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# How different can smart cities be? A typology of smart cities in China

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ABSTRACT

China, renowned for being one of the world's largest smart city testing fields, has witnessed the emergence of numerous smart cities. Existing publications highlight the diversity in smart city development, wherein cities with different contexts and institutional factors exhibit distinct characteristics. To delve deeper into this subject, we employed a mixed methods approach to classify 49 Chinese smart cities and subsequently developed a typology for Chinese smart cities in this study. Our methodology involved three steps. Initially, we devised a classification framework based on the input-throughput-output model and conducted content analysis to identify the characteristics of the 49 cities. Subsequently, we utilized a combination of principal component analysis (PCA) and K-means clustering analysis to categorize these cases. Finally, we formulated a typology consisting of five types of Chinese smart cities: knowledge-technocratic smart cities, holistic smart cities, green smart cities, equipment-technocratic smart cities, and emerging smart cities. The findings reveal that different smart city types are characterized by distinct features and priorities in input, throughput, and output. The development of smart cities should comprehensively consider and respect the local urban contexts and the challenges they present. The insights from this study hold relevance for both policymakers and academic researchers.

## 1. Introduction

The number of cities worldwide implementing smart city initiatives in various forms and sizes is on the rise, leading to a rapid expansion of research in this area (Mora et al., 2017). Extensive literature on the concept of smart cities has explored its boundaries, models, and implications. Numerous studies have revealed the diversity of smart city development on an international scale (De Jong et al., 2015; Dirks et al., 2010; Lim et al., 2019; Noori et al., 2020; Yigitcanlar et al., 2018). Neirotti et al. (2014) conducted an empirical analysis of 70 cities worldwide that claimed to be smart city projects and found that the evolution patterns of smart cities are closely linked to contextual factors. Smart city programs across different economic, institutional, cultural, and geographical contexts have exhibited distinct characteristics and patterns. Additionally, Noori et al. (2020) systematically compared design choices and features of four international smart city programs in Amsterdam, Barcelona, Dubai, and Masdar. They observed that smart city development in Dubai and Masdar is driven by state and service-oriented approaches (Aristocratic), as well as investment and technology-driven strategies (Technocratic), respectively. In contrast, Amsterdam and Barcelona place more emphasis on horizontal coordination compared to Dubai and Masdar (Noori et al., 2020). Moreover, Raven et al. (2019) compared emerging institutional arrangements across three international smart city programs in Amsterdam, Hamburg, and Ningbo and found that Ningbo follows a more conventional managerial model for smart city development compared to Hamburg and Amsterdam.

The aforementioned studies highlight the diversity of smart city development by comparing smart city programs across different countries. However, it is important to note that within a large country, contextual factors can result in significant differences in smart city programs throughout the country. Similarly, within the same country, variations in the characteristics and functions of smart cities across different localities can also be attributed to contextual factors (Angelidou, 2014; Mora et al., 2017; Neirotti et al., 2014; Wang et al., 2022). For instance, in a case study focusing on the Korean experience, Lim et al. (2023) explored the distinct characteristics and governance models of various smart cities in South Korea. Furthermore, Duygan et al.

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(2022) examined the spatial and socio-economic configurations of 22 Swiss smart cities to elucidate the differences in smartness among cities within the same country.

Although numerous studies have explored the characteristics and evolution patterns of smart cities in Western and developed countries, there remains a lack of systematic understanding regarding the characteristics and classification of smart cities in Asia. In recent years, several Asian countries, particularly China, have made substantial investments in smart city development. China, serving as one of the world's largest test fields for smart cities, boasts hundreds of smart city pilot projects (Guo et al., 2016). Due to socio-economic, institutional, cultural, and geographical differences, it is anticipated that smart cities in China will exhibit unique and diverse characteristics and patterns compared to other global cases. The varied nature of smart city development necessitates a comprehensive study to unravel the multiple patterns and characteristics of smart cities in China by systematically examining their underlying structure. To address the aforementioned research gap, we have developed a classification system for smart cities in China based on their characteristics in terms of inputs (resource investment), throughputs (management and governance structures), and outputs (smart applications). This study aims to address two main research questions:

1. What are the characteristics of smart cities in China?
2. How can different smart cities in China be classified based on their similarities and differences?

We conducted our research by selecting 49 smart cities in China, which encompass three batches of smart city pilot projects in the country. This comprehensive selection allows for a better understanding of smart cities in China and provides valuable insights into the potential future directions of Chinese smart cities. The selected smart cities represent a mix of developed, relatively less affluent, and underdeveloped cities and regions. The primary scientific contribution of this study lies in achieving a more comprehensive understanding of Chinese smart cities by classifying their characteristics and situating them within the global discourse of smart cities. Following this introduction, the study is organized into six sections. The next section presents the development of a classification framework for Chinese smart cities based on a review of the literature. In the third section, we provide an overview of smart city development in the Chinese context and describe the mixed methods approach employed in our study. The fourth and fifth sections present the results and discussions, respectively. Finally, in the last section, we offer recommendations and concluding thoughts for smart city researchers and policymakers based on the findings of our study.

## 2. Smart cities typologies

### 2.1. Classifications of smart cities

The concept and implementation of smart cities have been in existence for more than two decades, sparking numerous discussions in both academic and industry domains. However, the understanding of smart cities varies among researchers, international organizations, and business professionals due to their different perspectives (De Jong et al., 2015; Mora et al., 2017; Yigitcanlar et al., 2018; Yigitcanlar, Sabatini-Marques, et al., 2019). These differing interpretations and expectations have resulted in cities adopting smart approaches in diverse areas. Put simply, smart cities exhibit distinct characteristics and applications based on their unique urban contexts (Neirotti et al., 2014).

Various scholars have made efforts to classify smart cities based on their diverse characteristics and functions. Batty et al. (2012) identified seven categories of smart city initiatives, each displaying distinct characteristics. These categories include new cities branding themselves as smart cities, older cities undergoing digital transformation, tech parks and technopolis emphasizing advanced technologies, the utilization of ICT to enhance urban services, and new urban intelligence functions, as well as online participation. Angelidou (2014) categorized smart city development strategies from a spatial perspective, considering geographical level, urban development stage, smart city infrastructure, and reference area. Aina (2017) built upon Angelidou's categorization to develop a typology of smart cities in Saudi Arabia, which demonstrated variations in geographical level, urban development stage, and reference area strategies, while showing similarities in smart city infrastructure strategies that combine both hard and soft infrastructure. Perboli and Rosano (2020) created a taxonomic classification of 105 smart city projects in Europe, Canada, and the United States. Their findings highlighted energy as a common objective for smart city projects in these regions, with a focus on reducing $CO_2$ emissions in Europe and energy-related transportation initiatives in Canada and the United States. Moreover, the involvement of the public sector and universities in smart city development was found to be higher in Europe compared to North America.

Quantitative methods have been employed in several studies to develop classifications of smart cities. Praharaj & Han (2019) created a typology of 100 Indian smart cities based on seven thematic domains related to urban development and public services. Their research revealed distinct clusters of cities with varying characteristics. The first cluster consisted of 'edge smart cities' characterized by relatively poor infrastructure and a deficiency in traditional services. The second cluster comprised 'leading cities' that exhibited superior performance in delivering both physical and digital infrastructure. The third cluster consisted of 'moving smart cities' that showed a positive trajectory in smart city development compared to other Indian smart cities. Lastly, the 'reluctant smart cities' were categorized as cities that faced challenges in influencing change in infrastructure delivery and governance processes.

