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RESEARCH ARTICLE

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A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations sustainable development goals

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Abstract

Technology has indispensably been a part of the city evolution throughout history. In recent years, there has been a shift in the pattern of development in smart cities, where smart cities attempt to embrace practices of sustainability using Information and Communication Technologies and other smart solutions. Past studies reveal that these smart cities have failed in successfully incorporating sustainable development goals into their smart strategies, where they tend to focus more on achieving smartness goals rather than sustainability goals and targets. This paper presents a multi-faceted interrogative study on several ongoing smart city initiatives around the globe that supports United Nations Urban Sustainability Agenda. This paper aims to focus on harmonizing smart and sustainable city initiatives with the United Nations Sustainable Development Goals using a systems thinking approach. The study develops conceptual models that support the city transition into being a sustainable smart city. These conceptual models were designed based on the fundamentals of system thinking for a system of several elements under the key catalyzers "Policy and Governance," "Research & Development," and "Partnership." The causalities and interrelationships among elements in developed conceptual models justify the dynamicity and the impact of these elements within a system. The outcome of this research paper would support industry experts, policymakers, and city planners to adopt robust policy interventions and best practices for developing strategies that support the transition of smart cities to the futuristic label of sustainable cities.

KEYWORDS

smart city initiatives, sustainable smart City, systems thinking, United Nations sustainable development goals, United Nations urban sustainability agenda

1 | INTRODUCTION

1.1 | Background

Modern societies face tremendous sustainability challenges ranging from environmental (climate change, air quality issues, waste accumulation), economic (unemployment, economic inequality) to social (food security, water scarcity, and poverty) challenges (Zander & Mosterman, 2017). Addressing sustainability challenges is of paramount importance. In the modern era of escalated progress where cities push their boundaries to transform into smart and sustainable urban spaces, the concept of sustainable urban development (SUD) is seen only as a preview of what it eventually can do to cities in achieving selective development goals. It is often foreseen as a future development concept, but in reality, when visualized through the lenses of the tri-dimensional sustainable notion, it is a multigenerational solidarity concept that requires immediate attention. The concept of sustainability has gained momentum due to the prime concern of cities on the socio-economic wellbeing of the citizens worldwide rather than just the infrastructure development (Mori & Christodoulou, 2012).

With the emerging sustainability threats on cities, it is essential to upgrade even the highly sophisticated support systems, deployed technologies, and existing infrastructures (Hamman, Anquetin, & Monicolle, 2017). This calls for the replacement of the existing infrastructures and city services, where such changes are felt necessary. Smart city strategies and initiatives with an eye for SUD needs to be promoted to combat these challenges (Martosa, Pacheco-Torresa, Ordóñeza, & Jadraque-Gagoa, 2016). The SUD perspective needs to consider factors such as economic development, ecological conservation, and democratic equity. The 17 sustainable development goals (SDGs) launched in September 2015 by the United Nation (UN) are widely applied to harmonize the prime factors for urban development (United Nations Development Program, 2015). They focus more on long term benefits and covers several dimensions of smart and sustainable cities while addressing a broad picture of several prevalent challenges around the globe.

Smart city initiatives back the Information and Communication Technologies (ICT) based innovations and tech-driven opportunities to ensure a sustainable future for cities (Rodrigues & Franco, 2019). However, although cities have diversified their objectives in achieving these SDGs, it is highly unclear how the undertaken smart city initiatives by different countries contribute to achieving SDGs in the long run. Despite its rising popularity in the streams of academia, the smart city planning has been widely criticized for not successfully incorporating the goals of SUD into practice (Bibri, 2018; Angelidou et al., 2018; Bibri & Krogstie, 2017; Bifulco, Tregua, Amitrano, & D'Auria, 2016; Höjer & Wangel, 2014; Hollands, 2008). Hence, a systematic decision support system is felt necessary at the strategic level (Pichler, 2017), that would harmonize smart and sustainable city initiatives with the desired 2030 UN SDGs. Since, besides linking each initiative with the SDGs, predicting the system changes under uncertainties is crucial and a demanding task. Here lies the rationale of our research. This opens the door to integrated systems thinking approach. System dynamic and system thinking approaches are thus often regarded as the most appropriate method in troubleshooting problems (Sterman, 2000).

The research intends to investigate several ongoing smart city initiatives around the globe to identify possible existing knowledge gaps. Thus, the systems-thinking approach acts as catalysts in integrating all the dimensions of the smart city, covering all the themes and sub-themes addressed under each smart city initiative. This study acts as a backbone for future alterations to existing smart city initiatives to improve their strategies or for current smart city initiatives to expand their scope in connecting cities and communities. The new approach aids not only smart cities to connect with the UN SDGs but also to connect with all other sustainable development plans and strategies.

1.2 | Research objectives and organization of the research

This paper presents a novel multi integrated systems-thinking approach for harmonizing smart and sustainable city initiatives with the UN SDGs. The new integrated systems thinking approach would provide the business owners with a systematic framework for assessing smart city initiatives, strategic planning, cost-based analysis (CBA), and stakeholder engagement. The key objectives of this study can be summarized in the following points:

1. Investigate the extent to which several smart city initiatives around the globe interweave the sustainability and SUD themes in their proposed strategies. This helps in identifying the existing gaps and providing possible recommendations to build a more resilient community.
2. Harmonize smart city initiatives with UN SDGs using a system-thinking approach, to emphasize systems thinking as the most efficient tool in providing a possible feedback mechanism to unwind several challenges that arise in the urban ecosystem.
3. Analyze key catalyzers that stay as supporting plugins for bridging the existing gap and interlinking smart city initiatives with other possible SDGs to maximize future development and minimize city challenges.

The rest of this paper is organized as follows: Section 2 presents the methods used in conducting the systematic review, mapping process, and system thinking approach. The third section brings out an in-depth review of smart city initiatives and systems thinking approach. The relevance of why system thinking is required for smart cities to transform into a smart sustainable city is highlighted. Section 4 deals with the classification of smart city initiatives based on several key drivers of the smart city. This section also undergoes a mapping process where each selected smart city initiative is mapped to corresponding SDGs. Section 5 elucidates the proposed systems thinking approach. The next section presents a discussion along with the final Section 7 presenting possible recommendations for future research with concluding remarks.

2 | METHODOLOGY AND DATA COLLECTION

This paper applies a systematic literature review to identify the research gaps and demonstrate a strong understanding of the existing concepts of smart cities vis-a-vis systems thinking. A keyword-based search in the Scopus database has been conducted using a combination of words such as “smart city,” “systems thinking,” “system of system,” “Sustainable urban development.” The search has mainly

TABLE 1 A selected set of indicators and targets for the mapping purpose

Sustainable Development Goal	Targets	Examples of selected indicators
1 NO POVERTY	a Access to basic services and economic resources (1.1) b Societal and economic empowerment with socio-economic development (1.1, 1.2, 1.3, 1.4, 1.5) c Resilience to climate-related calamities and other socio-economic disasters (1.5)	
2 ZERO HUNGER	a Food security and self-sustenance (2.1, 2.2, 2.3, 2.c) b Societal and economic empowerment with socio-economic development (2.3, 2.4, 2.5)	2.1.1 Proportion of population at risk of food insecurity with respect to dietary quality data and anti-poverty scales. 2.3.1 Sustainable production with respect to the overall volume of production. 2.4.1 Portion of people getting benefited from the strengthened capacity for resilient farming and pastoral activities. 2.c.1 Increased level of nutritional value at flexible and affordable price points.
3 GOOD HEALTH AND WELL-BEING	a Access to basic services and economic resources (3.1, 3.2, 3.3, 3.4, 3.5, 3.8, 3.c) b Resource effective infrastructures (3.a, 3.b, 3.6)	3.2.1 Subsidized medical treatment schemes and the provision of medicines. 3.8.1 Coverage of essential health care and well-being related information via remote patient diagnosis and monitoring, and e- payment systems for health services. 3.b.3 Number of efficient infrastructures such as using digitalized supply chain and logistics operations for publicizing epidemic outbreaks supporting health-related big data collection. 3.b.2 Level of development assistance to better connect between patients and health care workers for emergency response and health-related services.
4 QUALITY EDUCATION	a Access to basic services and economic resources (4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.a, 4.b, 4.c) b Societal and economic empowerment with socio-economic development (4.4, 4.5, 4.b)	4.1 Participation rate in achieving standardized educational services. 4.a.1 Increased access of information for teachers and students through ICT supported services for e-learning, web-based certifications, advisory support and so forth. 4.3.1 Planned smart learning system for tailored learning outcomes and education for sustainable development. 4.7.1 Level of collaboration with the institution's academic support services for e-learning and technological innovation through diversified models.
5 GENDER EQUALITY	a Opportunities for women participation in the socio-economic and political development of the nation (5.5) b Eliminate any sort of discrimination against woman (5.1) c Access to reproductive health and associated rights (5.6) d Access to essential services and physical infrastructures (5.b)	5.1.1 Reinforced educational opportunities for both the secondary and tertiary level despite gender disparities and education received for girls are of high level 5.6.2 Legal and regulatory framework guaranteeing education and information related to sexual health. 5.5.2 Proportion of women employed in private and public sectors. 5.b.2 Proportion of women using digital platforms
6 CLEAN WATER AND SANITATION	a) Resource efficient infrastructures (6.1, 6.2, 6.3, 6.4, 6.b) b) Sustainable water management systems (6.1, 6.2, 6.3, 6.4, 6.5, 6.a, 6.b)	
7 AFFORDABLE AND CLEAN ENERGY	a Access to renewable, affordable and reliable energy resources (7.1, 7.2) b Technological development and socio-economic empowerment (7.3, 7.a, 7.b)	7.1.2 Number of people who hold proper access to renewable and reliable energy services. 7.2.1 Fraction of renewable energy per total of energy consumed. 7.3.1 Energy intensity estimate as a fraction of GDP. 7.b.1 Proportion of investment devoted to technological advancement and basic infrastructure compared to the GDP.
8 DECENT WORK AND ECONOMIC GROWTH	a Creation of sustainable employment (8.5, 8.6, 8.7, 8.8, 8.9) b Technological development and socio-economic empowerment (8.2, 8.3, 8.4, 8.5, 8.6, 8.7)	8.2.1 Employment growth and retention rate. 8.4.1 Ecological footprint per gross domestic product. 8.5.1 Scheduled hours of productive labor for all gender groups. 8.9.2 Number of jobs allocated for specific sectors.

