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A novel taxonomy of smart sustainable city indicators

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Building a smart city that follows sustainability goals enhances the quality of life and preserves environmental, human, and social capital. Yet, existing smart sustainable city projects have concentrated on the technological dimensions of smart cities such as using big data or smart devices to follow sustainability goals. Currently, there is no comprehensive category of smart sustainable city indicators in the literature. This paper aims to discover these indicators by considering the common features of sustainability and smart city concepts. Two rounds of the content analysis technique were employed to investigate semantic, lexical, and conceptual relationships between smart city and sustainability indicators. This paper employed the Sustainable Development Indicators suggested by OECD and the Smart City Index Master by Cohen as the two main groups of indicators. The findings offer a novel set of indicators that enables policymakers and researchers to consider the smartness and sustainability of their projects simultaneously. This includes socio-cultural, economic, environmental, and governance categories with 28 associated indicators. The outcome of this paper offers a unique combined category of smart sustainable city indicators by considering the key elements of sustainability and smart city concepts. Academics and policymakers can also employ this set of indicators as a guideline to build a smart sustainable community.

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Introduction

Smart cities initiatives offer city authorities and policymakers a new tool for improving municipalities. This concept will shape the future of urban habitation (Law and Lynch, 2019). Historically, the smart city concept focused on technology[1], smart devices, and urban infrastructures (Vanolo, 2014). More recently, however, several cities have expanded the concept to include socio-economic dimensions (Shichiyakh et al., 2016). Trencher (2019) provides the most relevant description of the concept applied to urban projects: "smart cities put people first and stresses technology as a tool to use predominantly in service of citizens" (p. 118). This evolution moves the smart city concept beyond focusing solely on its technological dimension and expands its potential impacts on urban studies and projects.

Researchers and urban planners are beginning to examine how smart cities concepts grounded in putting people first and using technology as a tool (Angelidou et al., 2018) can address socio-economic challenges in urban areas (Schaffers et al., 2011). Doing so can have two beneficial outcomes. First, it offers an additional strategy for decision-makers to employ smart cities initiatives to address urban projects, and second, it advances smart cities research by expanding the limited literature on urban issues. The challenge is offering practical sustainable solutions. There is still a gap in the literature to consider and show the sustainability of smart city initiatives in addressing urban affairs. This research, which explores and analyzes various aspects of the smart city concept, contributes to sustainable solutions by ultimately proposing a new tool for addressing urban projects using smart city initiatives.

The smart city concept includes various elements and indicators. On the other hand, sustainability concentrates on several aspects to address environmental, economic, and social challenges (Kuhlman and Farrington, 2010). Conventionally, researchers explored the intersection of sustainable development and smart cities (Angelidou et al., 2018) by focusing on the technological dimension of the smart city concept (Mondejar et al., 2021). Some scholars also considered only one dimension of sustainability such as energy (Gimpel, Graf-Drasch, Hawlitschek, and Neumeier, 2021) and health (Rahman, Hossain, Showail, Alrajeh, and Alhamid, 2021) and aimed to make a combination between the smart city and sustainability concepts. This paper aims to explore several aspects of this concept by considering technology as a facilitator to recommend sustainable solutions to address urban issues. The expected outcome of this paper is a set of non-technological smart sustainable ideas assisting decision-makers to investigate urban topics.

Smart cities and sustainability

Smart cities: definitions and generations. Many definitions of smart cities exist in the literature. One of the most comprehensive is provided by Caragliu et al. (2011): a city is smart "when investments in human and social capital and traditional (transport) and modern communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (p. 70). The notion of a smart city differs from other similar concepts like digital, technology, or intelligent cities. Even if information and communication technologies (ICTs)[2] are not one of the main pillars of smart cities, they play a facilitating role in creating and building a smart community. The smart city is a concept that conventionally consists of six urban-oriented elements: economy, environment, living, people, transportation, and government (Albino et al., 2015a). Each of these criteria encompasses several indicators, which vary from educational to green energy aspects of a city (Schaffers et al., 2011).

