smart Education	4.18	6.27	7.27	8.09	7.21	3	15
	Employment Information	3.64	4.82	6.00	7.00	5.94	4	23
Smart Governance	Data Development	4.27	6.36	7.36	8.09	7.27	2	13
	Public Safety	4.18	6.09	7.18	7.82	7.03	3	17
	Public Engagement	4.18	5.91	7.00	7.91	6.94	4	19
	Sustainability	4.82	7.36	8.27	8.82	8.15	1	1
Smart Innovation	University Strengths	3.55	4.82	5.91	6.91	5.88	4	24
	Research and Development	4.18	5.82	6.91	7.82	6.85	3	20
	Innovation and Entrepreneurship	4.55	6.82	7.73	8.55	7.70	2	6
	Talent Capacity	4.64	6.91	7.91	8.64	7.82	1	4
Green Production and Life	Resource Utilization	4.18	6.27	7.27	7.91	7.15	4	16
	Green Transport	4.45	6.64	7.55	8.36	7.52	2	8
	Ecological Environment	4.64	7.00	7.91	8.55	7.82	1	5
	Water Environment	4.36	6.55	7.45	8.18	7.39	3	10

surveys and data processing, we obtained a list of evaluation indicators after defuzzification. In the smart infrastructure, the mobile phone indicator was ranked 4th, and the experts believed that mobile phones were popular as a "basic configuration". The indicators of the smart economy generally showed lower scores so they were deleted in the following analysis. Public transportation was combined with green transportation in green production and life. Public safety and public engagement were ranked 3rd and 4th, respectively, so they were included in public engagement. The strength of universities was ranked 4th in the smart innovation. The experts believed that the content of research and development and university strength partially overlapped so they retained research and development but deleted university strength. In the green production and life dimension, resource utilization was duplicated with the sustainability in the smart governance so resource utilization was deleted.

After fuzzy processing, the previous evaluation system was revised with 15 indicators as shown in Table 3.

3.5 Fuzzy analytical hierarchical process (FAHP)

The analytical hierarchical process (AHP) is useful and important for MCDM.[41,42] *W* used FAHP to scrutinize decision-making. FAHP is designed to analyze and select alternatives in decision-making. It integrates the principles of hierarchical analysis and fuzzy set theory. The fuzzy approach allows decision-makers to incorporate quantitative and qualitative data to allow for more confident judgment compared with that based on fixed values.[43] This has made the FAHP one of the most popular MCDM methods, which has been widely used in research areas related to urban development issues. The FAHP method decomposes, groups, and arranges problems into a hierarchy and prioritizes criteria by comparing them in an identified measurement scale. In addition, experts' opinions are used as input to create subjective elements

Table 3
Revised evaluation system after fuzzy processing.

Target layer	Construct layer	Indicator layer	New code
Green Smart City	Smart Infrastructure	Artificial Intelligence Network	NC_1
		Outlet Broadband	NC_2
		Data Centre	NC_3
	Smart Services	Healthcare	NC_4
		Smart Education	NC_5
		Employment Information	NC_6
	Smart Governance	Data Development	NC_7
		Public Engagement	NC_8
		Sustainability	NC_9
	Smart Innovation	Research and Development	NC_{10}
		Innovation and Entrepreneurship	NC_{11}
		Talent Capacity	NC_{12}
	Green Production and Life	Green Transportation	NC_{13}
		Ecological Environment	NC_{14}
		Water Environment	NC_{15}

in the retrieval decision. In FAHP, data validity is considered a persistence constraint.[41] Although FAHP is similar to AHP, FAHP replaces possible uncertainties in the data based on fuzzy logic theory. FAHP converts the AHP scale into a fuzzy triangle scale for evaluation. The measurement results can refine the interval of the evaluation scale. AHP has been applied to complex decision-making.[44] Its computational procedure is described as follows.

(1) Analyzing a problem and creating a hierarchical structure

A problem to solve is analyzed to determine evaluation factors. The evaluation system was established on the basis of questionnaire survey results, expert interviews, and a literature review to establish a hierarchy in this study. The evaluation system of the smart city was composed of the target, construct, and indicator layers.