(Continues)

TABLE 1 (Continued)

Sustainable Development Goal	Targets	Examples of selected indicators
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	a Sustainable and resource-efficient infrastructures (9.1, 9.a) b Creation of sustainable employment (9.2) c Access to basic services and economic resources (9.3, 9.c)	9.1.1 Existence of roads and transborder infrastructures for equitable access. 9.2.2 No. of employees in manufacturing and infrastructure development per total of employment. 9.3.1 No. of small-scale industrial units set up in proportion to overall industries. 9.a.1 Measure of support for sustainable infrastructure development from foreign direct investment and government. 9.c.1 Population with access to the mobile network in proportion to the technology and innovation infrastructure.
10 REDUCED INEQUALITIES	a Societal and economic empowerment with socio-economic development (10.1, 10.2, 10.3, 10.5)	10.1.1 Possible employment opportunities created among the disadvantaged group and woman. 10.2.1 Proportion of small-medium sized enterprises and industrial units in the digital supply chain. 10.3.1 Cases reported on racial segregation at all possible levels. 10.5.1 Sustainable financial service indicators.
11 SUSTAINABLE CITIES AND COMMUNITIES	a Sustainable and resource-efficient infrastructures (11.a, 11.c) b Access to basic services and economic resources (11.2) c Resource planning and management (11.3) d Environmental impact assessment and mitigation (11.6)	11.2.1 Percentage of population with access to sustainable modes of transportation. 11.3.1 Land use pattern with respect to urban sprawl. 11.6.1 Measure of waste disposed to the total waste generated within the city boundaries. 11.a.1 Measure of infrastructure development and smart city pilot projects with respect to increasing urbanization. 11.c.1 Allocation of financial support for infrastructures to be more smart and sustainable with better material utilization.
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	a Access to renewable, affordable and reliable energy resources (12.4) b Sustainable waste and water management systems (12.2, 12.4, 12.5) c Food security and self-sustenance (12.3)	12.2.1 Measure of material footprint accounted for emissions to water. 12.3.1 Measures from the food loss index. 12.4.1 Percentage reduction of pollutants in the available resources. 12.4.2 Balance in the level of hazardous waste treated to generated. 12.5.1 Quantity of wastewater and solid waste being treated and recycled.
13 CLIMATE ACTION	a Mitigation and adoption of climatic changes (13.1, 13.2, 13.3, 13.b) b Renewable, affordable and reliable energy resources (13.1)	13.1.1 Mobilized amount of deaths associated with the risk involved during natural calamities per total population. 13.2.1 Climate-resilient retrofit/floor space. 13.3.2 Emission trading size 13.b Capacity development for climate-related risk management.
14 LIFE BELOW WATER	a Conservation of aquatic life and biodiversity (14.1, 14.2, 14.3, 14.6, 14.a) b Land use and sustainable resource management (14.4, 14.a, 14.b, 14.5, 14.6)	
15 LIFE ON LAND	a Conservation of aquatic life and biodiversity (15.1, 15.2, 15.3, 15.4, 15.5 15.b) b Land use and sustainable resource management (15.7, 15.8, 15.c, 15.a)	15.1.1 Measure of ecotoxicity and salinity 15.2.1 Progress towards increasing forest coverage and reducing the loss of biodiversity. 15.3.1 Coverage of reforested land over the total land area with wildlife settlements 15.5.1 Red life indices
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	a Access to jurisdictional rights and transparent frameworks for decision making (16.1, 16.3, 16.6, 16.7, 16.10)	16.1.4 Subjective well-being and safety factors for inhabitants in public places. 16.3.1 Percentage of conflicts resolved as a portion of overall cases of violence reported. 16.6.2 Measure of level of satisfaction to the smart solutions offered to the public. 16.7.2 Level of involvement of public institutions in ensuring peace and harmony at the nation.

TABLE 1 (Continued)

Sustainable Development Goal	Targets	Examples of selected indicators
		16.10.1 Openness of information to the public through the technological platform.
17 PARTNERSHIPS FOR THE GOALS	a Resource mobilization and development assistance (17.1, 17.2, 17.3) b Innovation and knowledge sharing (17.6)	17.1.1 Revenue spend to strengthen bilateral relationships. 17.2.1 Level of development assistance from international sources adding value to GDP growth. 17.3.1 FDI inflow as a portion of the overall domestic budget. 17.6.2 Proportion of population who has access to internet facilities.

targeted scholarly articles, conference proceedings, published books, book sections, and web-based sources, including industry reports and grey literature.

However, the primary focus of this search is to investigate research developments in the context of smart cities, including smart city initiatives, complex systems, and dynamic interactions within the smart cities. The search covered the period between 1997 and 2019, considering that the concept of SUD has gained popularity during the late 1990s (Bibri & Krogstie, 2017). More attention has been given to the period from 2016 to 2019 as this period witnessed the announcement of the 17 SDGs of the Sustainable Development agenda 2030 by the United Nations. A total of abstracts of 262 articles were investigated and then reduced to 147 articles. After completely reading these articles, the number of articles reduced to 86 articles exploring smart cities from a non-fragmented point of view and tools for studying system behaviors.

Each of the smart city initiatives was mapped to corresponding SDGs to investigate the extent to which smart city initiatives interweave the sustainability and SUD themes. A total of 118 smart city case studies and success stories were reviewed and then reduced to 50 case studies that are more relevant for the mapping process. These case studies were collected from official websites or government online e-resources. Moreover, the smart city initiatives are then individually reviewed to specify the degree of alignment with the SDGs.

The degree of alignment with SDGs was gauged by conducting an Assessment of Progress (AOP) for each smart city initiatives using 232 indicators. At least four indicators were selected under each goal. The selection was more focused on indicators relevant to the policy output. The reference Table 1 highlights the selected set of indicators corresponding to each target.

The new systems-thinking approach uses the causal feedback loop diagram (CLD) method to visualize systems behavior and dynamics. A rich picture was initially used to understand the complex situation. An iterative process was conducted to re-work on the existing perceptions of each group member, who siloed while creating the rich picture was undertaken. The individual mental modals were then grouped to form a good rich picture with a better understanding of the scenario. Once the rich picture was developed and the major elements in the system identified, an interrelationship digraph (IRD) was constructed. A paper and pen were used to create the IRD. The IRD approach provides a better understanding of the key drivers in the system and helps in identifying the feedback loops. The causalities between each element in the system were backed by expert judgments, literature reviews, and the author's conceptualization. These diagrams were constructed with elaborate behaviors and realistic hypotheses. Finally, the IRD was converted to a CLD through an iterative process. This study used the "Vensim PLE 7.3.5" for CLD development. Finally, the findings were presented in the written format. Figure 1 shows the research methodology.

3 | LITERATURE REVIEW

3.1 | Smart city initiatives

The phrase "smart city" has transpired to address several challenges and possibilities in urban planning and city development for a vast majority of the population across several disciplines. The concept has also gained immense popularity all over the research community (Camero & Alba, 2019). In simple terms, cities that strive to make it "smarter" is termed as smart cities (Chourabi et al., 2012). Smart city initiatives are transformational initiatives aimed at reforming the city services to deliver a better quality of life to the citizens (Odendaal, 2003). As of 2018, estimates show that there are around 473 smart city projects (both inclusive of on-going and completed projects) in 57 countries around the globe (Smart City Expo World Congress, 2018). In particular, countries like South Korea and Singapore have invested massive shares of spending on IoT based solutions to digitalize and sustainably transform the nation into an intelligent nation. Cities such as Masdar, Brisbane, and San Fransisco have invested a great deal in the digital transformation of their cities to step foot into the future goal of the smart planet (Yigitcanlar, Han, Kamruzzaman, Ioppolo, & Sabatini-Marques, 2019; Yigitcanlar, Kamruzzaman, Foth, et al., 2019). These smart city initiatives aim at implementing smart technologies to address the prevailing challenges in urban areas such as inaccessibility to safe and clean drinking water, lack of proper public health services, lack of employment opportunities, and social prosperity (Yigitcanlar et al., 2018). They also attempt to address challenges such as poverty, traffic congestion, global climatic changes, inadequate sustainable infrastructure, community living.

The primary objective of these initiatives is to transform cities into being smarter, greener, and sustainable, which means a better

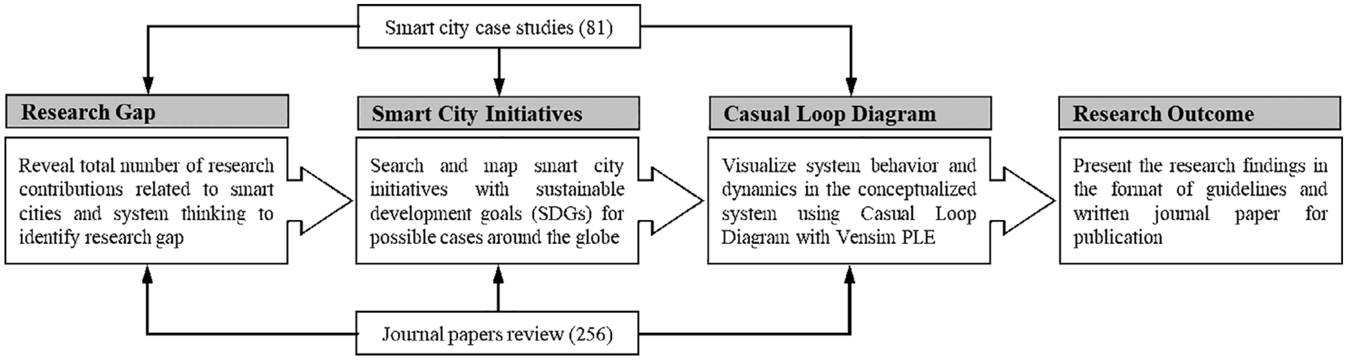

FIGURE 1 Proposed methodology

quality of life to the citizens and increased economic opportunities. The smart city initiatives use a wide range of ICT based intelligent services (Rodrigues & Franco, 2019), starting from capturing and disseminating information across the city through data centers. According to Lava Active inflow report, several government agencies are partnering with private firms to optimize city services and develop more sustainable and intelligent solutions by adopting open data and geospatial intelligence. The anti-poverty initiative, "The Poverty in NYC" partnered with the Poverty Research Team, is an excellent example of using open data sources to tackle the social inequality problems (Murray, 2018). These deep-lobed partnerships support decision making to address the concerns of citizens. For instance, the innovative funding mechanism pictured by the municipal government in Rio De Janeiro has been initiated to tackle the funding issues to support urban development and city transformation. Statistics show that around 35% of the investments for supporting the city development activities are managed through private investors. The Rio municipality has leveraged the bureaucratic restrictions imposed on private investments by certain policy reforms to encourage Public-Private Partnerships (PPP) (Smart City Hub, 2017). The Rio city administrations have extended the concept of PPP to invite not only foreign investments but also several service providers and asset builders who had partnered with the government to work on their behalf. An example of PPP arrangements can be seen in the case of the General Outpatient Clinic PPP Programme launched in Hong Kong, 2014. In this program, all the general outpatient services are outsourced to private healthcare service providers who substitute the Hong Kong Hospital Authority (HA) in providing these services to the city residents (Onag, 2018). This initiative ensures proper health and sanitation benefits to all its citizens. Here the government acts as an enabler, policy reformer, and procurer of city services, thus stimulating economic growth.

