sustainability

Review

Criteria for Smart City Identification: A Systematic Literature Review

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Abstract: The transition towards greater smartness is an emerging trend in the development of modern cities. This transition manifests itself in the widespread adoption of information and communication technologies (ICTs), cloud computing, Internet of Things (IoT), and other technological tools aimed at improving the level of city smartness. Although numerous studies have focused on the smart city (SC) phenomenon, knowledge about empirical criteria that can be used to define a city as "smart" and to measure the degree of a city's "smartness" remains limited. The present study aims to bridge this knowledge gap by a systematic literature review of recent studies, in which various empirical criteria are used for SC identification. The study helps to identify a total of 48 SC identification metrics, which are further split into three main categories—smart digital technology, living conditions, and environmental (ecological) sustainability. Among these groups of criteria, the "smart digital technology" group of metrics appears to be the most popular, while criteria pertinent to "ecological sustainability" are applied considerably less often. As the study also reveals, only about half of the criteria used by empirical studies for SC identification actually relate to urban residents' needs, with the rest being general technological measures. Therefore, for a balanced SC assessment, we suggest a ranking system based on the nine most important metrics, which equally represent all the main aspects of the SC phenomenon while placing an emphasis on the improvement of the quality of life of local residents. The proposed system is applied to several major cities across the globe to demonstrate its use and usefulness.

Keywords: smart city; criteria; systematic literature survey

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1. Introduction

In 2018, there were some 7.6 billion people in the world, of which 4.2 billion (or ~55%) lived in urban areas. By 2050, the global population is projected to increase to around 9.8 billion, of which some 6.7 billion will be living in cities [1].

According to the UN estimates [2], by 2030, the number of megacities with more than 10 million residents is expected to exceed 40. It is also expected that such megacities will consume 81% of the world's resources, while by 2050, energy demand might rise to about 620 exajoules (EJ) [3].

Although the rate of urbanization in Europe has been slowing in recent years, ~72% of the continent's population currently lives in urban areas, and in some countries, such as the Netherlands, the rate of urbanization already exceeds 90% [4].

As urbanization progresses, many cities accumulate problems, such as environmental degradation [5,6], deteriorating infrastructure [7], poverty [8], and societal inequality [6,8]. Solving these problems directly affects the level of well-being of citizens, the environmental situation, and the sustainable development of the city as a whole.

According to the UN, cities play a key role in promoting sustainable development, and the UN Sustainable Development Goals (SDGs) explicitly refer to Sustainable Cities and Communities as the 11th SDG, while the UN Agenda 2030 emphasizes an objective of making cities more inclusive, safe, resilient, and sustainable so as to improve people's lives [9].

In order to address urban issues, the smart city concept has emerged as one of the possible solutions.

On the positive side, many cities, especially in high-resource countries, have begun the process of transition towards greater smartness. This process manifests itself, inter alia, in a widespread adoption of information and communication technologies (ICTs) and a rapid spread of "big data", cloud computing, and Internet of Things (IoT) as ways of modernizing and improving urban performance and services [10–12].

Although the concept of smart cities (SCs) is still evolving, it has gained considerable interest among researchers [12,13] as well as among ordinary web users (Figure 1).

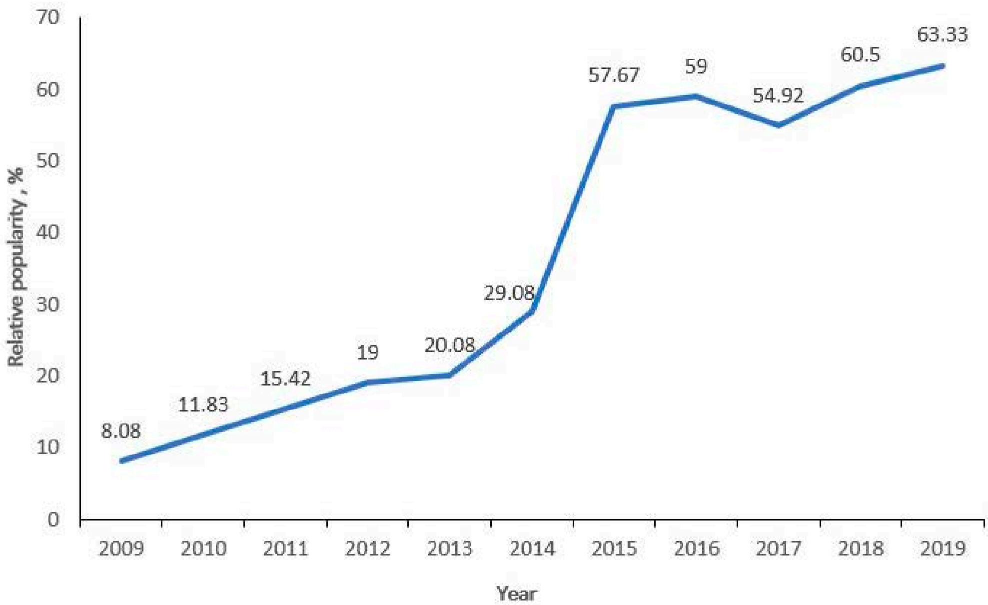

Figure 1. Web search interest in the smart city topic—relative popularity of queries in 2009–2019 (Source: Calculated using Google Data (n.d.)). *Note:* The relative popularity metric is calculated by dividing the number of searches on the topic by the total number of searches on any topic over a given period of time. The results are then ranked on a 100-point scale (from low (0) to high (100)), reflecting the popularity of the topic relative to the popularity of queries on any other topic.

As is well documented, new technological tools associated with SC transition help to monitor air pollution [14,15], optimize motor traffic [16], increase resource use efficiency [17], stimulate citizens' participation in urban affairs [18,19], and improve human welfare [20].

Previous studies of the SC phenomena looked into the nature and origin of SCs [21,22], quality of life in SCs [23], and ethical aspects of using artificial intelligence and big data technologies [24]. Yet only a handful of studies have attempted to determine empirical criteria that can help to identify SCs and gauge their progress towards greater smartness.

As of today, eight literature surveys have been carried out on the SC topic [25–32]. Thus, in an early survey on the topic, Lombardi et al. [25] identified five main groups of components that characterize a city as smart: citizen participation (smart governance), people's capabilities (smart human capital), efficiency of resource use (smart environment), quality of life (smart lifestyle), and competitiveness (smart economy).

In a separate study, Anthopoulos [28] suggests that a modern SC should include the following attributes—resources, transportation, urban infrastructure, living, government, economy, and coherency—all of which address the digital divide, social relations, and ICT connectivity. This classification of SC identification criteria corresponds to that suggested by Tregua et al. [26], who define the following three-tier structure of SCs: environmental component (smart environment and smart mobility), social component (smart people, smart lifestyle, and smart management), and economic component (smart economy).

In another literature survey, Albino et al. [27] examine the meaning of the word "smart" in the context of cities, emphasizing the following four most common SC characteristics: efficient network infrastructure, business-led urban development and creativity that fosters urban growth, social integration, and environmental preservation. This definition corresponds to that suggested by Silva et al. [29], who define four main attributes that create an SC: resilience (infrastructure and management, pollution and waste, energy and climate change, social issues, economy, and health), quality of life (emotional and financial well-being), level of urbanization (technology, economy, infrastructure, and governance), and intelligence (social, environmental, and economic indicators).

According to another recent study by Marchetti et al. [30], an SC is a place where government transparency is a common asset, where people are policy-driven and interested in participating in decision making, where shared cultural and recreational infrastructure is offered, where everyday needs are supported by urban amenities, and where a high level of comfort is provided. In this conceptual framework, an SC helps to reduce inequality and increase social, territorial, and economic integration by building effective relationships between a city's assets, services, and social environment, citizens' participation in urban affairs, and governmental transparency. These SC components are similar to those identified by Lim et al. [31]: ICT infrastructure and human, social, and institutional capital. In another recent survey, however, Li et al. [32] single out a different set of SC identification criteria, viz.: technological innovation, a smart economy, smart infrastructure, smart services, smart mobility, and a smart environment.

There are several international rankings that define criteria for classifying a city as smart, such as, e.g., the Italian ICity [33], the IMD Smart Cities Index [34], IESE City in Motion Index [35], CITYkeys [36], the European Smart Cities Ranking [37], and others. Yet these classification systems differ regarding how city smartness is assessed and measured. Such classifications are also not always balanced in terms of the social, economic, and environmental components that are key dimensions of sustainability. In particular, while one group of studies place an emphasis on ICT and infrastructure [21,27,30–32], other studies emphasize the social performance of cities and their physical environment [25,26,28].

These differences can be attributed to the fact that the SC phenomenon crosses different scientific fields, and studies covering specific research fields can lead to different results. Therefore, a holistic approach, based on an interdisciplinary review of the relevant literature, is needed to identify the full range of attributes that underline the existence and functioning of SCs.

The main goal of this study is to systematically review the recent literature on the SC phenomenon so as to develop a comprehensive and balanced set of empirical criteria that can help us to distinguish between SCs and the remaining urban localities and assess a city's progress towards greater smartness.

To achieve this goal, the present study employs the Preferred Reporting Items for Systematic Reviews (PRISMA) tools. In contrast to traditional survey methods, such as content analysis [38], analysis of joint citations [39], or citation-based content clustering (see, e.g., [40]), the PRISMA methodology prevents arbitrary decision making regarding the selection of studies [41,42]. In particular, this survey method uses the Boolean search query, which helps to identify relevant studies while providing fully replicable results [42]. This approach provides an important advantage over traditional surveys, which mainly use a random search method or "snowballing", and can be selective in terms of search scope and thus potentially overlook important bibliographic information [42,43]. Importantly, the PRISMA method employs the screening and data extraction tool known as "Covidence" [44], which helps to reduce the potential selection bias associated with prioritizing studies concomitant with a particular research perspective [41].

Previous studies of the SC phenomenon employed some elements of the PRISMA methodology to conduct a general analysis of SC development [31], identify different components of SC governance [45], and summarize support tools for active ageing in SCs [46]. However, to the best of our knowledge, no studies that conducted to date have attempted to use the PRISMA methodology to determine a comprehensive set of criteria that can help in distinguishing between SCs and the remaining urban localities and assess a city's progress towards greater smartness, which the present study aims to accomplish.

More than 40 different definitions of SCs are currently found in the literature (see Appendix A). While some definitions emphasize ICT and modern infrastructure [14,16,24,47–53], other SC categorizations emphasize the importance of human capital and quality of life [54–62] (see Figure 2A).

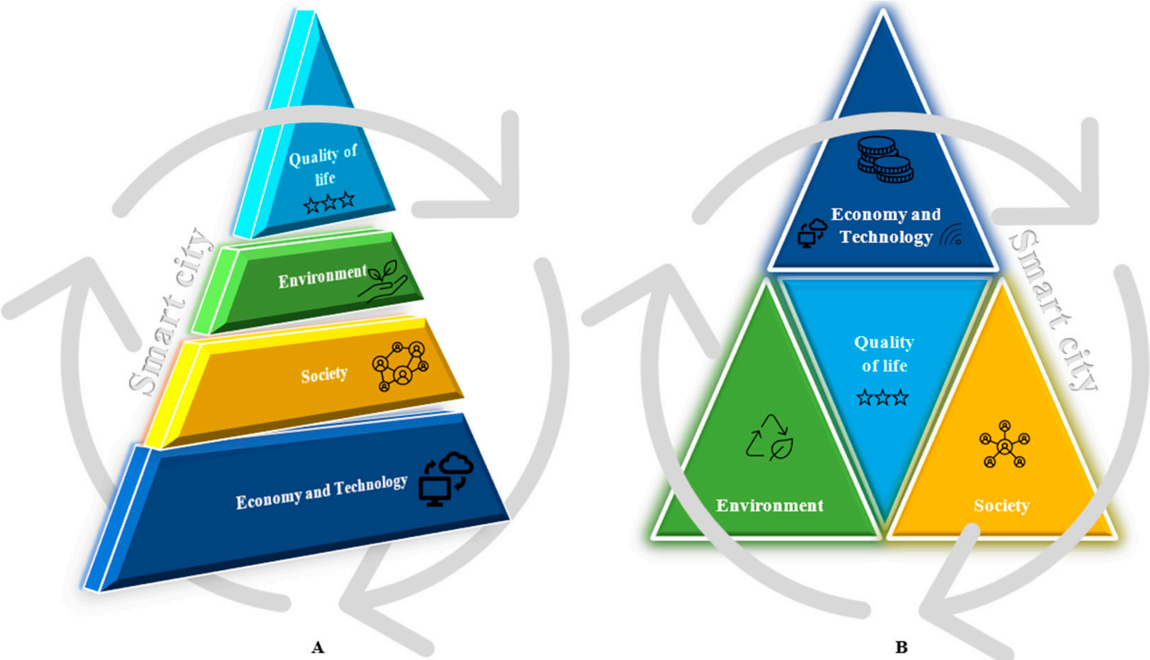

Figure 2. Alternative smart city (SC) concepts. (**A**)—traditional techno-centric concept; (**B**)—the proposed human-centric concept.

