Smart and Sustainable Cities (SSC)

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Contributor: Vaia Moustaka

The concept of SC, which was launched about 20 years ago, significantly influenced the city managers and paved the way for the transformation of cities to achieve their sustainability. More than 40 definitions and 30 conceptual models were proposed to clarify the term “smart city” that differ from each other due to the different perspectives and approaches developed for its modeling and design. Many SC definitions emphasize the use of ICT to effectively combine resources to make the city more interconnected, smart and viable, while some other sustainability oriented definitions focus on combining soft infrastructure (i.e., people, knowledge, communities, business processes, etc.) and the hard infrastructure (i.e., ICTs, buildings, city facilities, etc.) to provide a viable, efficient and sustainable city. In the latter case, the term SSC is often used instead of the term SC. Reference considers a smart (sustainable) city as an innovative city that exploits ICTs and other means, with the purpose of improving the quality of life, the efficiency of urban services and operation and competitiveness, while ensuring the needs of present and future generations regarding economic, social and environmental aspects. The improvement of the quality of life and the economy, the development of efficient urban infrastructure, ensuring social inclusion, sustainable management and conservation of natural resources and ensuring good governance are the main goals of SC. According to the conceptual model of, the SC ecosystem consists of six dimensions, which are: (i) smart economy, (ii) smart governance, (iii) smart environment, (iv) smart people, (v) smart mobility and (vi) smart living.

Keywords: cityDNA ; smart cities

1. Smart to Resilient Cities’ Transformation Principles

Many cities around the world are striving to leverage their resources to modernize the traditional mechanisms of their operation and to acquire dynamic behavior to deal with the urban problems arising from anarchic urbanization and urban aging, and to become a pole of attraction for citizens and investors. City transformation is a complex and multidimensional process as it depends on the collective integration of governance, technology, institutional and transitional components [1]. As [2] pointed out, city transformation is based on four key areas, which are: (i) urban planning, (ii) physical infrastructure, (iii) ICT infrastructure and (iv) smart solutions’ deployment, and aims at cultivating sustainability, smartness and resilience in cities. In the context of city transformation, particular emphasis is placed on modern governance models’ application, the exploitation of disruptive technologies, strengthening of communities and citizen participation, environment and resources’ protection and emergency management [2][3].

The concept of SC, which was launched about 20 years ago, significantly influenced the city managers and paved the way for the transformation of cities to achieve their sustainability [4]. More than 40 definitions and 30 conceptual models were proposed to clarify the term “smart city” that differ from each other due to the different perspectives and approaches developed for its modeling and design. Many SC definitions emphasize the use of ICT to effectively combine resources to make the city more interconnected, smart and viable, while some other sustainability oriented definitions focus on combining soft infrastructure (i.e., people, knowledge, communities, business processes, etc.) and the hard infrastructure (i.e., ICTs, buildings, city facilities, etc.) to provide a viable, efficient and sustainable city [5]. In the latter case, the term SSC is often used instead of the term SC. Reference [6] considers a smart (sustainable) city as an innovative city that exploits ICTs and other means, with the purpose of improving the quality of life, the efficiency of urban services and operation and competitiveness, while ensuring the needs of present and future generations regarding economic, social and environmental aspects. The improvement of the quality of life and the economy, the development of efficient urban infrastructure, ensuring social inclusion, sustainable management and conservation of natural resources and ensuring good governance are the main goals of SC [4]. According to the conceptual model of [7], the SC ecosystem consists of six dimensions, which are: (i) smart economy, (ii) smart governance, (iii) smart environment, (iv) smart people, (v) smart mobility and (vi) smart living.

Along with the establishment of smart city, the concept of resilient city (RC) emerged [8][9]. The term "resilience" came to the fore in 2012, after Hurricane Sandy, which caused a total of about USD 19 billion in damage, and is associated with risk management, ecology and political sciences [8]. In this context, international organizations and city associations promoted the term "resilient city" to improve cities' capabilities to deal with risks and external pressures, ranging from climate change and environmental degradation to poverty and congestion. As pointed out in [3], RCs are those that have the ability to absorb, recover and prepare for future shocks (economic, environmental, social and institutional) and promote sustainable development, well-being and inclusive growth. The COVID-19 crisis that spread around the world intensified the need to integrate resilience into local government recovery strategies [10]. The achievement of resilience in cities is driven by four interrelated areas, which are: (i) economy, (ii) environment, (iii) governance and (iv) society [3]. Citizen engagement and co-creation are also considered essential to achieving resilience in cities. Regarding this, the authors of Reference [11] proposed the redistribution of power and the redesign of urban services with the purpose of enhancing citizen participation and equality. Taking into account the abovementioned and the relevant literature [9][12], it appears that RCs, through the mechanisms they develop, aim at preventing natural disasters (e.g., floods, earthquakes, hurricanes, etc.), managing emergencies (e.g., health crises, fires, etc.) effectively, civil protection and maintaining social cohesion and economic development.