Cantuarias-Villessuzanne et al. (2021) conducted principal component analysis and hierarchical ascending classification on 40 European smart cities, resulting in the identification of three types of European Smart Cities with distinct characteristics. The first cluster included cities like Turin, Nicosia, Rome, and Athens, representing smart cities with emerging smart strategies. These cities exhibited core capabilities in traditional transport modalities and high levels of air pollution, while scoring relatively low in e-citizenship, e-government, e-commerce, and living dimensions. The second cluster consisted of cities with the largest population and income, such as Amsterdam, Dublin, Madrid, and Stockholm. These cities were labeled as technology-oriented smart cities, emphasizing e-commerce, e-citizenship, equipment and infrastructure, and e-government as their core capabilities. The third cluster comprised cities like Vienna, Cologne, Dusseldorf, and Hannover, categorized as sustainable smart cities striving to enhance quality of life and sustainable development. Sarthy and Choudhary (2022) applied the six characteristics of smart cities (smart economy, smart people, smart government, smart mobility, smart environment, and smart living) as metrics in their analysis of 102 cities worldwide. Through principal component analysis and K-means clustering, they identified four clusters. Cluster 1, represented by cities like Paris, exhibited an equitable outlook across all dimensions. Cluster 2, exemplified by cities like Budapest, placed a stronger focus on smart people, potentially at the expense of the smart economy. Cluster 3, represented by cities like Sydney, prioritized improving urban living standards. Finally, cities in Cluster 4, including Turin, placed significant emphasis on the smart environment. Table 1 provides a summary of the typologies and classifications of smart cities developed in empirical research.

The aforementioned studies contributed to identifying characteristics and classifications for smart cities. However, their frameworks have limitations in providing a holistic view. Angelidou (2014) and Aina (2017) focused on spatial perspectives, ignoring socioeconomic and cultural dimensions. Praharaj & Han (2019) emphasized context and infrastructure, neglecting smart city applications. Cantuarias-Villessuzanne et al. (2021) and Sarthy and Choudhary (2022) emphasized

**Table 1**
Smart city typologies and classifications.

| Source | Typologies/ classifications | Frameworks | Cities/ location |
|---|---|---|---|
| Cantuarias-Villessuzanne et al. (2021) | Cluster 1: Cities with emerging smart strategies<br>Cluster 2: Technology-oriented smart cities<br>Cluster 3: Sustainable smart cities | Seven smart dimensions identified by Ismagilova et al. (2019):<br>Smart architecture and technology, Smart citizens, Smart economy, Smart environment, Smart government, Smart living, and Smart mobility | 40 European smart cities |
| Sarthy and Choudhary (2022) | Cluster 1: Cities have an equitable outlook at all aspects of smart city, with greater attention on the smart economy<br>Cluster 2: Cities focus more on smart people while less on smart economy<br>Cluster 3: Cities emphasize smart living<br>Cluster 4: Cities put extra attention on smart environment | Six dimensions of smart cities:<br>Smart economy, Smart people, Smart government, Smart mobility, Smart environment, and Smart living | 102 smart cities worldwide |
| Perboli and Rosano (2020) | A classification of 105 outstanding smart city projects based on the taxonomy structured in three levels of detail | Three dimensions of smart cities:<br>Description, Business model, and Purpose | Europe and North America |
| Aina (2017) | National strategy, local strategy, new cities, existing cities, Hard infrastructure-oriented strategy, Soft infrastructure oriented strategy, Economic sector-based strategy, Geographically-based strategy | Four categories of smart city strategies developed by Angelidou (2014):<br>Urban development stage, Geographical level, Infrastructure, Reference area | Saudi Arabia |
| Praharaj & Han (2019) | Cluster 1: Edge smart cities<br>Cluster 2: Leading smart cities<br>Cluster 3: Moving smart cities<br>Cluster 4: Reluctant smart cities | Seven thematic domains:<br>Demography and social cohesion, Economy and jobs, Education and health, Physical infrastructure, Digital communication, Housing and shelter, Living and lifestyle | 100 Indian smart cities |
| Noori et al. (2021) | Innocratic smart cities, Sociocratic smart cities, Aristocratic smart cities, Technocratic smart cities | The Input-output model of smart city development | Amsterdam, Barcelona, Dubai, Masdar. |

applications but overlooked resource inputs, governance, and management. A more comprehensive and holistic classification is needed to understand smart cities fully (Yigitcanlar et al., 2018).

### 2.2. Smart city models

Numerous smart city models have been proposed to capture the multidimensional nature of smart cities. Chourabi et al. (2012) presented a framework incorporating eight key factors, including management, technology, governance, policy, community, economy, infrastructure, and environment. Meijer and Thaens (2018) developed a sociotechnical framework that explores urban technological innovation from technical, tool, collaborative, and symbolic perspectives. Fernandez-Anez et al. (2018) created a comprehensive model that integrates diverse stakeholders, different dimensions of smart city initiatives, and urban challenges. While these models contribute to conceptualizing smart cities, they have limitations in providing practical guidance for implementation. To address this, Yigitcanlar et al. (2018) developed a multidimensional smart city model emphasizing assets, drivers (policy, technology, community), and desired outcomes. However, it lacks detailed sub-facets necessary for implementation. In response, Noori et al. (2021) proposed an Input-throughput-output (ITO) model that offers a more comprehensive and detailed understanding of smart cities. The ITO model helps policymakers and practitioners conceptualize smart cities and make informed design choices during implementation. It provides support in decision-making and guides the development path of smart cities based on different design choices. By utilizing the ITO model, policymakers can take a sequence of actions aligned with their goals to develop the specific type of smart city they desire.

The ITO model categorizes smart city development into inputs, throughput, and outputs. Inputs encompass the facets of the smart city where goals are formulated and resources are allocated, including human resources, ICT infrastructure, and financial resources. Throughput involves the management and administration of these resources to achieve desired outcomes. Outputs are the deliverables of smart city policies, such as smart applications, representing the goals and reasons for resource investment (Noori et al., 2021). The ITO model provides a systematic framework for understanding smart city development, highlighting the interplay between inputs, throughput, and outputs in achieving objectives.

### 2.3. Classification framework for smart cities in China

We utilize the ITO model by Noori et al. (2021) to classify Chinese smart cities, considering inputs, throughput, and outputs. Inputs encompass the formulated goals and resources available, including human resources, entrepreneurship, ICT infrastructure, and financial resources. Throughput involves the transformation of inputs into outputs through governance, knowledge and innovation management, data management, financial management, and leadership. Outputs represent the smart application domains, such as mobility, energy, health, governance, and citizens, reflecting the goals and resource allocation of smart city policies (Noori et al., 2021). Our classification framework based on the ITO model considers multiple dimensions of smart cities, including resource input, governance, and application characteristics. By examining the design choices made in inputs, throughput, and outputs, we gain a comprehensive understanding of smart cities and explore the relationships between these facets (Noori et al., 2020).

Smart city evolution is influenced by diverse urban contexts, leading to different development pathways for smart cities (Neirotti et al., 2014). Considering the distinct urban contexts and numerous smart city pilot projects in China, this study aims to identify and classify Chinese smart cities. To adapt the ITO model to the Chinese context and study objectives, we made adjustments to the input and output facets. Human resources and entrepreneurship, financial resources, and ICT infrastructure were retained in the framework, as they are crucial for smart city development (Caragliu et al., 2013; Chourabi et al., 2012; Nam & Pardo, 2011). Given the diversity of smart city applications in China, we included the domains of security, environment, and economy in our classification framework. However, the domain of smart citizens was excluded due to limited description and explanation in the Chinese context. Additionally, smart security is treated as a separate facet rather than a sub-domain of smart governance in this framework. This decision was made to account for the various security applications in China, such as video surveillance systems, facial recognition systems, and smart police platforms (Kostka et al., 2021; Zhang et al., 2019). Furthermore, smart governance in China predominantly focuses on smart administration, including administrative service platforms for citizens and businesses (Lin, 2018).