As these examples suggest, smart city initiatives help in mitigating several urban development challenges. These challenges are overcome by utilizing data and services from intelligent technologies, like location intelligence, Geospatial technology, Internet of Things, Big data, and Cloud systems. This caters to the needs of the city residents, improves city stakeholder involvement, and provides a better understanding of the city operations. Although the concept of SUD in smart cities seems very practical and viable, in reality, however, it is very complex, demanding, and context determined (Yigitcanlar & Kamruzzaman, 2018). Assessing environmental sustainability performance remains a great challenge (Egilmez, Gumus, & Kucukvar, 2015). Challenges such as the inability of matching the urban sustainability demands to the real-time applicability context, lack of proper alignment in policy and technology implementation, and coercion on social and regional solidarity that demand diverse governance solutions, also deteriorate sustainable city performance.

3.2 | Smart cities and systems thinking

To tackle these challenges, cities have started adopting smart initiatives (Marsal-Llacuna, Colomer-Llinàs, & Meléndez-Frigola, 2015). These smart city initiatives are often assumed to be a successful approach in curbing possible city challenges. Table 2 highlights several peer-reviewed research articles published in the field of smart cities and systems thinking during the past decade. These researches emphasize the abundance of the research works in the field of harmonizing smart city initiatives with SDGs using a system-thinking approach.

Systems thinking provides a broader understanding of how a system functions by investigating the relations and changes within the system. The smart city challenges are often perceived as a product of structured relations between selective parameters addressing these challenges, rather than just identifying causes and behavioral changes separately like the traditional linear thinking. These parameters are considered as a part of the city holistically, or pillars that address the challenges of the city, where the smart city is seen as an integration of systems (Dirks & Keeling, 2009). Any alteration to these parameters will affect the system as a whole. Therefore, the flaws that affect the overall dynamics of the city can be overcome by bringing systems thinking into the context of smart cities.

Systems theory has recently been used to formalize smart city visions by playing a vital role in strategic city planning. Several other tools, along with systems thinking, are used to tackle the smart city challenges in urban planning, for instance, Kitemark recognition,

TABLE 2 Literature review based on SCOPUS online database search for keywords “Smart City” AND “Systems Thinking”

SL. No	Article	Abstract	Source
01.	Towards a system-thinking based view for the governance of a smart city's ecosystem: A bridge to link smart technologies and big data.	The research utilizes a system-thinking approach to investigate the challenges faced in several domains of smart city and act as a guide in managing several dimensions and paths of social dynamics.	(Caputo, Walletzky, & Štepánek, 2019)
02.	Systems thinking for developing sustainable complex smart cities based on self-regulated agent systems and fog computing	The study adopts a system-thinking approach along with self-regulating agent systems and fog computing techniques for molding the futuristic concept of complex smart systems.	(Abbas, Shaheen, Elhoseny, & Singh, 2018)
03.	Applying system science and systems thinking techniques to BIM management	The study adopts system science and the system-thinking to revitalize management norms on infrastructure development projects using augmented designs. A problem analysis and interpretation method are used by the author on a construction project in the UAE to validate the strategies proposed in the study.	(Redmond & Alshawi, 2018)
04.	Functional resonance analysis method based-decision support tool for urban transport system resilience management	The research connects the functional resonance analysis method with a system-thinking approach in order to develop a resilience decision support tool using smart data, thus helping to manage complex infrastructure resilience.	(Bellini, Nesi, Pantaleo, & Venturi, 2016)
05.	Case study of energy behavior: A system-thinking approach	A system-thinking approach is used to develop a three-tier based framework for smart city, focusing on changing the energy consumption behavior. The research outcomes focus on people who live in the more significant part of new York City.	(Khansari, Darabi, Mansouri, & Mostashari, 2015)
06.	Industrial and business systems for smart cities	The research adopts systems thinking approach along with continuous engineering and IoT based concepts to develop an integrated set of best practices for smart cities and several industries.	(Amaba, 2014)
07.	Conceptual modeling of the impact of smart cities on household energy consumption	The impact of smart city technologies on the behavioral change of household energy consumption using systems thinking and cognitive and learning approaches is attempted in this study	(Khansari, Mostashari, & Mansouri, 2014)
08.	Living labs, innovation districts, and information marketplaces: A systems approach for smart cities	This study attempts to develop a candidate model for implementing the smart city concept into practice by incorporating systems thinking and integrating the living lab and innovation district concept.	(Cosgrave, Arbuthnot, & Tryfonas, 2013)

Note: Source: Structured and complied by authors.

Bench-learning, Progress monitoring. (Pichler, 2017). System theory outweighs all other tools, because of its systematic behavior in integrating systems, the ability to predict composite changes within the system, and understanding the relevance of possible divergence.

Systems thinking addressed in the smart cities context considers socioeconomic and environmental characteristics and their dependencies with several systems and subsystems (Shmelev & Shmeleva, 2018). This feature paves ways to SUD in smart cities (Pretorius, Pretorius, & Benade, 2014).

Systems thinking as a tool can also help cities in framing a better idea on several input–output parameters, for example, population, urban space, air, water, waste, energy, safety, and transportation. System thining helps in a better understanding of how these parameters hold influence in the governance stage.

3.2.1 | Why systems thinking and how it works

Cities are often considered as complex systems (Berkowitz, Nilon, & Hollweg, 2003; Mora, Bolici, & Deakin, 2017; Portugali, 2016). These systems constitute several subsystems that are interconnected and interrelated with each other to perform specific functions (Bertalanffy, 1976). Functions are often related, and they tie-in connecting several elements within the system. Considering an example of the road as a function, we can see that the road functions to move vehicular traffic acting as a mediator for the movement- connecting people and vehicles from the source to destination. Thus, understanding these functions helps us in associating various elements and processes that are essential in filling these functions and facilitates us with a broader understanding of the results obtained when these functions are filled. Thus, applying systems thinking to understand these functions act as a potential leverage point since, systems thinking identifies necessities (Onat, Kucukvar, Halog, & Cloutier, 2017), possible knowledge gaps, correlations, and goals. Additionally, it helps in locating possible system paralysis, absent elements, inefficiencies in urban dynamics, and possible links that form a part of the function's work cycle.

Cities, when visualized as an urban ecological system, contain several subsystems (e.g., but are not limited to population, urban space, air, water, energy, food, waste, safety, health, and transportation) that act as a system itself in the network of systems. A slight disruption in the functioning of either of these subsystems would result in undesirable consequences in other subsystems within the network of systems, thus affecting the overall dynamics and efficiency of the system. "Systems thinking" is thus an answer to all these questions and challenges, where systems thinking acts as a support tool in addressing complexities, uncertainties, and identifying "what if" impacts (Onat et al., 2017). Systems thinking interconnects several elements of a system to the point of interest, better identified as a purpose. For example, let us say that the traffic and transportation modelers in a city wish to redesign the transportation system that has been existing as an integral part of the city infrastructure for the past 50 years. The conventional planning model of the city's transportation network would hold "transportation" as its prime focus. However, in a smart city, the modelers would extend their point of interest on factors such as smart mobility, zero-emission transportation alternatives, and increased connectivity for the city residents. Systems thinking provides a broader understanding of how a system functions by investigating the relations and changes within the system. When understanding the concept of systems thinking vis-à-vis smart cities, city challenges are perceived as a product of structured relations between selective parameters that address the challenges, rather than just identifying causes and behavioral changes separately like the traditional linear thinking. These parameters are considered as a part of the city holistically, or pillars that address the challenges of the city, where the smart city is seen as an integration of systems (Dirks & Keeling, 2009). Any alteration to these parameters will affect the system as a whole. Thus, bringing systems thinking into the context of smart cities, we can troubleshoot flaws that affect the overall dynamics of the city with marginal effort.

3.3 | Novelty statement and research gap

The comprehensive review revealed that only a handful of articles attempted to arrange and describe possible interactions between the key drivers/elements of the smart city at a strategic level. Little to no articles dealt with the complex system changes under several "what if" conditions from a global perspective. Most cases were region-specific which set boundaries that focused on interactions in a system to achieve smartness goals rather than the sustainability goals and targets. Also, the literature review saw the lack of a considerable amount of tools to understand the dynamic behavior of elements under system interaction. Although several implementation tools such as the Kitemark recognition and progress monitoring tools exist in the literature, neither of them attempts to consider the interdependencies between the socio-economic, environmental, and numerous subsystems that form the basis of any sustainable urban planning model. Despite prevalent methods used, cities also face a tremendous deal of criticism, challenges, and difficulties when it comes to the deployment and implementation of SDGs into the pre-conceptualized vision of smart sustainable city (Bibri & Krogstie, 2017). Accounting to the research gaps identified, this paper attempts to fill these gaps by:

1. Conducting a mapping process between the selected smart city initiatives around the globe with the UN SDGs based on a selected set of indicators and targets. This mapping intends to deliver good practices and guidelines for several initiatives to adopt a transition from the sustainable city or from smart city to smart sustainable city strategies while concurrently achieving the SDGs. These initiatives can further be redefined to align with other SDGs according to any sort of future challenges that may arise in that city, thus facilitating a smart sustainable city transformation.
2. Considering the complex interactions between several elements in smart cities through a systems thinking approach. The research attempts to consider smart cities as complex urban ecological systems (Berkowitz et al., 2003) that provide optimal solutions for the existing problems by analyzing the traits of these systems. Here, a strong realization and understanding of the system fundamentals are taken into account in context to the urban environment. Several conceptual models to better understand the dynamics of the key catalyzers that promote better harmonization of smart city initiatives with SDGs were developed. This participatory approach helps in identifying possible knowledge gaps and barriers and also helps in creating more opportunities for the development of a smart city. These participatory approaches are often considered as the building characteristics of the city's smart strategies (Angelidou, 2017).
3. Shedding lights on Systems thinking as a tool that evaluates complex feedback behaviors considering non-linear and endogenous characteristics in system interaction. Systems thinking as a tool presented in this study facilitates impeccable legitimacy of judgments for intercession and a collaborative approach to support decision making in smart cities. These aim at providing the best possible solutions for discursive judgment making. The system thinking tool in this paper considers all the interdependencies among various subsystems and all the dimensions of sustainability that support framing urban sustainability policies and bettering planning models for SUD.