Although the concepts of SCs and RCs have different roots and missions, they have many similarities, and there is an overlap of their key features, some of which are: efficiency, flexibility, learning and innovation capacity, participation, awareness, etc. The features that are unique to RCs and contribute to their adaptability are the following: persistence, modularity, redundancy, memory, robustness, resourcefulness and transformability. As far as SCs are concerned, their key features are: equity, monitoring capacity, reliability and anticipation [9]. In this respect, the McKinsey Institute [13] pointed out that "smarter cities are resilient cities", since city monitoring through smart infrastructure leads to the acquisition of profound knowledge and timely decision-making and execution of actions. Studying the differences and similarities between SCs and RCs, the authors of Reference [14] concluded that the impact of RCs is positive on smart cities from a physical, social and environmental point of view, while the impact of SCs on RCs can be both positive and negative from the above three aspects. Additionally, both SCs and RCs are equally important for urban planning and can complement each other through proper planning and governance. Therefore, city managers need to devise transformation strategies that will lead to the realization of both smart and resilient cities, to meet the challenges of rapid urbanization and to achieve sustainable urban development. Since each city has its own needs and characteristics (intrinsic and extrinsic) and there is no highroad to achieve city transformation, the acquisition of profound knowledge that will come from urban data and the use of relevant standards to steer and measure city performance are proving necessary.

2. Cities as Data-Driven Ecosystems: Urban Data Exploitation and Crowdsourcing

Cities act as "data prosumers", since huge amounts of data are generated and consumed on a daily basis [4]. The main driving force behind the urban data production is human activity, as people live and work in cities and manage them. The authors of Reference [4], conducting a systematic review on SC data analytics, found that the design, development and maintenance of smart services requires the exploitation of data from various urban data sources. Urban data constitutes a valuable asset of cities as its exploitation provides insights into their operation and performance, which are necessary for decision-making and urban planning [2], and as aptly pointed out by [15], "the city of tomorrow is designed using the data of today". In this context, several conventional cities that strive to transform into smart and resilient ones have recognized the important role of urban data and developed infrastructure for their collection and utilization [16]. However, the efficient use of urban data raises new issues related to: (i) urban data sources, (ii) data ownership and (iii) data storage and processing [16][17][18].

With regard to urban data sources, the majority of urban data comes from organizations, both public and private are included, that have monitoring and data recording systems or conduct surveys. The use of IoT technologies, despite the investments made in recent years, the value of which will exceed 2 trillion US dollars by 2025 [19], remains prohibitive for several cities due to their limited budgets [20][21][22]. Moreover, the recording of human activity that has great potential is almost negligible, since few tools have been developed for data collection by citizens, citizens have not been motivated to participate in the production of urban data that will benefit cities and themselves, while Online Social Networks (OSNs) offer limited opportunities for the exploitation of OSN data [4][16]. Several scholars, attempting to address these limitations, highlighted the dynamics of crowdsourcing (or crowd-sensing), since the majority of urban activities are performed and can be recorded by human capital [23][24][25][26]. Crowdsourcing, which is also known as Internet of People (IoP), constitutes a valuable and low-cost urban data source that can be used either independently or in conjunction with IoT to provide real-time data [27][28]. Citizens, using their personal devices such as smartphones, wearables, etc., act as social sensors, and create and provide valuable and real-time information and social content (or User-Generated Content

(UGC)), that is impossible to be derived from other technologies (e.g., IoT, GIS, etc.) [23][25]. UGC, which is produced in three different user-centric ways (i.e., participatory sensing, opportunistic sensing, opportunistic mobile social networks), is also used to verify and validate sensor data [4][26]. According to the authors of [29], who conducted a systematic review on crowdsourcing exploitation in SC, crowdsourcing applications are used in the fields of environment, disaster management, public safety, city innovation, transportation and health, while their feasibility is affected by systems' characteristics that are cost, duration, scalability, technical support and uncertainty. UGC is often exploited in Intelligent Transport Systems (ITS), in which real-time and valid information on traffic conditions is required [21][30][31][32]. Specifically, the authors of Reference [21] pointed out that crowdsourcing is a key mechanism for enhancing citizen participation and collecting urban data, which is necessary for transportation planning and operations. The authors of Reference [31] proposed a multi-agent system which uses UGC and IoT data to address the problem of Vulnerable Road Users (VRUs), while the authors of [33] presented a mobile crowdsourcing-based system, entitled CrackSense, which detects urban road crack, estimating its damage degree. Beyond ITS, crowdsourcing contributes to the improvement of public services and urban life, while enhancing citizen engagement and co-creation [4][34][35]. Therefore, as [36] pointed out, crowdsourcing should be utilized by cities as it effectively contributes to their transformation by enhancing citizen engagement and the exploitation of untapped data that captures and reveals the vibrancy of cities and enables real-time decision-making. However, issues related to the citizens' privacy protection, data usage rights, citizens' incentives to participate and the possible malicious involvement of some citizens in crowdsourcing activities should be carefully considered.

