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REVIEW ARTICLE

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# A systematic literature review: Setting a basis for smart and sustainable city performance measurement

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## Abstract

The growing amount of data and the inventive solutions that arise from it create opportunities to construct and manage smart sustainable cities. Before attempting to establish appropriate solutions in this regard, it is crucial to clearly grasp what smart and sustainable cities are and the aspects around which they are built. The purpose of this study is to critically analyze and evaluate the studies that have been conducted on smart and/or sustainable cities and to provide a basis for the measurement of smartness and sustainability of cities. In this context, using Systematic Literature Review (SLR) methodology, the smart city, sustainable city, and smart sustainable city concepts are firstly defined. After that, the indicators for the assessment of the smartness and sustainability of cities and the selection processes of these indicators are analyzed. According to the analysis, the studies were grouped based on the use of (i) selection criteria, (ii) selection methods/tools, and (iii) models used and 14 criteria were deduced from the literature for the evaluation of performance assessment indicators: measurability, availability, completeness, relevance, independence, reliability, currency, responsiveness, simplicity, representativeness, cost-effectiveness, consistency, comparability, and consensus. This study aims to support other studies and applications of authorities on creating and assessing a smart and sustainable city (i.e., the indicators) that want to join the 2030 Agenda but face problems regarding their cities' specific conditions. The first step towards creating a smart sustainable city can be taken by determining the most suitable indicators for the city.

KEYWORDS
indicator selection, performance measurement, smart sustainable city, smartness, sustainability

## 1 | INTRODUCTION

People searching for a job and a better life quality are continuously attracted by cities compared to the rural regions (Gonçalves et al., 2021). According to the United Nations, 68% of the world's population is going to live in cities by 2050 (United Nations, 2018). This percentage is estimated to be even higher in China, which will be 75% by 2050 (Liu et al., 2021). This ever-growing number of people that live in cities, poses a major threat to the administration and development of urban areas. This extremely challenging environment is also highlighted in one of the 17 SDGs (Sustainable Development Goals) in the Agenda 2030 for Sustainable Development, as "Goal 11: Sustainable Cities and Communities - Make cities and human settlements inclusive, safe, resilient and sustainable." (Project Everyone, n.d.). Agenda 2030 acts as a global roadmap for all stakeholders to meet the common challenges of the countries based on the environmental, social and economic dimensions of sustainable development.

With cities getting more crowded every day, preserving economic, environmental, and social sustainability will continue to be a major problem (Bibri & Krogstie, 2020; Pera, 2020). This problem is mainly caused by the pressure put on all the processes of urban systems (Bibri & Krogstie, 2020). These include challenges to infrastructure and environment (Patrão et al., 2020), rising resource consumption, traffic density, greenhouse gas emissions, etc. (Wong et al., 2020). Expanding geographically also negatively impacts the city's sustainability (da Silva Neiva et al., 2021). Additionally, climate change is an environmental concern that has surfaced in the last couple of decades and pressures cities to evolve in how they grow and adapt. The threats posed by climate change intensify the vulnerability of cities (Benites & Simões, 2021). Therefore, the urbanization rate is of great concern for the sustainable development of a city (Bayulken & Huisingh, 2015).

Even though new technologies present many opportunities for cities (Janik et al., 2020); to protect the public welfare, cities have to use their available resources (da Silva Neiva et al., 2021), which by implication affects the environment and the quality of life negatively (Janik et al., 2020). So the increasing population in urban areas forces cities to become smarter (Hajek et al., 2022).

As expected, the demands of citizens rise in line with the population living in the relevant cities. These demands and the sustainability complications call for innovative ways of urban management (Sharifi, 2019). Based on the same rationale, Gonçalves et al. (2021) analyze the effects of Industry 4.0 innovations on the sustainable development of urban areas and suggest that it has many contributions to it. In addition, Belli et al. (2020) present the Internet of Things as one of the many paradigms of innovation that takes the environment into account and behaves accordingly. On one hand, intelligent technologies are expected to decrease greenhouse gas emissions and improve energy efficiency (Ahvenniemi et al., 2017); but on the other hand, some argue that these rapid improvements damage many aspects of society (Sharifi, 2019).

The "smart city" concept and the "sustainable city" concept were introduced in the 1990s. But later on, the "smart sustainable city" concept emerged in the 2010s. Even though this concept was introduced by technologically advanced countries, it is also a concern for developing countries because of the high population growth expectancy (Janik et al., 2020). In this respect, it is crucial to create and maintain a suitable environment and management for a city, to become smart and sustainable (Manitiu & Pedrini, 2016).

Caputo et al. (2018) state that current managerial and governmental approaches become useless and fail to ensure a suitable global balance, because of industrialization, globalization, digitalization, and increasing competition. For cities to become sustainable, the "sustainability" and "smartness" concepts need to be well understood and redefined if necessary (Bayulken & Huisingh, 2015). Although in the current state of urbanization and uncertain conditions, this may be quite challenging (Bibri & Krogstie, 2020), it is worth mentioning here that particularly smartness plays a vital role in creating cities that ensure the quality of life while considering the environment (Bhattacharya et al., 2020). Therefore, once again, the "smart sustainable city" concept is underlined. But at this stage, as Martin et al. (2019) suggest, the transformative ability of smartness becomes the real question.

When we look at the 2030 Agenda more closely, we see a shared vision despite various values and norms, a path defined to ensure the protection of the planet, sustainable economic growth and quality of life. The 2030 Agenda many times underlines the importance of international commitment to the achievement of these objectives and the noteworthiness of the experience of local and regional governments in the facilitation of inclusiveness and formation of partnerships. Sustainable urban development and management is considered obligatory for people's quality of life.

Urban planning, transportation systems and infrastructure, water and energy supply, sanitation, waste management, disaster risk management and climate change are some examples of challenges to sustainable urban development and all of these issues are discussed in Goal 11 of the SDGs. But these are also issues that have various impacts on other goals, including 1, 6, 7, 8, 9, 12, 15, and 17 (See Figure 1). These linkages show that the achievement of SDGs is very much dependent on the solutions found for the sustainable development of the cities.

The 2030 Agenda demands all stakeholders to inform of their progress towards the implementation of the agenda. To achieve this, the UN defined indicators under each sustainable development goal. But the assessment of the progress is a challenge for the authorities because not every city or country has the means to measure performance using the indicators defined. However, the indicators defined by the UN are strongly associated with the indicators proposed by various studies in the literature to measure the performance of smart and sustainable cities. Therefore, any solutions delivered for smart and sustainable city issues would imply improvement towards the realization of the 2030 Agenda.

Considering the connection between sustainable urban development and the 2030 Agenda, this study primarily aims to establish a basis for a comprehensive and robust framework that serves as a solid foundation for the assessment of smart sustainable cities. By doing so, it aims to offer invaluable guidance to authorities and decision-makers, enabling them to effectively measure their advancements in addressing the SDGs. As cities play a crucial role in the implementation of the 2030 Agenda, this guidance aims to enable policymakers and city managers to make informed decisions, develop effective policies, and allocate resources efficiently to ensure the successful realization of the SDGs within their respective urban contexts. Moreover, this study seeks to contribute to the body of knowledge surrounding sustainable urban development and its link to the 2030 Agenda. By