## 3. Methodology

The objective of this study is to classify and map the nature and characteristics of smart cities in China using the adapted ITO model. To achieve this, we employed a multiple case study approach as our research strategy. This approach allows for an in-depth examination of specific cases within the real-world context, enabling us to gain a comprehensive understanding of the diverse features exhibited by different smart cities in China. By including a substantial number of cases, we aimed to explore representative commonalities and differences among various Chinese smart cities. We formulated a smart city classification framework for Chinese smart cities (see Annex 1) based on the ITO model. The variables and indicators in this framework were primarily derived from the interpretation of the ITO model by Noori et al. (2021) and the "Evaluation Indicators for New-Type Smart Cities" issued by the CNSA (2022). Subsequently, we applied this framework to each selected case as a classification tool, enabling us to depict their status across the three dimensions of input, throughput, and output. To examine the situations of these cases, we conducted content analysis on smart city plans, reports, and policy documents obtained from official government sources. Collecting data from official government websites was deemed the most authoritative data source in the Chinese context (Ma et al., 2021). Lastly, through a data analysis triangulation approach involving content analysis, principal component analysis, and K-means clustering analysis, we developed a typology of smart cities in China that captures the distinct characteristics exhibited by these cities.

China's smart city development has been part of its national strategy since 2012, leading to the emergence of 290 smart city pilot projects. The Ministry of Housing and Urban-Rural Development of China (MOHURD) issued the "Notice on the Pilot Work of the National Smart City" in December 2012, approving the first batch of 90 pilot smart cities in January 2013. Additional batches were approved in August 2013 and April 2015 for pilot smart cities at various levels (Yang & Chong, 2021). Pilot cities are required to follow evaluation indicators, formulate development plans, and provide annual evaluation reports to the MOHURD.

### 3.1. Case selection and data collection

To collect data for our study, we implemented two steps. Firstly, we conducted searches on the municipal government websites and Municipal Development and Reform Commission (MDRC) websites of the pilot smart cities using six keywords related to smart city development. These keywords included "smart city", "digital city", "smart government", "digital government", "smart [city name]", and "digital [city name]". We downloaded all available plans and policy documents up to 2022 for smart city development from these websites. This step obtained data for some cities. Secondly, we identified that certain pilot cities had established dedicated administrative departments for smart city development, such as the Wuxi Big Data Bureau. We extended our data collection by searching for the same six keywords on the websites of these specialized departments. This allowed us to collect additional data related to smart city development from these sources. Finally, we obtained at least two policy documents from each selected case, including their latest local smart city plans and the 14th Five-Year Plans. These two documents cover all key points in different smart fields and provide enough information for the classification.

The selection of cases for this study followed specific criteria based on existing literature (Seawright & Gerring, 2008). The criteria included factors such as location, city size, data availability, and diversity, ensuring a comprehensive and representative sample. By including cities of different scales, the study aimed to capture a range of urban contexts. Data availability was a key criterion, with selected cities having accessible and informative smart city plans, reports, and policy documents from official government sources. Furthermore, the study emphasized the inclusion of cities with diverse economic, social, and spatial contexts to provide a holistic understanding of smart city development in China. By adhering to these criteria, the selection of cases aimed to ensure the validity and reliability of the study's findings.

Case selection for this study began with 290 cities from the three batches of pilot smart cities in China (See Fig. 1). The selection process involved examining each city based on specific criteria. Firstly, we assessed the data availability of each of the 290 pilot cities and found that only 94 cities had published plans or policy documents related to smart city development on their official websites. Secondly, after a preliminary review of the data from these 94 cities, we excluded 45 cities due to the limited information provided in their plans and policy documents. In the end, we selected 49 cases that met all the criteria. Shanghai and Hangzhou were excluded because we had not collected the latest policy documents (smart city plans during the 14th Five-Year Plan period) from them by the end of data collection. All other cases' latest documents for smart city development in our study were available online, including smart city plans from 2019 onwards and the "14th Five-Year Plans for Smart City Construction". Therefore, we excluded Shanghai and Hangzhou to ensure that the policy documents of all cases were in the same time period. Among selected cases, 5 are supercities, 4 are small cities, and the rest are large cities and megacities, ensuring a diverse representation of city sizes. These selected cases are distributed across the country, encompassing developed cities on the east coast as well as less developed regions in central and western China (Fig. 2). They exhibit diverse geographic, spatial, and socio-economic characteristics. Given the large number of cases, this study relied on secondary data rather than conducting field trips and interviews. However, it is important to note that some data limitations were encountered during the review process. Authoritative data on financial resources, management, and leadership style for each city were not available. As a result, variables related to these aspects were excluded from the classification framework. It is also acknowledged that the case selection process may have introduced potential bias. Cities that have made faster progress in smart city development are more likely to document and publish their progress online, which could have influenced the inclusion of more cities with relatively faster progress in the study.