In terms of data ownership, most of the urban data belongs to municipalities and private organizations, where it remains locked and is utilized based on their purposes and interests. As part of open government, several cities, such as London, Boston, New York City, Amsterdam, Copenhagen, Barcelona, etc., set up open data platforms and dashboards to allow urban data to be accessed and used by cities' stakeholders [37][38]. However, the open data platforms of most cities contain archival data from other public or private organizations that are updated monthly or annually, and usually do not cover the full range of activities in cities, and especially human activity. This results in the provision of limited information that is insufficient for the composition of the urban profile and its evolution over time, and reduces the potential of city managers who need rich and qualitative datasets for knowledge acquisition and policy-making. Cities should invest in the development of digital applications that citizens can use to provide feedback to governments quickly and inexpensively through crowdsourcing, which will be interconnected with open data platforms, to increase their interaction with citizens and to improve the quality and quantity of urban data [34].

Regarding the methods of urban data exploitation, it is common to store it in databases and then retrieve and process it and visualize the results of its analysis. This time-consuming sequence is a brake on instant data visualization and real-time decision-making [4][17][18]. Data interoperability and integration constitutes one of the most difficult problems facing cities, as pointed out by [39]. With the purpose of addressing this issue, the large volumes of urban data generated by IoT devices and crowdsourcing activities need to be harnessed to help city applications make informed decisions on the fly. In this respect, the authors of Reference [17] presented the IES Cities platform, which was designed to streamline the development of urban applications that integrate heterogeneous datasets provided by different entities, such as citizens, municipality, IoT infrastructure and other data sources. In addition, the authors of [39] proposed a conceptual framework that aims to integrate data across the various systems of the city, urban data analytics and creation of value-added services using edge computing, cloud computing, data analytics and semantic integration. Of particular interest is the work of [18], which introduced a framework for a real-time decision support system for response during a crisis or disruption of critical infrastructure based on in-memory database technologies and urban data sources. Specifically, data that include decisions and strategies concerning urban resilience are better to be collected from the database according to current urban status and the type of disruption.

As evidenced from the above, and as the authors of [16] pointed out, the aforementioned three factors that determine both the quality and quantity of acquired urban knowledge that are necessary for the successful city transformation are highly volatile and depend on technological advancements. Cities are called upon to develop mechanisms for effective urban data management and to answer questions about urban data ownership and reliability, urban data protection, the usefulness and purpose of data collection and urban data processing and analytics methods to lay the foundations for achieving their smartness and resilience and for measuring their performance [16]. Moreover, local authorities should work closely with citizens and city stakeholders to prioritize needs, develop low-cost services that are delivered on time and achieve city transformation that accelerates urban smart growth. Special emphasis should be placed on the exploitation of crowdsourcing activities, since it offer many benefits, such as strengthening citizen participation, enhancing the city's vibrancy, decreasing costs of data production, etc. [29][36]. Consequently, cities need to invest in the development of data infrastructures and define the standards for the collection, utilization and ownership of urban data to ensure their fruitful exploitation and gain comparative advantages over other cities.

3. Standards for Smart and Resilient Cities

This section deals with cities' standardization, which is necessary to define the guidelines for urban transformation, to make feasible the measurement of cities' performance and to facilitate decision-making. Initially, the efforts made to define cities' indicators are discussed and then the focus is on the city standards proposed by ISO.

3.1. Smart Cities' Standardization and Profiling

With the purpose of achieving cities' transformation and their effective management, it is necessary to identify the urban opportunities and threats and to use metrics to evaluate policy actions and measure their impact. Since cities differ significantly in geophysical, social, economic and other characteristics, a representative set of KPIs should be created for each city [40]. These indicators enable the diagnosis and address challenges, facilitate urban design and offer cities the opportunity to monitor the progress and impact of interventions aimed at achieving smartness and resilience [41]. The importance of defining indicators is reflected in the work of the authors of [42], who conducted a literature review on research efforts to establish a framework of indicators for monitoring and evaluating the performance and sustainability of cities. Their findings revealed that 1152 indicators were proposed, which are categorized into six smart dimensions and the majority of them are related to the environment. According to OECD [43], indicators contribute to the policy-making process in two different ways, which are the following: (i) informing those responsible about the current conditions in the city, and (ii) providing information on the implementation of policies and their performance. Two main types of indicators were proposed: the policy-making indicators and baseline indicators (i.e., measurements of demographics, labor market, etc.). The policy-making indicators in turn are divided into four categories, which are the following: (i) input indicators which monitor effort, (ii) output indicators which monitor efficiency, (iii) outcome/result indicators which monitor effectiveness and (iv) process indicators that measure the implementation of actions [43]. Therefore, both intrinsic and extrinsic characteristics of cities that are the result of policy-making can be measured through the indicators to provide an overall view of the city by synthesizing its profile.