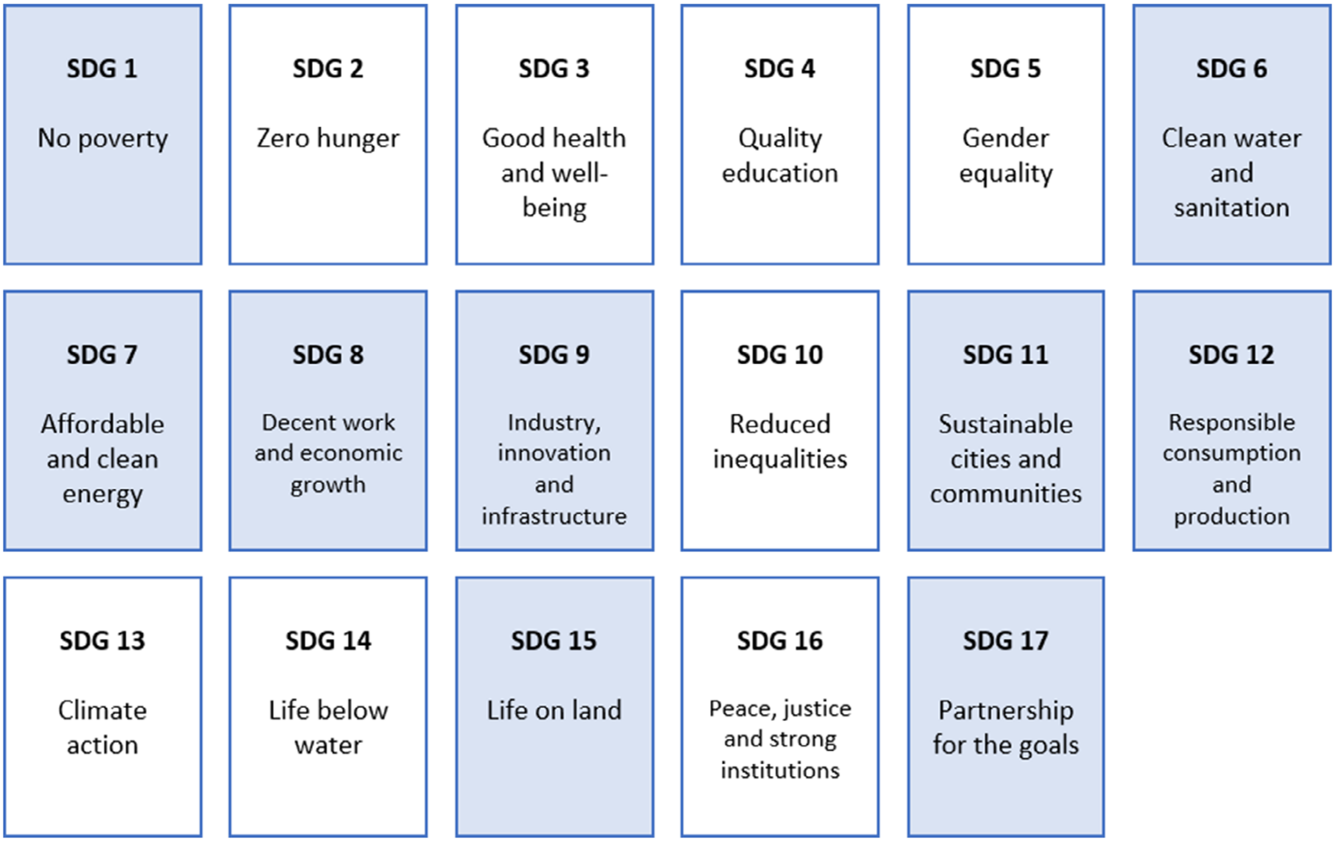


**FIGURE 1** 9 sustainable development goals directly affected by sustainable urban development issues.

providing a basis for smart sustainable city assessment and offering guidance to authorities, the study aims to pave the way for more informed and targeted actions towards achieving the SDGs and fostering a sustainable future for urban centers worldwide. A systematic literature review framework is used to find answers to what a smart sustainable city is, how its performance is measured, and how the performance indicators are selected. The answers to these questions will contribute to the literature by presenting the very first step of city smartness and sustainability performance assessment. By defining the smart sustainable city concept, methods and tools used for performance measurement, and the selection process of the performance indicators, essentially, this paper aims to fill the gap in the literature on how to measure the performance of the cities regarding their smartness and sustainability.

The rest of the paper is organized as follows: First, the concepts of smart city, sustainable city, and smart sustainable city are defined respectively in the following section. After that, the indicators for the assessment of the smartness and sustainability of cities and the criteria used for the assessment of these indicators are gathered from the literature in the third section. And then, the selection process of these indicators is investigated in detail in the fourth section. Finally, in the conclusions section, the results are discussed in relation to those reported by other studies and some recommendations for the selection of appropriate assessment indicators are presented.

## 2 | DEFINITIONS OF "SMART CITY", "SUSTAINABLE CITY" AND "SMART SUSTAINABLE CITY" CONCEPTS

Many have argued that cities are inherently unsustainable because of environmental damage caused by population growth and various other issues (Blassingame, 1998). But this has caused authorities to fail to see what benefits cities could provide regarding the prevention of such issues, even issues beyond the boundaries of cities (Satterthwaite, 1997). Lower birth rates, higher quality of life, less deforestation and better resource efficiency are some examples of social, economic and environmental features of highly urbanized cities (Blassingame, 1998; Satterthwaite, 1997) that show how urban development could directly support sustainable development. This situation reveals the need to distinguish the 'sustainable cities' and 'cities for sustainable development' (Ligorio et al., 2022; Satterthwaite, 1997) and the strategic importance of cities for sustainable development.

Even though the 2030 Agenda has caused a debate on what the definition of a sustainable city is and the concept of sustainable development has changed considerably, the study done by Ligorio et al. (2022) proved again that there exists a bond between the urban development and sustainable city concepts and suggested that the smart sustainable city concept was based on the use of smart city technologies for the achievement of sustainable development. But since the characteristics and objectives of the smartness and sustainability concepts differ in the literature, to understand what a smart sustainable city is predicated on, it is necessary to briefly elaborate on both "smart city" and "sustainable city" concepts firstly.

## 2.1 | Smart City

In a very recent study done by Hajek et al. (2022), more than a hundred articles on smart city assessment have been analyzed. In these studies, three main approaches towards the smart city concept have been observed: (i) a city that is shaped by technology, (ii) a city that emphasizes people, and (iii) a city that is both shaped by technology and focuses on people. But as the smart city concept evolved, the shift has been more towards a human and soft infrastructure (i.e., institutions, citizen engagement, data, social innovation, justice, etc.) centered approach (Sharifi, 2019).

Considering the definitions made in the literature for the smarty city, it can be said that the emphasis is placed on six dimensions: Economy, people, governance, mobility, environment, and living (Concilio et al., 2013; Hajek et al., 2022; Koca et al., 2021; Lazaroiu & Roscia, 2012; Ogrodnik, 2020; Sotirelis et al., 2022). The smart economy dimension comprises entrepreneurship, income and equality, and economic development; the smart people dimension comprises level of qualification, social and ethnic plurality, flexibility and creativity, and participation in public life; the smart governance dimension comprises of local smart strategy, participation, access and data, and transparent governance; the smart mobility dimension comprises local and international accessibility, smart and green transportation, and sustainable and innovative transport systems; the smart environment dimension comprises of pollution, natural resources and waste management, and built environment; and lastly the smart living dimension comprises of culture and education, health conditions, smart healthcare, and safety (Sotirelis et al., 2022). A smart city is defined to be based on information and communication capabilities that contribute to these six dimensions.

Information and communication technologies (ICTs) play a key role in the smart city concept. The smart city concept itself is seen to imply the utilization of ICT solutions in the city (Airaksinen et al., 2018). ICT is expected to integrate different dimensions of the city by providing connected platforms for the engagement of different stakeholders. The interconnectedness is expected to increase the efficiency, competitiveness and capacity of city operations (Sharifi, 2019). The smart integration enabled by ICT offers new insights and services for the city (Angelakoglou et al., 2019). A smart city realizes sustainable development and quality of life making use of ICT (Hajduk, 2020).

When we dive into the objectives of smart cities, we see an emphasis on efficient problem-solving. A smart city should identify and bring efficient solutions to urban problems, such as energy consumption, environmental protection, and quality of life (Angelakoglou et al., 2019; Patrão et al., 2020). Based on the literature, Sharifi (2019) indicates that smart city projects are of vital importance to "gain and maintain a competitive edge in a globally interconnected economy"; "appeal to the most talented, skilled, and creative citizens"; "overcome sustainability challenges and resource limitations that necessitate efficiency improvements"; "contribute to climate stabilization by speeding up the transition to low carbon society"; "improve the transparency of urban management"; "improve quality of life"; "deal with multiple socio-economic challenges, such as inequality, insecurity, unemployment, and aging population", and "make strides towards achieving the Sustainable Development Goals (SDGs)".

## 2.2 | Sustainable City

On the other side, the sustainable city concept is related to two well-known terms: (i) sustainability, which is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" by the World Commission on Environment and Development (WCED) and (ii) the "triple bottom line (TBL)", that is, the three pillars (economic, environmental, and social) of sustainable development (Crane et al., 2021). In a sustainable city, importance is attached to renewability and fair use of resources to conform with the capacity of the environment (Belli et al., 2020; Sodiq et al., 2019).

According to the literature review performed, Sodiq et al. (2019) line the principles that form the sustainable city as follows: (i) sustainable education, (ii) renewable energy, (iii) energy efficiency, (iv) sustainable buildings, (v) sustainable transportation, (vi) food wastes and sustainability issues, (vii) accommodating population growth, (viii) environmental management of natural resources, and (ix) water security. World Bank's urban sustainability framework indicates that a sustainable city has a growing economy, is competitive, protects the ecosystem and natural resources, reduces greenhouse gas emissions, and supports inclusion and habitability (World Bank, 2018).

The dimensions of the sustainable city concept are observed to vary across the literature. A sustainable city requires a combination of this variety of dimensions. Here, what matters is that these dimensions are addressed simultaneously (da Silva Neiva et al., 2021) and that all inhabitants and stakeholders of the city participate and make a contribution (Liu et al., 2021; Sodiq et al., 2019).