Following our understanding of SCs that emphasizes a human-centric rather than a techno-centric approach to city smartness (see Figure 2B), the following operational definition of SCs is adopted in this study:

SCs are cities that balance economic, environmental, and societal advances to improve the wellbeing of residents through a widespread introduction of ICT and other technological tools.

According to this definition, a particular urban feature (e.g., smart sensors or improved monitoring) contributes to city smartness *only* if it effectively improves the quality of life (QoL) of local residents; otherwise, it is not considered to contribute to city smartness.

Although the present study focuses on SC identification criteria, its methodological approach can be used for similar surveys on a wide range of socio-economic, technological, and environmental topics pertinent to urban development, such as healthcare, security, computing, environmental pollution, city infrastructure, residential reassurance, and others.

The remainder of the paper is organized as follows. In the next section (Section 2), we explain our methodological approach and define the sequence of research phases. In Section 3, we describe the results of the analysis, while in Section 4, we discuss our key findings. Conclusions and recommendations of the study are formulated in Section 5, which also outlines directions for future research.

2. Materials and Method

The literature survey approach we used for this study generally followed the PRISMA protocol guidelines [63] and was carried out in the following sequence: (1) selecting the search keywords; (2) selecting the databases and defining the search parameters; (3) building the initial search string and adapting it to specific databases; (4) conducting the primary search and assessing the abstract and full text for eligibility; and (5) evaluating the results. These phases are discussed, in some detail, in separate subsections below.

2.1. Selection of Search Keywords

Following our definition of the search topic as "SC identification criteria", the following search components were defined a priori: the search object ("City"), as well as alternative terms ("Urban area*", "Settlement*", "Urban region*", "Metropoli*", "Township*"), modifiers ("Smart", "Sustainable", "Green"), and measures ("Criteri*", "Measure*", "Index*", "Metric*", "Parameter*"). In addition, to focus the search, we also defined several exclusion terms that are not directly related to our focus on urban development issues: "Biodiversity", "Ecology", "Culture*", "Nation*", "Polic*", "Design*", "Health", "Climate", and "Educat*," where * represents a wildcat search term. Figure 3 features the main search terms used in the present systematic literature review of SC criteria.

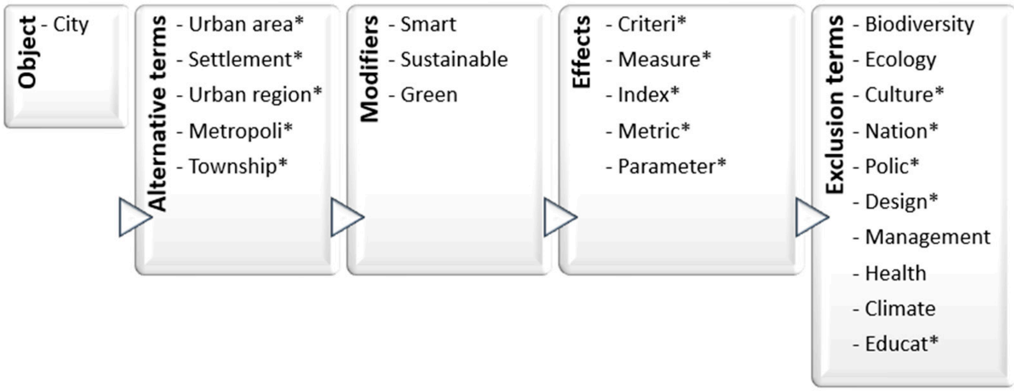

Figure 3. Search terms used in the systematic literature review of SC criteria. *Note:* * represents a wildcard search.

2.2. Selection of Search Databases and Definition of Search Parameters

According to a recent study by Gusenbauer and Haddaway [64], 14 out of the 28 popular academic search engines meet the necessary requirements for systematic reviews and are suited for synthesizing evidence by employing PRISMA tools. These search engines include: ACM Digital Library, BASE, ClinicalTrials.gov, Cochrane Library, EbscoHost, OVID, ProQuest, PubMed, ScienceDirect, Scopus, TRID, Virtual Health Library, Web of Science Core Collections, and Wiley Online Library. Among these search engines, Scopus, Web of Science Core Collections, and ScienceDirect are the most popular and widely adopted for systematic literature surveys [22,23,26,28,31,46,65,66]. These three databases are used in the present study.

According to Anthopoulos [28], the first articles on the SC topic appeared in 1999. In the following decades, the number of articles on the SC topic has started to increase [65], mainly due to the implementation of various SC projects worldwide [31]. Therefore, the present study covers the period from 1999 on. However, the search was effectively limited to the 2011–2019 period because no studies on SC identification criteria were found before 2011 and because, at the time of its initiation, in August 2020, it was technically impossible to correctly analyze the data for the entirety of 2020.

The survey covers only original articles published in English, the main language of modern science [67], focusing on papers published in peer-refereed journals. Concurrently, the survey excludes the so-called "grey" literature, which includes government reports, policy statements and issues papers, conference proceedings, pre-prints, post-prints, professional bulletins, etc. [68]. However, we did not limit the search by the geographic origin of the publication or the organizational affiliation of the authors, considering such limitations irrelevant.

2.3. Building the Initial Search String and Adapting It to Specific Databases

The initial search string used Boolean syntax based on a combination of the "AND", "NOT", and "OR" operators [69]. However, due to the specificity of individual databases [70–72], the search string was adopted for each database separately (see Appendix B).

2.4. Conducting the Primary Search and Assessing the Abstract and Full Text for Eligibility

An initial search was conducted in October 2020. According to the selection criteria defined for the study (see Section 2.1), a total of 2140 publications were identified in Scopus, 2127 publications were identified in the Web of Science Core Collection, and 3880 publications were identified in ScienceDirect—8147 publications in total. Figure 4 reports the flowchart diagram of the publication selection and validation process, along with the number of entries retained (or excluded) at each stage of the reviewing process.

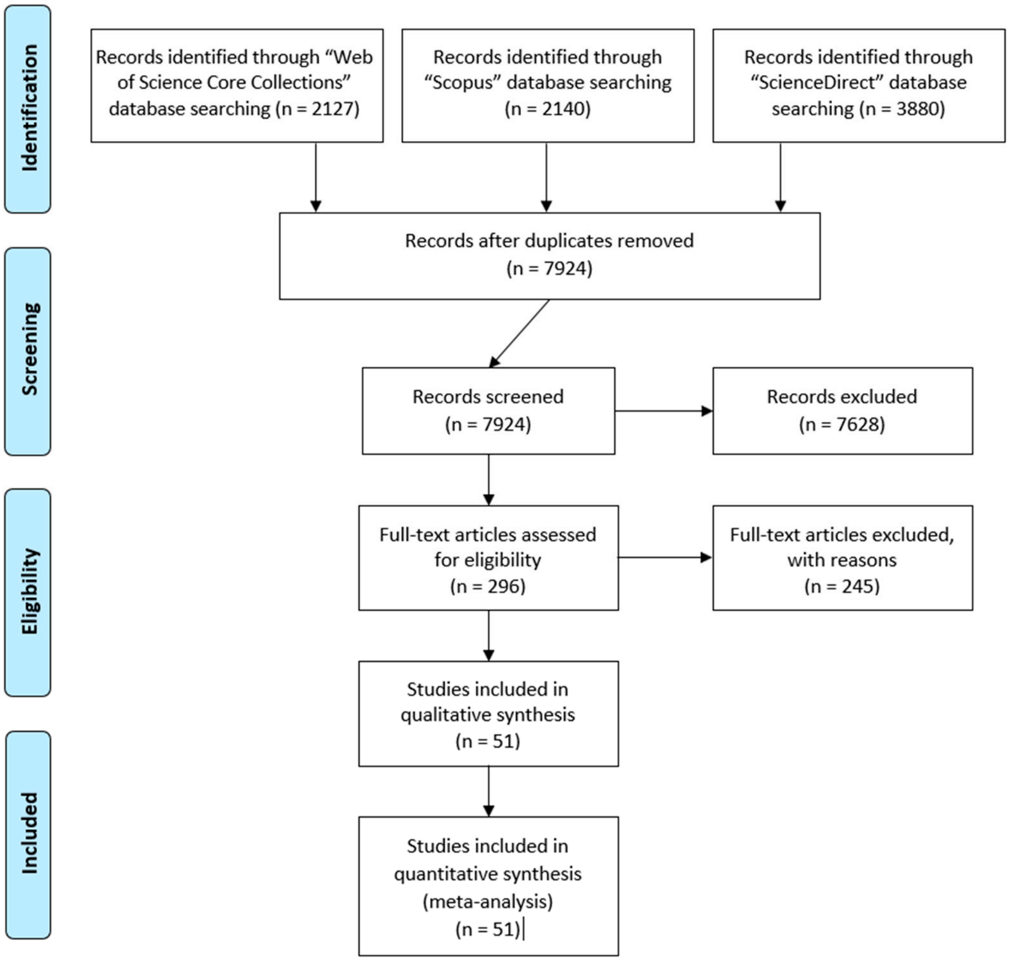

Figure 4. PRISMA flow diagram of the article screening process.

Following Moher et al. (2009), with the search performed in the "Scopus", "Web of Science—Core Collections", and "ScienceDirect" databases in October 2020.

The titles and abstracts of the pre-identified articles were screened next, with duplicate items and the following items excluded as not directly relevant to the research subject:

- Studies of longevity and health in SCs;
- Studies of societal inequality in SCs;
- Studies examining logistics and entrepreneurship in SCs;
- Studies of Big Data use in SCs;
- Studies of artificial intelligence (AI) in SCs;
- Studies on data protection and cyber security in SCs;

- Studies of navigation and urban topography;
- Studies of pricing in SCs;
- Studies of smartphone apps;
- Energy studies;
- Studies of social networks in SCs;
- Studies related to the physical parameters of urban space and patterns of land use;
- Studies related to specific ICT technologies, such as data collection, data storage, and data analysis.

Applying these exclusion criteria resulted in the selection of 296 papers eligible for the full-text analysis, which was our next step. At the final step of the screening process, only the papers reporting empirical criteria, measures, indexes, or quantifiable metrics of city smartness were retained, leaving us with 51 papers eligible for further categorization and analysis (see Figure 4).

2.5. Evaluation of Results

The 51 publications identified were analysed to extract the following information: year of publication, geographic origin, field of study, and empirical SC criteria used. Next, we grouped the extracted SC criteria into categories, and the frequency of their use was calculated.

3. Results

3.1. PRISMA Flow Diagram

The PRISMA flow diagram in Figure 4 illustrates the flow of information, details the number of records identified at each stage of the analysis, and reports the number of records included and excluded at each stage. As Figure 4 shows, the search started, as previously mentioned, with 8147 publications and then narrowed down to 51 publications, identified as relevant for subsequent reviewing.

3.2. Database Split

Out of the total number of 51 articles selected for full-text review, 12 articles (24%) came from Scopus, 7 articles (14%) from the Web of Science Core Collection, and 32 articles (63%) from the ScienceDirect. These differences in numbers can be explained by the fact that Scopus covers approximately 20% more journals compared to the Web of Science Core Collection [73]. Concurrently, the Scopus database mainly focuses on natural sciences, social sciences, humanities, engineering, medicine, and the arts [74], while ScienceDirect is a multidisciplinary platform which covers computer science, energy, engineering, life sciences, health sciences, economics, econometrics and finance, and social sciences [74,75], that is, topics directly relevant to ICT in general and SCs in particular.

3.3. Temporal Trends

Appendix C reports the thematic split of the studies based on SC identification criteria, while Appendix D summarizes the relevant studies in detail. Concurrently, in Figures 5–7 we report the temporal trends in the annual number of publications on SC identification criteria (Figure 5), publication distribution across research fields (Figure 6), and geographic origin of the publications (Figure 7).