Regarding the aforementioned, the city profile, which consists of the city character profile and city operation profile, is a way of presenting information about cities and is created using urban data, to analyze and visualize the requirements of urban services and to provide direct or indirect decision support to stakeholders in cities [44]. The city profile that emerges from the use of indicators as a unit of information aims to improve knowledge about structural changes in urban environments and measures the impact of these transformations on the quality of life in cities [45]. In this context, several organizations and research groups involved in urban planning and sustainability developed and proposed various tools and sets of indicators for evaluating the performance of cities [41]. The proposed indicators were examined by several scholars in their attempt to evaluate and compare urban strategies and their impact on cities' evolution and sustainability [46][47][5][48][49][50]. The findings revealed that although the proposed indicators are effective in benchmarking, their selection is often difficult, and in many cases they do not provide a comprehensive view of city performance since they focus on specific services or dimensions [41][48][49]. According to [47], their selection is usually determined by factors such as the spatial scale (country, region, city and neighborhood), the development phase of the city (planning, operation), the time scale of the evaluation (annual, periodic, real-time) and the purpose of the evaluation (planning, monitoring, marketing, benchmarking).

The need to simplify the selection of indicators that will allow their profiling and benchmarking led to efforts for cities' standardization. In this regard, several standardization bodies developed standards that propose indicators for measuring city performance in terms of achieving sustainability, smartness and resilience. Specifically, ITU drafted the ITU-T Y.4903/L.1603 (https://www.itu.int/rec/T-REC-L.1603/en (accessed on 10 February 2020)) Recommendation, that offers general guidance to cities and provides KPIs for SSCs, and the ITU-T Y.4904/L.1604 (https://www.itu.int/rec/T-REC-Y.4904/en (accessed on 10 February 2020)) Recommendation for SC maturity measurement, aiming at helping cities to achieve SDGs. On the other hand, the joint IEC and ISO working group drafted the ISO/IEC 30146 Standard in October 2019, which provides evaluation indicators and evaluation methods for measuring the functionality of different ICT systems within a city. In addition, these organizations are preparing ISO/IEC 21972, which will set out the general principles for a higher-level indicator ontology that allows the representation of the indicator definition and the data used to export the index, as well as ISO/IEC 30146, which provides evaluation indicators and evaluation methods for measuring the functionality of different ICT systems within a city [51]. The contribution of ISO in the standardization process and in the definition of appropriate indicators is also excellent, since its specialized Technical Committees, after a thorough investigation into cities, developed three city standards—for city services and quality, smart cities and resilient cities—whose indicators cover the majority of urban aspects [52]. The above standards present both similarities and differences between them, as they relate to cities, but differ in approaches, objectives and definition of indicators [47]. Since these standards have been recently developed, case studies need to be designed to investigate the success of their implementation and the demand for their revision and improvement.

3.2. ISO Standards and Indicators for Smart Cities: A Synopsis

ISO is significantly involved in cities' standardization by developing standards for both cities and the urban data required for the synthesis of KPIs. These standards are widely accepted, since they provide well-defined indicators, evaluation methods and guidance on data sources [47][37]. Focusing on city indicators, a family consisting of three different complementary standards was developed and proposed (**Figure 1**). The ISO 37120:2018 Standard [53], which is a revised version of the ISO 37120:2014 Standard and proposes indicators for city services and quality in cities [54], constitutes the basis for the development of ISO 37122:2019 [55] and ISO 37123:2019 [56] Standards, that proposed indicators for smart cities and resilient cities, respectively. These sustainability-driven standards can be used in combination to provide a holistic approach to urban sustainability and their indicators can be used by each city that undertakes to measure its performance in a comparable and verifiable way, regardless of its size and location.

Figure 1. Sustainable development of communities—relationship between the family of city indicators' standards [53].

The indicators of the above three standards are classified into 19 themes aiming to cover all aspects of the city. Additionally, the indicators of ISO 37120:2018 per theme are divided into three subcategories, which are the following:

- Core indicators: required to assess the effectiveness of urban services and quality of life.
- Supporting indicators: recommended to assess the effectiveness of urban services and quality of life, and depend on the city's objectives.
- Profiling indicators: proposed for the acquisition of statistics and the extraction of good practices resulting from the comparison between cities.