The relationship between the smart city and sustainable city concepts was not of great concern in the past, but now, the literature is more intrigued by it (Haarstad & Wathne, 2019). Recently, these two concepts are believed to be connected and share goals (Ahvenniemi et al., 2017). The smart city concept even replaces the sustainable city concept in some cases. "China's Tianjin Eco-City" project is an example mentioned by Yigitcanlar and Kamruzzaman (2018) to this fact, as the project is also named "Tianjin Smart City". At this point, the ultimate goal of a smart city is stated as "being sustainable" (Airaksinen et al., 2018).

There is also a discrepancy between these two concepts. For example, the study done by Kramers et al. (2014) unveiled that the opportunities provided by ICTs and the climate targets of a city do not always go along. The study also concluded that the definition of smartness does not give adequate information on how it is related to sustainability. In this respect, when the smart city and sustainable city frameworks in the literature are compared, it is observed that smart city frameworks are more focused on the social and economic aspects of the city (Ahvenniemi et al., 2017; Ahvenniemi & Huovila, 2021; Benites & Simões, 2021).

In a study done by Yigitcanlar and Kamruzzaman (2018), it is revealed that city smartness and carbon dioxide emissions do not have a linear relationship and that the smartness of a city does not have a time-varying impact on emissions. According to Yigitcanlar et al. (2019), heavy technocentricity, practice complexity, and ad-hoc conceptualization are the three major obstacles for a smart city to create sustainable outcomes, and so far, the current practice of smart cities did not succeed in providing sustainable solutions and it is still not clear whether it is possible to do so or not.

Because of this technocentric structure of smartness, the need for a more sustainable perspective, where close attention is also given to social needs, has been raised (Belli et al., 2020). The criticism of the neglection of some sustainability goals has led to the emergence of the "smart sustainable city" concept that combines smartness with sustainability (Ahvenniemi & Huovila, 2021; Antolín et al., 2020; Garau & Pavan, 2018; Gonçalves et al., 2021; Huovila et al., 2019; Kramers et al., 2014).

### 2.3 | Smart Sustainable City

There is an expanding body of literature on smart sustainable cities, but it is still limited (Bibri & Krogstie, 2017). To date, there are many different definitions proposed (Treude, 2021) and there is no consensus on these definitions (Chang et al., 2018). One underlying reason for this is the variation in smart city and sustainable city definitions (Janik et al., 2020). The literature agrees with the hypothesis that a city cannot be smart without being sustainable (Yigitcanlar et al., 2019). But this situation created another problem causing more confusion: the interchangeable use of smart and smart sustainable city concepts in the literature (Bibri & Krogstie, 2017).

A definition of the smart sustainable city concept was presented by the United Nations Economic Commission for Europe (UNECE) and the International Telecommunication Union (ITU): "A smart sustainable city is an innovative city that uses ICTs and other means to improve quality of life, the efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations concerning economic, environmental, social, as well as cultural aspects" (Ahvenniemi & Huovila, 2021; Akande et al., 2019). A smart sustainable city combines smartness with urban sustainability to provide the highest urban performance (Belli et al., 2020).

Webster and Leleux (2019) suggested sustainability, new technology, and participation, as the three conceptual pillars of smart sustainable cities. Parlina et al. (2021) on the other hand, analyzed the smart sustainable city literature using a deep learning-based topic detection algorithm and produced 30 topics polarized into 6 categories: (i) technology, (ii) energy, (iii) environment, (iv) transportation, (v) e-governance, and (vi) human capital and welfare. The multidimensional issues related to smart sustainable cities cause it to be an interdisciplinary field (Janik et al., 2020). Therefore, there are no frameworks in the literature able to address all dimensions of smart sustainable cities (Bibri & Krogstie, 2017).

As mentioned before, although the 'smart city' and 'sustainable city' concepts are sometimes used interchangeably in the literature, they are considered jointly for the exhibition of the 'smart sustainable city' concept in this study. Based on the definitions given above, the smart sustainable city is recognized as a city that has the features of both a smart city and a sustainable city simultaneously. In short, a smart sustainable city is recognized as a city that uses ICTs to ensure economic, environmental, and social sustainability.

## 3 | SMART SUSTAINABLE CITIES' PERFORMANCE MEASUREMENT AND PERFORMANCE INDICATORS

Regarding smartness and sustainability, various city rankings on different topics are popular and of high interest nowadays (Airaksinen et al., 2018). The analysis and ranking of a city's performance in smartness and sustainability are expected to help a city improve its position in the competitive game, improve its image, and attract businesses and workforce (Patrão et al., 2020; Stanković et al., 2017). Most of the assessment models/tools developed so far have been used by technology companies to promote the results of smart city technologies, rather than increasing the relevant cities' performance via feedback and decision-making guidance (Patrão et al., 2020). Accordingly, the developed city assessment and ranking models/tools, need to have the overall aims of determining the improvement areas of the relevant cities and developing urban and environmental strategies (Chang et al., 2018; Stanković et al., 2017).

In the literature, various models and tools for smartness and sustainability performance measurement have been introduced (Ahvenniemi et al., 2017; Shen et al., 2015; Sotirelis et al., 2022). Most of these models are based on TBL, that is, economic, environmental, and social dimensions (Airaksinen et al., 2018; Chen & Zhang, 2020; Hara et al., 2016) and require solid performance in all three dimensions simultaneously (Caldatto et al., 2021).

The multidimensional structure of the smart sustainability concept and the lack of a common operational definition cause this assessment to be a dynamic and continual process (Chang et al., 2018). Additionally, the conditions of cities also vary. As a result, to develop sustainability-compatible strategies, each city is obliged to determine indicators and tools distinctively for the assessment of its performance (Chen & Zhang, 2020; Tan et al., 2018).

To measure the progress being made in pursuing strategic targets towards becoming smart and sustainable, the decision-making process has to be assisted by using various tools (Ahvenniemi et al., 2017). In this context, for a city to be able to identify its strengths and weaknesses regarding becoming a smart sustainable city, a sustainability and smartness evaluation approach must be developed (Antolín et al., 2020). One initiative proposed for attaining this purpose has been the determination of performance indicators to develop a sustainability index and a smartness index (Antolín et al., 2020; da Silva Neiva et al., 2021). Today, many studies apply this indicator-based approach to assess the smart and sustainable characteristics of the cities (Akande et al., 2019; Amakpah et al., 2016; Carli et al., 2018; Dizdaroglu, 2017; Machado Junior et al., 2018).

The smartness and sustainability performance indicators are seen as a common set of criteria for assessing cities (Amakpah et al., 2016; Angelakoglou et al., 2019; Carli et al., 2018). Amakpah et al. (2016) argue that some common indicators could exist regardless of the physical and social differences between cities. However, some other researchers disagree with this statement. For example, Dizdaroglu (2017) argues that the selection of these criteria is mostly subjective and dependent on various factors. Correspondingly, it is also stated many times that no consensus is reached because of the varying definitions and models in the literature (Ahvenniemi & Huovila, 2021; Chang et al., 2018; Huovila et al., 2019).

The selection of the performance indicators to be included in a smartness and sustainability assessment model is vital for the assessment process because it could affect the smartness and sustainability performance of the cities dramatically. Therefore, this paper aims to fill the gap in the literature on smart and sustainable city performance measurement by defining the smart sustainable city concept, methods and tools used, and the selection process of the indicators.

## 4 | MATERIALS AND METHODS

For the analysis of indicators and indicator selection processes, the systematic literature review (SLR) methodology was followed. SLR aims to capture and evaluate the current research findings in a specific area of knowledge by answering research questions with data that satisfies pre-defined inclusion criteria (Snyder, 2019). SLR was chosen to guarantee a systematic and unbiased approach that produces reliable results (Farrukh et al., 2022). The PSALSAR framework suggested by Mengist et al. (2020) was followed for the review. PSALSAR stands for the six steps in the framework: Protocol, Search, Appraisal, Synthesis, Analysis and Report (See Figure 2).