The smart city concept is most often employed by city authorities and researchers to improve the quality of life in modern metropolitan cities by focusing on the beneficial aspects of ICTs (Bibri, 2020). In some cases, researchers have introduced a novel innovative solution to enhance the efficiency of the current system. A useful example of employing the smart city concept in urban projects is related to the traffic system (Lin et al., 2016) and its measurement methods (Mandal et al., 2011). For example, road and traffic engineers use Wireless Sensor Networks (WSNs) instead of manual and paper-based formats to measure, monitor, and control traffic in urban areas (Nellore and Hancke, 2016). This has led to the collection of more accurate data in order to create a comprehensive database. Therefore, smart city initiatives can offer practical solutions to policymakers to increase the reliability of their decisions regarding infrastructural issues (Anthopoulos and Reddick, 2016). So far, the smart city concept has experienced three different generations.

The first generation of smart cities, namely, smart city 1.0, is considered a technology-driven concept (Cohen, 2015). This version of smart cities focused on using technology to facilitate urban activities. This includes employing high-tech devices, software, and platforms in transportation, security, health, and government areas (Tahir and Malek, 2016). From the very first version of smart cities, six major pillars were identified as the main criteria for this concept, including economy, people, governance, mobility, environment, and living (Albino et al., 2015a).

As opposed to the first generation smart city where big technology companies led this movement in urban areas and intended to sell their products to cities, smart city 2.0 was directed by city authorities and decision-makers (Cohen, 2015). The main goal was to enhance the quality of life in urban areas by using the beneficial aspects of technologies. As Etezadzadeh (2016) states, stakeholders in smart city 2.0 projects "employ technical facilities to a great extent, but do not allow technology to expand uncontrollably, dominate urban life, or acquire decision-making authority" (p. 53). Moreover, Trencher (2019) highlights some specific features of smart city 2.0, such as addressing social challenges, enhancing citizen well-being and public services, as well as focusing on significant endogenous problems and citizen needs that are not directly connected to technologies.

The third generation of smart cities concentrated on the role of citizens in addressing their issues and assisting city managers to solve them (Cohen, 2015). Smart city 3.0 highlights the ability of all individuals to share their opinions and help decision-makers to find the most reliable and practical solutions for social, environmental, and government challenges in cities. Besides, this version considers smart solutions that are not necessarily tech-driven ideas (Bednarska-Olejniczak and Olejniczak, 2016). This approves the power of the smart city concept in addressing urban topics without solely focusing on its technological dimensions.

The smart city concept potentially leads researchers and policymakers to build a sustainable community (Höjer and Wangel, 2015) as many of its indicators directly or indirectly consider sustainable development initiatives. According to the existing literature, we cannot call all smart cities sustainable, but the basic approach in making smart communities is aligned with sustainable development goals. Therefore, employing a mix of smart and sustainable indicators enables city managers, urban planners, and academia to focus on two practical frameworks to build a community with high quality of life.

Key elements and indicators of smart cities. A unique category of elements for the smart city concept does not exist (Pirayegar Emrouzeh et al., 2019). Researchers, city authorities, and decision-makers employ one or a few smart city elements based on the objective of their projects. Nevertheless, some researchers traditionally categorized these elements into six groups, namely, people, economy, environment, mobility, living, and governance (Anthopoulos, 2015). This classification has been a guideline for researchers to study smart cities since the appearance of the first generation of this concept. It is conspicuous that technology is not one of the key elements of smart cities. Technology functions as a facilitator to enable analysis and identify opportunities across all categories (Pira, 2020). Each of these elements also includes several indicators.

The European Smart Cities[3] offers a database of smart city indicators. These indicators are extracted and analyzed from smart city projects in >90 cities across Europe. European scholars have classified the indicators based on the six elements previously introduced. The following points illustrate the smart city sub-elements they used: (a) people: education, lifelong learning, ethnic plurality, and open-mindedness; (b) governance: political awareness, public and social services, and efficient and transparent administration; (c) living: cultural and leisure facilities, health conditions, individual security, housing quality, education facilities, touristic attractiveness, and social cohesion; (d) economy: innovative spirit, entrepreneurship, city image, productivity, labor market, and international integration; (e) mobility: local transport system, (inter-) national accessibility, ICT-infrastructure, and sustainability of the transport system; and (f) environment: air quality, ecological awareness, and sustainable resource management.

Cohen (2014) introduces 18 smart city indicators and 46 sub-indicators based on the six key elements. The 18 indicators associated with the elements are (1) environment: smart buildings, resource management, sustainable urban planning, (2) mobility: efficient transport, multimodal access, technology infrastructure, (3) government: online services, infrastructure, open government, (4) economy: entrepreneurship and innovation, productivity, local and global connection, (5) people: inclusion, education, creativity, and (6) living: culture and well-being, safety, and health (see Table 1). This paper will employ the Cohen classification to explore various aspects of smart city indicators in offering sustainable solutions.