(2) Comparing two by two to create a fuzzy matrix

A pairwise comparison of indicators was conducted to determine the weight of each indicator. A comparison scale of 1 and 9 was used[45,46] as shown in Table 4.

The judgment matrix was created on the basis of pairwise comparisons of indicators. If the number of indicators is n, then $n(n-1)/2$ comparisons should be conducted. In the pairwise comparison, the characteristic of inverse exists. When the ratio of indicator i to j is $\tilde{a}_{ij}$, the ratio of j to i is $1/\tilde{a}_{ij}$. Similarly, the lower triangular portion of the pairwise comparison matrix A is the inverse of the triangular portion.

$$A=\left[\tilde{a}_{ij}\right]=\begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \dfrac{1}{\tilde{a}_{12}} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \dfrac{1}{\tilde{a}_{1n}} & \dfrac{1}{\tilde{a}_{2n}} & \cdots & 1 \end{bmatrix} \quad (2)$$

The geometric mean based on the assessment of expert questionnaires and evaluation criteria was used to integrate the comparative values of experts for each target.

$$\tilde{a}_{ij}=\left(\tilde{a}_{ij}^{1}\otimes\tilde{a}_{ij}^{2}\otimes\cdots\otimes\tilde{a}_{ij}^{k}\right)^{\frac{1}{k}} \quad (3)$$

Table 4
Fuzzy variables for evaluation system of smart city.

Fuzzy number	Semantic value	Fuzzy number endpoint
1	Equally important	(1,1,3)
2	Between equally important and slightly important	(1,2,4)
3	Slightly important	(1,3,5)
4	Between slightly important and fairly important	(2,4,6)
5	Fairly important	(3,5,7)
6	Between fairly important and clearly important	(4,6,8)
7	Significantly important	(5,7,9)
8	Between clearly important and absolutely important	(6,8,9)
9	Absolutely important	(7,9,9)

Here, $\tilde{a}_{ij}^{k}$ is the fuzzy number of row *i* and column *j* in the fuzzy matrix of the *k*-th expert, and a_{ij} is the fuzzy number of row *i* and column *j* in the fuzzy matrix of the group of experts after decision-making.

(3) Calculating fuzzy weights

The weight of an indicator is an eigenvector. A triangular fuzzy positive inverse value matrix was used to calculate weights using the column vector geometric mean normalization method.

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in}\right)^{\frac{1}{n}} \tag{4}$$

$$\tilde{w} = \tilde{r} \otimes \left(\tilde{r} \otimes \tilde{r} \otimes \tilde{r} \cdots \otimes \tilde{r}\right)^{-1} \tag{5}$$

Here, $\tilde{a}_{ij}$ is the number of fuzzy numbers in the *j*-th column of the *i*th row in the fuzzy matrix, $\tilde{r}_i$ is the average of the column vector of fuzzy numbers, and $\tilde{W}$ is the fuzzy weight of the *i*-th factor.

3.6 Consistency test

(1) Consistency indicator (*CI*)

In the matrices, the larger the *n*, the larger the *CI*. To determine whether the matrix has consistency, *CI* and the random index (*RI*) are calculated. *RI* is obtained by using the average random method in which *CI* is calculated and averaged[(45)] (Table 5).

(2) Consistency ratio (*CR*)

When $CR < 0.1$, the matrix has consistency; otherwise, the matrix must be readjusted.

3.7 Defuzzification

On the basis of the calculated fuzzy numbers, the triangular fuzzy number of each indicator was obtained. Since the fuzzy number was imprecise, anti-fuzzification had to be executed by fuzzy sorting.[(47)] The center of gravity method was used to solve this problem to find the centroid of the triangular area to represent the value of the fuzzy number.

3.8 Weight

The value obtained from the selected value *E* for constructs was multiplied by the weight *W* to obtain the total rating (*R*) of the structure [Eq. (6)]. The results are presented in Table 6.

Table 5
Coherence indicator of RI.

Number of indicators	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.90	1.12	1.24	1.36	1.41	1.46	1.49	1.52	1.54

Table 6
Weights of indicators in green smart city evaluation system.