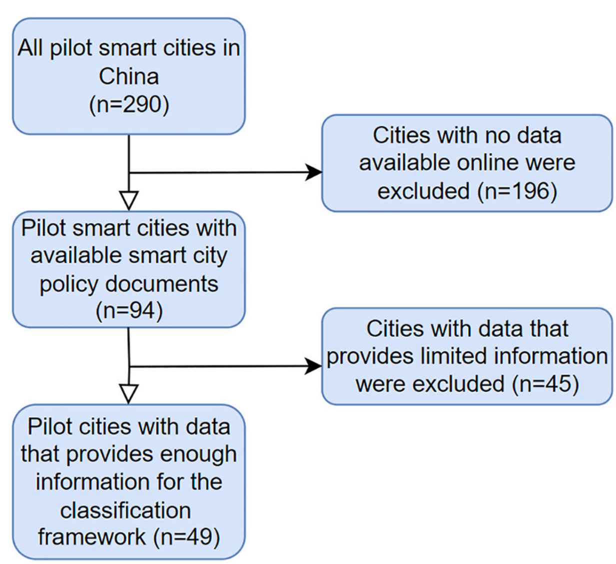


**Fig. 1.** Case selection process.
Source: Authors.

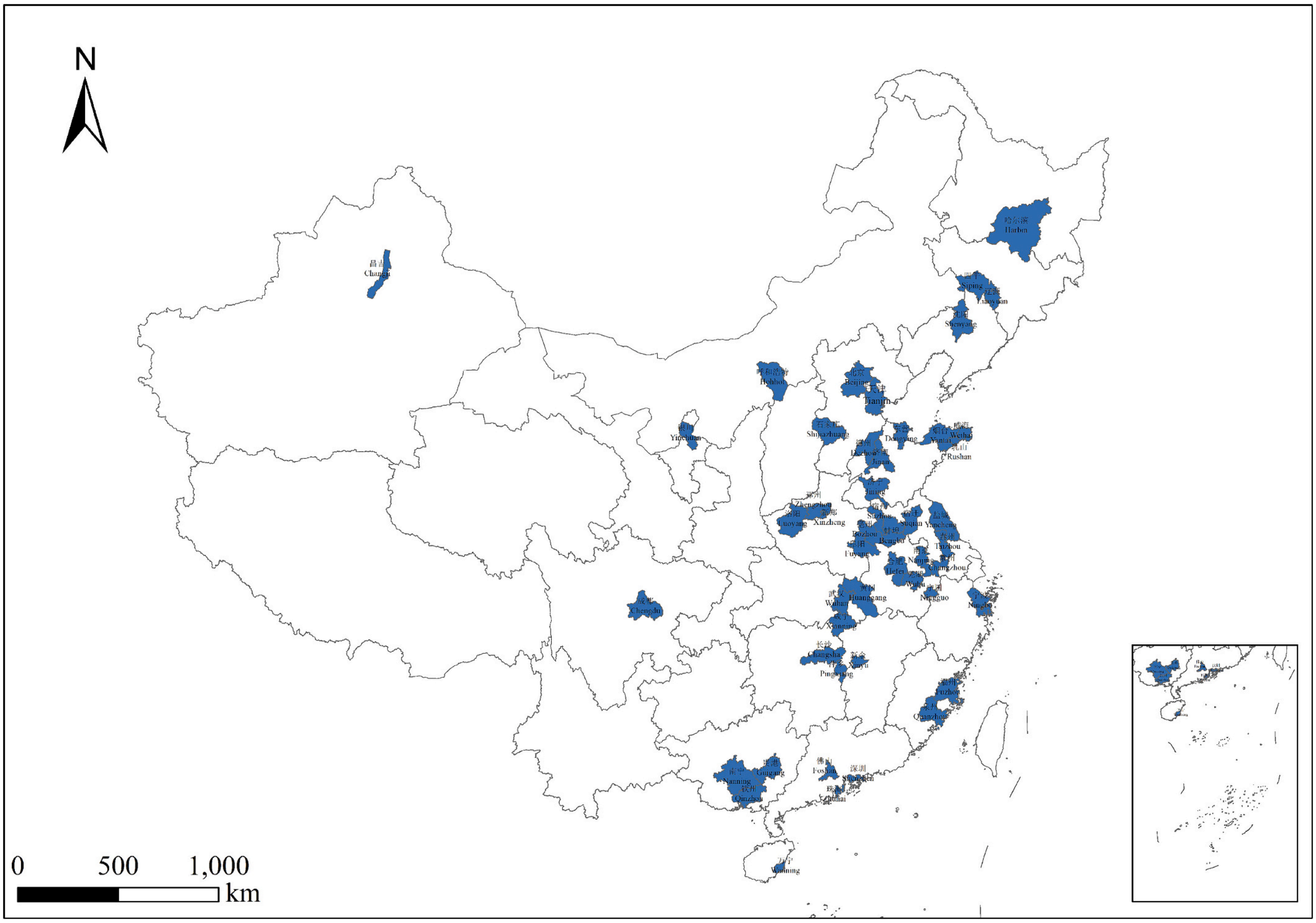


**Fig. 2.** Distribution of selected cities.
Source: GS (2019) 1822.

### 3.2. Data operationalization and analysis

After collecting the data, the operationalization and data analysis were conducted through several steps to compare the current situation of each case. Given the rich qualitative data available for the 49 selected cases, we employed specific methods to make the qualitative data more suitable for structural analysis. The smart city plans or reports of each pilot smart city typically provide information on the current status of smart city implementation, including lists and descriptions of completed, ongoing, and planned projects/initiatives. Firstly, we mapped the policy initiatives and smart applications adopted by each selected case. Subsequently, we assigned qualitative scores to each variable of all cases using an ordinal scale, based on the status of policy initiatives and applications. Specifically, a score of '0' was assigned when there was no plan or smart application/project in place at all. A score of '1' indicated the presence of at least one plan or smart application/project, but no implementation or progress yet. A score of '2' was given if there was actual progress in at least one plan or smart application/project. Lastly, a score of '3' was awarded when at least one plan or smart application/project had been completed.

The variables of government participation, private sector involvement, and citizen participation were scored in different ways. For government participation, a score of '3' was given to cases that had established a dedicated smart city working group at the municipal level to organize, lead, and promote local smart city development. A score of '2' and '1' were assigned to cases where government working groups were being established and were planned but not yet established, respectively. A score of '0' was given for cases where the government working group was absent. Regarding the involvement of the private sector, a score of '0' was assigned to cases without any involvement of the private sector. A score of '1' was awarded to cases that planned to introduce the private sector in smart city development but had not made progress yet. Cases with private sector involvement received a score of '2', and cases with multiple public-private partnership models were assigned a score of '3'. For citizen participation, a score of '0' was assigned to cases without any initiatives or projects to encourage and incorporate citizen participation in smart city planning, design, and implementation. A score of '1' was given to cases where initiatives or projects existed only in the plan but had not been implemented. A score of '2' was awarded to cases that were actively implementing these initiatives or projects. Finally, a score of '3' was assigned to cases that had at least one mature measure or initiative in place to encourage and incorporate citizen participation in smart city development.

After scoring all the cases, the study aimed to identify similarities and differences between them by comparing their characteristics in terms of input, throughput, and output. The process of developing a typology of smart cities in China involved four steps (see Fig. 3). In the first step, the cases were classified into three categories based on their input, considering human resources and entrepreneurship, as well as ICT infrastructure. Next, the cases were divided into two categories based on their characteristics in throughput, which represents the process of implementing smart city initiatives. Moving to the third step, since the output facet contained a multidimensional dataset with 23 variables, the study employed Principal Component Analysis (PCA) and K-means

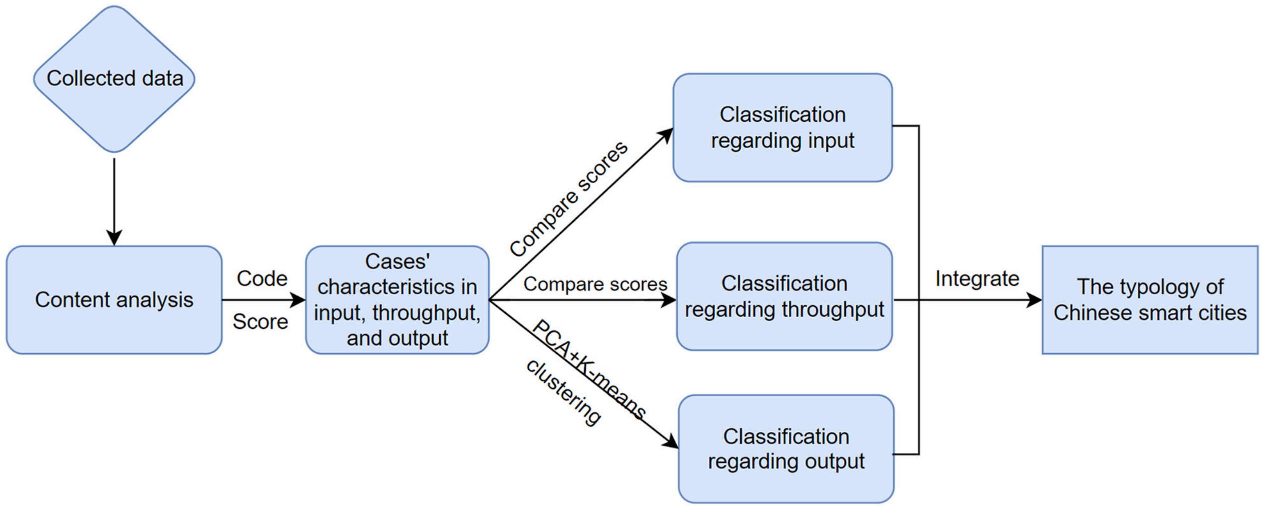


**Fig. 3.** Data analysis process.
Source: Authors.

clustering analysis. PCA was used to reduce the dimensionality of the output dataset and transform it into a new set of variables known as principal components (Jolliffe, 2002). These components are uncorrelated and ordered, capturing most of the variations present in the original dataset. Principal components with eigenvalues greater than 1 were selected for the subsequent K-means clustering analysis. The K-means clustering aimed to group cases based on their characteristics in output, minimizing variation within clusters and maximizing variation between clusters. Finally, in the last step, based on the correlation of the ITO model, the study developed a holistic typology of Chinese smart cities by combining the classification results for cases in terms of input, throughput, and output. This typology aimed to provide a comprehensive understanding of the different types of smart cities in China based on their unique characteristics.

## 4. Results

This section provides an overview of the characteristics of all cases in terms of their inputs, throughputs, and outputs. The detailed results of the Principal Component Analysis (PCA) and K-means clustering analysis can be found in annex 2.

### 4.1. Inputs

The inputs of human resources, entrepreneurship, and ICT infrastructure construction in all case cities for smart city development are summarized in Fig. 4. Overall, the case cities seem to prioritize human resources and entrepreneurship to a similar extent as ICT infrastructure. Specifically, over 30 cases have initiatives in place to attract highly skilled talent (HR2) and foster an innovative environment for businesses (HR3). However, digital literacy support for local residents through education and training, which is also crucial (Neirotti et al., 2014), receives less attention. It is evident that all case cities place particular emphasis on hard infrastructure, especially fibre optic broadband and 5G base stations (ICT1). Additionally, over half of the cases have made progress in developing integrated Internet of Things platforms (ICT3) and Spatio-temporal geographic information platforms (ICT4). These findings align with Neirotti et al.'s (2014) study, which highlights the focus of Asian smart cities on hard infrastructure. Conversely, the construction of big data centers (ICT2) receives less attention, likely due to high costs and location requirements (Shehabi et al., 2011).