The definition of core and supporting indicators is required by the different resources and capabilities of cities worldwide. The core indicators are considered essential for guiding and evaluating the performance of cities, while the supporting indicators are used only in cities where their composition is feasible, in addition to the core ones.

ISO 37120 includes a total of 111 indicators, while ISO 37122 and ISO 37123 include 80 and 68 indicators, respectively. Taking into account the conceptual model for SC of [7] and the typology of SC core functions suggested in [57], a mapping of the ISO themes and their corresponding indicators to six SC dimensions was performed and is presented in **Table 1**.

Table 1. Overview of ISO indicators and their mapping to city dimensions.

A. Indicators for Economy			
ISO Themes	**ISO 37120:2018**	**ISO 37122:2019**	**ISO 37123:2019**

Economy	**9 KPIs (5.1–5.9) for:** - labor market - entrepreneurship - urban productivity - household income - patents	**4 KPIs (5.1–5.4) for:** - new business - labor force in ICTs, the education, research and developments sectors - service contracts providing city services which contain open data	**7 KPIs (5.1–5.7) for:** - insurance coverage of the total value of the assets that exist in the city and disaster losses as a percentage of city product - employment concentration, labor force in informal employment and household disposable income
Finance	**5 KPIs (9.1–9.5) for:** - debt services and taxes - capital spending - own-source revenue - gross capital and operating budget	**2 KPIs (9.1–9.2) for:** - city revenues collected from the distribution of the economy compared to own resources revenues - electronic payments and invoices	**7 KPIs (9.1–9.7) for:** - expenditures on upgrades and maintenance of city, social and community services, green and blue infrastructure and emergency management planning

B. Indicators for governance

ISO Themes	ISO 37120:2018	ISO 37122:2019	ISO 37123:2019
Governance	**4 KPIs (10.1–10.4) for:** - voter participation - election of women to city council	**4 KPIs (10.1–10.4) for:** - city's IT infrastructure downtime - accessible city services that can be requested online - response time to inquiries of citizens - traffic of the municipal open data portal	**6 KPIs (10.1–10.6) for:** - disaster management plans' design and implementation - existence of secure and remote back-up storages for city electronic data - public meetings dedicated to resilience in a city
Urban planning	**5 KPIs (21.1–21.5) for:** - informal settlements - green area - jobs–housing ratio - basic service proximity - city population and built-up density	**4 KPIs (21.1–21.4) for:** - citizen engagement in the planning process - building permits (spent time for approval, electronic submission system)	**6 KPIs (21.1–21.6) for:** - risk assessment in planning and investment of city departments - city area covered by publicly available hazard maps - emergency management (expenditures on water retention measures, expenditures on water retention measures, etc.)

C. Indicators for environment

ISO Themes	ISO 37120:2018	ISO 37122:2019	ISO 37123:2019

Energy	**8 KPIs (7.1–7.8) which for:** - energy consumption in private and public buildings - end-use energy derived from renewable sources - electrical service interruptions	**10 KPIs (7.1–7.10) for:** - electrical and thermal energy production from solid and liquid waste - city electricity produced using decentralized electricity production systems - storage capacity of the city's energy grid - street lighting management - buildings with smart energy meters - vehicle charging stations - public buildings renovation	**3 KPIs (7.1–7.3) for:** - energy supply capacity - critical facilities served by off-grid energy services
Environment and climate change	**9 KPIs (8.1–8.9) which relate for:** - noise pollution - gas emissions - air quality - change in number of native species	**3 KPIs (8.1–8.3) for:** - real time remote air quality monitoring - public buildings equipped for monitoring indoor air quality - buildings built or refurbished in conformity with green building principles	**9 KPIs (8.1–8.9) for:** - management of extreme weather conditions (heat events, cold events, flood events, etc.) - management of urban heat islands effect and its mitigation through high-albedo materials in city area - soil restoration and ecological evaluation of natural urban areas for their protective services
Solid waste	**10 KPIs (16.1–16.10) for:** - solid waste generation and management (collection, recycling, disposal, etc.) - hazardous waste management	**6 KPIs (16.1–16.6) for:** - recycling of plastic and electrical and electronic waste - sensor-enabled garbage bins and drop-off center equipped with telemetering - energy generation from urban waste - door-to-door garbage collection with an individual monitoring of household waste quantities	**1 KPI (16.1) for active and temporary waste management sites available for debris and rubble**