4 | CLASSIFICATION AND MAPPING OF SMART CITY INITIATIVES

In order to add a high value to our research and achieve the research objective, we have selected some smart city initiatives around the globe that aim to catapult several smart city services in achieving the smart, sustainable city paradigm. These initiatives were selected based on their high potential to contribute significantly to the United Nations Urban Sustainability Agenda. Although several smart solutions implemented by cities contribute to the smart development prospect, these solutions do not constitute itself for smart city implementation as a whole. Hence, these smart solutions do not qualify as smart city initiatives to be included in our selection criteria. How well these selected initiatives contribute to achieving appropriate UN SDGs still remains a question and needs further investigation.

Attempting to understand how well certain aspects of SUD and smart cities have been incorporated in several smart city initiatives, each initiative has been categorized based on certain drivers or critical factors they address like sustainability, policy context, people and communities, SUD, and so forth (Table 3). This attempt measures the coverage of several drivers of the smart, sustainable city that has been addressed under the mentioned smart city initiatives. Similarly, to identify how well several smart city initiatives undertaken by different countries around the globe utilize ICTs to achieve the UN SDGs, the research maps different smart city initiatives with the 17 UN SDGs (Table 4).

5 | PROPOSED SYSTEMS THINKING APPROACH

Systems theory has recently been used to formalize smart city visions by playing a vital role in strategic city planning. Several other tools, along with systems thinking, are used to tackle the prevailing challenges in urban planning like Kitemark recognition, Bench-learning, Progress monitoring, and so forth (Pichler, 2017). System theory outweighs all other tools, because of its systematic behavior in integrating systems, the ability to predict composite changes within the system, and understanding the relevance of feasible divergence. Systems thinking addressed in context with smart cities considers socio-economic and environmental characteristics and their dependencies with several systems and subsystems in a model that helps in strategic city planning (Shmelev & Shmeleva, 2018). This paves ways to SUD in smart cities (Pretorius et al., 2014).

Several smart city initiatives have been mapped with the corresponding UN SDGs. This mapping strategy facilitates city planners, urban stakeholders, and policymakers to frame an outline of the diverse concepts, actions, policies, and models adopted by several countries. This would aid them in attenuating negative externalities and help them in redefining their policies and governance patterns. However, productive outcomes can result only through the deployment of new and innovative products, policy and governance, Research & Development (R&D), and partnerships between service providers, external private investors, and foreign technology drivers.

Proper policy and governance structure can play a very crucial role in molding the outcomes of ICT driven smart city development towards achieving SUD and achieving SDG 11, SDG 9, SDG 17, and other SDGs. A complex multi-level governance framework that supports sustainable transformation is often necessary. Such governance frameworks are often backed with concrete policies that are transparent and inclusive, include critical system thinkers, and intimate consumers. A landscape that propels the transition of initiatives into broader sustainability directions to achieve sustainability goals is essential. Such transitions are possible when the flaws and challenges prevailing in the economy are identified and answered. R&D objectives play a vital role in the identification of these challenges, new opportunities, and implementation of ICT processes. For instance, R&D identifies the critical issue prevalent in the city; for example, water quality (SDG 3: Good Health & Well-being). Scientific research shows that a decline in water quality adversely affects the climate, thus posing a critical challenge for SUD (SDG 13: Combating Climate change). The R&D scientists investigate and formulate a well-structured dataset with a high degree of information that is essential for developing a smart city platform aimed at mitigating the water quality issues in an attempt to deliver clean and safe drinking water to the city residents (SDG 6: Clean Water and Sanitation). They also develop frameworks to monitor the contamination and waste accumulation in the water and formulate methods to recycle and reuse it (SDG 12: Sustainable consumption and production). Properly funded research initiatives thus form the backbone in implementing sustainable results, when backed with proper policy reforms that support research initiatives. The adequate funding mechanism, as discussed in the case of Rio De Janeiro through Public-Private co-funding, is essential for the successful implementation of any initiative. These partnerships bring competitive advantage for sustainable growth in cities. Similarly, a significant contribution from the political sphere for development assistance is felt necessary (SDG: 17 Partnership for the Goals). When such socio-economic and environmental aspects are addressed with ICT driven smart technologies, it results in a more safe, inclusive, resilient, and sustainable strand of urbanization (SDG 11: Sustainable Cities and Communities).

Thus, we can see that “policy and governance,” “research & development” and “partnership” act as enablers, integrators, and connectors in harmonizing and linking smart city initiatives not only with SDG 11 (Sustainable Cities and Communities) but also with other possible SDGs and smart city targets. Hence, these three connectors are termed as “catalyzers” that aid in the harmonization process of smart city initiatives and strategies with SDGs.

5.1 | Systems thinking for Policy and Governance

Challenges associated with cities and sustainable urbanization are extremely difficult to address by single entities, thus requires strong collaboration among stakeholders, adaptive management strategies,

TABLE 3 Examples of smart city initiatives around the globe

Smart city initiatives	Directives	Drivers of smart city initiatives	Source
Covenant of mayors	a Upsurge the energy efficiency and usage of renewable energy sources	Sustainability, policy, governance	(Covenant of Mayors, 2008)
European Innovation Partnership on Smart Cities and Communities (EIP-SCC)	a Knowledge sharing on available funding sources for smart city projects. b Information on specific issues, practices, and initiatives, and c Links to potential peers and partners who work in similar smart city projects around Europe.	Community, technology, partnership, City smartness	(EIP-SCC, 2019)
European energy award	a Develop road maps, strategies, and sustainable energy policies. b Encourage the use of renewable energies to support sustainable urban development. c Compact the energy and climatic challenges for the present and future generations.	Sustainability, policy, governance, sustainable urban development	(European Energy Award, 1994)
SETIS	a Implementation of the SET-plan and the iSET-plan by calling for an integrated and lean monitoring approach on the R&I objectives, investments, and technology progress. b Identification of gaps in the action implementation stage.	Technology, research, and development, innovation	(Strategic Energy Technologies Information System, 2007)
Qatar smart program (TASMU)	a Utilize ICT to achieve desired outcomes in support of Qatar's National Vision 2030.	Sustainable urban development, technology, wellbeing, livability, governance, finance	(TASMU, 2018)
Smart Dubai	a Transform Dubai to be the happiest city to live on earth. b Empower, deliver, and promote an efficient, seamless, safe, and impactful city experience for residents and tourists.	Technology, wellbeing, livability	(Smart Dubai, 2014)
Smart City Berlin Strategy	a Enhance the international competitiveness of the Berlin- Brandenburg metropolitan area, b Adopt sustainable resource utilization and strategies to combact climate change issues of the metropolitan area by 2050. c Facilitate a marketplace for efficient, healthier and sustainable technological application.	Innovation, partnership, sustainability	(Smart City Berlin Strategy, 2015)
Urban agenda for EU	a Stimulate growth, enhance livability, and support innovative strategies in cities. To successfully tackle economic, environmental, and social challenges.	Livability, partnership, innovation, prosperity	(Urban Agenda for EU, 2016)
City VITAlity and Sustainability (CIVITAS)	a Remodel the transportation infrastructure in cities to promote clean and green transport policies.	Policy, governance, sustainability	(City VITAlity and Sustainability, 2002)
CITYKeys	a Address sustainability challenges such as the transition to a low carbon, inadequate resource allocation in cities, and climate change issues. With the help of cities, b Develop key performance indicators, efficient data collection procedures with transparent monitoring facilities, and compactable smart solutions across Europe.	Sustainability, innovation, City smartness	(CITYKeys, 2015)

Note: Source: Compiled and structured by authors.

and, well-structured and agile governance models. A well-structured governance framework aims to improve the quality of urban policymaking and implementation strategies (Blanc, 2015). A well-structured policy & governance system is based on several important variables including participation in governance and decision-making, involvement in political activities, and community-based

TABLE 4 Smart city initiatives mapped with 17 United Nations sustainable development goals

Smart City initiatives	1 No poverty	2 Zero hunger	3 Good health and well-being	4 Quality education	5 Gender equality	6 Clean water and sanitation	7 Affordable and clean energy	8 Decent work and economic growth	9 Industry, innovation and infrastructure	10 Reduced inequalities	11 Sustainable cities and communities	12 Responsible consumption and production	13 Climate action	14 Life below water	15 Life on land	16 Peace, justice and strong institutions	17 Partnerships for the goals
Covenant of Mayors							✓					✓	✓				
EIP-SCC											✓						✓
European energy award							✓		✓		✓						
Green digital charter							✓						✓				
SETIS							✓						✓				
Qatar smart program (TASMU)							✓	✓			✓						
Singapore intelligent nation 2015 (iN2015)		✓		✓				✓	✓								
Smart Dubai				✓					✓		✓					✓	✓
Smart city Berlin strategy								✓	✓		✓		✓				
Urban agenda for EU								✓	✓								
Fujisawa sustainable smart town (SST)			✓				✓				✓	✓				✓	
Peta Jakarta																	✓
PlanIT Valley									✓		✓						✓
Chiang rai City								✓								✓	
Grow smarter Europe							✓				✓	✓					
NEOM smart city initiative								✓	✓		✓						
Dallas innovation alliance (DIA)									✓		✓						✓
City VITAlity and Sustainability (CIVITAS)							✓		✓								
ESPRESSO									✓		✓						✓
Energy cities							✓				✓						✓
EERA joint program							✓		✓		✓						
Smart America challenge (green vision)							✓	✓	✓		✓		✓		✓		✓
Konza technology city									✓		✓						
Skolkovo smart city initiative									✓								✓
Cyberjaya								✓									✓
CITYKeys							✓		✓		✓	✓					✓
Smart London 2.0									✓		✓						
Global Digital Seoul 2020								✓	✓		✓						

(Continues)

TABLE 4 (Continued)

Smart City initiatives	1 NO POVERTY	2 ZERO HUNGER	3 GOOD HEALTH AND WELL-BEING	4 QUALITY EDUCATION	5 GENDER EQUALITY	6 CLEAN WATER AND SANITATION	7 AFFORDABLE AND CLEAN ENERGY	8 DECENT WORK AND ECONOMIC GROWTH	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	10 REDUCED INEQUALITIES	11 SUSTAINABLE CITIES AND COMMUNITIES	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	13 CLIMATE ACTION	14 LIFE BELOW WATER	15 LIFE ON LAND	16 PEACE, JUSTICE AND STRONG INSTITUTIONS	17 PARTNERSHIPS FOR THE GOALS
OneNYC								✓	✓	✓	✓	✓					✓
Helsinki's six city strategy								✓	✓		✓						✓
Montreal smart city strategy (MSCS)									✓								✓
Boston Beta blocks								✓	✓		✓						
Smart Melbourne			✓						✓								
Smart Shanghai									✓								
Smart city Barcelona strategy									✓		✓						
Reinventor Paris									✓		✓						
Amsterdam smart city (ASC) project			✓				✓				✓	✓	✓				✓
Oslo SSC project							✓				✓	✓					

Note: Source: compiled and structured by authors.

interrelatedness. Additional variables such as citizen engagement, quality of urban policymaking, city challenges, and SDGs also support this system.