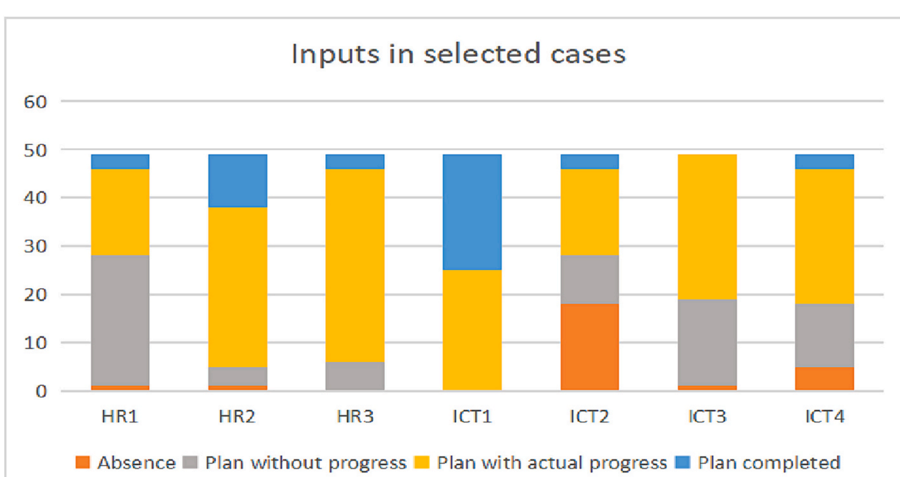


**Fig. 4.** Number of cases with reported initiatives by type of inputs.
Source: Authors.

### 4.2. Throughputs

Notably, as national pilot projects, all case cities in China have adopted a top-down approach in steering smart city development (see Fig. 5). This top-down mechanism is also observed in the development of eco-cities in China (Li & de Jong, 2017), highlighting the influence of the country's hierarchical and institutional structure on urban development (Geertman et al., 2015). Each case city has established a dedicated smart city working group at the municipal level, typically comprising the mayor, deputy mayor, and department heads. These working groups play a crucial role in organizing, leading, and promoting local smart city initiatives while coordinating private sector involvement (GOV3). The government's authority in driving smart city initiatives in China is significant. However, compared to public-private partnerships, citizen participation receives relatively less emphasis. Although 31 case cities mention citizen participation in their policy documents, the actual implementation of related initiatives and channels is limited. The promotion of citizen participation remains largely theoretical, with few concrete steps taken. This lack of citizen participation is further evident from the limited attention given to open innovation, as most cities have yet to prioritize this aspect (KM1). Among the case cities, Beijing stands out as the only city reporting a smart city living lab, located in the Zhangjiawan Design Town, where scientific and technological innovations and future smart city lifestyles are showcased.

Regarding knowledge management, some case cities (17) have established dedicated research institutes and centers (KM2) for smart city development. For instance, Chengdu set up the Smart Rongcheng Research Institute, which serves as a hub for experts in smart cities, smart governance, and public administration to provide intellectual support, including consultation and policy recommendations, for Chengdu's smart city development. More than half of the cases (34) recognize the importance of a collaborative ecosystem (KM3), promoting knowledge transfer among universities, research institutes, government, and industry, fostering a triple helix model (Leydesdorff & Deakin, 2011; Mora et al., 2019). Regarding data management, all cases prioritize the establishment of data security systems (DM3), particularly for e-government data. China has implemented national-level laws, such as the "Data Security Law of the People's Republic of China" and "Personal Information Protection Law of the People's Republic of China," to address data security and privacy concerns (Yang et al., 2023). At the local level (DM2), Shenzhen stands out as the only case city to have enacted the "Shenzhen Special Economic Zone Data Regulations" in 2020, which comprehensively addresses data ownership, data usage, and personal data protection. This local legislation serves as a pioneering example for other regions in China to enhance their data governance systems. In terms of data sharing (DM1), approximately half of the cases have made progress in sharing urban public data and establishing open data platforms, indicating that there is still a need for increased data transparency and sharing among smart cities in China.

### 4.3. Outputs

The varying priorities given by each case city to different smart applications in the output facet are illustrated in Fig. 6. While smart mobility, smart security, smart healthcare, smart governance (especially SG1 and SG2), and smart economy have been prioritized, cases have shown particular concern for smart healthcare and smart governance, with all cases reporting progress in these areas. Smart mobility, particularly in terms of smart transportation infrastructure (SM1), has made progress in over half of the cases. IoT facilities have been deployed in 38 case cities to collect real-time traffic data, enabling integrated transportation systems that offer parking information, traffic guidance, traffic control, and emergency response. Regarding smart logistics (SM2), less than half of the cases have made progress, likely due to the specific needs and focus of each city in developing logistics-related smart applications. Regional central cities like Nanning, Zhengzhou, and Chengdu, which serve as transportation hubs and logistics centers, have given higher priority to smart logistics compared to other cities. In terms of autonomous driving (SM3), only 17 cases have reported related applications, primarily in cities like Wuhan, Beijing, and Jinan, which are part of Intelligent Connected Vehicles pilot projects and autonomous driving application pilot projects. The central government's continuous launch of pilot projects for autonomous driving indicates a growing trend where more Chinese smart cities will adopt autonomous driving applications (Xu et al., 2022).

Smart security is a highly prioritized field in China, with all cases placing significant emphasis on enhancing public safety and surveillance. This involves deploying a multitude of cameras, facial recognition systems, and Internet of Things devices in urban public spaces. This emphasis can be attributed to the vigorous promotion of the "Xueliang program" by the central government in the 13th Five-Year Plan. The program focuses on establishing comprehensive governance and command platforms at the county, town, and village levels, with a specific focus on applications related to public security video surveillance networking, aimed at enhancing China's social security prevention and control system. Local governments have also invested substantial efforts in smart healthcare applications. More than half of the cases have reported significant progress in the three sub-facets of smart healthcare