Wastewater	**4 KPIs (22.1–22.4) for wastewater management and sanitation**	**5 KPIs (22.1–22.5) for:** - treated wastewater and bio solids reuse - energy generation from wastewater - wastewater pipeline network monitoring by real-time data-tracking sensor systems	**(–)**

D. Indicators for people

ISO Themes	ISO 37120:2018	ISO 37122:2019	ISO 37123:2019
Education	**6 KPIs (6.1–6.6) for:** - educational attainment level of citizens - teacher capacity	**3 KPIs (6.1–6.3) for:** - digital learning devices' usage - STEM higher education - city population with professional proficiency in more than one language	**4 KPIs (6.1–6.4) for:** - training on emergency preparedness and disaster risk management - educational disruption

E. Indicators for mobility

ISO Themes	ISO 37120:2018	ISO 37122:2019	ISO 37123:2019
Telecommunication	**2 KPIs (18.1–18.2) for Internet and mobile phone connections**	**3 KPIs (18.1–18.3) for:** - Internet services speed and quality - public Internet access	**1 KPI (18.1) for emergency equipment able to operate reliably during a disaster event**
Transportation	**8 KPIs (19.1–19.8) for:** - public transportation - commuting - bicycle paths and lanes - transportation deaths	**14 KPIs (19.1–19.14) for:** - parking spaces equipped with e-payment and real-time availability systems - autonomous vehicle and roads conforming with autonomous driving systems - public transport services covered by a unified payment system and equipped with accessible real-time systems - sharing economy transportation - bicycle-sharing - smart street lighting	**1 KPI (19.1) for available evacuation routes in a city**

F. Indicators for living

ISO Themes	ISO 37120:2018	ISO 37122:2019	ISO 37123:2019
Health	**6 KPIs (11.1–11.6) for:** - life expectancy and mortality - suicides - medical and paramedical staff capacity	**3 KPIs (11.1–11.3) for:** - e-patient services (online unified health file, remote medical appointments) - city population access to real-time public alert systems for air and water quality advisories	**4 KPIs (11.1–11.4) for:** - population immunization and health insurance - adequacy of electricity supply to hospitals - infectious disease outbreaks
Housing	**5 KPIs (12.1–12.5) for:** - housing quality	**2 KPIs (12.1–12.2) for smart energy and smart water meters**	**6 KPIs (12.1–12.6) for:** - vulnerability of residential buildings in high-risk hazards (flood, disasters) and residential cities not in conformity with building standards - capacity of designed emergency shelters - restoration of buildings damaged by disasters
Population and social conditions	**4 KPIs (13.1–13.4) for:** - poverty and inequality	**4 KPIs (13.1–13.4) for:** - improvement of lives of persons with special needs (mobility aids, devices and assistive technologies, accessibility to public buildings, etc.) - digital divide bridging	**5 KPIs (13.1–13.5) for:** - vulnerable population - population affected by natural hazards - population enrolled in social assistance programs - neighborhood with regular and open neighborhood association
Recreation	**2 KPIs (14.1–14.2) for indoor and outdoor recreation spaces**	**1 KPI (14.1) for online booking of public recreation services**	**(–)**
Safety	**10 KPIs (15.1 –15.10) for:** - civil protection (police, fire service, etc.) - deaths caused by natural hazards, industrial accidents, crimes, homicides, etc. - violent crimes against women - response time for emergency response services from initial call	**1 KPI (15.1) for city area covered by digital surveillance cameras**	**4 KPIs (15.1–15.4) for:** - multi-hazard early warning systems and local hazard warnings issued by national agencies that are received in an on-time fashion in a city - emergency responders with disaster response training - hospital beds destroyed by natural hazards

Sport and culture	**3 KPIs (17.1–17.3) for cultural and sport facilities and cultural events**	**4 KPIs (17.1–17.4) for:** - online booking for cultural activities - digitalization of city's cultural records - public libraries and e-book titles	**(–)**
Urban/local agriculture and food security	**4 KPIs (20.1–20.4) for:** - malnutrition and overfeeding of the population - urban agriculture and local food production	**3 KPIs (20.1–20.3) for:** - municipal budget spent on urban agriculture initiatives - composting of collected municipal food waste - city's land area covered by an online food-supplier system	**2 KPIs (20.1–20.2) for:** - citizens' proximity to grocery stores - capacity of city food reserves in case of emergency
Water	**7 KPIs (23.1–23.7) for:** - domestic water consumption - water quality (water service interruptions, city population with potable water supply service, etc.)	**4 KPIs (23.1–23.4) for water quality monitoring and water distribution using smart meters and smart water systems which provide real-time data**	**2 KPIs (23.1–23.2) for:** - alternative water sources - alternative methods for drinking water