After the research scope was determined, the research questions were formed in the Protocol step. The research scope of our study included the definitions of smart and sustainable cities, their performance measurement, and the selection of performance indicators. In line with these topics, the research questions were formed as follows:

> **RQ1.** *How can the smart and sustainable city concept be defined?*

> **RQ2.** *What methods or tools are used to measure the smartness and sustainability performance of a city?*

> **RQ3.** *How can the indicators for smart and sustainable city assessment be selected?*

In the Search step, the search strategy was developed. This strategy consists of the search queries and the respective databases. The search queries were focused on the following concepts: "smart city", "sustainable city", "urban smartness", "urban sustainability", and "smart sustainable city". The search was conducted in the title, abstract, and keyword search fields. To find all relevant studies, the following string was formed and used considering possible synonyms:

> "smart cit*" AND "assessment", "smart cit*" AND "measurement", "smart cit*" AND "evaluation", "smart cit*" AND "indicator", "smart cit*" AND "criteria",
> "urban smartness" AND "assessment", "urban smartness" AND "measurement", "urban smartness" AND "evaluation", "urban smartness" AND "indicator", "urban smartness" AND "criteria",
> "sustainable cit*" AND "assessment", "sustainable cit*" AND "measurement", "sustainable cit*" AND "evaluation", "sustainable cit*" AND "indicator", "sustainable cit*" AND "criteria",
> "urban sustainability" AND "assessment", "urban sustainability" AND "measurement", "urban sustainability" AND "evaluation", "urban sustainability" AND "indicator", "urban sustainability" AND "criteria",
> "smart sustainable cit*" AND "assessment", "smart sustainable cit*" AND "measurement", "smart sustainable cit*" AND "evaluation", "smart sustainable cit*" AND "indicator", "smart sustainable cit*" AND "criteria"

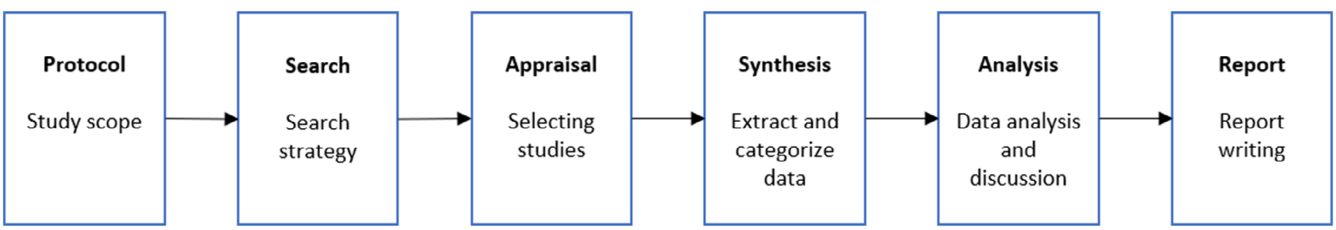


**FIGURE 2** The PSALSAR framework (adapted from Wurst et al. (2022)).

The Web of Science, Scopus, ScienceDirect, and Google Scholar databases were searched as they are internationally recognized, prominent and widely used abstract and indexing databases for peer-reviewed scientific literature. For testing the effectiveness of the search, queries were tried out in the databases determined for the study. The search has resulted in the retrieval of papers that were previously identified as relevant. Therefore, the search queries were considered valid.

The Appraisal step consisted of the evaluation of papers according to the predetermined inclusion and exclusion criteria. The papers were included in the study if they were written in the English language, if the keywords in the search queries existed in the title, abstract or keywords, and if they were published in a scientific peer reviewed journal in the last 15 years. 154 papers were selected from the literature using the inclusion criteria. All these papers were used for the definition of smart and sustainable cities. The papers were subjected to a filtering procedure before analysis. 64 of these papers had to be excluded because the text did not include the indicators or any description of the selection process for the indicators. At the end of the filtering procedure, 90 papers were found to be suitable for qualitative analysis.

Extraction and classification of data from the papers were conducted in the Synthesis step. Firstly, the papers were classified into three sub-categories according to the concepts they were dealing with: (i) Smart City/Urban Smartness, (ii) Sustainable City/Urban Sustainability, and (iii) Smart Sustainable City (See Table 1). After that, variables were identified to organize the papers: (i) Type, (ii) Author, (iii) Year, (iv) Application, (v) Indicators, and (vi) Selection. The Type variable showed if the paper was on smart cities, sustainable cities, or smart sustainable cities. The Author and Year variables were for the identification of the paper. The Application variable demonstrated the geographical region where the study was implemented. In the Indicator variable, all the indicators used for the measurement were listed and lastly the Selection variable comprised in what form the indicator selection procedure was conducted. All variables and the related data were extracted to an Excel spreadsheet and made ready for analysis.

In the Analysis step, all relevant information was retrieved from the data. Firstly, descriptive statistics were used to summarize the properties of the reviewed 90 articles. The articles were analyzed according to the keywords used, year of publication, journal the paper was published in, and the regional scale of the study. Further analysis was conducted on the indicators and their respective selection processes using the above-mentioned variables.

The Report step was the last step of the reviewing framework and consisted of the presentation of all information deduced from the analysis. All these steps are represented in detail under the "Results and Discussions" section.

## 5 | RESULTS AND DISCUSSION

In this section, firstly, the descriptive statistics are presented. The number of papers published by year is given in Figure 3. Figure 4 presents all keywords used in the papers and Table 2 presents the most frequently used keywords in the papers. The list of journals that include the highest number of articles (among the ones that were analyzed) can be seen in Table 3 and lastly in Table 4, the geographical regions of interest are presented. Looking at Figure 3, one can see that the number of papers is rising because the topic is becoming more critical with each day. The

**TABLE 1** Categorization of the reviewed articles according to the concepts they were dealing with (i.e., smartness, sustainability, smart sustainability).

| Category | # of articles | Study |
|---|---|---|
| Smart City / Urban Smartness | 25 | Sotirelis et al. (2022); Hajduk (2021); Hanine et al. (2021); Koca et al. (2021); Feizi et al. (2020); Ogrodnik (2020); Ur Rehman Tariq et al. (2020); Wong et al. (2020); Hajduk (2020); Milošević et al. (2019); Sharifi (2019); Zhu et al. (2019); Liu et al. (2018); Anand et al. (2017); Lopes and Oliveira (2017); Shi et al. (2018); Chowdhury and Dhawan (2017); Fang et al. (2016); Pang and Fang (2016); Concilio et al. (2013); Barrionuevo et al. (2012); Lazaroiu and Roscia (2012); Lombardi et al. (2012); Lombardi et al. (2011) |
| Sustainable City / Urban Sustainability | 50 | Kusakci et al. (2022); Yi et al. (2022); Ferreira, Corrêa, & de Alcantara Junior (2021); Lee and Xue (2021); Lee et al. (2021); Yi et al. (2021); Buzási and Jäger (2021); Caldatto et al. (2021); Li et al. (2021); Pedro et al. (2021); Xue et al. (2021); Mohsin et al. (2020); Chen and Zhang (2020); Chen (2020); Li and Yi (2020); Buzási and Jäger (2020); Steiniger et al. (2020); Chan and Lee (2019); Hély and Antoni (2019); Tang et al. (2019); Yi, Dong, and Li (2019); Yi, Li, and Zhang (2019); Zeng et al. (2019); Kaur and Garg (2019); Gonzalez-Garcia et al. (2018); Li et al. (2018); Yi et al. (2018); Boggia et al. (2018); Fernandes et al. (2018); Jiao et al. (2018); Tan et al. (2018); Dizdaroglu (2017); Zinatizadeh et al. (2017); Ghalib et al. (2017); Phillis et al. (2017); Musa et al. (2016); Lu et al. (2016); Tan and Lu (2016); Zhang et al. (2016); Ding et al. (2016); Xu et al. (2016); Egilmez et al. (2015); Shen et al. (2015); Yigitcanlar et al. (2015); Turcu (2013); Alpopi et al. (2011); Munier (2011); Rosales (2011); Shen et al. (2011); Moussiopoulos et al. (2010); Scipioni et al. (2008) |
| Smart Sustainable City | 15 | Quijano et al. (2022); de Oliveira et al. (2021); Pira (2021); Wey and Peng (2021); Antolín et al. (2020); Bhattacharya et al. (2020); Ozkaya and Erdin (2020); Wong et al. (2020); Akande et al. (2019); Bibri (2019); Yadav et al. (2019); Garau and Pavan (2018); Shmelev and Shmeleva (2018); Hara et al. (2016); Manitiu and Pedrini (2016) |

most frequently used keywords in the papers align with the search queries and the "Sustainability (Switzerland)" journal stands out with the greatest number of papers published.

Looking at the geographical regions of interest in Table 4, it can easily be seen that two third of the studies concern Asian and European countries. The number of studies conducted in Asia is dominated by China (27 out of 38), but no country or city in Europe stands out like China in Asia. There are only one to two publications each examining European countries such as France, Greece, Italy, Portugal, Spain, Turkey, the UK, etc.

As mentioned in the "Materials and Methods" section, the articles were examined elaborately to list all procedures and methods used for the selection of the assessment indicators. Accordingly, the articles were grouped and analyzed respectively according to:

i. whether they included any criteria for indicator selection or not,
ii. whether they applied a method for indicator prioritization/selection or not, and.
iii. whether they included a ready-made model for sustainability/smartness measurement or used only the indicators collected from the literature.