Target layer	Construct layer	Weight	Indicator layer	Weight
Green Smart City	Smart Infrastructure	0.366	Artificial Intelligence Network	0.120
			Outlet Broadband	0.097
			Data Centre	0.148
	Smart Services	0.138	Healthcare	0.073
			Smart Education	0.044
			Employment Information	0.022
	Smart Governance	0.104	Data Development	0.037
			Public Engagement	0.028
			Sustainability	0.039
	Smart Innovation	0.128	Research and Development	0.069
			Innovation and Entrepreneurship	0.028
			Talent Capacity	0.031
	Green Production and Living	0.264	Green Transportation	0.057
			Ecological Environment	0.123
			Water Environment	0.084

$$R = W \times E \tag{6}$$

Smart infrastructure had the highest weight of 0.366, indicating that it was the most important in the green smart city. The weight of green production and life was 0.264, and those of smart services and smart innovation were 0.128 and 0.138, respectively. The weight of smart governance was 0.104. Among the indicators, data center (0.148) was the most important, followed by ecological environment (0.123), artificial intelligence network (0.121), outlet broadband (0.097), water environment (0.085), healthcare (0.073), research and development (0.069), green transportation (0.057), smart education (0.044), sustainability (0.039), data development (0.037), talent capacity (0.031), innovation and entrepreneurship (0.028), public engagement (0.028), and employment information (0.022). Data center and ecological environment were important indicators in evaluating the green smart city.

4. Results and Discussion

In this study, 188 questionnaires were collected through interviews with people traveling between Shanghai and Taipei. After obtaining the evaluation of respondents for Shanghai and Taipei as green smart cities, the scores were multiplied by the weights of each indicator. The final scores for the respondent's evaluation of Shanghai and Taipei are presented in Table 7. The average scores of Shanghai and Taipei were 79.71 and 72.67, respectively. Shanghai scored higher than Taipei in all indicators of smart infrastructure, smart governance, and smart innovation. In smart services, Taipei scored higher than Shanghai in healthcare and smart education, while Shanghai scored higher than Taipei in employment information. In green production and life, Taipei scored higher than Shanghai in green transportation. In green production and life, Taipei scored higher than Shanghai in green transportation, while Shanghai scored higher than Taipei in ecological environment and water environment.

Table 7
Evaluation results of respondents for Shanghai and Taipei as green smart cities by indicators.

Construct	Indicator	Shanghai	Taipei	Combined weights	Score of Shanghai	Score of Taipei
Smart Infrastructure	Artificial Intelligence Network	77.92	70.83	0.120	9.43	8.57
	Outlet Broadband	78.11	70.54	0.097	7.58	6.84
	Data Centre	80.34	71.24	0.148	11.89	10.54
Smart Services	Healthcare	78.91	80.33	0.073	5.76	5.86
	Smart Education	77.63	80.16	0.044	3.42	3.53
	Employment Information	80.20	70.13	0.022	1.76	1.54
Smart Governance	Data Development	81.23	71.32	0.037	3.01	2.64
	Public Engagement	79.71	71.67	0.028	2.23	2.01
	Sustainability	79.95	70.75	0.039	3.12	2.76
Smart Innovation	Research and Development	81.61	70.73	0.069	5.63	4.88
	Innovation and Entrepreneurship	81.85	69.64	0.028	2.29	1.95
	Talent Capacity	83.85	70.47	0.031	2.60	2.18
Green Production and Life	Green Transportation	76.68	79.23	0.057	4.37	4.52
	Ecological Environment	80.58	72.21	0.123	9.83	8.81
	Water Environment	79.94	71.00	0.085	6.79	6.04

4.1 Smart infrastructure

The smart infrastructure contained artificial intelligence network, export broadband, and data center as indicators, and was the most important in the evaluation of the green smart city. The smart infrastructure significantly impacts the green smart city. The results showed that Shanghai scored higher than Taipei in artificial intelligence network, outlet broadband, and data center, indicating that Shanghai City had advantages in the smart infrastructure.