As evidenced in Figure 5, the first paper we identified on SC criteria was published in 2011, and research interest in the topic increased in 2013–2016, when 3–4 papers on the topic were published each year. After 2017, the number of publications on the topic surged, with eight papers being published in 2018 and twice as many in 2019. This increase of interest in SC identification is likely due to a number of recent developments, such as the initiation of Cisco's USD 1 billion City Infrastructure Financing Acceleration Program [76]; the beginning of the Neom Smart City construction in Saudi Arabia, termed "the most ambitious project in history" [77]; the initiation of Japan's national strategy for transitioning towards a Super Smart Society, or Society 5.0 [78]; and the implementation of Huawei's SC concept in 60 cities worldwide [79].

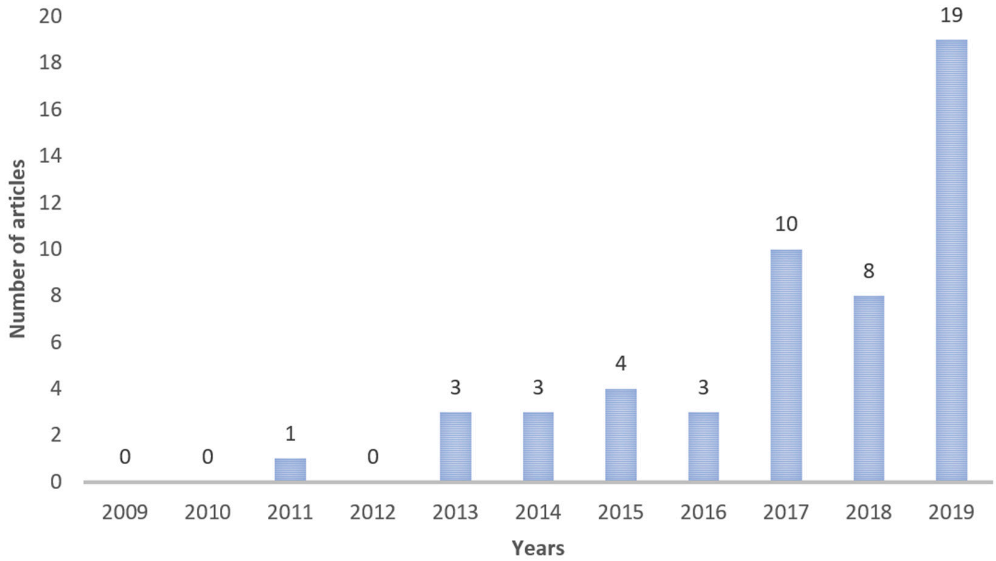

Figure 5. Temporal trends in the annual number of publications on SC criteria (the total number of papers identified and summarized = 51).

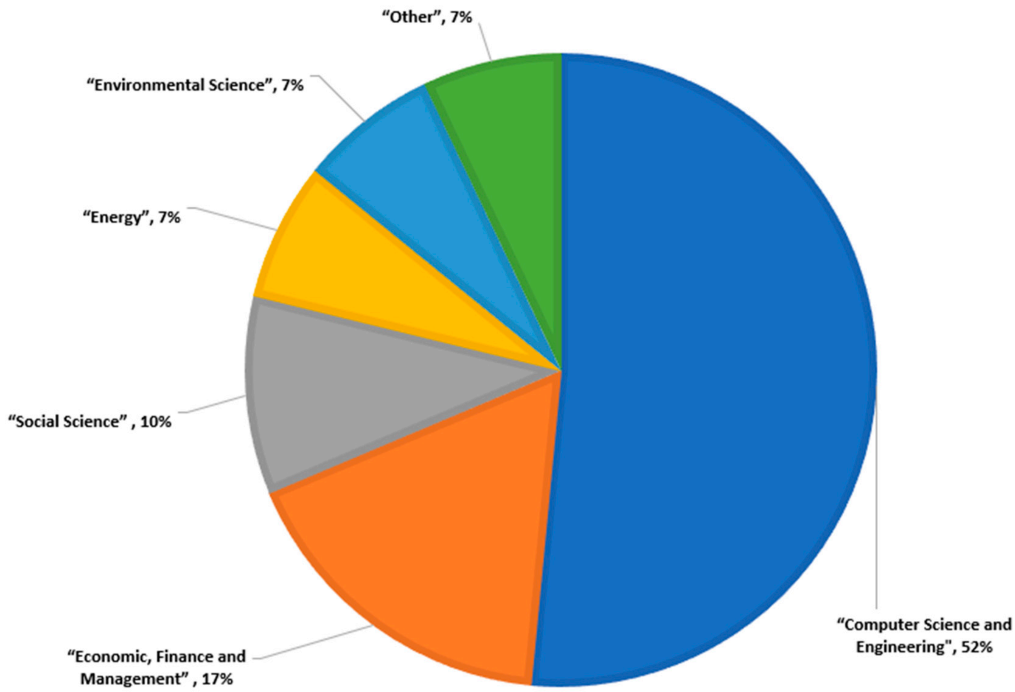

Figure 6. Distribution of publications on SC criteria according to the research field* (the total number of papers identified and summarized = 51). *Note:* Some of the papers can include two or three subject areas at the same time (according to analytical information from Scopus, Web of Science Core Collection, and ScienceDirect), and it is thus not possible to clearly relate these papers to a specific area. Accordingly, each paper was accounted for as a separate unit for each subject area. The total number of papers was 81, and this number was used to determine the percentage of each of the areas.

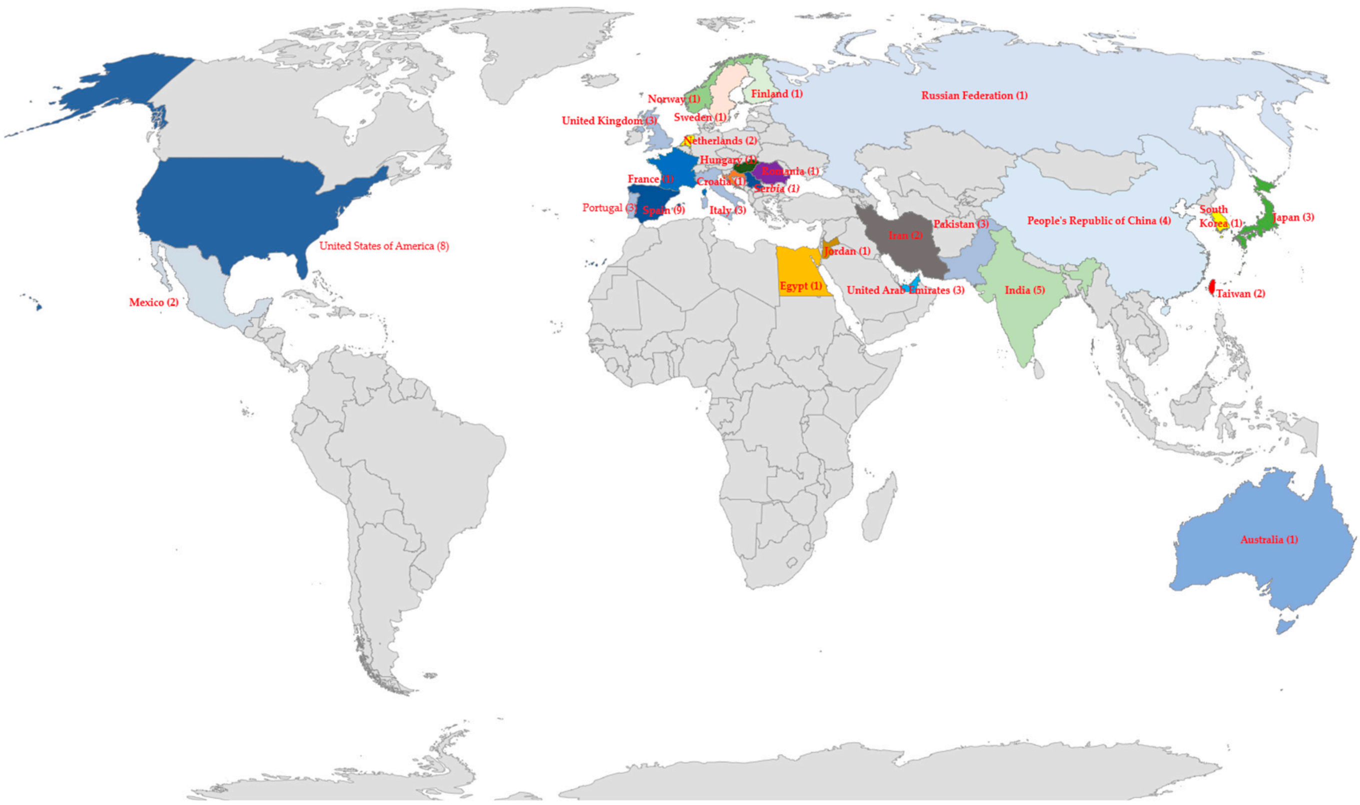

Figure 7. Geographic distribution of publications on SC criteria—the numbers of relevant publications identified and analyzed). *Note:* The papers under review include 51 relevant publications published in 2011–2019 and written by authors from 27 different countries: Sweden (1 publication), Taiwan (2), United Kingdom (3), Spain (9), Italy (3), Russian Federation (1), United Arab Emirates (3), United States of America (8), Croatia (1), Portugal (3), Pakistan (3), Japan (3), People's Republic of China (4), India (5), Finland (1), Iran (2), Egypt (1), Australia (1), Serbia (1), Mexico (2), South Korea (1), France (1), Jordan (1), Norway (1), Romania (1), Netherlands (2), and Hungary (1).

3.4. Research Fields and Geographic Coverage

As Figure 6 shows, publications on SC criteria cover six main areas: computer science and engineering; economy, finance, and management; social science; energy; environmental sciences and social sciences; and arts and humanities. However, publications in computer science and engineering appear to be most frequent, with 20 papers out of the total 51 papers analysed, while only one paper on the topic was published in the field of arts and humanities.

Geographically, most papers on SC identification criteria originated in Spain (13%), USA (12%), India (7%), China (6%), and UK/Italy/Portugal/UAE/Japan (4% each) (see Figure 7). The predominance of papers originating in these countries can be explained by the extraordinary popularity of the SC concept in Europe, the Far East, and North America, specifically in well-developed countries, which have the necessary economic, technological, and social resources to build a modern SC. Concurrently, the contributions of India and China can be explained by their rapidly increasing technological capabilities and the magnitude of the urban problems these countries face [80].

3.5. SC Categories and Metrics

Figure 8 categorizes the SC identification criteria, starting from three main categories (economy and technology, environment, and society) to the nine generalized subgroups (smart digital technology, smart use of resources and energy saving, competitiveness, economic development, environmental (ecological) sustainability, social capital, leisure, smart management and policy making, and living conditions), as well as the 48 specific empirical metrics identified.

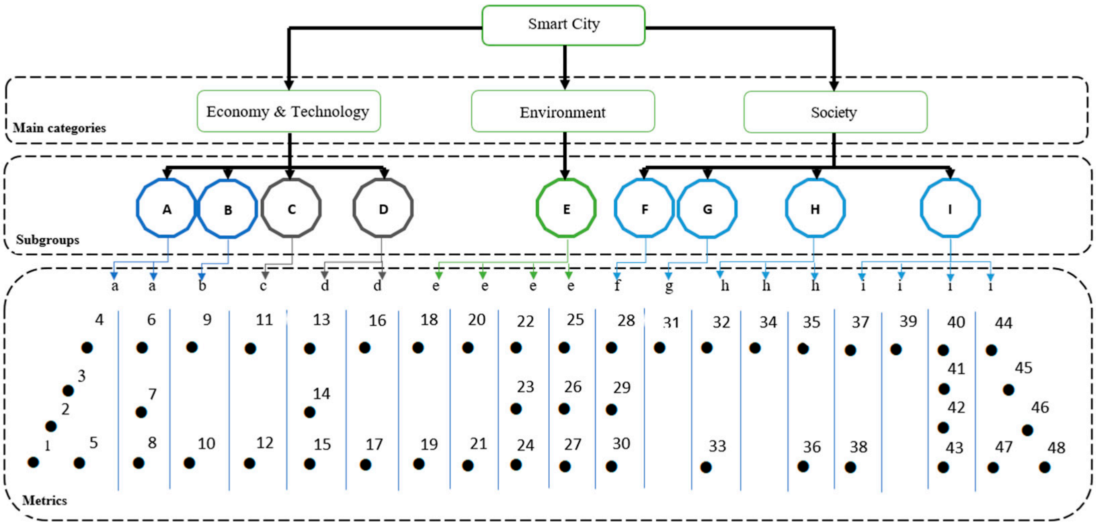

Figure 8. Classification of the SC identification criteria. *Notes: Subgroups*: A—Smart technology; B—Resource-saving; C—Competitiveness; D—Economy; E—Environmental sustainability; F—Social capital; G—Recreation and Leisure; H—Smart government; I—Quality of Life.