- The economy dimension, as defined in [7], concerns the competitiveness of a city, which includes entrepreneurship, innovation, productivity, the labor market, international integration and the capacity for transformation. The proposed indicators presented in **Table 1**A aim at measuring the abovementioned aspects of economy by approaching them from 3 different perspectives: ISO 37120 focuses on measuring the prosperity of the city, ISO 37122 focuses on measuring innovation and digitalization of services and ISO 37123 focuses on assessing the financial resilience of the city, and investing in the maintenance of urban assets and emergency response.
- The governance dimension includes the interaction of city managers with citizens, the provision of public and social services, transparent governance and policy-making[7] . The ISO themes and corresponding indicators proposed for its evaluation are presented in **Table 1**B. ISO 37120 indicators concern the assessment of voting participation and achievement of gender equality in politics, as well as the quality of social services provided to citizens, ISO 37122 indicators concern the evaluation of e-governance, transparency and the involvement of citizens in municipal e-services and ISO 37123 indicators relate to the evaluation of urban planning for the prevention and dealing with emergencies and the achievement of urban resilience. The data required for the synthesis of these indicators is collected by and owned by municipalities. Additionally, archival data is used mainly for the synthesis of ISO 37120 and 37123 indicators, while real-time and periodic data generated by crowdsourcing activities is used for ISO 37122 indicators.
- The environment dimension concerns the sustainable management and protection of natural resources and the environment. The issues and corresponding indicators proposed for this dimension are presented in **Table 1**C. Specifically, ISO 37120 proposes 31 indicators related to energy production and consumption, environmental quality, municipal waste and wastewater management, ISO 37122 proposes 24 indicators related to the exploitation of ICTs for monitoring and management of energy, the environment, solid and liquid waste and the use of alternative energy sources, with the aim of sustainability and improving the quality of life, and ISO 37123 proposes 13 indicators related to the management of extreme weather conditions and situations that threaten the ecosystem and the energy efficiency and the stability of the electricity supply network.

- The people dimension, which includes human and social capital, the proposed theme and its indicators are presented in **Table 1**D. ISO 37120 proposes indicators for assessing the level of citizens' education and the provided education services, ISO 37122 proposes indicators for the evaluation of e-learning services and ISO 37123 proposes indicators for evaluating the readiness of citizens in cases of emergency and the treatment of educational interruption.

- The mobility dimension is associated with transport and ICTs in a city, and the proposed ISO themes and their indicators are presented in **Table 1**E. ISO 37120 proposes 10 indicators concerning the availability and provision of both ICTs and transport services, ISO 37122 proposes 17 indicators concerning the use of ICTs in transportation management aiming at sustainability and ISO 37123 proposes 2 indicators concerning the assurance of the operation of the ICT infrastructure and the evacuation of the roads in case of emergency.

- The living dimension includes all services related to quality of life, such as cultural and education facilities, housing quality, health conditions, safety, etc., and the proposed ISO themes and their indicators are presented in **Table 1**F. Specifically, ISO 37120 proposes 41 indicators related to the availability of urban facilities and the provision of services aimed at the well-being and happiness of citizens, ISO 37122 proposes 22 indicators that are related to the digitalization of urban services and the use of smart metering systems for the collection of data that is necessary for urban planning and improvement of service quality and ISO 37120 proposes 23 indicators, concerning preventive actions in order to ensure the uninterrupted provision of civil services and the well-being of citizens as well as the prevention of dangerous situations that threaten the city's prosperity.

The number of indicators per dimension for each of the ISO Standards is shown in **Figure 2**. Considering the total number of indicators per dimension, it appears that the majority of indicators are associated with the dimensions of the living and environment, followed by the dimensions of the economy and mobility, governance and people. A similar trend is followed by the indicators of ISO 37120, which concerns city services and quality of life. With regard to ISO 37122, which concerns SCs, it appears that the majority of its indicators relate to the dimensions of environment, living, mobility and governance. This fact is justified, since ICTs have been widely used in recent years, aiming at the development of smart services related to these dimensions, and the measurement of cities' performance is considered necessary. Finally, as expected from the definition and aspects of RCs, the majority ISO 37123 indicators are associated with the dimensions of living, economy, environment and governance.

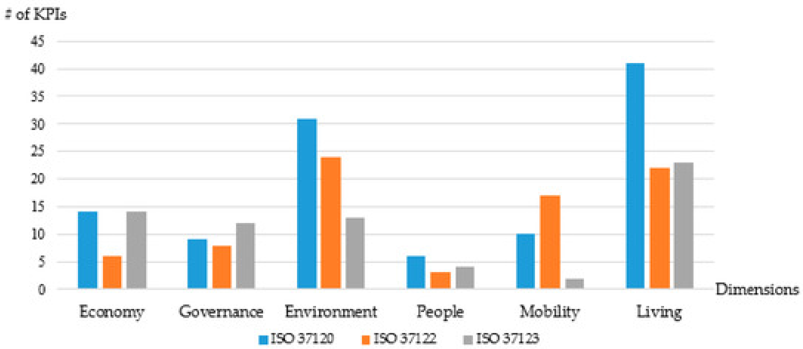

Figure 2. Number of KPIs per city standard and SC dimension.