4.2 Smart services

The smart service of the green smart city is provided for all aspects of citizens' lives. The levels of healthcare, smart education, and employment information reflect the quality of smart services. Taipei scored higher in healthcare and smart education than Shanghai, while Shanghai scored higher in employment information. Healthcare and smart education were weighted more in the evaluation system.

4.3 Smart governance

Smart governance serves to meet the requirements of the modernization of nationwide governance and is one of the intrinsic drivers and goals of smart city construction. The governance of a green smart city is executed for sustainability, productivity, innovation, reducing energy consumption, and mitigating the negative impacts of urban production on the environment. Shanghai scored higher than Taipei in data development, public engagement, and sustainability, indicating that Shanghai had a smarter governance system than Taipei.

4.4 Smart innovation

Research and development and talent capacity are the sources of continuous innovation. The results showed that Shanghai scored higher than Taipei in the two indicators, indicating that Shanghai had advantages in smart innovation over Taipei.

4.5 Greening production and life

In a green smart city, green and low-carbon policies are important to sustain a sound ecology and a clean environment. The average weight of green transportation, ecological environment, and water environment in the green production and life was 0.123, being ranked second. This indicated that the ecological environment was important in the development of green smart cities. For green transportation, Taipei scored higher than Shanghai, indicating that Taipei City had a better public transportation system. The ecological environment and water environment had higher weights and were advantages of Shanghai.

5. Conclusions

The construction of green smart cities impacts contemporary society significantly, but at the same time, social resources have not yet been effectively integrated and should be planned and managed effectively. The rapid development of industry is always ahead of policy and decision-making, which requires harmonious cooperation in government to invest in and support green smart cities. Therefore, it is necessary to improve the level of green smart city construction through accurate evaluation. Considering the present development of green smart cities, the evaluation system of the green smart city with five targets and fifteen indicators was developed in this study. The targets included smart infrastructure, smart services, smart governance, smart innovation, and green production and life. To establish the system, data were collected from Shanghai and Taipei through expert feedback and questionnaire surveys, and processed using FAHP; 11 experts and 188 respondents were involved in the survey and interviews to define the targets, construct, and indicators of the evaluation system. The results indicated that the smart infrastructure was the most significant in the development level of green smart cities, followed by green production and life. The least impact was found for smart governance. The developed system was applied to the evaluation of Shanghai and Taipei as green smart cities. The results showed that Shanghai scored higher than Taipei in artificial intelligence network, outlet broadband, data center, employment information, smart governance systems, research and development, talent capacity, ecological environment, and water environment. Taipei presented better healthcare, smart education, and green transportation.

With the rapid development of IoT technology, the construction of information infrastructure is required for the construction of green smart cities. Green smart cities must continue improving information infrastructure and developing related technologies. At the same time, green and sustainable development must be sustained to create a suitable environment for citizens with efficient and timely services. Therefore, to develop better green smart cities, information infrastructure should be developed continuously. Green smart cities should empower the economy and society but have neglected the ecological environment that is closely related to the lives of citizens. In the low-carbon and recycling development, “carbon peak” and “carbon neutral” strategies should be established in green smart cities by expanding green space, strengthening ecological governance, and utilizing information technology. Interconnected infrastructure is also required to improve the level of smart governance.

The level of green smart city development and management varies considerably from city to city, and the government should put efforts to lead cities to greener smart development and lowering barriers between cities. Cities with less development must create a social environment and a regional collaborative system with greener smart cities. More developed green smart cities must disseminate their capabilities to accelerate collaboration and co-development by building a new model of synergistic development. Cities should collaborate for the inter-regional exchange of talents and human resources. It is necessary to establish a government-led, market-oriented, and multi-party participation for sustainable urban development. More funds are required for the establishment of the smart infrastructure of green smart cities to provide clean energy, environmental governance, and green transportation.