Somewhat surprisingly, only 29 metrics used by the empirical studies for SC identification (60%) actually relate to citizens' needs—broadband subscriptions, access to free public Wi-Fi, the number of electric-vehicle charging stations, etc. The rest (i.e., 40%) are general technological or socio-economic performance measures, including the web use index, the number of startups, the share of the city's water distribution network monitored by smart water systems, etc.

Empirical metrics: (1) Broadband subscriptions per 100 inhabitants (*); (2) Percentage of households with access to Internet (*); (3) Web Index; (4) Share of people who order goods or services over the internet (*); (5) Access to public free Wi-Fi (the number of wireless access points) (*); (6) Number of users of public transportation per 100,000 (*); (7) Percentage of public parking spaces equipped with real-time availability systems (*); (8) Percentage of public transport lines equipped with a real-time information system (*); (9) Number of startups; (10) Innovation Cities Index; (11) Labor productivity; (12) GDP per capita; (13) Change in gross household income; (14) Hourly wage (*); (15) Purchasing power parity (*); (16) Number of jobs created (*); (17) Unemployment rate (*); (18) Share of the city water distribution network monitored by smart water systems; (19) Percentage of rain and grey water re-used to replace potable water; (20) Percentage of the urban population that has door-to-door garbage collection with individual telemetering of household waste quantities (*); (21) Proportional share of the wastewater pipeline network monitored by a real-time data tracking sensor system; (22) Percentage of street lighting remotely managed by light management systems; (23) Number of electric-vehicle charging stations per registered electric vehicle (*); (24) Percentage of buildings (or housing units) with smart energy or water meters; (25) Number of real-time remote air quality monitoring stations per km^2 (*); (26) Proportional share of public buildings equipped for indoor air quality monitors; (27) Environmental Performance Index (EPI); (28) Proportion of population with secondary and higher education; (29) Number of universities in the city (or number of students per 1000 (*); (30) Expenditure on education per capita (*); (31) Expenditure on leisure and recreation per capita (*); (32) Corruption perceptions index; (33) Share of residents participating in online platforms (*); (34) E-Government Development Index (EGDI); (35) Number of online government services (*); (36) Extent to which public amenities are available within 500 m (*); (37) Decreased rate of travel time (*); (38) Happiness index (*); (39) Access to basic health care services/waiting time (*); (40) Percentage of the city area covered by digital surveillance cameras; (41) Emergency service response time (*); (42) Number of transportation fatalities per 100,000; (43) Number of acts of violence, annoyances, and crimes per 100,000; (44) Access to public outdoor recreation space or public outdoor recreation spaces (m^2) within a 500 m radius from residential areas (*); (45) Increase in ground floor space for commercial or public use (*); (46) Life expectancy (*); (47) Morbidity and mortality (*); (48) Social inequality (GINI index or similar) (*).

(*) marks items that are oriented towards the needs of local residents (as opposed to general performance measures).

The breakdown of the SC identification criteria by research field is shown in Figure 9. As evidenced in this figure, papers on the economy and technology criteria compose 47% of the total number of publications, studies on societal criteria account for 40% of all publications, while environmental (ecological) criteria only appear in 13% of the publications. This uneven split effectively contradicts the sustainable development concept, which assumes a balance between the three main pillars of sustainable development—social, economic, and environmental [81].

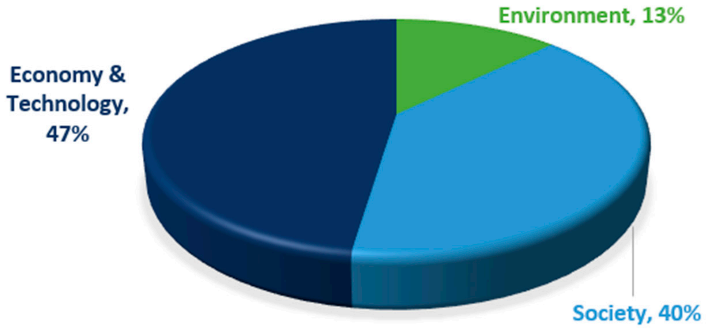

Figure 9. Frequency of the use of SC criteria by research field (% out of the 51 relevant publications identified and analyzed).

This observation is confirmed when the relevant publications are disaggregated even further, down to the subgroup level (see Figure 10). At this level, papers on innovative technologies form 30% of the publications, with criteria pertinent to digital technology being used most often (23% of studies), while leisure-related criteria are considerably less frequent (2% of studies).

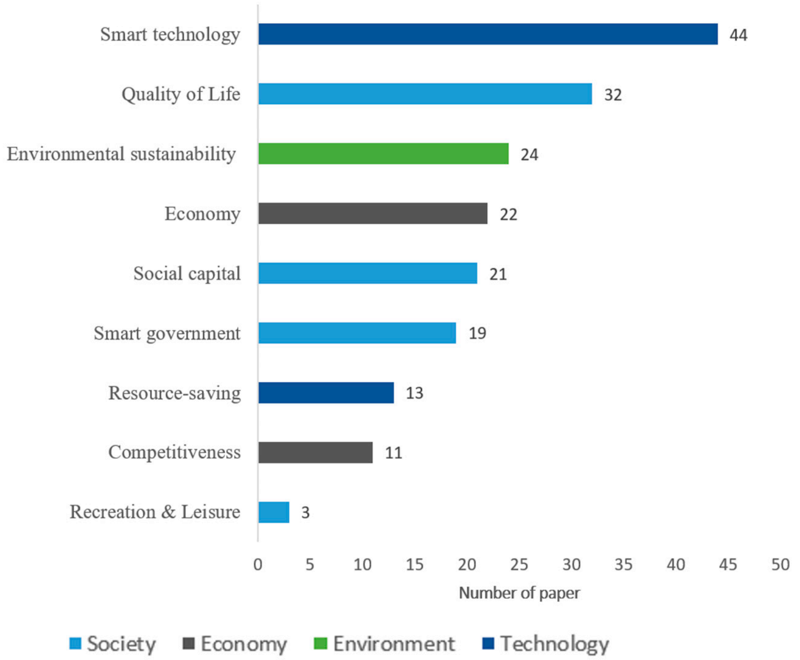

Figure 10. Frequency of the use of different subgroups of SC criteria (out of the 51 relevant publications analyzed; the sub-groups of the criteria are sorted in order of relative popularity).

Somewhat unexpectedly, several SC metrics, such as the use of renewable energy sources, urban waste recycling, and green space expansion, which are important components of sustainable urban development in general appear in less than 2% of the studies identified and analysed in this review.

4. Discussion

The main objective of this study was to identify and categorize the main empirical criteria that help to differentiate between SCs and the remaining urban localities and to monitor a city's progress towards greater smartness. The review helped us to identify 48 empirical metrics falling into 9 subgroups and 3 main groups—economy and technology, environment, and society. The study also enabled us to rank the identified criteria according to the frequency of their use in empirical studies, thus reflecting the current state of knowledge about metrics commonly used for SC categorization.

Sustainable development assumes an explicit balance between social, economic, and environmental development objectives [81]. Yet the present systematic literature review indicates that most previous studies placed an emphasis on the economy and technology and the society groups of the SC categorization criteria (87% of the studies analyzed), while the use of environmental criteria was less frequent (13% of studies).

SCs are meant to be designed and built around the experience of the people using them [82], with the main priority being citizens' needs [83]. However, as the present study shows, only 60% of the empirical metrics we identified as commonly used for SC identification actually relate to citizens' needs; the other indices are general technological measures. Most previous studies on the SC phenomenon also appear to have overlooked several important SC metrics, such as the use of renewable energy sources, urban waste recycling, and green space expansion, which are important components of sustainable development but appear in less than 2% of the studies identified and analyzed in this review.

The 2030 Agenda for Sustainable Development [9] specifies 17 Sustainable Development Goals. However, as the present study reveals, many of these goals are not covered by commonly used SC identification criteria. Such omitted categories include gender equality, peace and justice institutions, and partnerships to achieve the goals.

The results of this analysis correspond in part with the results reported by Tregua et al. [26], who define three main groups of criteria for SC categorization (environmental, social, and economic), and with the results reported by Lim et al. [31], who reveal that the availability of ICT infrastructure plays the key role in SC categorization. The results of this study are also similar to those reported by Ruhlandt [45], who emphasizes the importance of smart technology and smart governance, and to those reported by Marchetti et al. [30], who emphasize social and human capital, smart governance, and competitiveness as the most important factors for SC categorization.

Most previous reviews of the SC phenomenon placed an emphasis on resource management and ICT implementation [22,28,31,46,66], while this analysis was aimed at identifying empirical criteria for SC ranking and categorization.

In particular, the study identified 48 operational criteria for SC performance assessment (see Figure 8). The analysis also helped us to rank the SC criteria according to the frequency of their use, showing that the smart digital technology criterion was used most often in empirical studies (23% of the papers analyzed), while the use of the city leisure criterion was least frequent (2% of studies). This outcome contradicts the findings obtained by Ojo et al. [22] and by Lim et al. [31], according to which the most frequently used criteria for SC identification and categorization were participatory governance and ICT infrastructures, while the least frequently used criteria were developing an active self-decisive citizenry and social capital.

We explain these differences in findings by the fact that previous studies of SC metrics used survey approaches that do not set formal criteria for the literature selection; they may thus have introduced a selection bias. In particular, there is a possibility that a researcher performing a survey may be selective in collecting evidence based on the perspective adopted while ignoring evidence that points the other way [38]. By contrast, a systematic survey such as was used for this study provides an important advantage compared to other survey methods, such as content analysis [38], analysis of joint citations [39], or citation-based content clustering [40], that have no established study-section protocol and might thus overlook important bibliographic information [43].

The human-centric conceptual model of SCs proposed in this study (see Figure 2B) helps to differentiate urban features that contribute to city smartness from those that do not. In particular, according to our conceptual approach, a particular urban feature (e.g., sensors or improved monitoring) *is considered to contribute to city smartness only if it effectively helps to improve the quality of life of local residents; otherwise, it is not considered relevant to city smartness.*

Many SC identification criteria that are frequently used by empirical studies are general technological measures not directly relevant to human welfare, such as water reuse and the size of urban areas covered by surveillance cameras. The existing classifications are also often imbalanced, placing a major emphasis on technological elements. Therefore, we suggest an alternative, more balanced approach to SC identification and categorization, with an emphasis on human-centric objectives—*whether a particular metric measures a change that helps to improve human welfare*.

Following this approach, we suggest an SC classification system based on *nine* metrics, which are *directly relevant to human welfare and which evenly represent each of the three main groups of SC criteria—economy and technology, environment, and society*—with three identification criteria in each group. These nine metrics were selected from the list of 48 frequently used SC categorization metrics (see Figure 8) after applying two selection criteria: (*1) equal representation of societal, environmental, and technological development aspects, and (2) direct QoL relevance*.

Table 1 features the proposed identification and ranking system, with two cities—Dubai in the UAE and London in the UK—used as evaluation examples.

Table 1. The proposed SC ranking system with an example of a comparative evaluation of two cities—Dubai (UAE) and London (UK).

Main Category	Subgroup	Metric	Rank (1–3) *	City Grade (1–5) **	
				Dubai (UAE)	London (UK)
Economy and technology	Smart technology	Percentage of households with Internet access	3	5	4
		Access to public free Wi-Fi	2	4	5
	Economy	Hourly wage	1	4	5
Society	Social capital	Number of universities in the city (or number of students per 1000)	2	4	3
	Smart government	Online government services	3	3	4
	Quality of life	Life expectancy	1	4	5
Environment	Environmental sustainability	Percentage of the city population that has door-to-door garbage collection with individual telemetering of household waste quantities	1	1	3
		Number of electric-vehicle charging stations per registered electric vehicle	2	3	5
		Density of real-time remote air quality monitoring stations per km^2	3	1	4
Overall ranking:				29	38

Note: * Ranked according to frequency of use in the literature; larger numbers reflect the most frequently used metrics (within the main categories). ** *Information sources*: Aqicn.org, Country economy, Dubai Municipality, Electric Vehicle Council, IHS Markit, International Telecommunication Union, London Authority, the NationMaster database, NUMBEO, Our World in Data, The World Bank, United Nations Department of Economic and Social Affairs, QS World University Rankings, Waqi.info, WiGLE, Wi-Fi Map App, and Wi-Fi UAE initiative. Larger numbers reflect values close to the possible maximum (optimal) of the corresponding metrics.