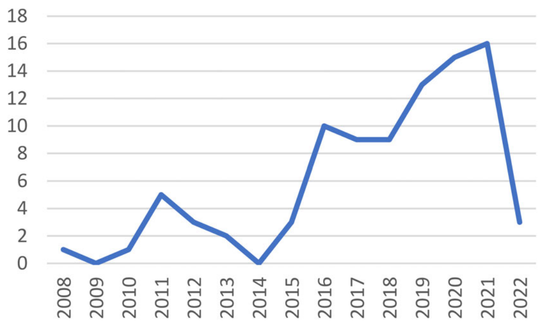


**FIGURE 3** The number of reviewed articles published by year.

At the beginning of the analysis, a clear division was noticed concerning the indicator selection processes. Some of the examined studies had predetermined criteria or principles for the indicator selection procedure. Therefore, the examined articles were first categorized according to whether they included any criteria for selecting indicators or not. 38 of the reviewed articles out of 90, had predetermined criteria or principles for the selection procedure. One of the

**TABLE 2** Most frequently used keywords in the reviewed articles.

| Keyword | Occurrence |
|---|---|
| Smart city | 19 |
| City | 19 |
| Sustainable city | 16 |
| Urban sustainability | 12 |
| Indicator | 12 |
| Sustainability | 11 |
| Sustainable development | 10 |
| Development | 10 |
| Sustainability assessment | 9 |

**TABLE 3** Journals in which the reviewed articles were published.

| Journal name | # of articles[a] |
|---|---|
| Sustainability (Switzerland) | 19 |
| Sustainable Cities and Societies | 10 |
| Journal of Cleaner Production | 9 |
| Habitat International | 4 |
| Cities | 4 |

[a]The number of articles does not sum up to 90, as only the journals with the highest number of articles were listed.


**FIGURE 4** Word cloud of keywords used in the reviewed articles.

**TABLE 4** The geographical regions considered in the reviewed articles.

| Region | # of articles | Study |
|---|---|---|
| Asia (Cambodia, China, India, Iran, Iraq, Japan, Malaysia, Pakistan, Taiwan) | 38 | Anand et al. (2017); Bhattacharya et al. (2020); Chan and Lee (2019); Chen (2020); Chen and Zhang (2020); Ding et al. (2016); Fang et al. (2016); Ghalib et al. (2017); Hara et al. (2016); Jiao et al. (2018); Lee et al. (2021); Lee et al. (2021); Li and Yi (2020); Li et al. (2018); Li et al. (2021); Liu et al. (2018); Lu et al. (2016); Mohsin et al. (2020); Musa et al. (2016); Pang and Fang (2016); Shen et al. (2015); Shi et al. (2018); Tan and Lu (2016); Tan et al. (2018); Wang et al. (2020); Wey and Peng (2021); Xu et al. (2016); Xue et al. (2021); Yadav et al. (2019); Yi et al. (2018); Yi, Dong, and Li (2019); Yi, Li, and Zhang (2019); Yi et al. (2021); Yi et al. (2022); Zeng et al. (2019); Zhang et al. (2016); Zhu et al. (2019); Zinatizadeh et al. (2017) |
| Europe (France, Greece, Hungary, Italy, Malta, Poland, Portugal, Romania, Serbia, Spain, Turkey, United Kingdom) | 22 | Akande et al. (2019); Alpopi et al. (2011); Antolín et al. (2020); Boggia et al. (2018); Buzási and Jäger (2020); Buzási and Jäger (2021); Concilio et al. (2013); Fernandes et al. (2018); Garau and Pavan (2018); Gonzalez-Garcia et al. (2018); Hajduk (2020); Hajduk (2021); Hély and Antoni (2019); Koca et al. (2021); Kusakci et al. (2022); Milošević et al. (2019); Moussiopoulos et al. (2010); Ogrodnik (2020); Quijano et al. (2022); Pedro et al. (2021); Scipioni et al. (2008); Turcu (2013) |
| N/A | 15 | Angelakoglou et al. (2019); Barrionuevo et al. (2012); Bibri (2019); Chowdhury and Dhawan (2017); Dizdaroglu (2017); Kaur and Garg (2019); Lazaroiu and Roscia (2012); Lombardi et al. (2011); Lombardi et al. (2012); Lopes and Oliveira (2017); Manitiu and Pedrini (2016); Munier (2011); Pira (2021); Sharifi (2019); Wong et al. (2020) |
| America (Brazil, Canada, Chile, Mexico, United States) | 7 | Caldatto et al. (2021); de Oliveira et al. (2021); Egilmez et al. (2015); Feizi et al. (2020); Ferreira et al. (2021); Rosales (2011); Steiniger et al. (2020) |
| Global | 5 | Sotirelis et al. (2022); Ozkaya and Erdin (2020); Phillis et al. (2017); Shen et al. (2011); Shmelev and Shmeleva (2018) |
| Oceania (Australia) | 2 | Ur Rehman Tariq et al. (2020); Yigitcanlar et al. (2015) |
| Africa (Morocco) | 1 | Hanine et al. (2021) |

prominent criteria was the consideration of the local conditions of the relevant cities. The studies conducted in China were at the forefront regarding this criterion. For example, Fang et al. (2016) constructed a quantitative analysis framework to understand the dynamic mechanism of smart low-carbon cities in China. They categorized the smart low-carbon city development indicators as (i) science and technology, (ii) resources and environment, (iii) economy and industry, (iv) facilities and functions, (v) critical capital, and (vi) institutional and cultural indicators. The first three types of indicators were related to endogenous power and the subsequent three types of indicators were related to exogenous stimuli.

Another example that expresses the importance of local conditions is the study done by Yi, Dong, & Li, (2019). In this study, the factors were divided into two groups such as internal and external factors. The internal factors referred to the specific structure and conditions of the respective city. The location, natural resources, and climate were some example factors included in this group. The external factors, on the other hand, included the improvable functions of the city, such as urban transportation. Another study conducted by Yi et al. (2022), investigated the sustainability performances of cities by using an MCDM method that considers the interrelationship among sustainability indicators. In this study, the correlation between the indicator values and assessment values of the three dimensions (i.e., economic, environmental, and social) of each city were analyzed. When the top three indicators affecting sustainable development were specified, it was stated that the difference among cities was caused by their varying local conditions.

Rosales (2011) stated that the inclusion of factors such as the metabolism of the city, the level of self-sufficiency of the urban system, city vulnerability, the certainty of land tenure, safety, and the quality of habitat are important for sustainability assessment. It is thought that the identification of local conditions is essential to resolve the gap between urban planning and cities' sustainability performance. Scipioni et al. (2008) adopted the ISO 14031 standard, which was developed by the International Organization for Standardization (ISO) and consists of performance indicators and context indicators. The context indicators in this standard define the city's economic, environmental, and social conditions.

As the properties covered under the three pillars of sustainable development were aimed to be demonstrated by sustainable cities, the sustainability concept was observed to be a principal guide for the indicator selection process. Some studies initially focused on these three pillars and built their assessment systems and indicators upon these economic, environmental, and social dimensions.

Data collection was another issue mentioned in the examined publications during the indicator selection process. Here, the quality of data is a key factor that forced the indicators to have various characteristics that were somewhat similar in meaning but conceptualized differently. Specifically, Ur Rehman Tariq et al. (2020) listed these characteristics briefly by suggesting that the data had to be (i) quantitative, (ii) publicly available, (iii) unbiased, (iv) free or of minimal cost, (v) collected at least annually, (vi) available for the relevant cities, (vii) uniformly managed at the national level, and (viii) should cover all aspects of the city. All criteria used in the publications, together with the varying terminology used and their descriptions, are listed in Table 5.

Providing a clear perspective for planners and meeting their needs for assessment, summarizing the characteristics and conditions of the city, and gaining the satisfaction of the community are the significant underlying objectives of the above-mentioned criteria (Moussiopoulos et al., 2010; Munier, 2011; Rosales, 2011). The criteria summarized in Table 5 can be referred to fulfill these objectives. Moussiopoulos et al. (2010) expressed that for a performance measurement system to meet the assessors' needs and satisfy the community, all indicators must be relevant, meaningful, transparent, testable, and easily understandable. Additionally, for the performance measurement system to suit the characteristics of the relevant area, the indicators must be clearly defined regarding calculation, the unit of measurement, sources, etc.

The quality of data influences the complementary indicator selection criteria dramatically. As can be seen in Table 5, many criteria are related to a certain characteristic of data. The four criteria most frequently proposed by the studies (among the others) are measurability, availability, relevance, and representativeness. While two of these criteria out of four (i.e., measurability and availability) are related to data quality, the remaining two (i.e., relevance and representativeness) are related to the scope of the indicator. Here, measurability is concerned with whether the data is measurable via various data collection methods (Quijano et al., 2022). In addition, regarding this criterion, the data should be quantitative and objective (Angelakoglou et al., 2019; Garau & Pavan, 2018). Availability is concerned with whether the data is easily attainable considering time, effort, and sources (Angelakoglou et al., 2019; de Oliveira et al., 2021). On the other hand, relevance and representativeness criteria focus on the indicators that are significant for the study and that reflect the state of the city (Garau & Pavan, 2018; Scipioni et al., 2008).