The Cohen category covers all key aspects of smart city indicators and is one of the most comprehensive cohorts in the literature. It is designed based on the six main elements of smart city, economy, environment, living, people, transportation, and government, and offers several sub-indicators associated with each main indicator. These unique sub-indicators enable researchers and policymakers to concentrate on the root causes of their community challenges by employing relevant smart city initiatives.

Sustainability and its indicators. Sustainability is a paradigm of thinking in the process of urban development (Bibri, 2021). Sustainability is also considered as a policy concept that originated in the Brundtland Report in 1987 (Martin et al., 2018), which pursues economic development, social equity, and environmental protection (Eizenberg and Jabareen, 2017). These dimensions correspond to three Ps: prosperity/profit, people, and planet (Kuhlman and Farrington, 2010). Recently, two other Ps, peace and partnership, have been added to the sustainability concept and created a new set of sustainable development elements (Organisation for Economic Co-operation and Development [OECD], 2016). Yet, a lot of studies form the basis of their conceptual framework according to social, environmental, and economic dimensions of sustainability (Eizenberg and Jabareen, 2017).

Regarding sustainability indicators, there are several references in the literature such as a study by Garnåsjordet et al. (2012) and another research study by Searcy et al. (2005) that concentrate on developing a set of policies and procedures for sustainable development projects. They offer various steps/stages in achieving the goals of sustainability and do not provide a taxonomy of indicators. Nevertheless, Hass et al. (2003) published a working paper for OECD targeting sustainable development indicators used by national and international agencies. The outcome of their project was a set of indicators categorized based on four social, environmental, economic, and institutional pillars, which included 15 themes and 38 indicators (see Table 2).

This set of indicators consists of three levels of elements including sustainability goals, themes, and indicators. These elements are derived from an international study and addresses global sustainability concerns in several international organizations. The importance of this category for the current study is related to several overlaps between its elements and the smart city indicators discussed in the last section, which assists the researcher to explore two sets of pertinent indicators for this paper.

The intersection of smart cities and sustainability. In recent years, researchers started to investigate the relationship between smart cities and sustainability in terms of various contexts. Sustainability is noted as a challenge for the practical implementation of smart cities by some scholars (Silva et al., 2018). Yigitcanlar et al. (2019) identify three major challenges in creating smart sustainable cities, including excessive attention to technology, practice complexity (Yigitcanlar and Kamruzzaman, 2018), and ad-hoc conceptualization of smart cities. The current paper addresses the first issue by exploring the non-technological aspects of smart cities. It also aims to offer a set of mutual indicators between sustainability and the smart city concept instead of focusing on the implementation of smart city initiatives in urban areas. The outcome of this paper will benefit all sorts of urban fields, including planning, design, and management to achieve smart sustainable cities goals.

Some scholars believe that smart cities potentially establish sustainable communities (Monzon, 2015). Basiri et al. (2017) consider the common features of smart cities and sustainability and concluded that a smart city inherently highlights several dimensions of sustainability such as citizen engagement, the need for responsible resource management, and energy efficiency. Nonetheless, they demure smart cities' abilities to address sustainable development with existing groundworks. They propose a new approach in merging the main characteristics of these two concepts. The current paper targets this objective to create a new set of merged indicators to address urban topics.

Bibri and Krogstie (2017) conducted a comprehensive literature review about smart sustainable cities and recognized several advantages and challenges of developing such cities. The importance of their study for the current paper is identifying 19 existing gaps in the research within the field of smart sustainable cities. Some of these gaps directly address a need for a set of common indicators to cover both smart cities and sustainability concepts. "There is a need for combining the typologies and design concepts of sustainable urban forms with smart methods to evaluate their practicality with regard to their contribution to sustainability" (p. 203). So far, it is still a gap in the literature and there is no research targeting a mutual framework between smart cities and sustainability.

Table 1 Smart city indicators and sub-indicators.