Visvizi and Lytras (2018) highlight the importance of proper policy measures in transforming cities to be smarter and more sustainable. Figure 2 shows a causal feedback loop diagram to explain the catalyzer role of policy & governance for the successful implementation of SDGs. All the variables depicted in the CLD are based on available smart city literature and they are harmonized and conceptualized in a way that too explains the main mechanism systematically and holistically. In Figure 2, two main loops, one balancing (B1) and one reinforcing (R1) are identified to explain two sides of the mechanism. **B1** is a balancing feedback loop explaining the relationship between urban population and city challenges, where the need for a proper policy framework is directly dependent on the influence of the city challenges. This is attained through effective participation in the governance and decision-making process. An increase in the urban population can bring about a series of socio-economic and environmental challenges in the city (Jarah, Zhou, Abdullah, Lu, & Yu, 2019). Through effective participation in the governance system, a set of quality policies and governance strategies are achieved (Ahrens & Meurers, 2011). This, in turn, supports UNSDGs for smart cities, thus reducing smart city challenges when SDGs are implemented. In some way, collective actions and participation can create a self-correcting or self-organizing structure for sustainable urban policy development and implementation.

Similarly, participation in governance and decision making will have a positive influence on the involvement of the city residents in political activities (Alghais, Pullar, & Charles-Edwards, 2018). This increases the community-based interrelatedness. This, in turn, facilitates opportunities for male and female representatives to engage in the policy & governance system, thus reinforcing the participation in governance & decision making via reinforcing loop **R1**; see Figure 2.

Thus, we can see that all the causal relations interlink and balance the policy & governance structure, strengthening the system by reducing city challenges and harmonizing SUD goals with the elements of the system. Thus, facilitating the transformation of a smart city into a smart sustainable city.

5.2 | Connecting systems thinking approach with research & development (R&D)

There are several potential leverage points or soft factors (Figure 3) that are influenced by the management discretion on the R&D activities like the influence of market demand, idea, resource allocation (staffing and time allotted per designated staff for the research activities) and R&D intensity. These leverage points can be attributed to decision support factors that drive R&D activities.

An empirical study conducted by Dalziel, Gentry, and Bowerman (2010) on R&D capital reveals a positive correlation between R&D capital and R&D spending. Poyago-Theotoky, Beath, and Siegel (2002) reveals the merits of partnership in stimulating technological and revenue related growth opportunities in universities and

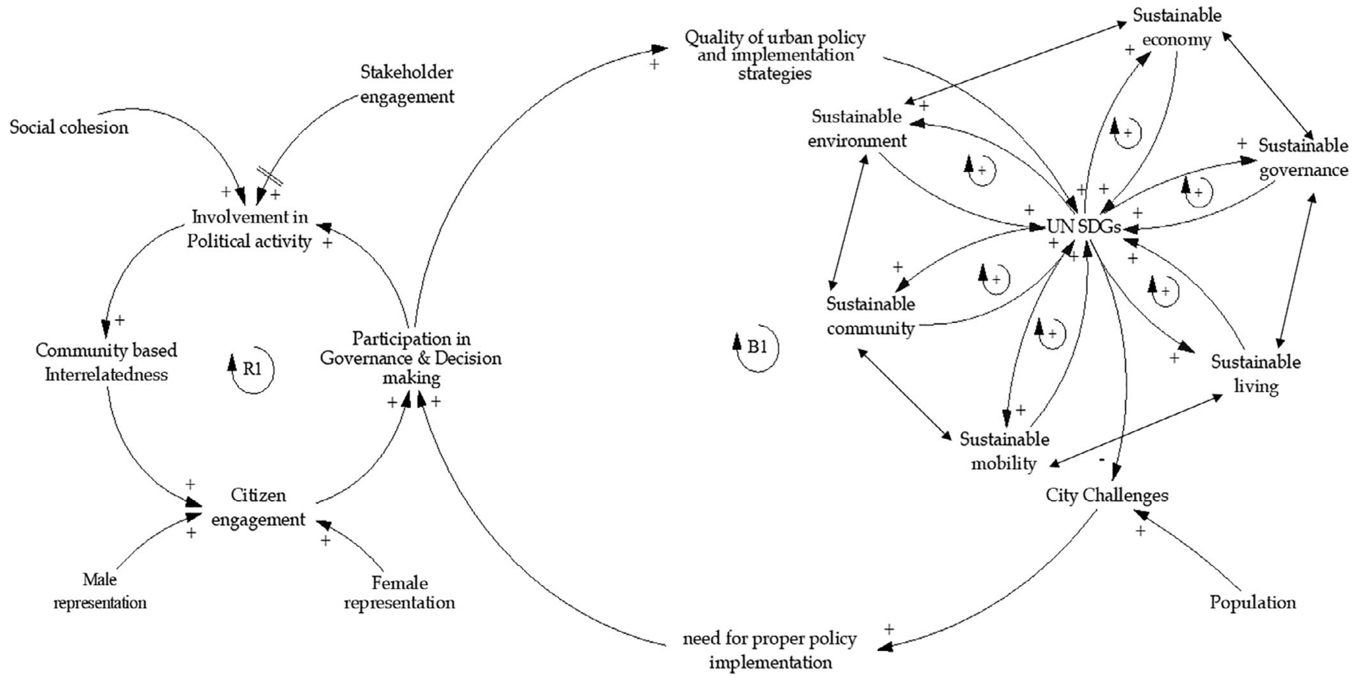

FIGURE 2 Causal loop representation for the catalyzer Policy & Governance (Source: conceptualized and designed by authors using Vensim PLE 7.3.5 Software)

fundamental research institutions. Technology utilization and potential R&D investments endure possible benefits and are considered as a source of revenue (Ayming, 2017). While observing the loop **R3**, we can see that a positive influence on the R&D intensity (revenue generated and spent on R&D related activities) along with positive market influence and partnership yields a positive response on the revenue factor. This, in turn, leads to a positive influence on the R&D capital assigned for conducting R&D activities, resulting in a positive response on the ICT based technologies that itself act as a source for additional revenue. This positively influences the R&D capital and the R&D activities, consequently reinforcing the loop through the loop **R3**.

Data infrastructures are perceived as backbones for stimulating substantial value for public and private ventures, enterprises, and citizens alike (Ahdoot, 2019). Real-time data offers a fundamental change to the existing infrastructures by offering the potential for integrating services through networked structures (Hashem et al., 2016). The loop **B2** emphasizes the dynamic relation of the need for smart solutions that have occurred as a result of the positive response of city challenges due to the population (**R2**). This positively influences the real-time data available, thus influencing positively the number of data centers for capturing and disseminating real-time data to support the ICT based technological innovation, which in turn will cause a positive response (either decrease or increase) in the smart solutions. A positive response in the smart solution will have a negative influence on the need for smart solutions, that is, an increase in the smart solutions will lead to a decrease in the need for smart solutions and vice versa, thus balancing the loop through balance loop **B2**.

Loop **B3** emphasizes the relationship of city challenges and SDGs, where city challenges positively influence the need for smart solutions. This positively influences the real-time data available, which influences positively the number of data centers available for capturing and disseminating real-time data to support the ICT based technological innovation, which in turn causes a positive response (either decrease or increase) in the smart solutions. Smart solutions tend to address social, economic, political, and environmental sustainability challenges and support the SUD and harmonization of smart initiatives with SDGs. Thus, an increase in smart solutions would facilitate addressing the sustainability challenges and integrating smart initiatives with SDGs in a better manner. This reduces city challenges or vice versa as the case may be, thus balancing the feedback loop through balance loop **B3**.

Loop **R4** emphasizes the dynamic relationship of R&D activities on SDGs. ICT based technologies act as enablers when attempting to remodel a sustainable city with smart solutions into a smart sustainable city (Prakash, 2017). Here, ICT based technological stock exerts a positive response on the smart solutions, which in turn tend to support the harmonization of smart initiatives with SDGs in a positive influence manner. This facilitates optimal resources to support R&D activities, thus consequently reinforcing the loop (**R4**), and the loop continues.