As Table 1 shows, according to the proposed ranking system, both cities scored relatively highly—29 and 38 points, respectively (out of the 45 points possible). This corresponds to the results of other assessments which place these cities high on the SC ranking scale [84,85].

We argue that the proposed ranking system can help several SC shareholders. In particular, using this system, urban decision makers can streamline their municipal policies by setting appropriate targets and gauging the progress achieved by their cities during transition toward greater smartness. Concurrently, technology providers can design and develop SC technologies, software products, and solutions for "smartening" cities by focusing on the most important aspects of transition from conventional cities to SCs.

Moreover, researchers can focus their studies on the least researched topics related to SC transition, thus helping to further our understanding of the SC phenomenon and formulate informed development policies.

5. Conclusions

The present study was aimed at determining a comprehensive *set of criteria that can help us to distinguish between SCs and the remaining urban localities and to assess a city's progress towards greater smartness, while focusing on the human-centricity of each criterion, that is, its potential impact on the quality of life of urban residents.*

The proposed SC identification system includes *nine* identification criteria, equally representing three main sustainable development categories—economy and technology, environment, and society—and directly relevant to improving the QoL of local residents.

This classification thus differs from traditional SC categorizations in which some categories contain more metrics than others and many metrics are general technological measures not directly related to human welfare.

The study also helps us to identify topics which require further research attention. These topics include: (1) ranking SC criteria according to their temporal attributes (i.e., short-term progress evaluation vs. strategic long-term impact assessment), and (2) ranking SC evaluation metrics according to their performance in assessing the extent of a city's "smartness".

Lastly, we should remark that although the present study focuses solely on SC identification criteria, its methodological approach can be used in similar surveys on a wide range of urban development topics.

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Appendix A

Table A1. Alternative definitions of SCs.

№	Publication	Definition
1	Louise [54]	Mentions that a smart city should "improve quality of life, environmental sustainability, efficient/wise use of resources" (Louise, 2011, [54], p. 2).
2	Yamagata and Seya [86]	A future smart city "is to combine appropriate land use (compact city with energy-efficient buildings and photovoltaic panels (PVs)), transportation (electric vehicles (EVs) and public transportation system) and energy systems (smart grid systems), because of the interaction between these elements" (Yamagata and Seya, 2013, [86], p. 1467).
3	Lee et al. [55]	The smart city concept "focuses on factors such as human capital and education as drivers of urban growth, rather than singling out the role of ICT infrastructure" (Lee et al., 2013, [55], p. 287).
4	Nanni and Mazzini [87]	"Development of value-added services, based on existing services, through the use of new technologies" (Nanni and Mazzini, 2014, [87], p. 188).
5	Lee et al. [56]	Smart cities are "better, more sustainable cities, in which people's quality of life is higher, their environment more livable and their economic prospects stronger" (Lee et al., 2014, [56], p. 82).

Table A1. *Cont.*

№	Publication	Definition
6	Ishkineeva et al. [57]	"Smart city is the city where investments in human and social capital and in traditional and modern infrastructure provide sustainable city development and high quality of life with wise use of natural resources and with smart use of the city potential (human, ecological, economic, management, absorption, and marketing) based on the participative management" (Ishkineeva et al., 2015, [57], p. 72).
7	Abellá-García et al. [88]	"Smart city is a public-private ecosystem providing services to citizens and their organizations with a strong support of technology" (Abellá-García et al., 2015, [88], p. 1076).
8	Marsal-Llacuna et al. [14]	"Smart Cities initiative seeks to improve urban performance by using data, information, and Information Technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration between different economic actors and to encourage innovative business models in both the private and public sectors" (Marsal-Llacuna et al., 2015, [14], p. 621).
9	Regalia et al. [47]	The vision of smart cities as "unifying sensor networks, cyber-infrastructures, interoperability, and predictive analytics research for the purpose of improving the quality of life" (Regalia et al., 2016, [47], p. 383).
10	Aelenei et al. [89]	"A Smart City ... an answer for improving energy efficiency, human living, and environment, economy, and governance" (Aelenei et al., 2016, [89], p. 970).
11	Joshi et al. [90]	"Smart city is a futuristic approach to alleviate obstacles triggered by the ever-increasing population and fast urbanization which is going to benefit the governments as well as the masses" (Joshi et al., 2016, [90], p. 902).
12	Navarro [58]	A smart city is "a certain harmony between the quality of human life, economic activity and the exploitation of non-renewable resources, in other words economic, social and environmental sustainability" (Navarro, 2017, [58], p. 273).
13	Mundoli et al. [48]	"A smart city with its emphasis on technology is yet another static model of planning, which fails to recognize important aspects of city life especially the diversity of social and ecological relations that urban residents have with different spaces (spatial) in the city over different periods of time (temporal)" (Mundoli et al., 2017, [48], p. 118).
14	Stankovic et al. [91]	A smart city "is seen as a holistic process of redesigning urban areas, aimed at achieving sustainable urban growth, efficient service systems and increasing the citizens' quality of life" (Stankovic et al., 2017, [91], p. 520).
15	Sampson [7]	"The "smart cities" movement aims to connect urban transportation, energy, disaster preparedness, health emergency, and other systems of urban service delivery" (Sampson, 2017, [7], p. 8957).
16	Aletà et al. [92]	"The Smart City concept differs from the others by emphasizing environmental and social capital and not only technology. It implies the use of ICT to provide sustainable economic development, tools for the judicious management of natural resources, and improvements to our quality of life, and offers an excellent opportunity to manage the urban future" (Aletà et al., 2017, [92], p. 164).
17	Afzalan et al. [18]	"Smart city approaches should contribute to innovation and enhance democratic decision making and transparency through public participation" (Afzalan et al., 2017, [18], p. 22).
18	Strzelecka et al. [93]	The smart city concept integrates aspects of "water, waste, energy, transport and ICT" (Strzelecka et al., 2017, [93], p. 610).
19	Lacinák and Ristvej [94]	"The Smart City by the integration of technology and natural environment increases the effectiveness of processes in every field of its functioning, in order to achieve sustainable development, safety and health of inhabitants with the aim for increasing the quality of life of citizens, near community and environment" (Lacinák and Ristvej, 2017, [94], p. 523).
20	Girardi and Temporelli [49]	"A smart city can be defined as a city able to facilitate and satisfy citizens, companies and organization needs, by an integrated and original use of Information and Communication Technologies (ICT), especially in communication, mobility, environment and energy efficiency fields" (Girardi and Temporelli, 2017, [49], p. 811).
21	Hassan and Awad, [50]	Smart cities are "places that depend on certain digital devices to facilitate city work" (Hassan and Awad, 2018, [50], p. 36435).
22	Nayak [95]	"A city that provides mobility, health, safety and productivity is important, but alongside sustainability must be taken into consideration" (Nayak, 2018, [95], p. 616).
23	Grubesa et al. [96]	Smart city "development provides added value of existing public services and improves the quality of citizens' lives" (Grubesa et al., 2018, [96], p. 286).

Table A1. *Cont.*

№	Publication	Definition
24	Zaree and Honarvar et al. [97]	Smart cities are "promising solutions to future challenges for providing better services to all citizens and improving efficiency" (Zaree and Honarvar et al., 2018, [97], p. 1302).
25	Santos et al. [59]	Smart cities aim at improving "citizens' quality of life by leveraging information about urban scale processes extracted from heterogeneous data sources collected on citywide deployments" (Santos et al., 2018, [59], p. 523).
26	Malik et al. [51]	"The term smart city comes from tasks involving ubiquitous and persistent computing with the use of digital devices planted and distributed in the environment of the city" (Malik et al., 2018, [51], p. 548)
27	Voda and Radu [52]	"Smart cities are urban regions very advanced in terms of technology, where people and organizations are ultra-connected" (Voda and Radu, 2018, [52], p. 110).
28	Honarvar and Sami [98]	A smart city is "a place, which integrates multiple technological solutions to manage the city assets" (Honarvar and Sami, 2019, [98], p. 56)
29	Solanki et al. [99]	"The term 'smart' city is given to a city that incorporates technology to make the lives of people living in the city better in terms of healthcare, transportation, urban governance, and waste management" (Solanki et al., 2019, [99], p. 718).
30	Patel and Doshi [60]	"A smart city is comprised of different viewpoints that incorporate residents, city authorities, nearby organizations and businesses and local gatherings" (Patel and Doshi, 2019, [60], p. 693).
31	Praharaj and Han [100]	"[T]he smart city is a part of contemporary language games around urban management and development that involves professionals, marketing authorities, consultants and so on" (Praharaj and Han, 2019, [100], p. 2).
32	Mark and Anya [24]	"A smart city is typically a city grounded on a drive towards technological innovation to improve the lives of city-dwellers" (Mark and Anya, 2019, [24], p. 3).
33	Dameri et al. [101]	"Smart city concept puts under the same umbrella several aspects of the urban strategies, such as the technological basis, the role of people in building smart communities, the aim of sustainable economic growth, the importance of the environmental preservation, and the final goal to deliver better quality of life" (Dameri et al., 2019, [101], p. 27).
34	Wang and Kong [102]	A smart city "is a good intelligent response to the needs of people's livelihoods, environmental protection, public safety, etc." (Wang and Kong, 2019, [102], p. 172892).
35	Ruohomaa et al. [103]	"The smart city concept brings together technology, government, and different layers of society, utilizing technological enablers, such as the internet of things (IoT) and artificial intelligence (AI). These enablers, in turn, facilitate development of various aspects of the smart city, including, e.g., transportation, governance, education, safety and communications" (Ruohomaa et al., 2019, [103], p. 5).
36	Trencher [61]	"Smart Cities 2.0 strategies … put people first and stresses technology as a tool to use predominantly in service of citizens" (Trencher, 2019, [61], p. 118).
37	Ameer et al. [16]	"A smart city is an urban municipality that utilizes information and communication technologies (ICT) to provide better health, transport and energy related facilities to its citizens and enables the government to make efficient use of its available resources, for the welfare of their people" (Ameer et al., 2019, [16], p. 325).
38	Haarstad and Wathne [104]	The smart city "consists of both a technological aspect as well as a managerial side and can potentially include an infinite number of policies, innovations, and targets" (Haarstad and Wathne, 2019, [104], p. 919).

Table A1. *Cont.*

№	Publication	Definition
39	Nagy et al. [62]	Smart cities "contribute to improving living standards, increasing urban competitiveness and overcoming obstacles such as poverty, social exclusion or environmental problems" (Nagy et al., 2019, [62], p. 93).
40	Barba-Sánchez et al. [105]	"A smart city is a concept that positively affects the development and growth of a city" (Barba-Sánchez et al., 2019, [105], p. 9).
41	Estrada et al. [53]	"Smart Cities concept is based on the use of information and communication technologies . . . in order to face the problems of diverse metropolises, such as reducing energy consumption or the negative impact of the city on the environment, the concept of Smart Cities has gained notoriety" (Estrada et al., 2019, [53], p. 1).

Note: Publications not presented in the table (out of the 51 relevant studies) refer to other authors in the definition of "Smart city".

Appendix B

Table A2. Search query strings used for Scopus, Web of Science, and ScienceDirect database searches.

Database Name	Suggested Query Strings for Search	№ of Results
Scopus	TITLE-ABS-KEY (City OR "Urban area*" OR Settlement* OR "Urban region*" OR Metropoli* OR Township*) AND (Smart OR Sustainable OR Green) AND (Criteri* OR Measure* OR Index* OR Metric* OR Parameter*) AND NOT (Biodiversity OR Ecology OR Culture* OR Nation* OR Illumin* OR Polic* OR Design* OR Management OR Health OR Climate OR Educat*) AND DOCTYPE (ar OR re) AND (PUBYEAR > 1999 AND PUBYEAR < 2019) AND (LIMITTO (LANGUAGE, "English"))	2140
Web of Science Core Collections	#1 (TS = (City OR "Urban area*" OR Settlement* OR "Urban region*" OR Metropoli* OR Township*)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) #2 (TS=(Smart OR Sustainable OR Green)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) #3 #2 AND #1 #4 (TS = (Criteri* OR Measure* OR Index* OR Metric* OR Parameter*)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) #5 #4 AND #3 #6 (TS=(Biodiversity OR Ecology OR Culture* OR Nation* OR Polic* OR Design* OR Management OR Health OR Climate OR Educat*)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) #7 (#5 NOT #6) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article)	2127
ScienceDirect	Find articles with these terms: (Smart OR Green OR Sustainable) AND (Criteria OR Measure OR Index OR Metric OR Parameter) Year: 1999–2019 Title, abstract, keywords: NOT (Ecology OR Culture OR Nation OR Policy OR Design OR Management OR Health OR Climate) Title: (City OR "Urban area" OR Settlement OR "Urban region" OR Metropolitan OR Township) Article types: Review articles, Research articles	3880

Note: * represents wild-card search.