Criteria	Indicator	Sub-indicator	Description
Environment	Smart buildings	Sustainability-certified buildings	• Number of LEED or BREAM sustainability-certified buildings in the city (note: if your city uses another standard please indicate) • % of commercial and industrial buildings with smart meters • % of commercial buildings with a building automation system
		Smart homes	• % of homes (multifamily & single family) w/ smart meters
	Resources management	Energy	• % of total energy derived from renewable sources (ISO 37120: 7.4) • Total residential energy use per capita (in kWh/yr.) (ISO 37120: 7.1) • % of municipal grid meeting all of following requirements for smart grid: (1) 2-way communication; (2) Automated control systems for addressing system outages; (3) Real-time information for customers; (4) Permits distributed generation; (5) Supports net metering
		Carbon footprint	• Greenhouse gas emission measured in tons per capita (ISO 37120: 8.3)
		Air quality	• Fine particular matter 2.5 concentration (μg/m3) (ISO 37120: 8.1)
		Waste generation	• % of city's solid waste that is recycled (ISO 37120: 16.2) • Total collected municipal solid waste in city per capita (in kg) (ISO 37120: 16.3)
		Water consumption	• % of commercial buildings with smart water meters • Total water consumption per capita (liters/day) (ISO 37120: 21.5)
	Sustainable urban planning	Climate resilience planning	• Does your city have a public climate resilience strategy/plan in place? (Y/N) If yes provide link.
		Density	• Population-weighted density (average densities of the separate census tracts that make up a metro)
		Green space per capita	• Green areas per 100,000 (in m2) (ISO 37120: 19.1)
Mobility	Efficient transport	Clean-energy transport	• Kilometers of bicycle paths and lanes per 100,000 (ISO 37120: 18.7) • # of shared bicycles per capita • # of shared vehicles per capita • # of EV charging stations within the city
	Multimodal access	Public transport	• Annual # of public transport trips per capita (ISO 37120: 18.3) • % non-motorized transport trips of total transport • Integrated fare system for public transport
	Technology infrastructure	Smart cards	• % of total revenue from public transit obtained via unified smart card systems
		Access to real-time information	• Presence of demand-based pricing (e.g., congestion pricing, variably priced toll lanes, variably priced parking spaces). Y/N • % of traffic lights connected to real-time traffic management system • # of public transit services that offer real-time information to the public: 1 point for each transit category up to 5 total points (bus, regional train, metro, rapid transit system (e.g. BRT, tram), and sharing modes (e.g., bike sharing, car-sharing) • Availability of multimodal transit app with at least 3 services integrated (Y/N)
Government	Online services	Online procedures	• % of government services that can be accessed by citizens via web or mobile phone
		Electronic benefits payments	• Existence of electronic benefit payments (e.g., social security) to citizens (Y/N)
	Infrastructure	Wi-Fi coverage	• Number of Wi-Fi hotspots per km^2
		Broadband coverage	• % of commercial and residential users with internet download speeds of at least 2 Mbit/s • % of commercial and residential users with internet download speeds of at least 1 gigabit/s
		Sensor coverage	• # of infrastructure components with installed sensors. 1 point for each: traffic, public transit demand, parking, air quality, waste, H2O, public lighting
		Integrated health + safety operations	• # of services integrated in a singular operation center leveraging real-time data. 1 point for each: ambulance, emergency/disaster response, fire, police, weather, transit, air quality
	Open government	Open data	• Open data use
		Open apps	• # of mobile apps available (iPhone) based on open data
		Privacy	• Existence of official citywide privacy policy to protect confidential citizen data
Economy	Entrepreneurship and innovation	New startups	• Number of new opportunity-based startups/year
		R&D	• % GDP invested in R&D in private sector
		Employment levels	• % of persons in full-time employment (ISO 37120: 5.4)
		Innovation	• Innovation cities index
	Productivity	GRP per capita	• Gross Regional Product per capita (in US$, except in EU, in Euros)

Table 1 (continued)

Criteria	Indicator	Sub-indicator	Description
	Local and global connection	Exports	• % of GRP based on technology exports
		International events held	• Number of international congresses and fairs attendees.
People	Inclusion	Internet-connected households	• % of internet-connected households
		Smart phone penetration	• % of residents with smartphone access
		Civic engagement	• # of civic engagement activities offered by the municipality last year • Voter participation in last municipal election (% of eligible voters) (ISO 37120: 11.1)
	Education	Secondary education	• % of students completing secondary education (ISO 37120: 6.3)
		University graduates	• Number of higher education degrees per 100,000 inhabitants (ISO 37120: 6.7)
	Creativity	Foreign-born immigrants	• % of population born in a foreign country
		Urban living lab	• # of officially registered ENOLL living labs
		Creative industry jobs	• Percentage of labor force (LF) engaged in creative industries
Living	Culture and well-being	Life conditions	• Percentage of inhabitants with housing deficiency in any of the following 5 areas: potable water, sanitation, overcrowding, deficient material quality, or lacking electricity
		Gini index	• Gini coefficient of inequality
		Quality of life ranking	• Mercer ranking in most recent quality of life survey
		Investment in culture	• % of municipal budget allocated to culture
	Safety	Crime	• Violent crime rate per 100,000 population (ISO 37120: 14.5)
		Smart crime prevention	• # technologies in use to assist with crime prevention. 1 point for each of the following: livestreaming video cameras, taxi apps, predictive crime software technologies
	Health	Single health history	• % of residents w/ single, unified health histories facilitating patient and health provider access to complete medical records
		Life expectancy	• Average life expectancy (ISO 37120: 12.1)