When the methods applied for indicator prioritization/selection are taken into consideration, some of the examined publications (24 out of 90) utilized specific methods, models, or tools. These selection/prioritization processes differ firstly regarding their top-down or bottom-up approaches. These two approaches were also referred to as "expert-led" and "citizen-led" approaches respectively (Steiniger et al., 2020; Turcu, 2013). The expert-led approach involves experts and international or national standards, whereas the bottom-up approach involves the participation of different stakeholders such as the local community (Mori & Christodoulou, 2012; Steiniger et al., 2020). Even though the expert-led paradigm could have the advantage of objectiveness, it could also cause difficulties for the local community during implementation (Mori & Christodoulou, 2012; Turcu, 2013).

Most studies adopted an expert-led approach, where meetings, panels, or workshops were organized, and surveys were conducted. In this context, the Delphi method (Chan & Lee, 2019; Liu et al., 2018; Mohsin et al., 2020; Wey & Peng, 2021), brainstorming (Caldatto et al., 2021) and cognitive maps (Caldatto et al., 2021; Fernandes et al., 2018) are among the decision-making techniques that were used for this purpose; and Principal Component Analysis (Lombardi et al., 2012; Manitiu & Pedrini, 2016; Shmelev & Shmeleva, 2018), Correlation Analysis (Buzási & Jäger, 2021) and Inter-relationship Analysis (Jiao et al., 2018) are among the statistical methods that were used. Additionally, the DPSIR Framework (Driver-Pressure-State-Impact-Response Framework) developed by the European Commission was used for determining environmental, social, and cultural indicators to assess the sustainability and smartness of cities (Manitiu & Pedrini, 2016; Xue et al., 2021), and the MobiSim Simulation Tool (Hély & Antoni, 2019) was used for geographical analysis to support sustainable planning.

Finally, when the sources of indicators used in the studies are considered, it can be seen that some of the studies used ready-made models or systems that could take the form of an index, a framework, a report, etc., while some others only studied the literature on indicators and came up with a set of indicators suitable for assessing the sustainability and/or smartness of cities.

The "ISO 37120 standards" by the International Organization for Standardization (ISO) (Hajduk, 2020; Hajduk, 2021), the "Sustainable Development Indicators" by the Organization for Economic Co-operation and Development (OECD) (Pira, 2021), the "Environment Protection Standards of the European Environment Agency" (Chen, 2020), the "BRIC Framework (Baseline Resilience Indicators for Communities)" (Zhu et al., 2019), the "SAFE Model (Sustainability Assessment by Fuzzy Evaluation)" (Phillis et al., 2017), and "Neighborhood Sustainability Assessment" (Pedro et al., 2021) are some of the models/tools used for this purpose. Here, the ISO 37120 standard, in particular, is a framework adopted in many studies. It consists of 104 indicators, of which 45 are core and 59 are supporting. The indicators are grouped under 19 themes: economy, education, energy, environment and climate change, finance, governance, health, housing, population, and social conditions, recreation, safety, solid waste, sport and culture, telecommunication, transportation, urban/local agriculture and food security, urban planning, wastewater, and water.

Furthermore, the "Smart Cities: Ranking of European Medium-Sized Cities" report (Hajduk, 2021; Koca et al., 2021; Ozkaya & Erdin, 2020), the "Smart City Index Master" (Pira, 2021), the "Gross Social Feel Good" (Hara et al., 2016), and the "US & Canada Green City" indexes (Egilmez et al., 2015) were utilized to assess the sustainability and/or smartness of cities. Especially, the "Smart Cities: Ranking of European Medium-Sized Cities" edited by the Centre of Regional Science, Vienna University of Technology is a commonly used report. This report consists of 74 indicators grouped under smart economy, smart people, smart governance, smart mobility, smart environment, and smart living categories.

China, in particular, was observed to have many government-initiated applications, for example, the "PSF Model (People-Oriented, City-System, and Resource-Flow)" (Shi et al., 2018; Wang et al., 2020), the "Technical Criterion for Ecosystem Status Evaluation" (Chen, 2020), the "NNUP (National New Urbanization Planning)" (Xu et al., 2016), and the statistical yearbooks (Tan & Lu, 2016; Zhang et al., 2016). All these applications were also used as a source to select assessment indicators. For example, the PSF model by the National

**TABLE 5** The criteria used for indicator selection in the reviewed articles.

| Criterion | Study | Description |
|---|---|---|
| Availability<br>Accessibility | Scipioni et al., 2008; Ding et al., 2016; Chowdhury & Dhawan, 2017; Tan et al., 2018; Gonzalez-Garcia et al., 2018; Akande et al., 2019; Angelakoglou et al., 2019; Buzási & Jäger, 2020; Ogrodnik, 2020; de Oliveira et al., 2021; Quijano et al., 2022 | The indicator data should be easily attainable through available resources and databases. |
| Measurability<br>Quantifiability<br>Quantitativeness<br>Objectivity | Moussiopoulos et al., 2010; Ghalib et al., 2017; Garau & Pavan, 2018; Gonzalez-Garcia et al., 2018; Angelakoglou et al., 2019; Antolín et al., 2020; Buzási & Jäger, 2020; Ur Rehman Tariq et al., 2020; Quijano et al., 2022; Yi et al., 2022 | The indicators should be measurable via different methods and should rely on objective data. |
| Relevance<br>Significance | Scipioni et al., 2008; Alpopi et al., 2011; Ghalib et al., 2017; Garau & Pavan, 2018; Angelakoglou et al., 2019; Antolín et al., 2020; Buzási & Jäger, 2020; Ferreira et al., 2021; Quijano et al., 2022 | The indicators should be critical and should be relevant to urban issues and policies. |
| Representativeness<br>Specificity | Scipioni et al., 2008; Munier, 2011; Dizdaroglu, 2017; Garau & Pavan, 2018; Gonzalez-Garcia et al., 2018; Buzási & Jäger, 2020; Ferreira et al., 2021; Yi et al., 2022 | The indicators should be representative of and specific to the city. |
| Comparability | Munier, 2011; Chowdhury & Dhawan, 2017; Dizdaroglu, 2017; Garau & Pavan, 2018; Antolín et al., 2020; Ur Rehman Tariq et al., 2020; Ferreira et al., 2021 | The indicators should be comparable to goals and other indicators. |
| Completeness<br>Comprehensiveness | Chowdhury & Dhawan, 2017; Angelakoglou et al., 2019; Antolín et al., 2020; Buzási & Jäger, 2020; Yi et al., 2021; Quijano et al., 2022 | The indicators should consider and cover all aspects and dimensions, such as economic, environmental, and social. |
| Independence | Chowdhury & Dhawan, 2017; Ghalib et al., 2017; Angelakoglou et al., 2019; Buzási & Jäger, 2020; Ur Rehman Tariq et al., 2020; Quijano et al., 2022 | The indicators should not be externally influenced and not influence other indicators' assigned values. |
| Simplicity<br>Intelligibility<br>Familiarity<br>Understandability<br>Unambiguousness | Munier, 2011; Chowdhury & Dhawan, 2017; Dizdaroglu, 2017; Ghalib et al., 2017; Angelakoglou et al., 2019; Antolín et al., 2020 | The indicators should be easily interpreted by users. |
| Reliability<br>Reputation<br>Validity<br>Integrity | Scipioni et al., 2008; Ding et al., 2015; Garau & Pavan, 2018; Angelakoglou et al., 2019; de Oliveira et al., 2021 | The indicator data should be trustworthy regarding source and content, able to be verified, and methodologically sound. |
| Responsiveness<br>Maneuverability<br>Effectivity<br>Sensitivity | Moussiopoulos et al., 2010; Dizdaroglu, 2017; Ghalib et al., 2017; Liu et al., 2018 | The indicators should be responsive, flexible, and sensitive to changes. |
| Consistency<br>Stableness | Scipioni et al., 2008; Dizdaroglu, 2017; Yi et al., 2021 | The indicators should be consistent over time and should be compatible with the planned actions. |
| Cost-effectiveness | Moussiopoulos et al., 2010; Munier, 2011; Ur Rehman Tariq et al., 2020 | The indicator data should be of minimal cost regarding both capital and time. |
| Currency<br>Recency<br>Timeliness | Dizdaroglu, 2017; de Oliveira et al., 2021; Ferreira est al., 2021 | The indicator data should be up to date and collected regularly. |
| Consensus | Moussiopoulos et al., 2010; Ferreira et al., 2021 | The indicators selected should be the result of consensus. |

Center for Intelligent Urban Research states that the smart city consists of three layers: the input support layer, the application layer, and the target layer. The input support layer includes the smart infrastructure, human and social capital; the application layer includes the smart economy, smart environment, and smart governance; and lastly, the target layer includes the quality of life.