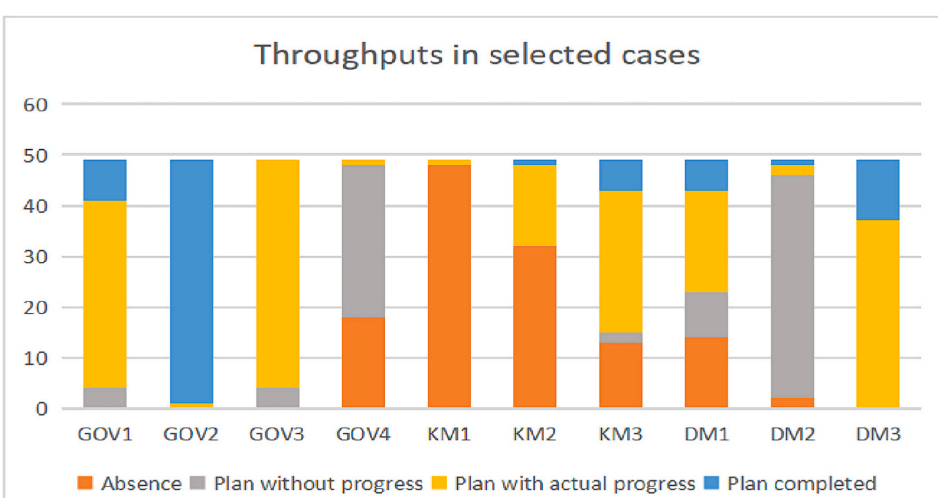


**Fig. 5.** Number of cases with reported initiatives by type of throughputs.
Source: Authors.

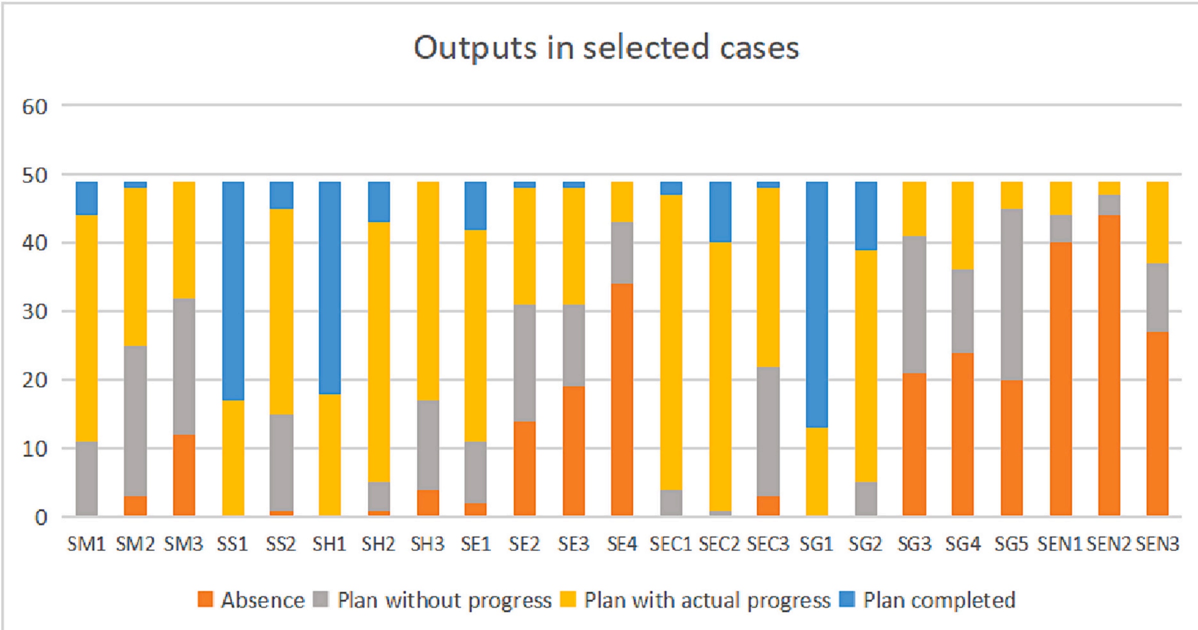


**Fig. 6.** Number of cases with reported initiatives by type of outputs.
Source: Authors.

(SH1–3). Notably, all cases have developed a comprehensive application (SH1) that integrates personal healthcare information, including digital health cards and health insurance. Furthermore, some cities are exploring the integration of additional personal information from medical care, education, administrative services, transportation, and finance into the health code, such as the "Ankang code" implemented in smart cities within Anhui province.

Local governments have generally placed less emphasis on the development of the smart environment compared to smart security and smart healthcare. The primary focus in the smart environment is on pollution monitoring (SE1). Out of the total cases, 38 have made progress in the development of smart environmental monitoring platforms, enabling real-time data collection, management, and analysis of environmental parameters. However, there are fewer cases that have reported advancements in the other three dimensions of the smart environment (SE2, SE3, SE4), indicating a need for improved monitoring and management of natural resources. Particularly in the area of smart waste management (SE4), only six case cities have reported relevant initiatives. Many of these cases, including Weihai, Tianjin, and Shenzhen, are also part of the national program known as the "Zero Waste Pilot Cities" (MEE, 2019).

The smart economy is another area where local governments have made significant efforts. Specifically, in the domain of industrial upgrading (SEC1), 45 case cities have implemented initiatives to promote high-tech industries and revitalize traditional industries through the integration of ICTs. These initiatives focus on the digital transformation of manufacturing processes (smart manufacturing) and the establishment of industrial Internet platforms and ecosystems. Additionally, more than half of the cases have reported applications related to digital financial services and supervision (SEC3). The emphasis placed by these cases on industrial upgrading, digital financial services, and supervision highlights the importance of the digital economy and digital transformation in the development strategies of Chinese cities. It is worth noting that in 2014, the State Council launched the "Planning Outline for the Construction of the Social Credit System" at the national level, which aims to evaluate the trustworthiness of individuals, organizations, and businesses (Liang et al., 2018). As shown in Fig. 6, nearly all cases have made tangible progress in implementing social credit systems.

Cases have allocated different priorities to various applications of smart governance. In the Western context, smart governance emphasizes promoting interaction and collaboration among stakeholders through technology. For instance, Barcelona is dedicated to developing a participatory democratic digital platform that facilitates stakeholder interaction and empowers citizens (Noori et al., 2021). In contrast, smart cities in China prioritize smart administration for smart governance (Lin, 2018; Wang et al., 2022). As is demonstrated in Fig. 6, nearly all cases have made tangible progress in implementing comprehensive administrative service platforms (SG1) and inter-departmental information platforms (SG2). This finding suggests that smart governance in Chinese smart cities focuses on smart administration, which encompasses various administrative service platforms for citizens, enterprises, and governments. While some cases have implemented digital participatory platforms/applications (SG3), such as hotlines, digital platforms, and WeChat official accounts developed by local governments, these channels primarily handle citizen criticisms, suggestions, and complaints regarding administration, public services, and the work of government departments and staff. In other words, these digital channels serve as means of mass supervision rather than participant governance platforms. The presence of only a few cases reporting on the other two subfacets (SG4, 5) of smart governance suggests the need for greater efforts and attention towards digital inclusion and smart decision-making.

Progress in smart energy has been relatively limited compared to applications in other fields. Fewer than 10 cases have reported initiatives in renewable energy (SEN1) and green buildings (SEN2). These cases are primarily located in northern China, including Beijing, Hohhot, and Tianjin. In contrast, energy-driven smart cities in Europe, such as Vienna and Amsterdam, place significant emphasis on smart building and smart grid solutions to achieve low-carbon development and enhance energy efficiency (Mora et al., 2019). The development of smart energy cities in China is still in its early stages, and progress varies across regions (Liang et al., 2020).

### 4.4. *Towards a typology of Chinese smart cities*

In this section, we developed a typology of Chinese smart cities through three steps. The stepwise process of developing the typology is illustrated in Fig. 7. In the first step, we divided cases into three types

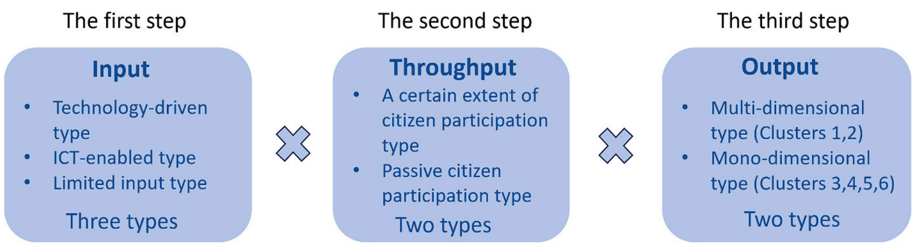


**Fig. 7.** The stepwise process of developing the typology.
Source: Authors.

based on their input characteristics. In the second step, we classified all cases into two types according to their throughput characteristics. We then divided cases into two types regarding the results of K-means clustering analysis (more details in annex 2) in the third step. Finally, we developed the typology by combining the classifications of input, throughput, and output. Specifically, we classified the cases into three categories based on their input characteristics: technology-driven, ICT-enabled, and limited inputs. The technology-driven category focuses primarily on ICT infrastructure, while the ICT-enabled category emphasizes human resources, entrepreneurship, and ICT infrastructure. On the other hand, the limited inputs category has limited investment in both human resources and entrepreneurship, as well as ICT infrastructure. In terms of throughput, all cases follow a top-down approach. However, within this approach, there are a few cases that encourage a certain degree of citizen participation. We divided the cases into two categories based on the presence of specific initiatives or projects, such as smart city living labs that aim at encouraging citizen participation and engagement in smart city design, implementation, and decision-making. One category is that it encourages a certain level of citizen participation. In another category, its citizen participation is largely passive. Regarding output, the results of PCA and K-means clustering analysis show that cases are clustered into 6 clusters based on their output characteristics (see annex 2). When developing the final typology, we further divided these six clusters into two types according to the dichotomy logic proposed by Mora et al. (2019): Mono-dimensional and Multi-dimensional. Clusters 3, 4, 5, and 6 represent Mono-dimensional cases because they prioritize an individual smart field. Meanwhile, clusters 1 and 2 represent multi-dimensional cases since they focus on multiple smart fields (see annex 2 for further details). As demonstrated in Fig. 7, there are theoretically 12 different combinations/types ($3 \times 2 \times 2$) when we combine the classifications of input, throughput, and output. The 49 cases we studied represent five of them, as is shown in Table 2 (annex 2 presents more detailed divisions under the output types).