Adapted from *Smart City Index Master Indicators Survey* (Cohen, 2014).

More importantly, smart sustainable cities do not call for and cannot cover all aspects of these two concepts. Only their common features are important in forming such cities. Some researchers (Höjer and Wangel, 2015) embarked on defining smart sustainable cities by consolidating simply the goals of sustainability with the ICT dimension of smart cities. A research project by Aelenei et al. (2016) examined energy efficiency plus smart building solutions as a smart sustainable city framework. This approach does not provide an integrated and comprehensive understanding of the concept.

Evans et al. (2019) propose a new attitude in forming smart sustainable cities. They offer a mix of the technological and non-technological framework to consider community engagement, policymakers' learnings, innovation, and governance to cover all dimensions of these two concepts. Although their idea lacks a set of smart sustainable indicators to create such cities, they point out the power of non-technological aspects of smart cities and sustainability to build a quality community by scrutinizing their common indicators. So, while a few theoretical frameworks are dealing with the relationship between smart city initiatives and sustainability, there is still no significant practical example of a smart city project that has focused on an urban project to offer sustainable solutions using non-technological aspects of smart cities.

Methodology

This paper employs the descriptive research method to identify the association between two sets of indicators: sustainability and smart cities. The smart city concept shares common ground with sustainability. This paper uses the Smart City Index Master Indicators (Cohen, 2014) that includes 18 indicators and 46 unique sub-indicators as well as a taxonomy of sustainable indicators by Hass et al. (2003) to discern a new set of indicators of smart sustainable cities. The content analysis (Elo and Kyngas, 2008) technique was adopted to analyze the two cohorts of indicators. Using this method is a common procedure in identifying mutual characteristics of two sets of variables collected through interviews and surveys, or using secondary data (Neuendorf, 2017). This study employed quantitative and qualitative content analysis methods. The quantitative method considered the lexical relationships between words/phrases by analyzing the frequency of each term in the sets of indicators. The qualitative method focused on the semantic correlation between words/phrases.

This paper followed five steps to accomplish the content analysis technique:

Content selection: The two mentioned sets of indicators.
Define the unit and category: The only defined unit was the *presence* of a word in the two categories and the frequency of phrases was not a prominent factor. There was also no specific category assigned to the indicators.
Rules: Different meanings and forms of a word/phrase were taken into account. For example, *transport* and *transportation* were considered similar.
Coding: This step occurred manually by the researcher.
Analysis: Discovering the semantic and lexical relationship of words/phrases.

Some researchers employ existing software and platforms such as NVivo to complete the coding step (Bai et al., 2020; Sheng, 2020). In this case, it was possible to review all content manually due to the small amount of data. After finishing the first round of the content analysis and considering semantic and lexical relationships between the two sets of indicators, another round of analysis was conducted to address conceptual correlations between smart city and sustainability indicators. The reason for running this additional round was to investigate the remaining indicators to identify any potential relationship.

Table 2 Sustainable development indicators suggested by OECD.