5.3 | Connecting systems thinking approach with partnership

The catalyzer role of "partnership" is presented by the CLD through the loops **B4** and **B5** (see Figure 4). These relationships are based on the existing smart city literature and conceptualization of these

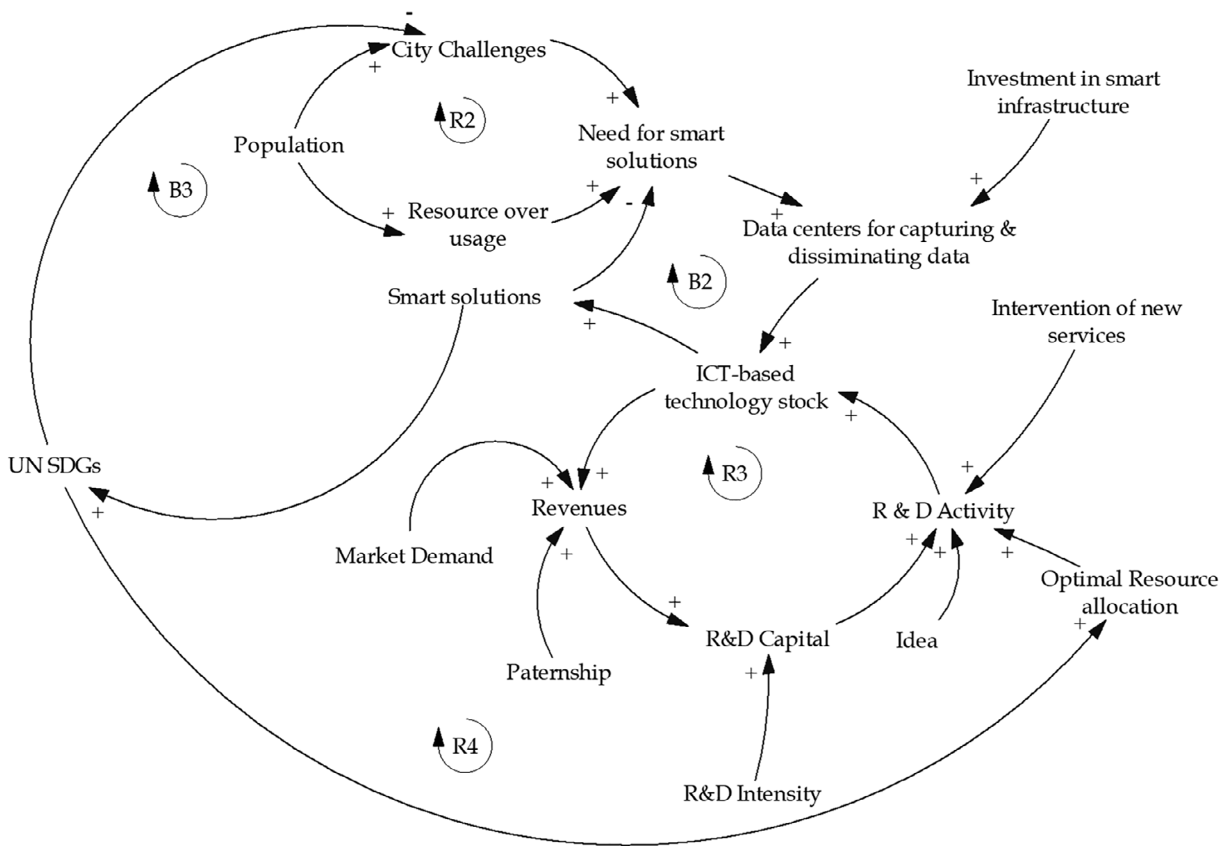

FIGURE 3 Causal loop representation for the catalyzer research & development (Source: Conceptualized and Designed by authors using Vensim PLE 7.3.5 Software)

separately studied relationships in a single CLD. The dynamics of the loop **B4** explain a positive response to the urban population that leads to an outbreak of several city challenges, hindering economic growth. In some way, this loop explains the limits of economic growth given the growth capacity of the city. Increased economic growth facilitates better job opportunities and availabilities in the current market (Donor Committee for Enterprise Development [DCED], 2019). This facilitates an appealing urban space that brings more job seekers into that urban space, thus increasing the urban population or vice versa (keeping the response of the loop as positive). However, the increased population would increase the city challenges and hinder economic growth to some degree. Hence, cities look for potential improvement areas to support population growth.

The loop **B5** shows that a positive response to the economic growth would positively influence the quality of life of the citizens. The economic growth, along with other factors such as social development, has a positive influence on the quality of life (Joshua, 2017). This, in turn, would lead to a negative response on the PPP and thus negatively influencing the investment factor. Smart city investments come from PPP and other soft factors like revenue sharing agreements and pay-for-performance agreements. An increase in the investment would lead to better funding opportunities for business establishments that result in a transformational change leading to an increase in economic growth (Zangoueinezhad & Azar, 2014). Similarly, a decrease in the investment would lead to poor funding opportunities, which would reduce the urban attractiveness for business establishments to set up their enterprises, thus decreasing economic activity. A considerable decrease in economic activities hinders economic growth, hence balancing the relation through the balancing loop **B5**. Hence, as discussed in the case of policy & governance, we can see that all the causal relations interlink and balance the partnership structure, strengthening the system by reducing city challenges and adopting a transformational change. This context is better understood as harmonizing SUD goals with the elements of the system, thus facilitating the transformation of a smart city into a smart sustainable city. The self-correcting mechanisms (balancing loops) play an important role to determine the boundaries of the economic growth potential of the city and this boundary can be leveraged up by involvement of transformational changes and innovation.

6 | DISCUSSION

This paper provides readers a glimpse of the current status of several smart city initiatives around the globe and their contributions to achieving the UNSDG's. Results show that although smart city strategies have echoed the inclusion of sustainability goals in their smart agenda, in practice, cities have not adopted these goals to its full

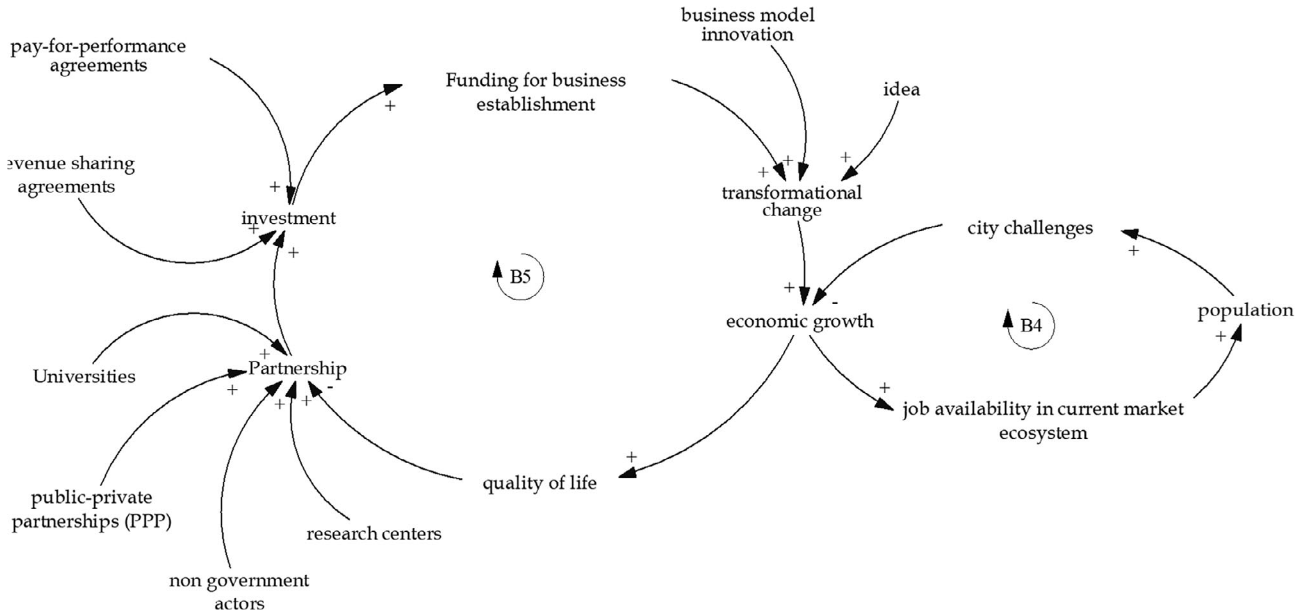

FIGURE 4 Causal loop representation for the catalyzer partnership
(Source: Conceptualized and Designed by authors using Vensim PLE 7.3.5 Software)

potential in addressing future city challenges in several possible domains. The authors have adopted a system-thinking approach to unwind several possible causal relations in real-world cases, where a CFLD was conceptualized since, experimental methods often hold complexities when practically applied in real-time situations.

At the first stage, the authors conducted an in-depth literature analysis based on several scholarly works and expert opinions in the respective field of smart cities. This helped them in categorizing smart city initiatives based on certain drivers or themes each initiative address and understand the research gap. This has provided readers an insight on the extent to which several initiatives around the globe address the concept of SUD in their smart city development agenda. In the second stage, the research identified on how several smart city initiatives around the globe utilized ICTs to achieve the UN SDGs, whereby mapping smart city initiatives with the 17 UNSDGs. Based on several existing smart city literature and conceptualization by the authors, the third stage identified certain enablers in harmonizing smart city initiatives with several UN SDGs, where a multi-integrated system thinking approach was used. The authors concluded that "policy and governance," "research & development" (R&D), and "partnership" are key catalyzers in harmonizing smart city strategies. Later, to visualize the system behavior for each catalyzer using the integrated systems thinking approach, the CFLDs were used. The causalities and the dynamic interactions among elements in the developed conceptual models justify the dynamicity and the impact of these elements within a system. The influence of these feedback relations is very important for successful policy interventions that support future smart sustainable city development. These catalyzers would help future development strategies in smart cities to align with not only SDG11 (smart and sustainable cities) but also with other potential SDGs and are predominantly applicable in the global context.

While analyzing the possible interactions of each SDGs with the smart city case studies, along with the positive interactions, the negative interactions were also taken into consideration. Although these negative interactions were excluded in the mapping process, they were considered while building the CFLD. For example, the sustainability concern related to renewable energy usage (target 7.2) holds a negative interaction with the biofuel expansion and food security. But these negative interactions were accounted as concerns dealing with governance aspects than biofuel production itself.

Nevertheless, the relevance of these catalyzers and their interactions, in the global scale leans on to the degree to which city challenges are being approached in context to the smart targets and goals. This highly depends on the income level of the countries as well. The catalyzers considerably interact with most of all the SDGs, but their interaction possibly fades as we move up the income ladder, however, they do not fritter away. The way these interactions are held possibly vary based on the context they address. For example, SDG 2: Zero Hunger is mainly considered as a pressing challenge in several underdeveloped countries. It is often seen among the language of development priority in low-income countries. However, the goal of "end hunger" also holds great significance among the high-income nations. "Improved nutrition" does not only point to chronic undernourishment but also poor supplement quality (micro-nutrient deficient) in the food consumed and increased obesity levels among the people. Managing obesity challenges is linked closely with education in more affluent countries in a single direction (as a good knowledge helps in understanding nutrition habits). While the undernourishment is linked strongly with education in lower-income nations in multi-direction (a healthy diet can result in better school performance, and contrariwise, education brings a healthier choice of nutrition to the house).

The mapping process and the CFLDs helped in identifying the connectivity and complexities within the system, thus facilitating better learning opportunities. All intend to deliver good practices and guidelines for several initiatives to adopt a transition from a sustainable city or from smart city to smart sustainable city paradigm while concurrently achieving the SDGs.