#### 4.4.1. *Knowledge-technocratic smart cities*

This type of smart city is the most common among the cases analyzed, with 22 out of 49 cities belonging to this category. These cities place significant emphasis on inputs related to human resources, entrepreneurship, and ICT infrastructure. Unlike equipment-technocratic smart cities, this type of smart city recognizes the importance of attracting highly skilled individuals and innovative companies involved in smart city development. They also acknowledge the value of fostering a collaborative ecosystem that facilitates knowledge transfer among academia, industry, and government. However, citizen participation is not a priority for this type of smart city, as there are no specific initiatives or smart city living labs in place to actively engage citizens in the design, implementation, and decision-making processes of smart cities. In terms of output, these cities tend to focus on a specific dimension. For instance, some prioritize smart transportation, as observed in cities like Foshan, Nanjing, and Nanning. Others emphasize smart healthcare, as seen in cities like Weihai, Yancheng, and Suqian (see annex 2 for further details).

**Table 2**
The typology of Chinese smart cities.

| Types | Main characteristics | Cases |
|---|---|---|
| Knowledge-technocratic smart cities | Focus on both human resources and entrepreneurship and ICT infrastructure, passive citizen participation, mono-dimensional output | Xinyu, Liaoyuan, Shenyang, Guigang, Jining, Pingxiang, Rushan, Suqian, Wanning, Weihai, Yancheng, Yinchuan, Bengbu, Changsha County, Dezhou, Dongying, Foshan, Huaibei, Nanjing, Nanning, Suzhou (Anhui), Wuhu |
| Holistic smart cities | Focus on both human resources and entrepreneurship and ICT infrastructure, with certain extent of citizen participation, multi-dimensional output | Beijing, Zhuhai |
| Green smart cities | Focus on both human resources and entrepreneurship and ICT infrastructure, passive citizen participation, multi-dimensional output with the emphasize on green and low-carbon development | Shenzhen, Bozhou, Changzhou, Chengdu, Fuzhou, Fuyang, Harbin, Hefei, Hohhot, Ningbo, Quanzhou, Taizhou (Jiangsu), Tianjin, Wuhan |
| Equipment-technocratic smart cities | Focus on ICT infrastructure, technology-driven with passive citizen participation, mono-dimensional output | Yantai, Qinzhou, Jinan |
| Emerging smart cities | limited input in human resources and entrepreneurship and ICT infrastructure, passive citizen participation, mono-dimensional output | Ningguo, Changji, Huanggang, Luoyang, Siping, Xinzheng, Xianning, Zhengzhou. |

Source: Authors.

#### 4.4.2. *Holistic smart cities*

Beijing and Zhuhai are categorized as holistic smart cities due to their adoption of a comprehensive strategy. In terms of input, these cities have placed significant emphasis on human resources and entrepreneurship, including initiatives to enhance digital literacy among residents and officials, as well as attract talented individuals and innovative companies. They have also made substantial efforts to build ICT infrastructure. While operating under a top-down mechanism, they also encourage a certain level of citizen participation. Among all the cases analyzed, Beijing stands out as the only city that has reported the establishment of a smart city living lab. The living lab, located in the Zhangjiawan Design Town, showcases scientific and technological innovations and future smart city lifestyles, aiming to encourage citizens to share their ideas and contribute to smart city development. In Zhuhai, there is an initiative in place to actively gather demands, application scenarios, and solutions for smart city development from the public. Moreover, these cities have recognized the importance of promoting knowledge transfer among universities, government entities, and industries, thus fostering a broader collaborative ecosystem. This acknowledgment aligns with previous research emphasizing the significance of knowledge exchange in smart city development (Leydesdorff & Deakin, 2011; Mora et al., 2019). In terms of output, holistic smart cities prioritize multiple dimensions instead of focusing solely on one. This approach is crucial because urban challenges encompass various application domains. Smart city strategies should provide solutions that extend across different sectors (Mora et al., 2019).

#### *4.4.3. Green smart cities*

Among the cases analyzed, 14 cities can be classified as green smart cities, with half of them located in eastern China and the other half in central and western regions. Like holistic smart cities and knowledge infrastructure-oriented smart cities, green smart cities prioritize both human and entrepreneurial resources, as well as ICT infrastructure. However, unlike holistic smart cities, these cities do not currently have specific initiatives in place to encourage citizen participation. Green smart cities place a strong emphasis on multiple application areas in terms of output, with a particular focus on green and low-carbon development. They have made tangible progress in the areas of smart environment and smart energy.

#### *4.4.4. Equipment-technocratic smart cities*

In our case studies, we did not identify any equipment-technocratic smart cities with multi-dimensional output. This finding suggests that technocratic smart cities, which primarily prioritize technology and infrastructure, may have limitations. These cities tend to focus on addressing specific urban challenges through the introduction of smart solutions. However, they often overlook the input of human resources and fail to consider the voice and needs of the public. As a result, their output tends to be limited to a single dimension rather than encompassing a variety of application domains.

#### *4.4.5. Emerging smart cities*

Among our case cities, we identified eight emerging smart cities. These cities have developed comprehensive smart city plans or strategies; however, many of these plans remain largely theoretical and have not been fully implemented. In terms of resource input, emerging smart cities have limited investments in human resources, entrepreneurship, and ICT infrastructure. Additionally, citizen participation has been neglected in these cities. While some progress has been made in the implementation of smart city initiatives, the output dimension of emerging smart cities has advanced at a slower pace compared to other types of smart cities in China.

## 5. Positioning Chinese smart cities globally

Our findings support previous research by Shen et al. (2018) and Li et al. (2018) regarding the development gap between smart cities in eastern and western China. However, we also observed that this gap is gradually narrowing. Many cities in central and western China have made significant progress in multiple application domains, as demonstrated by cities like Chengdu and Wuhan (refer to Section 2 in the Annex 2). Furthermore, we discovered that the level of economic development does not solely determine the progress of smart city development. Some cases with relatively lower economic levels, such as Bozhou, Fuyang, and Harbin, have shown significant advancements in smart city development due to their emphasis on human resources and knowledge management. This finding further underscores the importance of human resources and knowledge in the development of smart cities, as highlighted by previous studies (Caragliu et al., 2013; Nam & Pardo, 2011).

When comparing Chinese smart cities with smart cities in other parts of the world, we can identify both similarities and differences. According to Perboli and Rosano (2020), European smart cities place significant emphasis on the environment, natural resources, and sustainability, distinguishing them from smart cities in North America. This emphasis on environmental sustainability is supported by the findings of Cantuarias-Villessuzanne et al. (2021), where European smart cities in the third cluster exhibit a focus on the environment and sustainability. Our own research aligns with these findings, as cities like Shenzhen, Chengdu, and Ningbo, which belong to the green smart city type, demonstrate a similar emphasis on environmental sustainability. It is worth noting that these green smart cities tend to have a higher GDP per capita compared to other smart cities, a characteristic that can be explained by the Environmental Kuznets Curve theory. This theory suggests that as economic development reaches a certain level, people become more concerned about improving the environment and promoting sustainability (Dinda, 2004).