References

1 S. Pandya, G. Srivastava, R. Jhaveri, M. R. Babu, S. Bhattacharya, P. K. R. Maddikunta, S. Mastorakis, M. J. Piran, and T. R. Gadekallu: Sustain. Energy Technol. Assess. **55** (2023) 102987. https://doi.org/10.1016/j.seta.2022.102987
2 S. Graham: Cities **14** (1997) 21. https://doi.org/10.1016/S0264-2751(37)00037-8
3 W. J. Mitchell: City of Bits: Space, Place, and the Infobahn (The MIT Press, Cambridge, MA, 1995).
4 D. van den Buuse and A. Kolk: Technol. Forecasting Social Change **142** (2019) 220. https://doi.org/10.1016/j.techfore.2018.07.029
5 C. Harrison, B. Eckman, R. Hamilton, P. Hartswick, J. Kalagnanam, J. Paraszczak, and P. Williams: IBM J. Res. Dev. **54** (2010) 1. https://doi.org/10.1147/JRD.2010.2048257
6 N. Komninos: Intelligent Cities: Innovation, Knowledge Systems and Digital Spaces (Routledge, London, 2002).
7 Helping Cios Understand "Smart City" Initiatives: https://www.forrester.com/report/Helping-CIOs-Understand-SmartCity-Initiatives/RES55590 (accessed January 2024).
8 R. Giffinger, H. Gudrun, Gudrun, and G. Haindlmaier: ACE: Architecture, City and Environment **4** (2010) 7. https://doi.org/10.5821/ace.v4i12.2483
9 R. Florida: City Community **2** (2003) 3. https://doi.org/10.1111/1540-6040.00034
10 S. Alawadhi, A. Aldama-Nalda, H. Chourabi, J. R. Gil-Garcia, S. Leung, S. Mellouli, T. Nam, T. A. Pardo, H. J. Scholl, and S. Walker: Proc. Electronic Government (Springer, Berlin Heidelberg, 2012) pp. 40–53.
11 T. Yigitcanlar, M. Kamruzzaman, L. Buys, G. Ioppolo, J. Sabatini-Marques, E. M. da Costa, and J. J. Yun: Cities **81** (2018) 145. https://doi.org/10.1016/j.cities.2018.04.003
12 Y. Alshamaila, S. Papagiannidis, H. Alsawalqah, and I. Aljarah: Int. J. Disaster Risk Reduct. **85** (2023) 103521. https://doi.org/10.1016/j.ijdrr.2023.103521
13 J. K. Park and K. W. Lee: Sens. Mater. **32** (2020) 3853. https://doi.org/10.18494/SAM.2020.2911
14 Z. Wu: Intelligent City Evaluation Systems in West: In Intelligent City Evaluation System (Springer, Berlin Heidelberg, 2018) pp. 87–99.
15 N. Esmaeilpour Zanjani, M. Moulaii, F. Kharvari, and G. Shahhosseini: Int. J. Urban Management and Energy Sustainability **1** (2019) 15. https://doi.org/10.22034/ijumes.2017.06.15.012
16 V. Roblek: 5 - the Smart City of Vienna: In Smart City Emergence (Elsevier, Amsterdam, 2019) pp. 105–127.
17 F. Roussel and F. Alexandre: Landscape Urban Plann. **210** (2021) 104062. https://doi.org/10.1016/j.landurbplan.2021.104062
18 B. Fernandez Agueda: Plan. Perspect. **32** (2017) 1. https://doi.org/10.1080/02665433.2016.1185960
19 Q. Hu and Y. Zheng: J. Urban Affairs **43** (2021) 504. https://doi.org/10.1080/07352166.2019.1694413