7 | CONCLUDING REMARKS

The integrated management and thematic approach to the interaction of several elements within the complex system may vary significantly based on several national circumstances. This may depend on the degree of technology used to achieve the SDGs and mitigate the challenges within the regional boundary. Although the catalyzer "policy and governance" act as an enabler in harmonizing the 2030 Agenda, the interactions among the several elements within the system depend on the degree to which several institutional measures are exerted. In most cases, the prevailing sectoral institutions provide essential competencies. But only a strong interaction with the counter-institutions can help in better understanding the problem and design possible action plans. This fact is often neglected until today in practice.

In the designed CFLD, the elements and their possible level of interaction are limited despite the existence of a relatively greater number of interactions. Despite this constrain, the conceptual models help in understanding the big picture of smart city challenge mitigation through the key catalyzers. Thus, attempting to strengthen these key catalyzers in the smart city context can help solve complex city challenges to a great extent and foster sustainability. A more comprehensive mapping selecting more indicators and pointing more possible system interactions can be done over time. This can be done by understanding possible seasonality in data and correlations on longer terms. The feedback relations obtained can be validated by applying them into real-time cases of small, medium, and large-scale smart city projects globally. This can be performed by System dynamics modeling of several parameters and factors that constitute the CFLD model for smart city harmonization can be done by adopting a qualitative methodology, where opinions from several stakeholders are taken into consideration. Further, a computer-simulated model for the structured systems thinking causal feedback model can be developed to identify gaps, flaws, inconsistencies, and inefficiencies in the currently developed model.

Based on the outcomes of the study, the authors have provided a blueprint of recommendations for cities embarking on tailoring their landscape to achieve SDGs outlined under the United Nations Urban Development Agenda 2015. To attain the meta goal of SUD in smart cities by 2030, smart cities around the globe can adopt the following guidelines, namely:

- Even though the smart city is a multi-perspective concept, human-centric approaches are often assumed to be the keystone of city development and comprehensive smart strategies as they support economic development in cities. Human-centric approaches often act as an antidote for smart growth. For this, smart cities should act as active learning centers that support quality education and lifelong learning opportunities that would, in turn, support the growth of smart people. Smart people would contribute to more economic growth and flexibility and would act as an inviting factor for innovative industries to establish a place in the market. This, in turn, would open a new job market. Such approaches can undoubtfully connect city development with SDGs such as SDG 8, SDG 9, and SDG 4.
- A multi-level policy and governance framework that includes; civil society, multiple stakeholders, public and private sectors, investors, and digitally and sustainably enabled landscape is felt necessary. Governance strategies should be transparent and should include all the actors and common people to facilitate an unambiguous bureaucracy, thus structuring better responsible governance for citizens. Such governance strategies should offer incentives for actors who engage in compacting several sustainability challenges (social, economic, and environmental) and promoting sustainable growth in smart cities. Such initiatives can link smart city development with SDGs such as SDG 1, SDG 2, SDG 6, SDG 7, SDG 9, SDG 11, SDG 13, SDG 14 and SDG 15.
- Cities must tap into creating a smart plan that includes engagement with universities, research centers, non-profit organizations, non-government foreign actors, and international advisory boards. These partnerships facilitate several benefits to smart cities. One such benefit is the maximization of limited government budget allotted for smart city development. This is acquired through PPP. Another benefit is the continuity of ongoing smart city projects that may face certain challenges and oppressions due to changes in the ruling party during the project execution phase. This is acquired by partnering with non-profit organizations, non-government foreign actors, and international advisory agents. Partnerships can also offer better expertise in the field of smart cities, which cannot be acquired otherwise. This is made possible through educational institutions and research centers. Such initiatives can link smart city development with SDGs such as SDG 9, SDG 11, SDG 16, and SDG 17.
- Smart cities are often perceived as a web 2.0 and industry 4.0 marketplace that act as competing rings for self-made goals of corporates and multinational firms. This may raise several development challenges in specific areas of community-based development, as selfish competitions by corporates to reap high profits from multibillion projects often fail to address the social challenges of the weaker sections of the community, like the availability of clean and safe drinking water (SDG 6), sustainable consumption patterns (SDG 12) and food security issues (SDG 2). These corporates often tend to focus on the needs of the elite class like home automation, smart banking, smart cars, sophisticated apps, and platforms for commercial purposes, and so forth. As a result, a socially inclusive and adaptive framework is necessary to curb social inequalities and other social challenges prevailing in cities, thus aligning these

futuristic change strategies of smart cities with SDG 1, SDG 3, SDG 5, SDG 6, SDG 10 and SDG 12.

- Smart city transformation is not complete if the smart projects are not backed by committed leaders that support the smart city development prospect. These strong leaderships need not necessarily be within the local governing bodies like Mayors, District Attorneys, or Governors but can also be the project managers, planning directors, members of the execution community, NGO activists, and so forth. These initiatives can connect SDGs 11, 16, and 17 with smart city development strategies.
  - For any smart city initiative to be successful, the authors have suggested the adoption of the 4I's while implementing smart strategies to support city transition. The elements of the "4I's strategy implementation pyramid" developed by the authors include:

1 *Innovation*: Digital innovation provides opportunities for cities to embrace sustainability practices by tackling several social, economic, and environmental challenges. Smart cities are platforms that utilize technological innovation in testing several innovative strategies and approaches. Innovation brings in reliable alternatives to compact smart city-related challenges.

2 *Investment*: Investments are often considered as keystones in fostering innovation in smart cities. Smart city investments are often income-generating, and they facilitate sufficient funding for city maintenance and another day to day operations of cities by generating sufficient cash flow along with several economic benefits.

3 *Inclusion*: Social disparities and exclusions are some of the development challenges that cities face. A socially inclusive framework supporting smart strategies is important in steering economic growth and prosperity.

4 *Improvement*: Continuous improvement programs are often important to ensure the quality and sustainability of several production and consumption practices and services offered in cities such as healthcare, sanitation, infrastructure, transportation, water supply, and so forth.

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REFERENCES

Abbas, H., Shaheen, S. I., Elhoseny, M., & Singh, A. K. (2018). Systems thinking for developing sustainable complex smart cities based on self-regulated agent systems and fog computing. *Sustainable Computing: Informatics and Systems*, *19*, 204–213. https://doi.org/10.1016/j.suscom.2018.05.005

Ahdoot, A. A. (2019). Data centers: The least flashy, most important element of a functional smart city. Smart Cities Dive. Retrieved from https://www.smartcitiesdive.com/news/data-centers-the-least-flashy-most-important-element-of-a-functional-smar/557429/

Ahrens, J., & Meurers, M. (2011). How Governance Affects the Quality of Policy Reform and Economic Performance: New Evidence for Economies in Transition. CiteSeerX.

Alghais, N., Pullar, D., & Charles-Edwards, E. (2018). Accounting for peoples' preferences in establishing new cities: A spatial model of population migration in Kuwait. *PLoS One*, *13*(12), e0209065. https://doi.org/10.1371/journal.pone.0209065

Amaba, B. A. (2014). Industrial and business systems for Smart Cities. Paper presented at: EMASC 2014 - Proceedings of the 1st International Workshop on Emerging Multimedia Applications and Services for Smart Cities. Orlando, United States: Association for Computing Machinery, Inc. pp. 21–22 doi:https://doi.org/10.1145/2661704.2661713

Angelidou, M. (2017). The role of smart city characteristics in the plans of fifteen cities. *Journal of Urban Technology*, *24*, 1–28. https://doi.org/10.1080/10630732.2017.1348880

Angelidou, M., Psaltoglou, A., Komninos, N., Kakderi, C., Tsarchopoulo, P., & Panori, A. (2018). Enhancing sustainable urban development through smart city applications. *Journal of Science and Technology Policy Management*, *9*(2), 146–169. https://doi.org/10.1108/JSTPM-05-2017-0016

Ayming. (2017). Revenue or capital? Initial tech start-up costs for R&D tax explained. Ayming. Retrieved from https://www.ayming.co.uk/insights/opinion/tech-start-ups-capital-not-capitalquestion/

Bellini, E., Nesi, P., Pantaleo, G., & Venturi, A. (2016). Functional resonance analysis method based-decision support tool for urban transport system resilience management. Paper presented at: IEEE 2nd International Smart Cities Conference: Improving the Citizens Quality of Life, ISC2 2016 - Proceedings. Trento, Italy: IEEE. doi:https://doi.org/10.1109/ISC2.2016.7580833

Berkowitz, A. R., Nilon, C. H., & Hollweg, K. S. (2003). *Understanding urban ecosystems: A new frontier for science and education*, Newyork, NY: Springer Verlang.

Bertalanffy, L. V. (1976). *Perspectives on general system theory: Scientific-philosophical studies*. The International library of systems theory and philosophy (1st ed.). New York, NY: George Braziller.

Bibri, S. E. (2018). *The untapped potential of big data analytics and context–aware computing for advancing sustainability*. Switzerland Springer.

Bibri, S. E., & Krogstie, J. (2017). Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable Cities and Society*, *31*, 183–212. https://doi.org/10.1016/j.scs.2017.02.016

Bifulco, F., Tregua, M., Amitrano, C. C., & D'Auria, A. (2016). ICT and sustainability in smart cities management. *International Journal of Public Sector Management*, *29*(2), 132–147. https://doi.org/10.1108/IJPSM-07-2015-0132

Blanc, D. L. (2015). Towards integration at last? The sustainable development goals as a network of targets. *Sustainable Development*, *23*, 176–187. https://doi.org/10.1002/sd.1582

Camero, A., & Alba, E. (2019). Smart city and information technology: A review. *Cities*, *93*, 84–94. https://doi.org/10.1016/j.cities.2019.04.014

Caputo, F., Walletzky, L., & Štěpánek, P. (2019). Towards a systems thinking based view for the governance of a smart city's ecosystem: A bridge to link smart technologies and big data. *Kybernetes*, *48*(1), 108–123. https://doi.org/10.1108/K-07-2017-0274

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., Scholl, H. J. (2012). Understanding Smart Cities: An Integrative Framework. Paper presented at: 45th Hawaii International Conference on System Sciences. pp. 2289–2297.