Finally, when the indicators used in the relevant articles were examined according to the dimensions used for grouping them, it was observed that they were generally grouped under three main categories: (i) economic, (ii) environmental, and (iii) social. These three categories consisted of a variety of sub-dimensions and indicators.

Under "economy", topics such as employment, the flexibility of the job market, innovation, productivity, entrepreneurship, e-commerce, transformation capacity, and international embeddedness are mentioned (Akande et al., 2019; Bhattacharya et al., 2020; Koca

**TABLE 6** Dimensions used for grouping the indicators used for smartness/sustainability assessment and their underlying topics.

| Dimension | Topic | Study |
|---|---|---|
| Governance (Management, institutional) | Strategies and perspectives | Lazaroiu & Roscia, 2012; Concilio et al., 2013; Milošević et al., 2019; Koca et al., 2021 |
| | Public and social services | Lazaroiu & Roscia, 2012; Concilio et al., 2013; Bibri, 2019; Sharifi, 2019; Ozkaya & Erdin, 2020; Koca et al., 2021 |
| | E-government service | Lombardi et al., 2012; Lopes & Oliveira, 2017; Shi et al., 2018; Bibri, 2019; Milošević et al., 2019; Mohsin et al., 2020; Wang et al., 2020; Pira, 2021 |
| | Government data availability | Lopes & Oliveira, 2017; Milošević et al., 2019; de Oliveira et al., 2021; Pira, 2021; Sotirelis et al., 2022 |
| | Transparency | Shen et al., 2011; Lazaroiu & Roscia, 2012; Concilio et al., 2013; Bibri, 2019; Milošević et al., 2019; Sharifi, 2019; Ozkaya & Erdin, 2020; Koca et al., 2021; Wey & Peng, 2021; Sotirelis et al., 2022 |
| | Citizen participation in decision-making | Shen et al., 2011; Lazaroiu & Roscia, 2012; Concilio et al., 2013; Musa et al., 2016; Lopes & Oliveira, 2017; Bibri, 2019; Sharifi, 2019; Milošević et al., 2019; Hajduk, 2020; Ozkaya & Erdin, 2020; Steiniger et al., 2020; Ur Rehman Tariq et al., 2020; Wang et al., 2020; Ogrodnik, 2020; Hajduk, 2021; Wey & Peng, 2021; de Oliveira et al., 2021; Koca et al., 2021; Sotirelis et al., 2022 |
| Planning (Organization) | Planning of space, mobility, buildings, etc. | Moussiopoulos et al., 2010; Dizdaroglu, 2017; Fernandes et al., 2018; Antolín et al., 2020; Hajduk, 2020 |
| Living (Quality of Life) | Housing | Lazaroiu & Roscia, 2012; Concilio et al., 2013; Bibri, 2019; Milošević et al., 2019; Sharifi, 2019; Ozkaya & Erdin, 2020; Ur Rehman Tariq et al., 2020; Hanine et al., 2021; Koca et al., 2021 |
| | Health | Lazaroiu & Roscia, 2012; Concilio et al., 2013; Chowdhury & Dhawan, 2017; Lopes & Oliveira, 2017; Liu et al., 2018; Bibri, 2019; Sharifi, 2019; Milošević et al., 2019; Ur Rehman Tariq et al., 2020; Ozkaya & Erdin, 2020; Caldatto et al., 2021; Hanine et al., 2021; Koca et al., 2021; Sotirelis et al., 2022 |
| | Culture and education | Lazaroiu & Roscia, 2012; Lombardi et al., 2012; Concilio et al., 2013; Chowdhury & Dhawan, 2017; Lopes & Oliveira, 2017; Liu et al., 2018; Bibri, 2019; Milošević et al., 2019; Sharifi, 2019; Ozkaya & Erdin, 2020; Koca et al., 2021; Sotirelis et al., 2022 |
| | Tourism | Lazaroiu & Roscia, 2012; Concilio et al., 2013; Lopes & Oliveira, 2017; Milošević et al., 2019; Ozkaya & Erdin, 2020; Koca et al., 2021 |
| | Social cohesion | Lazaroiu & Roscia, 2012; Concilio et al., 2013; Bibri, 2019; Milošević et al., 2019; Sharifi, 2019; Koca et al., 2021 |
| | Safety | Lazaroiu & Roscia, 2012; Concilio et al., 2013; Chowdhury & Dhawan, 2017; Lopes & Oliveira, 2017; Bibri, 2019; Milošević et al., 2019; Sharifi, 2019; Bhattacharya et al., 2020; Ur Rehman Tariq et al., 2020; Ozkaya & Erdin, 2020; Koca et al., 2021; Sotirelis et al., 2022 |
| Infrastructure | Physical infrastructure (Transportation, water, and power supply systems, etc.) | Fernandes et al., 2018; Yadav et al., 2019; Zhu et al., 2019 |
| | ICT infrastructure (Data availability, internet access, information sharing) | Shi et al., 2018; Liu et al., 2018; Wang et al., 2020; Quijano et al., 2022 |
| Mobility | Transport systems | Lazaroiu & Roscia, 2012; Concilio et al., 2013; Lopes & Oliveira, 2017; Bibri, 2019; Milošević et al., 2019; Yadav et al., 2019; Ozkaya & Erdin, 2020; Koca et al., 2021; Sotirelis et al., 2022 |
| | Energy sources for transport | Lopes & Oliveira, 2017; Quijano et al., 2022 |
| | Services (Transport information, Car/bike sharing) | Lopes & Oliveira, 2017; Bibri, 2019; Hanine et al., 2021 |
| Technology | Information and communication | Chowdhury & Dhawan, 2017; Fernandes et al., 2018; Yadav et al., 2019 |
| | Science, research, education | Moussiopoulos et al., 2010; Fang et al., 2016; Pang & Fang, 2016 |
| Energy | Energy consumption | Moussiopoulos et al., 2010; Egilmez et al., 2015; Chan & Lee, 2019; Hajduk, 2020; Mohsin et al., 2020 |
| | Renewable energy sources | Moussiopoulos et al., 2010; Anand et al., 2017; Dizdaroglu, 2017; Lopes & Oliveira, 2017; Chan & Lee, 2019; Yadav et al., 2019; Hajduk, 2020; Mohsin et al., 2020; Quijano et al., 2022 |

et al., 2021; Milošević et al., 2019; Sharifi, 2019; Wey & Peng, 2021). GDP (Gross Domestic Product) per capita (Yi, Dong, & Li, 2019), self-employment rate (Sharifi, 2019), the employment rate in high technology and innovation industries (Wang et al., 2020), and amount of foreign investment (Yi et al., 2018), could be given as examples to the economic indicators.

Energy, pollution, waste, resources, and environmental protection were some themes mentioned under the "environment" dimension (Chowdhury & Dhawan, 2017; Lazaroiu & Roscia, 2012; Manitiu & Pedrini, 2016; Sotirelis et al., 2022; Ur Rehman Tariq et al., 2020). Share of solid waste recycled (Akande et al., 2019), particulate matter emissions (Pira, 2021), and domestic water use (Wey & Peng, 2021) are some examples of environmental indicators.

The "society" dimension consisted of issues such as demography, health, safety, education, and culture (Caldatto et al., 2021; Hara et al., 2016; Kaur & Garg, 2019; Phillis et al., 2017; Shen et al., 2015). Literacy rate (Bhattacharya et al., 2020), number of hospital beds (Shen et al., 2015), the share of murders and violent deaths (Akande et al., 2019), and teacher-student ratio (Ding et al., 2015) are some social indicators mentioned under this dimension.

In addition to these three pillars, some other dimensions were also encountered, which were sometimes given under the economy, environment, and society dimensions. The distinguishable (most commonly encountered) dimensions were governance, planning, living, infrastructure, mobility, technology, and energy (See Table 6 for details).

Building a smart and sustainable city requires governing bodies to develop strategies and take respective administrative actions. In a smart sustainable city, citizens are expected to participate in decision-making and governments are expected to be transparent. The smartness aspect of the city forces governments to digitalize public and social services (i.e., e-government applications) and provide open data.

Urban planning includes the design of space, transport, building, and housing in the city. With its broad content, the planning dimension is very much related to the life quality of citizens. Another dimension that deals with the quality of life, is living conditions. The fundamental necessities such as housing, health, and security are included in performance measurement systems together with the educational, cultural, and touristic facilities.