Goal	Theme	Indicators	Description
Social	Equity	Poverty	• Percent of population living below poverty line • Gini index of income inequality unemployment rate
		Gender equality	• Female to male number ratio • Female to male wage ratio
	Health	Nutritional status	• Nutritional status of children • Nutritional status of population
		Mortality	• Mortality rate under 5 years old • Life expectancy at birth
		Sanitation	• Percent of population with adequate sewage disposal facilities
		Drinking water	• Population with access to safe drinking water
		Healthcare delivery	• Percent of population with access to primary health care facilities • Immunization against infectious childhood diseases • Contraceptive prevalence rate
	Education	Education level	• Children reaching grade 5 of primary education • Adult Secondary education achievement level
		Literacy	• Adult literacy rate
	Housing	Living conditions	• Floor area per person
	Security	Crime	• Number of recorded crimes per 100,000 population
	Population	Population change	• Population growth rate • Population of urban formal and informal settlements
Environmental	Atmosphere	Climate change	• Emissions of greenhouse gases
		Ozone layer depletion	• Consumption of ozone depleting substances
		Air quality	• Ambient concentration of air pollutants in urban areas
	Land	Agriculture	• Arable and permanent crop land area • Use of fertilizers • Use of agricultural pesticides
		Forests	• Forest area as a percent of land area • Wood harvesting intensity
		Desertification	• Land affected by desertification
		Urbanization	• Area of urban formal and informal settlements
	Oceans, seas, and coasts	Coastal zone	• Algae concentration in coastal waters • Percent of total population living in coastal areas
		Fisheries	• Annual catch by major species
	Fresh-water	Water quality	• Annual withdrawal of ground and surface water as a percent of total available water
		Water quantity	• Biological oxygen demand • (BOD) in Water bodies • Concentration of fecal coliform in freshwater
	Biodiversity	Ecosystems	• Area of selected key ecosystems • Protected area as a % of total area
		Species	• Abundance of selected key species
Economic	Economic structure	Economic Performance	• GDP per capita • Investment share in GDP
		Trade	• Balance of trade in goods and services
		Financial status	• Debt to GNP ratio • Total ODA given or received as a percent of GNP
	Consumption & production patterns	Material consumption	• Intensity of material use
		Energy use	• Annual energy consumption per capita • Share of consumption of renewable energy resources • Intensity of energy use
		Waste generation and management	• Generation of industrial and municipal solid waste • Generation of hazardous waste • Generation of radioactive waste • Waste recycling and reuse
		Transportation	• Distance traveled per capita by mode of transport
Institutional	Institutional framework	Strategic implementation of sustainable development	• National sustainable development strategy
		International cooperation	• Implementation of ratified global agreements
	Institutional capacity	Information access	• Number of internet subscribers per 1000 inhabitants
		Communication and infrastructure	• Main telephone lines per 1000 inhabitants
		Science and technology	• Expenditure on research and development as a percent of GDP
		Disaster preparedness and response	• Economic and human loss due to natural disasters

Results and discussion

The smart city sub-indicators included 46 unique phrases that corresponded to 18 main indicators. There was a total number of 38 sustainability indicators. The results of the first round of the content analysis showed that 29 smart city sub-indicators had direct relationships with 22 sustainability indicators. This consisted of both semantic correlations such as *life conditions* vs *living conditions* and lexical correlations such as a few common words/phrases: *crime, air quality*, and *waste generation*. The second round of the content analysis revealed additional relationships between the two sets of indicators. *Quality of life* vs. *poverty* and *foreign-born immigrants* vs. *population change* are two examples of such findings. The following is a list of smart sustainable city indicators concluded from the two rounds of the content analysis:

Healthcare delivery, quality drinking water, individuals' health monitoring, quality food, education funding, free education, low crime rate, green spaces, population density, population growth rate, air quality, affordable housing, low pollution, start-ups, international collaboration, low poverty rate, job opportunities, civic engagement, investment in culture, e-governance, sustainability-certified buildings, waste generation, energy use, public transport, clean-energy transport, real-time data monitoring, Internet and Wi-Fi coverage, and disaster preparedness.

These indicators are implementation factors to assists policymakers, project managers, and researchers to create smart sustainable cities to better address urban projects. They can also be employed to measure the smart sustainability degree of a community. According to the literature review, these smart sustainable city indicators can be categorized into different smart and sustainable groups such as economy, society, or government (Kaswan and Rathi, 2020; Lazaroiu and Roscia, 2012). Table 3 shows the classification of smart sustainable city indicators based on their mutual characteristics and existing literature.

As can be seen in Table 3, most of the indicators are associated with socio-cultural contexts, including people and living considerations. *Smart people* is a key element in creating a smart community (Meijer and Bolívar, 2016). *People* is also one of the three (Eustachio et al., 2019), or according to other references, one of the five (OECD, 2016) main categories of sustainability. Basic needs such as healthy food and water along with education and population factors form the significant socio-cultural indicators. Moreover, this category provides policymakers with some indicators to increase community engagement in social activities, project development, and crime prevention.