Appendix C

Table A3. Publications classified by the sub-group of the SC identification criteria.

Subgroup	Reference, Year	Focus	Keywords
Smart technology	Nanni and Mazzini, 2014 [87]; Ishkineeva et al., 2015 [57]; Nayak, 2018 [95]; Grubesa et al., 2018 [96]; Akande et al., 2019 [106]; Ameer et al., 2019 [16]; Yamauchi et al., 2014 [107]; Lin et al., 2019 [20]; Mundoli et al., 2017 [48]; Ruohomaa et al., 2019 [103]; Hassan and Awad, 2018 [50]; Praharaj and Han, 2019 [100]; Dameri et al., 2019 [101]; Trencher, 2019 [61]; Lee et al., 2014 [56]; Navarro, 2017 [58]; Patel and Doshi, 2019 [60]; Aletà et al., 2017 [92]; Jamil et al., 2015 [108]; Solanki et al., 2019 [99]; Alvarez-Campana et al., 2017 [109]; Santos et al., 2019 [15]; Zaree and Honarvar et al., 2018 [97]; Stankovic et al., 2017 [91]; Wang and Kong, 2019 [102]; Santos et al., 2018 [59]; Estrada et al., 2019 [53]; Malik et al., 2018 [51]; Lee et al., 2013 [55]; Haarstad and Wathne, 2019 [104]; Voda and Radu, 2018 [52]; Afzalan et al., 2017 [18]; Joshi et al., 2016 [90]; Mark and Anya, 2019 [24]; Sahu et al., 2019 [110]; Strzelecka et al., 2017 [93]; Kairui, 2018 [111]; Marsal-Llacuna et al., 2015 [14]; Walravens and Ballon, 2013 [112]; Barba-Sánchez et al., 2019 [105]; Lacinák and Ristvej, 2017 [94]; Girardi and Temporelli, 2017 [49]; Abellá-García et al., 2015 [88]	ICT, sensors, infrastructure, new technology, open data, artificial intelligence (AI), the internet of things (IoT), machine learning, smart building, big data, road mapping, smartphone app	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; criteria*; measure*; index*; metric*; parameter*
Environmental sustainability	Ishkineeva et al., 2015 [57]; Louise, 2011 [54]; Akande et al., 2019 [106]; Honarvar and Sami, 2019 [98]; Dameri et al., 2019 [101]; Lee et al., 2014 [56]; Navarro, 2017 [58]; Aletà et al., 2017 [92]; Aelenei et al., 2016 [89]; Solanki et al., 2019 [99]; Yamagata and Seya, 2013 [86]; Alvarez-Campana et al., 2017 [109]; Santos et al., 2019 [15]; Zaree and Honarvar et al., 2018 [97]; Sampson, 2017 [7]; Stankovic et al., 2017 [91]; Wang and Kong, 2019 [102]; Estrada et al., 2019 [53]; Joshi et al., 2016 [90]; Sahu et al., 2019 [110]; Kairui, 2018 [111]; Nagy et al., 2019 [62]; Lacinák and Ristvej, 2017 [94]; Girardi and Temporelli, 2017 [49]	Sustainability, ecology, environmental preservation, environment, pollution, monitoring	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; green; criteria*; measure*; index*; metric*; parameter*
Social capital	Ishkineeva et al., 2015 [57]; Nayak, 2018 [95]; Yamauchi et al., 2014 [107]; Mundoli et al., 2017 [48]; Honarvar and Sami, 2019 [98]; Praharaj and Han, 2019 [100]; Dameri et al., 2019 [101]; Trencher, 2019 [61]; Navarro, 2017 [58]; Patel and Doshi, 2019 [60]; Aletà et al., 2017 [92]; Zaree and Honarvar et al., 2018 [97]; Manchester and Cope, 2019 [19]; Stankovic et al., 2017 [91]; Lee et al., 2013 [55]; Voda and Radu, 2018 [52]; Joshi et al., 2016 [90]; Kairui, 2018 [111]; Walravens and Ballon, 2013 [112]; Barba-Sánchez et al., 2019 [105]; Lacinák and Ristvej, 2017 [94]	Education, society, investments in human and social capital, citizen needs	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; criteria*; measure*; index*; metric*; parameter*

Table A3. *Cont.*

Subgroup	Reference, Year	Focus	Keywords
Smart government	Ishkineeva et al., 2015 [57]; Nayak, 2018 [95]; Ameer et al., 2019 [16]; Ruohomaa et al., 2019 [103]; Honarvar and Sami, 2019 [98]; Dameri et al., 2019 [101]; Patel and Doshi, 2019 [60]; Aletà et al., 2017 [92]; Aelenei et al., 2016 [89]; Solanki et al., 2019 [99]; Santos et al., 2019 [15]; Stankovic et al., 2017 [91]; Malik et al., 2018 [51]; Haarstad and Wathne, 2019 [104]; Afzalan et al., 2017 [18]; Joshi et al., 2016 [90]; Kairui, 2018 [111]; Barba-Sánchez et al., 2019 [105]; Lacinák and Ristvej, 2017 [94]	E-government, e-services, digital services, safety features, tracking, management, smart government, public amenities, corruption.	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; criteria*; measure*; index*; metric*; parameter*
Economy	Ishkineeva et al., 2015 [57]; Ameer et al., 2019 [16]; Lin et al., 2019 [20]; Mundoli et al., 2017 [48]; Ruohomaa et al., 2019 [103]; Honarvar and Sami, 2019 [98]; Dameri et al., 2019 [101]; Trencher, 2019 [61]; Lee et al., 2014 [56]; Navarro, 2017 [58]; Aletà et al., 2017 [92]; Aelenei et al., 2016 [89]; Zaree and Honarvar et al., 2018 [97]; Sampson, 2017 [7]; Stankovic et al., 2017 [91]; Joshi et al., 2016 [90]; Kairui, 2018 [111]; Marsal-Llacuna et al., 2015 [14]; Barba-Sánchez et al., 2019 [105]; Lacinák and Ristvej, 2017 [94]; Girardi and Temporelli, 2017 [49]; Abellá-García et al., 2015 [88]	Sustainable city development, economy, production, welfare, economic prospects, employment, finance, income.	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; criteria*; measure*; index*; metric*; parameter*
Quality of life	Nanni and Mazzini, 2014 [87]; Ishkineeva et al., 2015 [57]; Nayak, 2018 [95]; Louise, 2011 [54]; Grubesa et al., 2018 [96]; Ameer et al., 2019 [16]; Lin et al., 2019 [20]; Praharaj and Han, 2019 [100]; Dameri et al., 2019 [101]; Lee et al., 2014 [56]; Patel and Doshi, 2019 [60]; Aletà et al., 2017 [92]; Jamil et al., 2015 [108]; Aelenei et al., 2016 [89]; Solanki et al., 2019 [99]; Alvarez-Campana et al., 2017 [109]; Zaree and Honarvar et al., 2018 [97]; Manchester and Cope, 2019 [19]; Stankovic et al., 2017 [91]; Santos et al., 2018 [59]; Estrada et al., 2019 [53]; Lee et al., 2013 [55]; Mark and Anya, 2019 [24]; Sahu et al., 2019 [110]; Kairui, 2018 [111]; Marsal-Llacuna et al., 2015 [14]; Walravens and Ballon, 2013 [112]; Nagy et al., 2019 [62]; Barba-Sánchez et al., 2019 [105]; Lacinák and Ristvej, 2017 [94]; Girardi and Temporelli, 2017 [49]; Abellá-García et al., 2015 [88]	Civil society, safe city, high quality of life, smart health, smart transportation, citizen needs, smart mobility, public outdoor recreation spaces, life expectancy, social inequality.	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; green; criteria*; measure*; index*; metric*; parameter*
Competitiveness	Nanni and Mazzini, 2014 [87]; Ishkineeva et al., 2015 [57]; Ruohomaa et al., 2019 [103]; Honarvar and Sami, 2019 [98]; Santos et al., 2019 [15]; Zaree and Honarvar et al., 2018 [97]; Manchester and Cope, 2019 [19]; Stankovic et al., 2017 [91]; Marsal-Llacuna et al., 2015 [14]; Walravens and Ballon, 2013 [112]; Nagy et al., 2019 [62];	Economic development, smart manufacturing, economic prospects.	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; criteria*; measure*; index*; metric*; parameter*
Resource saving	Ishkineeva et al., 2015 [57]; Nayak, 2018 [95]; Louise, 2011 [54]; Regalia et al., 2016 [47]; Ameer et al., 2019 [16]; Patel and Doshi, 2019 [60]; Aelenei et al., 2016 [89]; Yamagata and Seya, 2013 [86]; Alvarez-Campana et al., 2017 [109]; Strzelecka et al., 2017 [93]; Walravens and Ballon, 2013 [112]; Lacinák and Ristvej, 2017 [94]; Girardi and Temporelli, 2017 [49]	Smart use of resources, smart energy, availability of resources, waste management.	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; green; criteria*; measure*; index*; metric*; parameter*
Recreation and leisure	Ishkineeva et al., 2015 [57]; Patel and Doshi, 2019 [60]; Lacinák and Ristvej, 2017 [94]	Leisure, recreation, society, quality of life.	city; urban area*; settlement*; urban region*; metropoli*; township*; smart; sustainable; green; criteria*; measure*; index*; metric*; parameter*

Appendix D

Table A4. Summary of studies on SC identification criteria.

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
1	Louise [54]	Smartening up the city	Data on Cagne-sur-mer, France (“A Smart City initiative” of PACA France Telecom-Orange, 2007–2011)	Smart cities concept, energy costs, CO_2, NO_2, and SO_2	As a result of the Smart City initiative focusing on setting up a data sensor collection network, local authorities expect to see a 20–30% reduction in energy costs, a 20–40% reduction in greenhouse gas emissions, and 20–40% energy savings on heating bills for public buildings.
2	Yamagata and Seya [86]	Simulating a future smart city	Data on the Tokyo metropolitan area (Japan), 2005 (Ministry of Land, Infrastructure, Transport and Tourism; Ministry of International Affairs and Communications; National Tax Agency)	Smart city, income, number of populations, land rent, land area	The concept of the “compact” urban form created for the smart city Tokyo is presented, which may contribute to a reduction in electricity demand and a reduction in CO_2 emissions from the residential sector compared with normal “dispersion”.
3	Lee et al. [55]	Smart city development	Data on Smart City R&D project (South Korea), 2008 and 2013 (Korean Ministry of Construction and Transport)	Smart city, smart service, smart technology, roadmapping	A national roadmap for smart cities considering convergence of technology, devices, and services was presented; “different types of roadmap can be coordinated with each other to produce a clear representation of the technological changes and uncertainties.” (Lee et al., 2013, [55], p. 286).
4	Walravens and Ballon [112]	Platform Business Models for Smart Cities	Data on mobile services of smart cities worldwide (NYC311; Fixmystreet; Pulsepoint; Apps for Amsterdam; App Van’t Stad; London Bike App; Visit Brussels)	Smart city, digital services, business models	“The analysis of platform business models (mobile services) that involve public actors, and city governments in particular, in the value network”, was presented; These models are “important elements in a local government’s Smart city strategy as tools to help reach certain policy goals.” (Walravens and Ballon, 2013, [112], pp. 72, 78).
5	Lee et al. [56]	Towards an effective framework for building smart cities	Data on Seoul metropolitan area (Republic of Korea) and San Francisco City (USA), 2011–2012 (Interviews based in “City Hall”, media reports, relevant smart city project reports, smart-city-related international conference presentations, and city web pages)	City transformation, smart city, quality of life	“A smart city aims to resolve various urban problems (public service unavailability or shortages, traffic, environmental or sanitation shortcomings and other forms of inequality) through ICT-based technology connected up as urban infrastructure.” Smart cities are “creating a better, more sustainable city, in which people’s quality of life is higher, their environment more livable and their economic prospects stronger.” (Lee et al., 2014, [56], p. 82).
6	Nanni and Mazzini [87]	Pollution monitoring using the SensorNet system	Data on Emilia and Romagna region, Italy (“Telematic Regional Planning Framework 2011–2013”, SensorNet project)	Smart cities, environment monitoring (without determining the type of pollution)	The proposed system allows for merging different environmental monitoring tools using technology which is independent of the data transmission type. The system can thus form a basis for a smart city or smart community.