20 T. Song, J. Cai, T. Chahine, and L. Li: J. Knowl. Econ. **12** (2021) 1. https://doi.org/10.1007/s13132-017-0493-x
21 J. Yan, J. Liu, and F.-M. Tseng: Technol. Forecast. Soc. **153** (2020) 119371. https://doi.org/10.1016/j.techfore.2018.07.009
22 T. Yao, Z. Huang, and W. Zhao: Sustain. Cities Soc. **60** (2020) 102008. https://doi.org/10.1016/j.scs.2019.102008
23 D. Meadows: The Limits to Growth (Potomac Associates – Universe Books, London, 1972).
24 WCED: Our Common Future: http://www.ask-force.org/web/Sustainability/Brundtland-Our-Common-Future-1987-2008.pdf (accessed January, 2024).
25 J. Blanco and H. Kheradmand. Climate Change (IntechOpen, Rijeka, 2011).
26 D. Wang: From Green Building to Green City: The Practice in Jiangsu Province, China: In Chinese Urban Planning and Construction: From Historical Wisdom to Modern Miracles (Springer, Berlin Heidelberg, 2021), pp. 225–241.
27 Green Cities Declaration: https://www.fundacionciudad.org.ar/pdf/SanFranciscoAccords2005.pdf (accessed January, 2024).
28 G. Hariem Brundtland: Environ. Policy Law **14** (1985) 26. https://doi.org/10.1016/S0378-777X(85)80040-8
29 B. Purvis, Y. Mao, and D. Robinson: Sustain. Sci. **14** (2019) 681. https://doi.org/10.1007/s11625-018-0627-5
30 C.-S. Chan and L. M. Marafa: Sustainability **10** (2018) 107. https://doi.org/10.3390/su10010107
31 L. Shen, Z. Huang, S. W. Wong, S. Liao, and Y. Lou: J. Cleaner Prod. **200** (2018) 667. https://doi.org/10.1016/j.jclepro.2018.07.281
32 L. A. Zadeh: Inform. Control **8** (1965) 338. https://doi.org/10.1016/S0019-9958(65)90241-X
33 A. Ishikawa, M. Amagasa, T. Shiga, G. Tomizawa, R. Tatsuta, and H. Mieno: Fuzzy Sets Syst. **55** (1993) 241. https://doi.org/10.1016/0165-0114(93)90251-C
34 M. Danacı and U. Yıldırım: Ocean Eng. **278** (2023) 114371. https://doi.org/10.1016/j.oceaneng.2023.114371
35 M.-L. Tseng, S.-X. Li, C.-W. R. Lin, and A. S. F. Chiu: J. Ind. Prod. Eng. **40** (2023) 35. https://doi.org/10.1080/21681015.2022.2070934
36 E. Marlina, A. N. Hidayanto, and B. Purwandari: Libr. Inform. Sci. Res. **44** (2022) 101141. https://doi.org/10.1016/j.lisr.2022.101141
37 V. Mahajan: J. Marketing Res. **13** (1976) 317. https://doi.org/10.2307/3150755
38 L. C. Dias, C. H. Antunes, G. Dantas, N. de Castro, and L. Zamboni: Omega **76** (2018) 100. https://doi.org/10.1016/j.omega.2017.04.004
39 C. J. Lin, T. T. Belis, D. Caesaron, B. C. Jiang, and T. C. Kuo: Sustainability **12** (2020) 6378. https://doi.org/10.3390/su12166378
40 A. F. Roldán López de Hierro, M. Sánchez, D. Puente-Fernández, R. Montoya-Juárez, and C. Roldán: Mathematics **9** (2021) 2323. https://doi.org/10.3390/math9182323
41 T. L. Saaty: Eur. J. Oper. Res. **48** (1990) 9. https://doi.org/10.1016/0377-2217(90)90057-I
42 W.-L. Hsu, K. Lan, Z. Dong, H.-L. Liu, S. Y.-R. Yang, and B.-W. Jeang: Sens. Mater. **35** (2023) 2783. https://doi.org/10.18494/SAM4457
43 S. Perçin: J. Enterp. Inf. Manag. **21** (2008) 263. https://doi.org/10.1108/17410390810866637
44 J. J. Buckley: Fuzzy Sets Syst. **17** (1985) 233. https://doi.org/10.1016/0165-0114(85)90090-9
45 T. Saaty: Int. J. Serv. Sci. **1** (2008) 83. https://doi.org/10.1504/IJSSCI.2008.017590
46 R. W. Saaty: Math. Modell. **9** (1987) 161. https://doi.org/10.1016/0270-0255(87)90473-8
47 W.-L. Hsu, F.-M. Tsai, and Y.-C. Shiau: Microsyst. Technol. **27** (2021) 1051. https://doi.org/10.1007/s00542-018-4023-y