CITYKeys. (2015). CITYKeys Experinece: Recommendations from cities to cities. Retrieved April 24, 2019 from http://www.citykeys-project.eu/citykeys/project

City VITAlity and Sustainability. (2002). City VITAlity and Sustainability: Cleaner and better transport in cities. Retrieved April 24, 2019 from https://civitas.eu/

Cosgrave, E., Arbuthnot, K., & Tryfonas, T. (2013). Living labs, innovation districts and information marketplaces: A systems approach for smart cities. *Procedia Computer Science*, *16*, 668–677. https://doi.org/10.1016/j.procs.2013.01.070

Covenant of Mayors. (2008). Covenant of Mayors for Climate & Energy: Key facts and Figure of Covenant of Mayors in Europe. Retrieved April 24, 2019 from https://www.covenantofmayors.eu./

Dalziel, T., Gentry, R. J., & Bowerman, M. (2010). An integrated agency–resource dependence view of the influence of directors' human and relational capital on firms' R&D spending. *Journal of Management Studies*, *48*(6), 1217–1242. https://doi.org/10.1111/j.1467-6486.2010.01003.x

Donor Committee for Enterprise Development. (2019). Link between economic growth and employment. The Donor Committee for Enterprise Development-DCED. Retrieved from https://www.enterprisedevelopment.org/what-works-and-why/evidence-framework/link-between-employment-and-economic-growth/

Dirks, S., & Keeling, M. (2009). A Vision of Smarter Cities: How Cities Can Lead the Way into a Prosperous and Sustainable Future. IBM Institute for Business Value. IBM Global Business Services. Retrieved from https://www-03.ibm.com/press/attachments/IBV_Smarter_Cities_-_Final.pdf

Egilmez, G., Gumus, S., & Kucukvar, M. (2015). Environmental sustainability benchmarking of the U.S. and Canada metropoles: An expert judgment-based multi- criteria decision-making approach. *Cities*, *42*, 31–41. https://doi.org/10.1016/j.cities.2014.08.006

European Innovation Partnership on Smart Cities and Communities. (2019). The Marketplace of the European Innovation Partnership on Smart Cities and Communities. Retrieved April 24, 2019 from https://eu-smartcities.eu/

European Energy Award. (1994). Welcome to the European Energy Award. Retrieved April 24, 2019 from https://www.european-energy-award.org/welcome-to-the-european-energy-award

Hamman, P., Anquetin, V., & Monicolle, C. (2017). Contemporary meanings of the 'Sustainable City': A comparative review of the French- and English-language literature. *Sustainable Development*, *25*(4), 336–355. https://doi.org/10.1002/sd.1660

Hashem, I. A., Chang, V., Anuar, N. B., Adewole, K., Yaqoob, I., Gania, A., … Chiroma, H. (2016). The role of big data in smart city. *International Journal of Information Management*, *36*(5), 748–758. https://doi.org/10.1016/j.ijinfomgt.2016.05.002

Höjer, M., & Wangel, J. (2014). Smart sustainable cities: Definition and challenges. In B. A. Lorenz Hilty (Ed.), *ICT Innovations for Sustainability* (pp. 333–349). Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-09228-7_20

Hollands, R. G. (2008). Will the real smart city please stand up? *City*, *12*(3), 303–320. https://doi.org/10.1080/13604810802479126

Jarah, S. H., Zhou, B., Abdullah, R. J., Lu, Y., & Yu, W. (2019). Urbanization and urban sprawl issues in City structure: A case of the Sulaymaniah Iraqi Kurdistan region. *Sustainability*, *11*(2), 485. https://doi.org/10.3390/su11020485

Joshua, J. (2017). Economic development and the quality of life. In *China's economic growth: Towards sustainable economic development and social justice* (pp. 167–198). London, England: Palgrave Macmillan. https://doi.org/10.1057/978-1-137-59435-8_7

Khansari, N., Darabi, H. R., Mansouri, M., & Mostashari, A. (2015). Case study of energy behavior: Systems thinking approach. Paper presented at: 9th Annual IEEE International Systems Conference, SysCon 2015 - Proceedings. Vancouver, Canada. (pp. 373–376.

Khansari, N., Mostashari, A., & Mansouri, M. (2014). Conceptual modeling of the impact of smart cities on household energy consumption. *Procedia Computer Science*, *28*, 81–86. https://doi.org/10.1016/j.procs.2014.03.011

Marsal-Llacuna, M.-L., Colomer-Llinàs, J., & Meléndez-Frigola, J. (2015). Lessons in urban monitoring taken from sustainable and livable cities to better address the smart cities initiative. *Technological Forecasting and Social Change*, *90*, 611–622.

Martosa, A., Pacheco-Torresa, R., Ordóñeza, J., & Jadraque-Gagoa, E. (2016). Towards successful environmental performance of sustainable cities: Intervening sectors. A review. *Renewable and Sustainable Energy Reviews*, *57*, 479–495.

Mora, L., Bolici, R., & Deakin, M. (2017). The first two decades of smart-city research: A bibliometric analysis. *Journal of Urban Technology*, *24*(1), 3–27. https://doi.org/10.1080/10630732.2017.1285123

Mori, K., & Christodoulou, A. (2012). Review of sustainability indices and indicators: Towards a new city sustainability index (CSI). *Environmental Impact Assessment Review*, *32*(1), 94–106. https://doi.org/10.1016/j.eiar.2011.06.001

Murray, P. (2018). 40 Brilliant Examples of Smart City Projects Which Uses Open Data. Retrieved from https://lavaprotocols.com/2018/06/28/40-smart-city-projects-open-data/

Odendaal, N. (2003). Information and communication technology and local governance: Understanding the difference between cities in developed and emerging economies. *Computers, Environment and Urban Systems*, *27*(6), 585–607. https://doi.org/10.1016/S0198-9715(03)00016-4

Onag, G. (2018). PPPs essential to a successful smart city. Online source. Retrieved from https://www.cw.com.hk/smart-city/ppps-essential-to-a-successful-smart-city

Onat, N. C., Kucukvar, M., Halog, A., & Cloutier, S. (2017). Systems thinking for life cycle sustainability assessment: A review of recent developments, applications, and future perspectives. *Sustainability*, *9*(5), 706.

Pichler, M. (2017). Smart City Vienna: System Dynamics Modelling as a Tool for Understanding Feedbacks and Supporting Smart City Strategies. (desertation Thesis). Universidade Nove de Lisboa. Faculdade De Ciencias E Technologia.

Portugali, J. (2016). What makes cities complex? In *Complexity, cognition, urban planning and design* (pp. 3–19) Springer proceedings in complexity book series (SPCOM). Switzerland: Springer International Publishing.

Poyago-Theotoky, J., Beath, J., & Siegel, D. S. (2002). Universities and fundamental research: Reflections on the growth of University–Industry partnerships. *Oxford Review of Economic Policy*, *18*(1), 10–21. https://doi.org/10.1093/oxrep/18.1.10

Prakash, S. D. (2017). Leveraging ICT based smart solutions in smart cities development. Mark and Focus Retrieved from https://markandfocus.com/2017/06/29/leveraging-ict-based-smartsolutions-insmart-cities-development/

Pretorius, L., Pretorius, J.-H. C., & Benade, S. (2014). A system dynamics approach to technology interaction: From asymptotic to cyclic behavior. *Technological Forecasting and Social Change*, *97*, 223–240. https://doi.org/10.1016/j.techfore.2014.11.001

Redmond, A. M., & Alshawi, M. (2018). Applying System Science and System Thinking Techniques to BIM Management. Paper presented at: 10th International Conference on Developments in eSystems Engineering, DeSE. Paris, France. pp. 3–8.

Rodrigues, M., & Franco, M. (2019). Measuring the urban sustainable development in cities through a composite index: The case of Portugal. *Sustainable Development*, 1–14. https://doi.org/10.1002/sd.2005

Smart City Expo World Congress. (2018). World Smart City Awards: 2018. Fira Barcelona. Retrieved from http://www.smartcityexpo.com/en/awards

Strategic Energy Technologies Information System. (2007). SETIS in the Energy Union landscape. Retrieved April 24, 2019 from https://setis.ec.europa.eu/about-setis

Shmelev, S. E., & Shmeleva, I. A. (2018). Global urban sustainability assessment: A multidimensional approach. *Sustainable Development*, *26*(6), 904–920. https://doi.org/10.1002/sd.1887

Smart City Berlin Strategy. (2015). Berlin is Smart. Retrieved April 24, 2019 from http://www.berlin-partner.de/en/the-berlin-location/smart-city-berlin/

Smart Dubai. (2014). Our Vision to make Dubai the happiest city on earth. Retrieved April 24, 2019 from https://www.smartdubai.ae/

Smart City Hub. (2017). Nine examples of low investment smart city innovations with maximum output. Retrieved from https://smartcityhub.com/technology-innnovation/nine-examples-smart-city-innovations-minimal-costs/

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Cambridge, MA: McGraw-Hill Higher Education.

TASMU. (2018). The design process behind the TASMU playbook. Retrieved April 24, 2019 from https://www.tasmu.gov.qa/en/story

United Nations Development Program. (2015). Sustainable Development Goals. [online]. United Nations. Retrieved from https://www.undp.org/content/undp/en/home/sustainable-development-goals.html

Urban Agenda for EU. (2016). What is the Urban Agenda for the EU? Retrieved April 24, 2019 from https://ec.europa.eu/futurium/en/urban-agenda-eu/what-urban-agenda-eu

Visvizi, A., & Lytras, D. M. (2018). Rescaling and refocusing smart cities research: From mega cities to smart villages. *Journal of Science and Technology Policy Management*, *9*(2), 134–145. https://doi.org/10.1108/JSTPM-02-2018-0020

Yigitcanlar, T., Han, H., Kamruzzaman, M., Ioppolo, G., & Sabatini-Marques, J. (2019). The making of smart cities: Are Songdo, Masdar, Amsterdam, San Francisco and Brisbane the best we could build? *Land Use Policy*, *88*, 104187.

Yigitcanlar, T., & Kamruzzaman, M. (2018). Does smart city policy lead to sustainability of cities? *Land Use Policy*, *73*, 49–58.

Yigitcanlar, T., Kamruzzaman, M., Buys, L., Ioppolo, G., Sabatini-Marques, J., da Costa, E. M., & Yun, J. J. (2018). Understanding 'smart cities': Intertwining development drivers with desired outcomes in a multidimensional framework. *Cities*, *81*, 145–160.

Yigitcanlar, T., Kamruzzaman, M., Foth, M., Sabatini-Marques, J., da Costa, E., & Ioppolo, G. (2019). Can cities become smart without being sustainable? A systematic review of the literature. *Sustainable Cities and Society*, *45*, 348–365.

Zander, J., & Mosterman, P. (2017). *Computation for humanity: Information technology to advance society* (1st ed.). Boca Raton, FL: CRC Press.

Zangoueinezhad, A., & Azar, A. (2014). How public-private partnership projects impact infrastructure industry for economic growth. *International Journal of Social Economics*, *41*(10), 994–1010. https://doi.org/10.1108/IJSE-04-2013-0083

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