Table A4. *Cont.*

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
7	Yamauchi et al. [107]	Quantitative evaluation method regarding the value and environmental impact of cities	Data on the representative city in Japan (City A) with a population of 1.5 million	Smart city, CO_2	Was developed "a quantitative evaluation method (of the environmental impact of cities) focusing on the efficiency of a city (degree of smartness) and the effect that ICT has on a city"; "ICT not only reduces the environmental impact of a city but also improves its value." (Yamauchi et al., 2014, [107], pp. 112, 119).
8	Ishkineeva et al. [57]	Major approaches towards understanding the smart cities concept	Laws and regulations on the use of information and communication technologies; data from periodical press	Smart cities concept	The smart city is defined as a partnership between the state and the private sector which is economically efficient in terms of new workplaces created, improving ecology, and decreasing energy waste.
9	Marsal-Llacuna et al. [14]	Urban monitoring to better address the Smart Cities initiative	Data on Barcelona city (Spain), 1999–2009 (Barcelona Local Agenda 21)	Smart city, urban indicators	The process of monitoring the Smart Cities initiative was presented—creating "a final index summarizing Smart Cities' real-time set of indicators". Using a final index can make it possible "to easily visualize a city's steps towards "smartness"." (Marsal-Llacuna et al., 2015, [14], pp. 611, 612).
10	Abellá-García et al. [88]	The Ecosystem of Services Around Smart Cities	Data from the EU "MEPSIR" final report on the exploitation of public sector information (2006)	Smart city, open data, apps	Smart cities data-driven ecosystems were explored: "Open collaboration between ecosystem's actors (citizens, businesses, organizations, and the city managers) allows the development of new data-driven services; data of interest for the ecosystem's actors is key for the reusability of the released information and could condition the degree of citizens final satisfaction." (Abellá-García et al., 2015, [88], p. 1075).
11	Jamil et al. [108]	Smart Environment Monitoring System by Employing Wireless Sensor Networks on Vehicles	Data on industrial cities in Pakistan (Zigbee-based wireless sensor networks deployed on public transport vehicles)	Smart city, smoke, carbon oxides and other gases in the environment which cause air pollution	The model for evaluating indoor and outdoor hazardous gases was developed using wireless sensor networks; sensor nodes can directly communicate with the moving nodes deployed on public vehicles; the records can be read in the web application.
12	Regalia et al. [47]	Crowdsensing smart ambient environments and services	Data from the citizens-as-sensors platform (ambient mobile sensor readings from a network of volunteers)	Smart cities, humidity, illuminance, temperature, magnetic, pressure, and audio	A crowdsensing mobile-device platform (GeoTracer app) was developed that "empowers citizens to collect and share information about their surrounding environment via embedded sensor technologies"; the data can be read in either the web application or the mobile phone application (Regalia et al., 2016, [47], p. 382).

Table A4. *Cont.*

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
13	Aelenei et al. [89]	Smart City: Urban Transformation	Data on Lisbon city, Portugal (an MIT–Portugal research project "Suscity Project"; HOBO and Testo sensors; Chauvin Arnoux air quality meter)	Smart city, indoor temperature, relative humidity, CO_2 emissions	The monitoring of houses as part of a smart buildings solution is one of the tasks presented in the SusCity project (project regarding urban transformation needs towards a smart city model); a sensor network was developed to measure indoor CO_2 concentrations, temperature, and humidity in a real-time mode.
14	Joshi et al. [90]	Developing Smart Cities: An Integrated Framework	Data from research in public governance, information technology, e-governance, 2000–2013	Smart cities, conceptual framework	Various aspects and dimensions of the concept of smart cities and its implementation were explored. The Sc framework (SMELTS) was developed which "would help better understand smart city initiatives, provide a managerial purview to the same" as well as help in reducing manpower for the long term. (Joshi et al., 2016, [90], p. 908).
15	Navarro [58]	The effect of ICT use and capability on knowledge-based cities	Data on 158 European cities (Eurostat's Urban Audit database for 2009–2011)	Smart cities concept, ICT, quality of life	"The use and application of ICTs help provide citizens with an infrastructure that allows for an improvement in their quality of life, sustainable growth and efficient use of resources." In other words, the concept of a "Smart City"—"a certain harmony between the quality of human life, economic activity and the exploitation of non-renewable resources." (Navarro, 2017, [58], pp. 272, 273).
16	Mundoli et al. [48]	Urban ecosystems in smart cities	Data on Bengaluru city, India (Results of observations, interviews, and fieldwork carried out by the author from 2013 to 2015)	Smart city, environmental conditions	"A smart city with its emphasis on technology is a static model of planning" which ignores key elements of the environment. "It fails to recognize the diversity of social and ecological relations that urban residents have with different spaces (spatial) in the city over different periods of time (temporal)." (Mundoli et al., 2017, [48], p. 118).
17	Aletà et al. [92]	Smart Mobility and Smart Environment in the Spanish cities	Data on 62 Spanish Smart Cities ("Holistic Concept of Spanish Smart Cities Network", 2015; "+CITIES" project and Competitiveness State Plan for Scientific and Technical Research and Innovation 2013–2016)	Smart city clusters	"Smart City projects are classified according to six axes: Mobility, Environment, Government, Economy, People and Living". "Mobility and environmental issues, as two of the fundamental axes of Smart City development". "Spanish smart cities have good results for mobility and quality-of-life factors, which people see as key aspects in a city. However, environment results require improvement." (Aletà et al., 2017, [92], pp. 163, 169).
18	Stankovic et al. [91]	Evaluation of the European cities' smart performance	Data on 23 Central and Eastern European cities, 2015 (EUROSTAT and the perception survey "How citizens perceive the quality of life in their home cities")	Smart city, smart performance, quality of life	The comparison of QoL rankings ("regarding economic, social, political, or environmental aspects") obtained by the constructed multi-criteria model indicates a rather weak relationship between quality of life and smart performance (Stankovic et al., 2017, [91], p. 539).

Table A4. *Cont*.

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
19	Sampson [7]	Urban sustainability	Data on three American cities—Boston, Chicago, and Los Angeles (community surveys, Google Street View, network analysis of community leaders and organizations, newspaper coding of collective civic events, and "lost letter" field experiments; archival records on crime, violence, health, community organizations, and population characteristics)	Smart city, well-being, inequality	"The explosion of Big Data and real-time monitoring devices are major features to enhance ecological challenges". Smart cities are "integrating environmental sustainability with the promotion of human welfare, or social sustainability" (human well-being and environmental outcomes are "intertwined") (Sampson, 2017, [7], p. 8957).
20	Alvarez-Campana et al. [109]	Smart CEI Moncloa: An IoT-based Platform for Environmental Monitoring	Data of sensor network based on the Smart Citizen Kit of Smart CEI Moncloa platform (Arduino motherboard including an array of sensors)	Smart city, temperature, humidity, light, noise, CO, and NO_2	The IoT-based Smart CEI Moncloa platform, integrated into the metropolis of Madrid, was presented. The platform offers service environmental monitoring by indoor and outdoor sensor networks; the data can be read in real-time mode.
21	Afzalan et al. [18]	Creating smarter cities	Data from theories of planning, organization, and information science	Smart cities, online participatory tools	"Various factors that cities and planning organizations should consider in deciding upon new online participatory tools was discussed"; "Slowing down and taking time to evaluate the planning context help cities with making more appropriate decisions in choosing"; "Smarter cities should adopt new technologies", considering the capacities and needs of communities. (Afzalan et al., 2017, [18], pp. 21, 27).
22	Strzelecka et al. [93]	Integrating Water, Waste, Energy, Transport, and ICT Aspects into the Smart City Concept	Data on Leicester city (Great Britain), 2016 (Leicestershire City Council, EU BlueSCities project)	Smart city, trends and indicators for Leicester city	Partial results of the EU BlueSCities project were presented. Within the framework of the project and the concept of "Smart cities and communities", a methodology for the integration of the water and waste sectors as well as the City Amberprint Framework for energy, transport, and ICT.
23	Lacinák and Ristvej [94]	Smart City, Safety and Security	Data from the Ministry of Environment of the Slovak Republic, Centre of Regional Science and European Commission (2016)	Smart city, safe city	Several ideas on how to define the concept of a Smart City was proposed. The main focus was on the question of safety and security in Smart cities. The definition of a Safe City was introduced.
24	Girardi and Temporelli [49]	A Methodology for Assessing the Sustainability of the Smart City	Data on Milan city (Italia), 2015 (Ricerca sul Sistema Energetico—RSE SpA; Expo Milano 2015)	Smart city, performance Indicators	A new methodological approach (Smartainability) for assessing the development of smart cities is presented. This methodology can provide decision makers with useful information about the benefits of implementing smart solutions (benefits are quantified; metrics are assessed before technology or solutions are introduced; benefits are associated with technology or solutions deployment).

Table A4. *Cont.*

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
25	Nayak [95]	Around-the-clock vehicle emission IoT monitoring system suitable for smart cities	Data from the 24/7 Vehicle Emissions Sensing System with an HC–CO (hydro carbon–carbon monoxide) tester.	Smart cities concept, carbon Monoxide (CO)	The prototype device is connected to the exhaust of a vehicle and the data collected are transferred to the cloud, helping to constantly monitor carbon emissions from the vehicle. The prototype can track the emission and warns the vehicle owner about timely performance of vehicle maintenance.
26	Santos et al. [59]	PortoLivingLab: An IoT-Based Sensing Platform for Smart Cities	Data on Porto city (Portugal), 2014–2016 (PortoLivingLab Smart Platform with UrbanSense sensors)	Smart city, O_3, CO, NO_2, humidity, and temperature	The PortoLivingLab platform was presented which "leverages IoT technology to achieve city-scale sensing of four phenomena: weather, environment, public transport, and people flow. The data is collected in a common backend". "Received data is made publicly available in real-time." (Santos et al., 2018, [59], pp. 523, 525).
27	Voda and Radu [52]	Artificial Intelligence and the Future of Smart Cities	Data on online survey "Importance and Benefits of AI" (112 respondents, during August to November 2017)	Smart cities, artificial intelligence	The public attitude regarding the influence of AI on smart city characteristics was analysed; respondents perceive AI as an important aspect that influences smart city development; gender and age group also influence public attitudes.
28	Grubesa et al. [96]	Mobile crowdsensing accuracy for noise mapping in smart cities	Data on Zagreb city (Croatia), 2017 (B&K 2250 sound level meter, iPhone 6S, and the MCS smartphone application)	Smart cities, noise pollution	The Mobile Crowdsensing measurement method of cities noise pollution (based on MCS application) is developed; it "can make noise mapping easier, cheaper and less time-consuming in terms of creating representative noise maps"; "citizens can engage in noise monitoring in urban areas and become aware of the noise pollution in their cities." (Grubesa et al., 2018, [96], p. 286).
29	Zaree and Honarvar et al. [97]	Improvement of air pollution prediction in a smart city using metrological big data	Data on Brasov city in Romania (CityPulse open dataset)	Smart city, O_3, $PM_{2,5}$, PM_{10}, CO, SO_2, NO_2, longitude, latitude, timestamp, humidity, wind speed, temperature, and air pressure	"A K-means clustering algorithm using the Mahout library is used as a big data mining tool". Results "indicate the high efficiency and accuracy of the proposed method in predicting"; "the proposed method is applied in large cities to find polluted and cleanest areas in real-time" and which improves citizens' quality of life (Zaree and Honarvar et al., 2018, [97], pp. 1302, 1312).
30	Malik et al. [51]	A methodology for real-time data sustainability in smart city	Data on the cities of Aarhus (Denmark) and Brasov (Romania), 2014 (weather IoT sensors of CityPulse)	Smart city, dew point, humidity, pressure, temperature, wind direction, and wind speed	Automated system monitoring and data modeling for a smart city was presented; information is colected from smart city sensors and transformed through data modeling into RDF and JSON data forms. Received data is made publicly available in real time.