The economic category plays a significant role in creating a smart city (Vanolo, 2014) or developing a sustainable community (Gittell et al., 2012) and it forms one group of smart sustainable indicators in this paper. These indicators address three different target groups: the marginalized population, smart- and medium-sized enterprises, and big firms. Paying attention to each of them requires decision-makers' thoughtfulness to cover the needs and demands of citizens. Creating more job opportunities, supporting start-ups, mitigating poverty, encouraging international collaborations, and offering affordable housing lead key stakeholders to achieve economic smart sustainable goals.

Environmental considerations are as much imperative factors for the sustainability concept (Halepoto et al., 2015) as the smart city implementation (Albino et al., 2015b). Energy efficiency, low air and water pollution, the green space ratio in cities, waste disposal and recycling, and creating sustainable buildings are the most important indicators of the environment category. These factors must be taken into account for all long-term, mid-term, or short-term urban projects, including strategic plans, master and detailed plans, neighborhood planning, land development, or even park and building development. Employing smart ideas to create a sustainable environment should not be limited to parks, green spaces, and open spaces. A combination of environmental indicators with educational, cultural, and behavioral factors can lead policymakers to develop a knowledgeable and informed community that respects and follows environmental proceedings.

The fourth category of smart sustainable indicators is governance. Having educated, trained, and skilled decision-makers is an essential factor for smart communities (Anthopoulos and Reddick, 2016). It is also a fundamental component of a sustainable development approach (Maria Smits, 2019). Without government support in policymaking and legislation, implementing a smart sustainable city idea will face practical, administrative, and bureaucratic adversities. In order to facilitate this process, governments must consider employing high-end technologies and devices to access real-time data of citizens and urban activities such as transportation, health condition, or unexpected disasters. Transport-oriented indicators are also added to this category as they pertain to infrastructure development and decisions at a high level of governance.

The implication of this study directly addresses a gap in the literature about creating a smart sustainable city. So far, no academic studies or community-based projects have considered introducing a set of indicators for both smart and sustainability concepts. Although there are significant examples of practical elements, themes, indicators, and sub-indicators of smart cities and sustainability in the literature, none of these includes a combination of the two cohorts of factors. The findings of this paper recommend a new category of smart sustainable indicators to assist researchers, policymakers, and planners to concentrate on these two advanced concepts simultaneously.

This unique set of indicators can also be employed to measure the smartness and sustainability of urban projects by city managers and acadmemics. It is also a new guideline for project managers to follow smart sustainability requirements when creating a high-quality community by focusing on socio-cultural, economic, environmental, and governance factors. Moreover, subsequent research can apply these indicators to their case studies by collecting relevant data to analyze the degree of smart sustainability in their projects. However, these indicators need to be customized based on the characteristics of communities at the local and regional levels.

Previous studies have confirmed the usefulness of considering smart city indicators to achieve sustainable development goals (Strelkova, Antropov, and Ivanovckya, 2020; Wey and Peng, 2021). The main focus of this paper was on the descriptive explanatory research method to identify the association between two sets of indicators: sustainability and smart cities. Additional investigations are needed to prove the effectiveness of the offered smart sustainable city indicators. This paper has not considered the practical capability of the indicators as implementing a sustainable smart city project and measuring its outcome must happen through a mid-term or a long-term perspective. This can be a research topic for future studies to conduct empirical analysis and evaluate the effectiveness of these indicators.

Conclusion

Smart city is an urban development concept that has been employed by researchers and project managers to address urban affairs by considering six major elements, including society, economy, people, living, environment, transportation, and government as well as various indicators. On the other hand, sustainability is an approach that is construed as a key factor to protect resources for current and future generations while implementing regional, urban, or rural projects. Creating a smart sustainable city has been recently the main objective of several

Table 3 Smart sustainable city indicators.