Indeed, the common features of smart cities in Europe and North America, such as embracing ICT infrastructure and emphasizing the human aspects, are also observed in Chinese smart cities (Perboli & Rosano, 2020). Most Chinese smart cities in our cases have placed significant emphasis on ICT infrastructure and human aspects, with the exception of equipment-technocratic smart cities and emerging smart cities. Examples of the equipment-technocratic approach can be seen in cities like Qinzhou, Yantai, and Jinan, which prioritize ICT infrastructure over other resource inputs (Noori et al., 2021; Yigitcanlar, Han, et al., 2019). Historically, the technocratic approach was supported by technological optimists who believed that advanced technologies alone could solve urban problems. Smart cities like Songdo in South Korea and Masdar in the United Arab Emirates are prominent examples of the technocratic approach (Noori et al., 2021; Yigitcanlar, Han, et al., 2019). However, this approach neglects the importance of other components within complex urban ecosystems. Focusing solely on ICTs is limited because a technocratic smart city lacks the voices and knowledge of citizens and civil society (Meijer, 2018; Trencher, 2019). Human resources and knowledge play crucial roles in smart city development. Technologies are not the only element in the triple helix model proposed by Leydesdorff and Deakin (2011). In the triple helix model, universities, government, and industry interact with each other. A more comprehensive approach recognizes that the smart city should also acknowledge the importance of knowledge to promote the education-industry partnership even though it has a rigorous framework based on ICTs (Carayannis & Campbell, 2014). In Europe, smart city projects often involve universities and research institutions, actively contributing as knowledge providers in smart city development (Perboli & Rosano, 2020). Similarly, our findings demonstrate that the majority of cases (34 out of 49) in China have recognized the importance of involving universities and research institutions in smart city development. Seventeen of these cases have even established dedicated research institutions and centers to foster local smart city initiatives, such as the Smart Rongcheng research institute in Chengdu.

Although Chinese cases have addressed resource input and knowledge transfer, they lack public participation. Unlike smart city projects in Canada and the United States, where citizens actively engage in smart city development (Perboli & Rosano, 2020), citizen participation in Chinese smart cities is limited. It is important to note that Chinese smart cities may have a different understanding of the people-centered approach. While many cities claim to follow a human-centric approach, their interpretation differs from that in Western contexts. The Western approach aims to facilitate stakeholder interaction and empower citizens in smart city development, as exemplified by Barcelona's inclusive and participatory approach (Noori et al., 2021). In contrast, smart cities in China predominantly adopt a top-down approach, providing limited opportunities for active citizen participation. Citizens are often seen as passive participants rather than active and influential actors contributing ideas to smart city design, planning, and implementation (Engelbert et al., 2019). The absence of living labs and programs encouraging citizen engagement further underscores the limited active participation. This finding aligns with Raven et al.'s (2019) observation that Ningbo follows a more technocratic approach compared to Hamburg and Amsterdam. Similar circumstances exist in smart city implementations in Saudi Arabia, where Aina (2017) found a top-down governance approach with limited public participation. China and Saudi Arabia demonstrate the significant influence of higher tiers of government on local urban development (Alsayel et al., 2023).

The holistic smart cities of Zhuhai and Beijing can be seen as a transitional form, employing a combination of top-down and bottom-up approaches. While the governments hold significant authority in driving and executing smart city initiatives, they also encourage a certain level of citizen participation within the top-down framework. This approach may be attributed to the stage of smart city development. In comparison to other cases examined in the study, Zhuhai and Beijing have reached a relatively advanced level of smart city development. Similar findings have been observed by Lim et al. (2023) in South Korea, where the maturation of Korean smart cities has provided greater opportunities for civic actors to participate.

## 6. Conclusion

This article examines the characteristics and typology of smart cities in China, comparing them with global counterparts. Our findings indicate that Chinese smart cities prioritize human resources, entrepreneurship, and ICT infrastructure. Consistent with the smart city accelerator concept proposed by Mora et al. (2019), all cases have established dedicated smart city working groups at the municipal level to foster partnerships and acquire resources. Similar to early smart cities in South Korea and smart cities in Saudi Arabia, Chinese smart cities primarily employ a top-down implementation approach (Aina, 2017; Lim et al., 2023). While many cases claim a human-centric approach, there are few initiatives to encourage active citizen participation in smart city development. Beijing and Zhuhai exhibit an early combination of top-down and bottom-up approaches, encouraging limited citizen involvement. In contrast, most North American and some European smart cities exhibit more robust citizen participation (Noori et al., 2020; Perboli & Rosano, 2020). In terms of output, smart security and smart administration receive significant attention, while digital inclusion is generally overlooked. Most cases focus on a single application domain, whereas Shenzhen and Zhuhai have made progress across multiple domains.

The typology of smart cities in China, derived from 49 cases, consists of five distinct types. The first type is characterized as knowledge-technocratic smart cities, prioritizing the role of experts and technology in governance while neglecting public input. The second type encompasses holistic smart cities, emphasizing all smart application domains, human resource input, and citizen participation. The third type pertains to green smart cities, which place special emphasis on green and low-carbon development. The fourth type encompasses equipment-technocratic smart cities, focusing on ICT infrastructure and technology while overlooking other vital components of complex urban ecosystems. The fifth type represents emerging smart cities, which possess sophisticated smart city plans and are in the process of transformation but are still in the early stages of development.

While Chinese smart cities have achieved significant progress, several actions and policy recommendations have been identified based on the analysis of overall characteristics and a comparison with smart cities in other countries. Firstly, although most cases have established comprehensive smart city implementation frameworks, citizen involvement is often lacking. To adopt a human-centric approach and foster a more inclusive and collaborative ecosystem, a strategy that combines both top-down and bottom-up approaches is recommended. This approach allows the government to play a pivotal role in promoting smart city development by coordinating resources while also considering the ideas and needs of citizens and civil society through various initiatives and activities. Moreover, enhancing educational opportunities to improve the digital skills and knowledge of citizens and staff is also essential. Activities and exhibitions can be organized to raise awareness and encourage citizen engagement in smart city development. It is important to acknowledge that Chinese smart cities develop in diverse contexts and exhibit varying levels of progress. Therefore, smart cities should tailor their priorities for development based on local urban environments and goals. Lastly, it is crucial to enhance the accessibility and digital inclusiveness of smart cities. This entails addressing the challenges and needs of marginalized urban groups and ensuring their integration within the smart city development framework. By prioritizing the inclusion of these groups, smart cities can work towards creating a more equitable and sustainable urban environment.

However, it is important to acknowledge the limitations of this paper. One of the key limitations is the lack of authoritative data on financial aspects, which hinders the exploration and comparison of the cases in terms of financial resources. This aspect represents a significant factor in smart city development, and its exclusion is a limitation of this research. Another limitation is the potential bias in the selection of cases. We excluded Shanghai and Hangzhou due to their data were not available, but we would like to include them in the future research. The study focused on cases from three batches of pilot smart cities in China, which allowed for a more objective comparison as they were guided by the same central government policy and began implementing smart city initiatives around the same time. However, this approach overlooked other non-pilot cities that have also adopted smart city strategies. Additionally, considering data availability, there is a possibility that more cases with faster progress in smart city implementation were included, potentially biasing the typology and overlooking other types of Chinese smart cities. For instance, some cities may solely brand themselves as smart cities to attract investment without implementing substantial steps. Furthermore, the study primarily emphasized cities as the main units of analysis, while smart city strategies are introduced not only at the city level but also at the county and district levels in China. Future research could focus on comparing smart city development across different administrative divisions, such as counties, towns, and districts, to provide a more comprehensive understanding of the subject. Lastly, it is suggested that a longitudinal study be conducted to further explore the complex causal relationship between resource input and application output in smart city development. This would provide a deeper understanding of how different resources contribute to the outcomes and progress of smart city initiatives over time.

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## CRediT authorship contribution statement

**Jialong Zhu:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft. **Alberto Gianoli:** Conceptualization, Formal analysis, Methodology, Supervision, Writing – review & editing. **Negar Noori:** Conceptualization, Formal analysis, Supervision, Writing – review & editing. **Martin de Jong:** Conceptualization, Formal analysis, Supervision, Writing – review & editing. **Jurian Edelenbos:** Conceptualization, Formal analysis, Supervision, Writing – review & editing.

## Declaration of competing interest

The authors declare no conflict of interest.

## Data availability

Data will be made available on request.

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