Table A4. *Cont.*

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
31	Hassan and Awad [50]	Urban Transition in the Era of the Internet of Things	Data of the Hwaseong Dongtan project, the Republic of Korea (64 cities throughout Korea)	Smart city, IoT, ICT, quality of life	The U-city concept of a smart city "that operates based on ICTs embedded in the urban design" is described; "any citizen can use any service anywhere and anytime through ICT devices." ICT provides "residents with high-quality environmental resources and saves energy using automatic water and air pollution monitoring systems"; it also reduces greenhouse gas emissions and generally improves the quality of life (Hassan and Awad, 2018, [50], p. 36430).
32	Kairui [111]	Intelligent evaluation approach for smart city based on DEA model	Data on Wuhan city (China), 2013 to 2016 (China Statistical Yearbook, China City Statistical Yearbook, China Statistical Yearbook on Science and Technology, Hubei Statistical Yearbook, and Wuhan Statistical Yearbook; Wuhan Municipal Government)	Smart city, evaluation index system, Malmquist productivity index	Evaluation index system of input–output of Smart City was established and presented, with the aim of intelligently evaluating research on the efficiency of construction and the work effectiveness of the government and the whole society in building a smart city in Wuhan.
33	Trencher [61]	Towards the smart city 2.0: using smartness as a tool for tackling social challenges	Data on Aizuwakamatsu Smart City (Japan), 2015–2017 (12 semi-structured interviews (involving 17 respondents); internal project documentation, media and think-tank reports, scholarly articles, and symposium presentation materials)	Smart city	"The first-generation of smart cities fail to advance social agendas and address resident needs"; the second-generation smart cities is "people-centric, using technologies to tackle social problems and resident needs." (Trencher, 2019, [61], p. 117).
34	Akande et al. [106]	Assessing the Gap between Technology and the Environmental Sustainability of European Cities	Data on 129 EU cities (Organization for Economic Co-operation and Development, International Telecommunications Union, and Eurostat)	Smart city, CO_2, two-dimensional ICT index	A single two-dimensional ICT index was developed; "there are four groups of cities with similar ICT (an indicator of smartness) and different CO_2 levels (indicator of sustainability) characteristics", i.e., it is possible for a city to be smart but not sustainable and vice versa. (Akande et al., 2019, [106], p. 596).
35	Solanki et al. [99]	Smart cities-A case study of Porto and Ahmedabad	Data on Porto and Ahmedabad cities (The GrowSmarter project; the URBACT program; the FIWARE community; Smartnet; MC Ahmedabad; SmartCitiesWorld's mission)	Smart city, ICT, quality of life	"Both Porto and Ahmedabad are developing cities facing challenges like pollution, waste treatment, congestion, and traffic. The solutions to these problems can be provided with the help of smart cities". "With smart cities (ICT), can get less traffic and reduce pollution which would lead to an increase in the overall quality of life of residents." (Solanki et al., 2019, [99], p. 721).

Table A4. *Cont.*

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
36	Lin et al. [20]	Smart City Development and Well-Being	Data on 220 new smart cities in China, 2018 (Questionnaire survey data from 247 residents in China's smart cities)	Smart city, well-being	The development of smart cities "pays attention to the general needs of urban residents and also satisfies their personalized needs", which is improving the well-being of smart cities; "usefulness and convenience experiences of obtaining information, services and networks in smart cities all have positive impacts on subjective well-being" (Lin et al., 2019, [20], pp. 1,12).
37	Ameer et al. [16]	Predicting Air Quality in Smart Cities	Data on Guangzhou, Chengdu, Beijing, Shanghai, and Shenyang cities (China), 2010 to 2015 (Statistical Yearbooks of individual cities)	Smart cities concept, $PM_{2,5}$, temperature, humidity, pressure, wind speed, precipitation	"A 4-layer architecture for predicting air pollution has been proposed"; "Random Forest regression was the best technique, performing well for air pollution prediction"; "PM2,5 has a negative correlation with temperature and also a negative correlation with wind speed." (Ameer et al., 2019, [16], pp. 128329, 128330, 128336).
38	Dameri et al. [101]	Smart cities as a glocal strategy	Data on Bologna, Milan, Turin, Florence, Genoa, Shanghai, Beijing, Tianjin, Guangzhou, and Chengdu cities (ANCI Vademecum "about Italian Smart Cities" (2013); EU–China Smart and Green Cities Cooperation report "Comparative studies of smart cities in Europe and China" (2014); China National Bureau of Statistics)	Smart city	"A smart city is a glocal urban strategy, depending on both global, standard drivers and local contingencies". "Italian and Chinese smart cities are both conceived like urban policies to face the environmental impact of the large metropolis and to spread new technologies, especially ICT, to deliver better services to the citizens." (Dameri et al., 2019, [101], pp. 26, 37).
39	Santos et al. [15]	Air Quality Monitoring in Smart Cities	Data on Santander city, Spain, 2018 (a Spec Sensors network located on static points and installed on public vehicles)	Smart city, SO_2, NO_2, O_3, and PM_{10}	The Smart Santander platform was presented. The platform offers a mobile air pollution remote monitoring system; data are available through the platform in real time; the system hardware architecture provides energy consumption savings rates up to 50% and an extra battery lifetime.
40	Honarvar and Sami [98]	Smart Particulate Matter Prediction Using Urban Big Data	Dataset of Aarhus city (Denmark), 2014 (Wunderground's website, The Smart City Pulse project, Google Maps, Openstreetmap's website)	Smart city, PM_{10}, temperature, humidity, wind speed, sea level	"A predictive model for particulate matter prediction was developed", which "integrate[s] heterogeneous multiple sources of urban data and predicts the particulate matter based on transfer learning perspective". "The method can be used to infer the air quality of each road or region of cities in real-time." (Honarvar and Sami, 2019, [98], pp. 56, 65).
41	Praharaj and Han [100]	Perception of a Smart city in India	Perception survey of urban development professionals in India who are implementing a massive "100 Smart Cities Mission", 2018	Smart city concept	Smart city discourse is predominantly corporate-driven and technology-focused. Smart city models should also engage with sustainability and community issues. India's smart city concept is strongly associated with sustainable city and eco-city, which aim to improve the environmental conditions in the city.

Table A4. *Cont.*

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
42	Patel and Doshi [60]	Social implications of smart cities	Data from the United Nations agency "International Telecommunication Union"; the United Nations Population Fund; "Recode" website	City transformation, smart city	The main reason for the transformation of modern cities is the challenges associated with achieving goals related to quality of life and social development; smart cities are the result of knowledge-comprehensive and creative strategies aiming at reinforcing the socio-economic, ecological, and competitive performance of cities.
43	Ruohomaa et al. [103]	Smart City Concept in Small Cities	Data on small cities in Finland: Hämeenlinna, Riihimäki, and Forssa. (The smart mobility pilot project "Electronic bike service", "Smart Green Forssa Region" project, "Industry 4.0 framework" EU)	City transformation, smart city, inequality	"The transition towards smarter cities involves not only technological development but also the changing and evolving roles of citizens, service providers and city authorities". "Cities are platforms for smart city development projects, which enable inhabitants and other stakeholders to participate in his planning and development, thereby minimizing intra-city inequality." (Ruohomaa et al., 2019, [103], pp. 5, 12).
44	Estrada et al. [53]	Smart cities big data algorithms for sensors location	Data on Guadalajara metropolitan zone (Mexico), 1996–2017 (Secretariat of the Environment and Territorial Development of Jalisco State)	Smart city, SO_2, PM_{10}, CO, NO_2, O_3	A process for air quality monitoring through a system of city sensors was presented which integrates data into IoT to identify the "hot" zones and present their visualization in a geo-referenced map; the records can be read on the web application.
45	Wang and Kong [102]	Smart Air Quality Predictive Modeling	Data on Wuhan city (China), 2014–2018	Smart city, air quality index (PM_{10}, $PM_{2.5}$, SO_2, NO, NO_2)	"A novel predictive-model-based decision tree method was proposed, based on the C4.5 decision tree"; an improved algorithm "is more efficient in addressing classification and prediction with a large amount of air quality data; it has a good prediction ability for future data." (Wang and Kong, 2019, [102], pp. 172892, 172900)
46	Barba-Sánchez et al. [105]	Smart cities as a source for entrepreneurial opportunities	Data on 44 Spanish cities (National Statistics Institute (INE), 2016)	Smart city, economic growth	"The impact of smart city initiatives on the creation of new business opportunities" was studied; smart city movement encourages entrepreneurship—"ICT companies promote the creation of auxiliary companies, which leads to growth in local employment"; "ICT is major player in boosting the local economy" (Barba-Sánchez et al., 2019, [105], p. 2, p. 9).
47	Haarstad and Wathne [104]	Smart city projects catalyzing urban energy sustainability	Data on Stockholm (Sweden), Nottingham (United Kingdom), and Stavanger (Norway), 2015–2018 (interview of 27 informants across the three cities)	Smart city initiative, urban energy sustainability	Relations between smart city agenda and energy sustainability were studied. "Sustainability measures are not necessarily driven by advanced technology"; smartness agenda increases sustainability ambitions of cities (Haarstad and Wathne, 2019, [104], p. 1).

Table A4. *Cont.*

№	Publication	Topic	Data Sources	Assessment Criteria	Main Results
48	Sahu et al. [110]	Evaluating the variability, transport and periodicity of particulate matter over smart city	Data on Bhubaneswar (India), 2016–2016 (Monitoring of Atmospheric Pollutants and Network MAPAN program; an Air Quality Monitoring Station (AQMS) and Automatic Weather Station (AWS))	Smart cities, PM_{10}, $PM_{2.5}$, humidity, pressure, temperature, wind	A process for monitoring and analyzing changes in particulate matter (PM) was presented using data from automatic monitoring stations and Environment S.A. optical analyzers; data are available through the website in real time, which helps to quickly identify areas of pollution sources.
49	Nagy et al. [62]	A link between Smart cities and successful cities	Data on 23 Hungarian towns (incl. Budapest), 2010–2015 (Hungarian Central Statistical Office)	Smart city, Theil index, energy use	Regional disparities and the spatial distribution of Hungarian urban energy use were examined; belonging to the smart groups of cities does not cause "significant changes in urban electricity and natural gas consumption patterns." (Nagy et al., 2019, [62], p. 98)
50	Manchester and Cope [19]	Learning to be a smart citizen	Data on Bristol city, UK (Mimeo project, 2016–2021)	Smart city, inequality, quality of life	"The inequality is producing patterns of ownership (access and control of technologies) there are obstacles to city inhabitants finding routes to influence technology shaping the development of the city". "Smart city initiatives to offer city inhabitants opportunities (to co-create smart city services with citizens) address the inequalities that constitute the contemporary city" and increase the quality of life for citizens (Manchester and Cope, 2019, [19], pp. 224, 227).
51	Mark and Anya [24]	Ethics of Using Smart City AI and Big Data	Data on Amsterdam (Netherlands), Copenhagen (Denmark), Hamburg (Germany), and Helsinki (Finland), 2018 (the websites, policy documents, and newspaper articles and interviews)	Smart cities, aartificial intelligence, big data, smart information systems	The effects of using and implementation Smart information systems within smart city projects were studied, which "will help for policy development in the areas of the ethical use of SIS in smart cities of the future." (Mark and Anya, 2019, [24], p. 31).

Appendix E

Table A5. PRISMA Checklist.

Section/Topic		Checklist Item	Reported on Page Number
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	See p. 1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	See p. 1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	See pp. 1–4
Objectives	4	Provide an explicit statement of the questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	See p.3
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	See pp. 4–5, The protocol is not registered
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	p. 4–5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and the date last searched.	p. 5
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	pp. 4–6
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	See pp. 6–7
Data collection process	10	Describe the method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	See pp. 4–7
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	Reported in Figure 3
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	
Synthesis of results	14	Describe the methods of handling data and combining the results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	Reported in Appendix D
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	Reported in Figure 4
Study characteristics	18	For each study, present the characteristics of the data that were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	See p. 5, Figure 3
Risk of bias within studies	19	Present data on the risk of bias of each study and, if available, any outcome level assessment (see item 12).	See p. 3
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	See p. 5
Synthesis of results	21	Present the results of each meta-analysis conducted, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present the results of any assessment of the risk of bias across studies (see Item 15).	
Additional analysis	23	Give the results of additional analyses, if conducted (e.g., sensitivity or subgroup analyses, meta-regression (see Item 16)).	
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of the evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	See pp. 7–14
Limitations	25	Discuss limitations at the study and outcome level (e.g., risk of bias) and at the review-level (e.g., incomplete retrieval of identified research, reporting bias).	See p. 3

Table A5. *Cont.*

Section/Topic		Checklist Item	Reported on Page Number
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	See pp. 14–15
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data), as well as the role of funders in the systematic review.	See p. 15

Note: from Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6 (7): e1000097.

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