Category	Indicator	Description
Socio-cultural	Healthcare delivery	• Percent of population with access to primary health care facilities
		• Immunization against infectious childhood diseases
		• Contraceptive prevalence rate
	Quality drinking water	• Population with access to safe drinking water
	Individuals' health monitoring	• Number of services integrated in a singular operation center leveraging real-time data. 1 point for each: ambulance, emergency/disaster response, fire, police, weather, transit, air quality
		• Percent of residents w/ single, unified health histories facilitating patient and health provider access to complete medical records
	Quality food	• Nutritional status of children
		• Nutritional status of population
	Education funding	• Number services and resources for education fund
	Free education	• Children reaching grade 5 of primary education
		• Adult secondary education achievement level
	Low crime rate	• Violent crime rate per 100,000 population
	Population density	• Population-weighted density (average densities of the separate census tracts that make up a metro)
	Population growth rate	• Population growth rate
	Investment in culture	• Percent of municipal budget allocated to culture
	Civic engagement	• Number of civic engagement activities offered by the municipality last year
		• Voter participation in last municipal election (percent of eligible voters)
Economic	Affordable housing	• Percentage of inhabitants with housing deficiency in any of the following 5 areas: potable water, sanitation, overcrowding, deficient material quality, or lacking electricity
	Start-ups	• Number of new opportunity-based startups/year
	International collaboration	• Number of international congresses and fairs attendees.
	Low poverty rate	• Poverty rate
	Job opportunities	• Employment rate
		• Percentage of labor force (LF) engaged in creative industries
Environmental	Green spaces	• Green areas per 100,000 (in m^2)
	Air quality	• Ambient concentration of air pollutants in urban areas
	Low pollution	• Measurement of particulate matter ($PM_{2.5}$ and PM_{10}), Ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO) emissions
	Energy use	• Annual energy consumption per capita
		• Share of consumption of renewable energy resources
		• Intensity of energy use
	Waste generation	• Generation of industrial and municipal solid waste
		• Generation of hazardous waste
		• Generation of radioactive waste
		• Waste recycling and reuse
	Sustainability-certified buildings	• Number of LEED or BREAM sustainability-certified buildings in the city
		• Percent of commercial and industrial buildings with smart meters
		• Percent of commercial buildings with a building automation system
		• Percent of homes (multifamily & single family) w/ smart meters
Governance	E-governance	• Open data use
		• Number of mobile apps available (iPhone) based on open data
		• Existence of official citywide privacy policy to protect confidential citizen data
	Real-time data monitoring	• Presence of demand-based pricing (e.g., congestion pricing, variably priced toll lanes, variably priced parking spaces). Y/N
		• Percent of traffic lights connected to real-time traffic management system
		• Number of public transit services that offer real-time information to the public: 1 point for each transit category up to 5 total points (bus, regional train, metro, rapid transit system (e.g., BRT, tram), and sharing modes (e.g., bike sharing, car-sharing)
		• Availability of multimodal transit app with at least three services integrated (Y/N)
	Internet and Wi-Fi coverage	• Number of internet subscribers per 1000 inhabitants
		• Percent of commercial and residential users with internet download speeds of at least 2 Mbit/s
		• Percent of commercial and residential users with internet download speeds of at least 1 gigabit/s
	Disaster preparedness	• Economic and human loss due to natural disasters
	Public transport	• Annual # of public transport trips per capita
		• % non-motorized transport trips of total transport
		• Integrated fare system for public transport
	Clean-energy transport	• Kilometers of bicycle paths and lanes per 100,000 (ISO 37120: 18.7)
		• of shared bicycles per capita
		• Number of shared vehicles per capita
		• Number of EV charging stations within the city

academic and government studies. Both concepts have proven their abilities to mitigate such issues. Thus, exploiting smart plus sustainable initiatives will offer a powerful tool to alleviate urban challenges.

The smart city concept must be differentiated from a digital city or an intelligent city and its non-technological aspects must be taken into account. Most of the smart sustainable city projects considered only technological dimensions of the smart city concept to cover sustainability goals. This paper examined non-technological aspects of smart sustainable cities by introducing a new set of indicators categorized into four groups: socio-cultural, economic, environmental, and governance. This is a novel classification of smart sustainable city indicators in the literature. Combining these two concepts assists decision-makers and researchers to bring a high quality of life to communities. They can also employ these indicators to address urban challenges such as poverty, public education, housing, and crime. This taxonomy can be a guidebook for researchers targeting the smart sustainable city concept.

Furthermore, project managers can benefit from technology-driven solutions to better implement these indicators in their communities. Although I highlighted the importance of non-technological aspects of smart cities and sustainability, employing productive and vigorous aspects of ICTs can facilitate the speed of implementing smart sustainable ideas. Future studies can focus on supplementary indicators or ideas for these non-technological smart sustainable city indicators.

Data availability

All data analyzed are included in the paper.

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Notes

1 Hereafter, technology refers to Information and Communication Technologies.
2 Hereafter, technology refers to ICTs in all sections related to smart cities.
3 This organization has an online platform. It categorizes the smart cities criteria and indicators annually and generates some visual reports and ranking of smartness in European cities.

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The author declares no competing interests.

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