The number and variety of services provided by the cities are also other important aspects. But together with these services, access becomes a critical matter. Access to services and facilities is enabled via mobility and ICT. Some of the reviewed studies dwelled upon these topics under the infrastructure dimension, whereas some others included them separately.

For a city to improve the citizens' quality of life, many physical and digital services must be provided. But these services increase energy consumption drastically. Therefore, studies also focus on the usage of renewable energy sources in order not to jeopardize the sustainability of the city.

## 6 | CONCLUSIONS

To evaluate the performance of cities regarding their smartness and sustainability, there exist many steps to be followed. Before taking these steps, the indicators that reveal what city systems are built upon should be determined. However, the selection of the appropriate indicators is not a straightforward process, as there are many different definitions proposed for smartness and sustainability, and there is no consensus on these definitions. In this study, firstly the concepts of smart, sustainable, and smart sustainable cities were introduced to present a general idea. After that, studies concerning smart and/or sustainable city performance measurement in the literature were examined. For this purpose, the Web of Science, Scopus, ScienceDirect, and Google Scholar databases were searched using an SLR framework. Articles related to smart city, sustainable city, and smart sustainable city concepts that were published in the last 15 years were chosen to be analyzed to gain insight into the indicator selection processes.

In these articles, China was seen to be a leading country in researching the evaluation of the smartness and sustainability of cities. A couple of reasons behind this could be the communist regime (Sustainable Development Goals Knowledge Platform, 2021), China's increasingly unstable and unsustainable economy in the past (Roach, 2019), and the challenges caused by rapid urbanization (Wang et al., 2020; Yi et al., 2022). In addition, commitment to the economic, environmental, and social goals of the 2030 Agenda is also undoubtedly a valid reason. China, with a holistic approach, funds actions towards sustainable development, implements integrated strategies, and encourages public participation and local innovative solutions by launching projects and programs (Jiang, 2020). The topic was also acknowledged globally, as it should be.

Because the smart sustainable city concept is relatively new, fewer papers were attained from the literature. In total, 90 studies were gathered and analyzed. These articles were grouped and analyzed respectively according to the making use of (i) criteria for indicator selection, (ii) a method for indicator prioritization/selection, and (iii) a ready-made model for sustainability/smartness measurement or indicators collected from the literature.

Measurability, availability, completeness, relevance, independence, reliability, currency, responsiveness, simplicity, representativeness, cost-effectiveness, consistency, comparability, and consensus were among the criteria identified from the literature set to distinguish performance indicators (See Table 5 for details). The quality of data was observed to be one of the main concerns. The selection of a performance indicator was affected by the fact that its data was measurable via several methods, easily attainable, trustworthy, verified, and up to date. Measurability, availability, reliability, and representativeness were the most frequent criteria in the literature that were used for indicator selection.

Decision-making techniques such as brainstorming, the Delphi method, cognitive maps, etc., and statistical methods such as Principal Component Analysis, Cluster Analysis, Correlation Analysis, etc. were frequently utilized in the papers that made use of methods or tools for the indicator selection process. In most of these studies, an expert-led approach was applied where meetings, panels, workshops, or surveys were conducted to get the opinions of field experts.

Standards presented by well-known, credible organizations such as the ISO, OECD, and European Environment Agency or the previous literature on indicators were made use of for achieving a credible performance measurement system. The ISO 37120 standard, which consists of 104 indicators under 19 dimensions, and the "Smart Cities: Ranking of European Medium-Sized Cities" report by Giffinger et al. (2007), which consists of 74 indicators under 6 dimensions, were two frequently used models.

It was also realized that the dimensions under which the indicators were grouped varied across studies. The well-accepted structure of sustainable development (i.e., economic, environmental, social) was taken as a basis in most of the studies. In addition to these three pillars, governance, planning, living conditions, infrastructure, mobility, technology, and energy were included in many frameworks. In these frameworks, quality of life was observed to have great importance. And because of the significance of access to the physical and digital services provided by the city, mobility and ICT were many times addressed under different dimensions.

As can be understood, the construction of measurement systems for smart sustainable city performance evaluation may follow varying paths. The path chosen may depend on the city chosen, the available data, or the approach taken by the decision-makers. This study pointed out that in most of the studies, an expert-led approach was applied to indicators collected from the smart and sustainable city performance measurement literature. This way of thinking in the literature revealed the need for more citizen-led and global approaches to these performance measurement systems.

It is also thought to be important that all stakeholders of a smart and sustainable city must be taken into account while constructing a performance measurement system. The government, citizens, companies, institutions, and the environment are expected to be affected by the transformation of the cities. Therefore, it must be guaranteed that the performance measurement systems consist of indicators that are about each stakeholder and do not compromise one side's benefit over the others. This matter also holds for the "smartness" and "sustainability" sub-dimensions. Both concepts must be considered simultaneously while building the performance measurement system.

Today, building smart sustainable cities or transforming cities into smart and sustainable ones is an obligation but numerous limitations and challenges lie ahead in this respect. The increasing amount of data (Huovila et al., 2019) and the resultant innovative solutions (Bibri, 2019) create opportunities to establish and administrate smart sustainable cities but at the same time challenges the implementation of the 2030 Agenda. The everchanging definition of sustainable development and the availability of reliable data complicates the evaluation of sustainability performance. Although not all countries possess data regarding the SDGs, they have the responsibility to measure their performance to make progress towards achieving these goals. It appears reasonable to make use of the indicators suggested in the literature, but suitability and accountability are always in question. In this respect, this study suggests a set of criteria compiled from the literature that can be used to evaluate the performance measurement indicators present at hand. Moreover, the smartness dimension is included in the sustainability concept and the smartness and sustainability performance indicator selection procedures in the literature are elaborated on to guide the smartness and sustainability assessment process towards the achievement of the 2030 Agenda, SDG 11 in particular.

In this respect, the main objective of this study is to form a basis for smart sustainable city assessment and to contribute to the constitution and administration of these cities by analyzing the concept and what it's built upon (i.e., the indicators). By understanding how these indicators were determined in the past, the very first step of achieving a smart sustainable city, as required by the 2030 Agenda, could be taken.

This study showed that the varying conditions of a city and the availability of data are major issues for applying standard models for smartness and sustainability performance measurement. Using the indicator selection criteria derived from this study, more cities could join the ongoing agenda and city authorities could form their own index for assessing performance that is most suitable to their specific conditions and available data at hand. The wide-reaching implementation made possible with customization could be more effective in the realization of sustainable development goals.

From a theoretical perspective, this study critically analyzed and evaluated the studies on smart and/or sustainable cities and provided a basis for the measurement of the smartness and sustainability of cities. In the SLR conducted in the study, the smart city, sustainable city, and smart sustainable city concepts are defined and the indicators for the assessment of the smartness and sustainability of cities and the selection processes of these indicators are analyzed. On the other hand, the studies were grouped based on the use of (i) selection criteria, (ii) selection methods/tools, and (iii) models used for performance indicators. In addition, this SLR contributes to the literature by deducing criteria for evaluating performance assessment indicators. This study can support other studies and applications on creating and assessing smart and sustainable cities and can serve as a basis for knowledge development and extending research in this domain. It serves as the ground for future research.

The results of this study can be used by local authorities to determine the performance measurement indicators that will be used in the "Smart Sustainable City Performance Index" to be formed for their cities. As it provides the city authorities with a basis for smart sustainable city assessment, this study gives them the opportunity to measure their progress towards the SDGs and therefore, support the implementation of the Agenda 2030. Moreover, the study can also provide to meet the common challenges faced by cities based on the environmental, social, and economic dimensions of sustainable development. In addition, policymakers can use this study for developing legislative frameworks and for the assessment of different policies, regulations, strategies, and scenarios together with their expected impacts.

It was observed that the previous research respectively on smart cities and sustainable cities, contained studies that used both criteria and methods for selecting indicators. However, this was not the case for smart sustainable cities. Therefore, as future research, a "Smart Sustainable City Performance Index" can be developed by applying appropriate decision-making techniques to prioritize smart sustainable performance indicators. Another idea for future research could be the investigation of studies on smart and sustainable cities using qualitative methods such as meta-analysis and the results could be compared. Additionally, the indicators themselves could be examined in detail to develop a standard system that could provide an opportunity for global comparison among cities, if possible.

This review has some limitations such as the type of publications that was focused on. Only peer-reviewed journal articles were gathered for analysis; books, book chapters or other publication types were not included in the review. Further, the current research was conducted through the Web of Science, Scopus, ScienceDirect, and Google Scholar databases; therefore, articles from apart from these databases are not included in this review. Another limitation could be the language of the selected articles (i.e., English) that can lead a bias towards certain types of research. Further limitation could be the fact that the topic of the study comprises concepts that own different representations in the literature. Terms such as "eco-city" or "digital city" could be included for further analysis.

## CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

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