Regarding the urban data required for the synthesis of the indicators proposed by ISO standards, the following conclusions are drawn:

- Indicators related to the dimensions of economy and people mainly require archival data that are collected by public organizations (e.g., municipalities, chambers, labor organizations, tax services, ministry of education, etc.) and belong to local, regional and national authorities.

- The indicators proposed by ISO 37120 and ISO 37123, which concern the dimensions of governance, environment, mobility and living, require mainly archival data (e.g., data related to installed electric power, number of landfills, power generation mix, statistics for air pollution, etc.), which is collected and belongs to local, regional and national authorities. Additionally, the synthesis of some indicators requires the exploitation of real-time data, which is generated and collected by urban infrastructure and belongs to either local authorities or private companies.

- The indicators proposed by ISO 37122, which concern the dimensions of governance, environment, mobility and living, require mainly real-time data generated from the installed infrastructure owned either by local authorities or private companies, and from personal devices that are used by citizens to record their activities (e.g., energy consumption, amount of discarded solid waste, online booking, e-payments, etc.). This demand for real-time data utilization is due to the fact that these dimensions include services that affect the quality of life and performance of the city on a daily basis, and therefore real-time monitoring is required to enable immediate interventions.

Based on the previous discussion on the demand for cities' standardization and the standards for cities proposed by ISO, the next core observations and open issues require further consideration:

- Different indicators are included in each standard aiming at the evaluation of different aspects of cities. Specifically, ISO 37120 includes indicators that measure mainly the quality of life and services in cities, ISO 37122 includes indicators that measure the exploitation of ICTs in urban services, while the indicators of the standard ISO 37123 aim at measuring the readiness of the city in dealing with emergencies and its resilience. Therefore, these standards can be used either separately by synthesizing the city profile and measuring city performance based on the indicators they include, or in combination by synthesizing the overall profile of the city and measuring its overall performance.

- The proposed indicators, which were defined and proposed after a thorough investigation and study by the ISO Technical Committees to provide a comprehensive view of the cities, focus unilaterally on specific urban services and aspects, ignoring the rest, which are probably important for other cities. As pointed out in [47], further analysis of the needs of cities and the enrichment of existing standards with new indicators is required to capture the overall city profile.

- The identification of the proposed indicators requires the existence and exploitation of relevant KPI-driven urban data. In this respect, it appears that the majority of indicators are determined by archival data, which is collected by various organizations (i.e., local authorities, private companies, citizens, etc.) and becomes available to local authorities for consumption and sharing through their open data platforms [58]. In addition, real-time data is required for the synthesis of the indicators proposed by ISO 37122. However, the existence and availability of KPI-driven urban data remains limited in several cities worldwide. This is due either to the lack of resources required to develop the appropriate infrastructure for data collection and management, or to the lack of standardization of urban data and to the limited exploitation of crowdsourcing activities. Recognizing the demand for city standardization and benchmarking, WWCD, which is the global leader in standardized city data aiming at creating smart, sustainable, resilient and prosperous cities, has developed the WCCD Global Cities Registry (https://www.dataforcities.org/global-cities-registry (accessed on 10 February 2020)), that is the internationally recognized list of cities certified according to ISO 37120 and its certification system. The certification concerns the cites' data that are verified and comply with ISO 37120, which are then published in the WCCD Open Data Portal for a period of one year, offering city-to-city comparisons, data analytics and visualization.

- The proposed indicators are common to all cities that differ in their intrinsic and extrinsic characteristics. As [59] pointed out, each city has its own peculiarities, and for this reason, they have to adapt the ISO standards and international best practices based on them, in order to achieve their transformation. As a result, the synthesis of ISO indicators may not be feasible for some cities since they may not support the services listed in these standards or may not have relevant data.

- In the context of urban standardization, it would be practical to study and to set up a city model, which will become the reference city, and the indicators will have the ideal values for achieving smartness and resilience. According to [60], the standards developed in ISO 37120 do not provide recommended values or thresholds for cities, but provide what and how to measure ambitiously to help cities compare and evaluate performance metrics. The definition of a reference city requires a lot of effort since cities differ from each other, and they should be categorized based on their common characteristics (e.g., size, location, socio-economic situation, etc.). However, it will facilitate benchmarking of cities and the adoption of best practices for urban improvement.

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